

MANAGEMENT OF FLOOD RISK WITH SPATIAL PLANNING

Herath Mudhiyanselage Malani Herath

158039L

Degree of Doctor of Philosophy in Civil Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

December 2021

MANAGEMENT OF FLOOD RISK WITH SPATIAL PLANNING

Herath Mudhiyanselage Malani Herath

158039L

Thesis submitted in partial fulfillment of the requirements for the Degree
of Doctor of Philosophy in Civil Engineering

Department of Civil Engineering

University of Moratuwa
Sri Lanka

December 2021

DECLARATION OF CANDIDATE AND SUPERVISOR

“I declare that this is my work and this thesis does not incorporate without acknowledgment any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgment is made in the text. Also, I hereby grant to the University of Moratuwa the non-exclusive right to reproduce and distribute my thesis/dissertation, in whole or in part in print, electronic, or another medium. I retain the right to use this content in whole or part in future works (such as articles or books).”

UOM Verified Signature

.....

Signature

25.12.2021

.....

Date

The above candidate has researched the Ph.D. Thesis under my supervision.

Name of the supervisor: Professor R.L.H.L Rajapakse

UOM Verified Signature

.....

Signature of the supervisor

2021-12-28

.....

Date

ACKNOWLEDGEMENTS

First of all, I would like to express my heartfelt gratitude to Emeritus Professor N.T.S Wijesekera, for his valuable contribution and support, motivation, patience, and immense knowledge, and for guiding me throughout the whole study. His supervision helped me immensely at all times, during the research as well as in the writing of my thesis. I could not have imagined a better mentor to guide me throughout this study.

I am deeply in debt to my present supervisor, Professor R.L.H. Lalith Rajapakse, Department of Civil Engineering, University of Moratuwa for his patient and steadfast support to finish this study. I would also like to take this opportunity to express my deepest gratitude to my external reviewer Dr. (Mrs.) T.N. Wickramarachchi for her excellent guidance and encouragement provided throughout the whole study.

I would like to take this opportunity to convey my heartfelt thankfulness to Professor J.N. Munasinghe, Department of Town and Country Planning, University of Moratuwa. Further, I offer my sincere gratitude to Professor Dileeka Dias, Former Dean, and Professor Ajith de Alwis, Dean, Faculty of Graduate Studies, University of Moratuwa, Professor L.W.P.R. Udayanga, Director Postgraduate Studies Division, Professor SAS Kulathilake, Former Head, Professor Mrs. Chintha Jayasinge, Head, Department of Civil Engineering, Professor J.C.P.H. Gamage, Former Research Coordinator, and Dr. T.M.N. Wijayaratna, Research Coordinator, Department of Civil Engineering.

My deepest gratitude is conveyed to all the staff members of the UNESCO Madanjeet Singh Center for South Asia Water Management (UMCSAWM) and the Department of Town and Country Planning, University of Moratuwa. I am much grateful for all of the people who have contributed their valuable time, energy, ideas, experience, and encouragement to help me complete this study. I would also like to express my heartfelt gratitude to my mother, my family for their spiritual support, understanding and for all the strength you gave throughout my research.

ABSTRACT

Management of Flood Risk with Spatial Planning

Flood risk has become a significant issue particularly in urban regions of Asia. Climate change will intensify existing flood vulnerability and further strengthen it due to socio-economic inequalities. A new set of problems are created by the traditional decision-making of flood management in the face of climate change and rapid urban development. The concept of the socio-ecological system suggests that resilience is the key to managing complex systems and reducing flood vulnerability. In addition, recognizing the significance of nonlinear and non-stationary interactions of flood risk in decision making has highlighted the transition of flood management towards Flood Risk Management (FRM). Acknowledging the uncertainty associated with flood risk has become a key aspect in decision-making. Decision-makers agree on the need for adaptive and integrated policies and strategies of FRM rather than modifying the flood and making it easier to cope with by eliminating the highest probability of floods. Flood resilience embeds the incorporation of spatially distributed land-use policies, strategies, and guidelines which are a must for the management of flood vulnerability. As a result, the characterization, assessment, and management of flood risk were subjected to a critical review during the past years. Risk-based flood management is yet in its early period of development. Though the theory has advanced over the years, there still are visible shortcomings in the operationalization of the concepts and methods, mainly due to the lack of a framework for clear recognition and understanding of the components of the FRM system.

The FRM and spatial planning domains have developed their knowledge bases separately over a long period. Recently, FRM and spatial planning have begun to share a similar perspective in the decision-making process. The role of spatial planning as an integrated planning tool has been emphasized in the decision-making of flood risk management. It is largely evident that as at present, the role of spatial planning in flood risk management remains inadequate mainly because of the absence of a common framework for stakeholders' integration. The main objective of this research is to identify the complete FRM system and its components with recommendations for its operationalization. This research has developed a solution model to structure the complexity of the planning process of FRM. The criteria and sub-criteria of the conceptual framework of the decision model have been identified based on the systematic literature review. Further, the criteria and sub-criteria of the conceptual framework have been selected and prioritized using the Delphi technique and Analytical Hierarchical Process (AHP). Forty-two experts have participated in this research and the established framework has been validated using a case study. Panadura urban area which is located in the coastal wet zone and Colombo Metropolitan Region has been selected as the case study area for application of the framework. This research has established a methodological framework for the operationalization of FRM. The main criteria which determine the practicing of FRM are the conceptualization of flood risk in the planning process, assessment of flood risk in the planning process, as well as the discourse of the governance structure, and the available participatory tools in the context. This study has identified and prioritized sixteen sub-criteria to manage the uncertainty in the planning process. The established framework can be used to identify the strengths and the weaknesses of the planning process in a given context and to guide the planning process to operate risk-based flood management objectives, strategies, and guidelines. The established framework can be used to evaluate the alternative options of flood risk management for achieving flood resilience. The case study has revealed that the existing decision-making process of FRM does not recognize the complex interdependencies between flood risk, spatial form, and spatial planning. As a result, the current practices of FRM are unable to achieve flood resilience. Therefore, this research recommends the integration of FRM with spatial planning. The developed framework is more sensitive to the governance structure of the context, therefore more case studies are needed to conduct in different governance contexts for further refine

Keywords: AHP, Delphi, Framework, Integration, Nonlinearity, Stakeholders, Uncertainty

TABLE OF CONTENTS

DECLARATION OF CANDIDATE AND SUPERVISOR.....	i
ACKNOWLEDGEMENTS	ii
ABSTRACT.....	iii
TABLE OF CONTENTS	iv
LIST OF FIGURES	x
LIST OF TABLES	xi
LIST OF APPENDICES.....	xiii
LIST OF ABBREVIATIONS	xv
CHAPTER 1 - INTRODUCTION.....	1
1.1 Background	1
1.2 Problem Statement	7
1.3 Objective	7
1.4 Specific Objectives.....	8
1.5 Thesis Outline	8
CHAPTER 2 - LITERATURE REVIEW	11
2.1 Decision Making Framework.....	11
2.2 Decision-making Frameworks of Flood Risk Management (FRM)	12
2.3 Traditional Decision-making Frameworks of Flood Management.....	13
2.3.1. Conceptualization of flood risk.....	13
2.3.2 Assessment of flood risk	13
2.3.3. Flood management	14
2.3.4 Limitations of the rationalist approach in decision making	15
2.4 Constructivist Approach to Flood Management	19
2.4.1 Flood vulnerability	20
2.4.2 Flood vulnerability assessment	24
2.4.3 Limitations of assessment and management of flood risk	27
2.5 Transformation of Flood Risk Management Towards an Adaptive and Integrated Process	33

2.6 Components of the Flood Risk Management System	34
2.7 Current Status of Knowledge Related to the Components of the Flood Risk Management	36
2.7.1 Flood risk	36
2.7.2 Flood risk management objectives.....	38
2.7.3 Flood risk management options	40
2.7.4 Assessment of risk	43
2.7. 5 Evaluation of the merits long term and short term of flood management goals.....	46
2.7.6 Evaluation of the merits long term and short term of flood management strategies	48
2.7.7 Development of guidelines	52
2.7.8 Achievements of objectives	55
2.8 Current Status of the Flood Risk Management	58
2.9 Interplay between Spatial Planning and Flood Risk Management	62
2.9.1 Spatial planning and flood risk management in the early period.....	62
2.9.2 Limitations of traditional spatial planning practices.....	63
2.9.3 Integrating of flood risk management and spatial planning.....	64
2.10 Challenges for Operationalization of the Flood Risk Management System ..	69
2.10.1 Stakeholders' plural understanding on interdependencies of land and water	70
2.10.2 Public indifference to natural disasters	70
2.10.3 Territorial development	71
2.10. 4 Institution culture	71
2.10.5 Shared dilemmas in the planning process	71
2.10.6 Lack of political support	72
2.10.7 Over-reliance on top-down planning	72
2.10.8 Lack of flexibility of planning process	73
2.10.9 Planning context.....	73
2.10.10 Flexibility of governance system	74
2.10.11 Lack of participatory governance tools.....	75

2.11 Gap of the Current Status of Operationalization of Flood Risk Management with Spatial Planning.....	76
2.11.1 Variety of stakeholders	76
2.11.2 Stakeholder participation	77
2.11.3 Joint definition	78
2.11.4 Absence of a common framework	79
2.11.5 Reframing planning.....	80
2.11.6 Governance arrangement and participation of stakeholders	81
2.11.7 Absence of guidelines	82
2.11.8 Adaptive capacity.....	83
2.12 Need of Research	83
CHAPTER 3 - METHODOLOGY	86
3.1 Development of a Framework.....	86
3.2 Development of a Decision Making Framework in Flood Risk Management	88
3.3 Application of Multi-Criteria Decision Making (MCDM)	88
3.4 Development of Decision Making Framework with Analytic Hierarchical Process (AHP)	89
3.5 Application of AHP in Flood Risk Management.....	93
3.6 Methodology of the AHP	93
3.6.1 Develop a hierarchical structure of the problem	93
3.6.2 Literature review to extract possible criteria and sub-criteria.....	94
3.6.3 Setting up the decision hierarchy using the Delphi technique and AHP ..	94
3.6.4 Pairwise comparison	97
3.6.5 Synthesis of priorities.....	103
3.6.6 Checking the Consistency Ratio	104
3.7 Validation of the Developed Framework.....	104
3.7.1 Validation with the case study	104
3.7.2 Selection of case study for validation	105
3.7.3 Stakeholders selection for validation of the decision model.....	106
3.7.4 Preparation of questions for validation	107
CHAPTER 4 - ANALYSIS	109

4.1 Development of the Framework.....	109
4.1.1 Structure of the framework for operationalization of flood risk management	109
4.1.2 Governance Context.....	111
4.2 Adaptive and Integrated Planning Process.....	113
4.2.1 Conceptualization of flood risk management (FRM)	113
4.2.2 Assessment of the planning process.....	114
4.3 Adaptive and Integrated Governance System / Planning Context.....	116
4.3.1 Discourses of Stakeholders	116
4.3.2 Participatory governance arrangements	117
4.4 Conceptualization of flood risk.....	118
4.4.1 Flood risk as a complex phenomenon.....	118
4.4.2. Scale sensitivity of flood vulnerability and risk.....	119
4.4.3 Inherent uncertainties associated with flood risk	120
4.4.4 Flood risk management as socially assesses, integrated and adaptive process	121
4.5 Place-based Assessment.....	122
4.5.1 Adaptive capacities to maintain the ecological functions of the floodplains	122
4.5.2 To develop diverse flood risk management options for different uncertain futures	126
4.5.3 Hydrological interactions of floodplains	127
4.5.4 Socio-spatial interactions of floodplain	128
4.6 Discourses of Stakeholders	130
4.6.1 Social Learning	131
4.6.2 Multilevel governance systems.....	131
4.6.3 Flexibility in governance arrangements for continuous learning and experimentation	132
4.6.4 Local initiatives.....	133
4.7 Integrated and Adaptive Governance Mechanism	134

4.7.1 Integration among the land and water institutions at all scales and levels	134
4.7.2 Integrated goal setting and catchment-scale approach.....	135
4.7.3 Multiple Governance.....	136
4.7.4 Local stakeholders for participation.....	136
4.8 Proposed Framework for Flood Risk Management	137
4.9 Calibration of the Proposed Framework	141
4.10 Experts Consensus on the Criteria and Sub-Criteria of the Framework	141
4.10.1 Prioritization of the main criteria	147
4.10.2 Prioritization of sub-criteria of conceptualization.....	153
4.10.3 Prioritization of sub-criteria of place assessment.....	156
4.10.4 Prioritization of sub-criteria of discourse.....	169
4.10.5 Prioritization of sub-criteria of participatory tools.....	165
4.11 Ranking of Sub criteria.....	169
4.12 Relative Importance of the Criteria and the Sub-Criteria for Criteria for Implementation of FRM	181
CHAPTER 5 - VALIDATION OF FRAMEWORK	181
5.1 Increasing of Flood Damage	181
5.2 Urban Flood Disasters.....	181
5.3 Increasing of Urban Flood Risk in the Colombo Metropolitan Region (CMR)	181
5.4 Increasing Flood Risk in Bolgoda River Basin.....	181
5.5. Selection of Case Study	183
5.5.1. Panadura Urban area in the Bolgoda Basin.....	183
5.5.2 Land use changes over the period in Panadura	185
5.5.3 Karapen Ela.....	187
5.5.4. Flood risk management measures in Panadura	192
5.6. Land-Use Regulations in The Panadura Area.....	193
5.7 Role of Different Stakeholders in the Flood Risk Management	195

5.8 Evaluation of the Existing Decision-Making Process for Operationalization of Flood Risk Management.....	197
5.9 Assessment of the Existing Decision-Making Process for Operationalization of Flood Risk Management.....	207
5.10 Review of Flood Risk Management (FRM) Practices in Panadura	209
5.10.1 Conceptualization of flood risk.....	209
5.10.2 Place-based assessment	218
5.10.3 Discourse of the stakeholders.....	222
5.10.4 Participatory Tools	226
5.11 Validation of the Framework	233
CHAPTER 6 - DISCUSSION.....	234
6.1 Uncertainty of Flood Risk	235
6.2 Risk-based Flood Management.....	235
6.3 Socio-Spatial Integration for Risk-based Flood Management	237
6.4 Operationalization of Flood Risk Management with Spatial Planning	238
6.5 Transformation of Spatial Planning for Stakeholder Integration.....	239
6.6 Managing of Flood Risk with Spatial Planning	241
6.7 Framing of Complex Decision Making with AHP	243
6.8 Conceptualization and Calibration of the Framework	244
6.9 Validation of the Framework	245
6.10 Selection of Case Study for Validation.....	246
6.11 Applicability of the Developed Framework for Operationalization of Flood Risk Management.....	248
6.12 Gaps of Existing Practices of FRM.....	250
6.13 Recommendations for Sustainable Management of Flood Risk	252
6.14 Future Research Needs	256
CHAPTER 7 - CONCLUSIONS	258
REFERENCES.....	260
APPENDIX	294

LIST OF FIGURES

Figure 1.1 Research methodology	9
Figure 2.1 Decision-making process of Flood Risk Management.....	12
Figure 2.2 Transformation of decision-making process of FRM.....	32
Figure 2. 3 Identification of flood risk management system.....	35
Figure 3.1 Schematic diagram of the framework development process.....	91
Figure 3.2 Methodology flow chart.....	92
Figure 3.3 Hierarchical structure.....	93
Figure 3.4 Pairwise comparison matrix	103
Figure 4.1 Framework for operationalization of flood risk management.....	110
Figure 4.2: Main Criteria of the Framework for operationalization of flood risk management.....	113
Figure 4.3 Sub criteria of conceptualization.....	122
Figure 4.4 Sub criteria of the place-based Assessment.....	129
Figure 4.5 Sub criteria of discourse of the stakeholders	134
Figure 4.6 Sub criteria of participatory governance context.....	137
Figure 4.7 Criteria and sub-criteria of the framework for operationalization of flood risk management	140
Figure 4.8 Prioritization of the main criteria.....	152
Figure 4.9 Prioritization of the sub-criteria of Conceptualization	156
Figure 4.10 Prioritization of the sub-criteria of Place assessment.....	169
Figure 4.11 Prioritization of the sub-criteria of Discourse	169
Figure 4.12 Prioritization of the sub-criteria of Participatory tools.....	181
Figure 5.1 Flooded areas around Metropolitan Colombo Area	181
Figure 5.2 Hydrological pattern of the Colombo metropolitan region	181
Figure 5.3 Urban areas in Bolgoda river basin	182
Figure 5.4 Distribution of human settlement over the Bolgoda river basin.....	183
Figure 5.5 Population Density of the Bolgoda River Basin.....	184
Figure 5.6 Elevation of the area.....	184
Figure 5.7 Flood damage in 2016 May (Field survey).....	186
Figure 5.8 Flood affect areas of Karepen Ela	188

Figure 5.9 Flood damage in the vicinity of the Karepen Ela.	189
Figure 5.10: Land use changes in the catchment area of Karepen Ela in 1994.....	190
Figure 5.11 Land use changes in the catchment area of Karepen Ela in 2004	191
Figure 5.12 Land use changes in the catchment area of Karepen Ela in 2020	192
Figure 5.13 Bolgoda Environmental Protection Area (EPA)	192
Figure 5.14 Floodplain guidelines	194
Figure 5.15 Land use zoning plan	195
Figure 5.16 Hydrological pattern of the study area.....	211

LIST OF TABLES

Table 2.1 Critical Component of the Flood Risk Management	59
Table 3.1 Classification framing of complex problems	86
Table 3.2 Approaches used for the development of methodological frameworks.....	87
Table 3.3 Selection of experts	98
Table 3.4 Priority values of the main criteria.....	100
Table 3.5 Priority values of the sub-criteria of conceptualization	100
Table 3.6 Priority values of the sub-criteria of place assessment	100
Table 3.7 Priority values of the sub-criteria of discourse	101
Table 3.8 Priority values of the sub-criteria of participatory tools	101
Table 3.9 Pairwise comparison matrix structure.....	101
Table 3.10 Comparative Judgment Structure of Criteria	102
Table 3.11 Saaty's nine-point ratio scale (Saaty, 1987).....	102
Table 3.12 Stakeholders related to the flood risk management in Panadura	106
Table 4.1 Results of Expert consensus (overall assessment)	141
Table 4.2 Results of Expert consensus (Engineers)	142
Table 4.3 Results of Expert consensus (Town Planners).....	143
Table 4.4 Pairwise comparison matrix for main criteria.....	147
Table 4.5 Normalized matrix for main criteria	148
Table 4.6 Priority vector for main criteria	148
Table 4.7 Principal Eigen value calculation for main criteria.....	148
Table 4.8 Main criteria weights obtained from AHP.....	149
Table 4.9 Pairwise comparison matrix for sub-criteria of conceptualization	153
Table 4.10 Normalized matrix for sub-criteria of conceptualization.....	153
Table 4.11 Priority vector for sub-criteria of conceptualization.....	153
Table 4.12 Principal Eigenvalue calculation for sub-criteria of conceptualization .	154
Table 4.13 Weights of Sub criteria conceptualization obtained from AHP.....	155
Table 4.14 Pairwise comparison matrix for sub-criteria of Place assessment	156
Table 4.15 Normalized matrix for sub-criteria of Place assessment.....	169
Table 4.16 Priority vector for sub-criteria of Place assessment.....	169
Table 4.17 Principal Eigenvalue calculation for sub-criteria of Place assessment..	169

Table 4.18 Weights of sub-criteria Place assessment obtained from AHP.....	169
Table 4.19 Pairwise comparison matrix for sub-criteria of discourse	169
Table 4.20 Normalized matrix for sub-criteria of discourse	169
Table 4.21 Priority vector for sub-criteria of discourse	169
Table 4.22 Principal Eigenvalue calculation for sub-criteria of discourse	169
Table 4.23 Weights of sub-criteria discourse obtained from AHP	169
Table 4.24 Pairwise comparison matrix for sub-criteria of participatory tools.....	165
Table 4.25 Normalized matrix for sub-criteria of participatory tools.....	181
Table 4.26 Priority vector for sub-criteria of participatory tools.....	167
Table 4.27 Principal Eigenvalue calculation for sub-criteria of participatory tools	181
Table 4.28 Weights of Sub criteria discourse obtained from AHP.....	181
Table 4.29 Relative importance of criteria and the sub-criteria of the planning process.....	181
Table 5.1 Estimated flood damage.....	181
Table 5.2 Role of stakeholders in flood risk management.....	197
Table 5.3 Evaluation of existing approach for flood risk management	197
Table 5.4 Assessment of existing flood risk management practices in Panadura.....	206
Table 5.5 Rainfall analysis.....	209
Table 5.6 Recommendations to improve the conceptualization of FRM in the present decision making	217
Table 5.7 Recommendations to improve the assessment of FRM in the present decision making	221
Table 5.8 Recommendations to improve the discourses related to FRM in the present decision making.....	225
Table 5.9 Review the existing governance tools of stakeholders of existing decision making of flood risk management	231

LIST OF APPENDICES

Appendix A: Questions used for the development of the framework.....	294
Appendix B: Questions used for calibration of the framework	320
Appendix C: Questions used for validation of framework	322
Appendix D: Consensus development with the experts.....	338

LIST OF ABBREVIATIONS

Abbreviation	Description
AHP	Analytic Hierarchy Process
CBA	Cost Benefit Analysis
EAD	Expected Annual Damage
EPL	Exceedance Probability-Loss
FPGAS	Flood Risk Governance Arrangements
FRM	Flood Risk Management
FRMS	Flood Risk Management Strategies
NWSDB	National Water Supply and Drainage Board
SER	Socio Ecological Resilience
USD	United States Dollar

CHAPTER 1 - INTRODUCTION

1.1 Background

The occurrence of floods is becoming a worsening disaster for many urban societies, despite the constant resource inputs provided for the flood management systems. Every government invests large sums of public money each year for flood control infrastructural measures and disaster recovery. Floods severely interrupt the functions of the cities and lead to significant impacts on the economy, environment, and on the people, particularly the urban poor (Hammond et al., 2011). Floods are known around the world to be one of the most common natural disasters that severely impair the functionality of the social system (Driessen et al., 2018). The impacts of flooding are greater in the present than in the past mainly due to rapid and concentrated urban growth, the intrusion of urban settlements into flood-prone areas, further, the extreme dependence of the society on the safety provided by flood control structural measures increases flood impacts (Kundzewicz, 1999).

Globally, flood frequency has increased over the last decades (Kundzewicz, 2014). Predictions of climate change have forecasted an increase in extreme flood events in the future. Population density and the extent of urban areas in flood-prone areas are estimated to increase significantly by 2050 (Jongman et al., 2012). Flood exposure on rivers and coasts was estimated to be around \$ 46 trillion in 2010. These estimated figures are expected to reach 158 trillion USD by 2050. After the 1980s, “globalization” became the key driver for urban development. Annual flood losses are projected to increase significantly with the increase of urban development (Jongman, 2014). Globalization has changed the type of interactions of cities and has increased the pressures on cities. Flood hazard-prone zones have transformed towards urban areas despite the spatial planning policies and regulations. Conversion of flood hazardous areas for urban growth is an essential part of flood exposure. Changes in exposure can cause significant differences in flood risk. Controlling land development in areas prone to flooding is one of the main intentions of traditional land-use planning.

However, floodplain invasion yet continues, and these floodplains provide locational advantages for various urban uses (Burby, 1981).

Flood control structural measures such as levees, dams, etc. were built or raised to protect floodplains when the urban settlements were established over the floodplains (Baldassarre, 2013). Recently, extreme flooding has occurred in many parts of Asia, suggesting that the structural flood control measures are insufficient to provide resilient solutions. Moreover, these flood control structural measures could not cope up with the extreme flood events. As a result, flooding has become a major problem, especially in many urban areas in South Asia.

In a traditional flood management system, the national government bears most of the costs of infrastructures for flood protection and compensation for flood damage (Pahl-Wostl, 2011). Communities around the world have questioned the reasons for the increasing impacts of floods. The key question, therefore, arose as; ‘who will bear these costs when the magnitude of the flood impact increases as such’ (Pahl-Wostl, 2011). Therefore, it became clear that the continuing increase of flood impacts around the world was beginning to contest the traditional flood risk management systems. Climate changes and the growth of urban development pose huge challenges for urban planning for sustainable cities. Accordingly, communities have questioned the planning and design criteria of flood control infrastructure measures and the land use planning guidelines. Recently, decision-makers have realized that complete flood protection is not practically feasible, financially viable, or sustainable. The dynamics of the social and the natural systems are likely to affect the operational profiles of flood control infrastructure.

Therefore, when planning and designing flood risk management measures to cope up with climate change and intensive urban development, it is important to understand the long-term effectiveness of investments of public funds, as well as the impact on all of the stakeholders and the functionality of the urban system. Decision-makers have gradually realized the limitations of understanding and assessing the complexities incorporated with flood risk following the proactive approaches. Therefore, research

studies on flood risk management have gradually transformed from traditional probabilistic flood forecasting and decision-approaching to flood risk analysis and management (Shi, 2019; Shah, 2018).

In the early 2000s, policymakers recognized that inadequate management of the fundamental uncertainties of flood risk would be costly and thus viewed rationalist thinking as an unproductive measure to achieve flood risk management objectives. It has been pointed out that uncertainties associated with flood risk due to climatic changes and morphological changes of floodplains have been neglected in the traditional flood risk assessment process. Flood risk management efforts based on rationalist thinking have largely failed to address the underlying multiple causes which affect increasing flood risks such as uncontrolled urbanization and the spread of socio-economic activities in areas prone to floods (Keating et al., 2017).

Decision-makers recognized that challenges that are associated with flood risk management cannot be managed by the conventional probability-based risk assessment (Chandler, 2014; Davoudi, 2012; Hadzikadic et al., 2010). Accelerated population growth and rapid changes to land use due to urban development have aggravated the human vulnerability to floods, thereby raising questions about the capacity of social systems to remain stable amidst the changing environment. It can be interpreted that the flood hazard and vulnerability have increased due to the changes in the socio-economic system, hydrological system, natural ecosystem, and climatic and atmospheric systems (Kundzewicz, 2004). As a result, the objectives of the flood risk management system were often not met in the past planning systems. Decision-makers in the earlier periods, could not recognize the uncertainty associated with the flood risk and they were unwilling to embrace the factor of uncertainty in the decision-making process.

The analysis of flood disasters with a risk perspective compelled the decision-makers to evaluate the flood risk management practices to cope up with unforeseen and emerging issues. The recurrence of flood disasters and the severity of socio-economic and environmental consequences have led to an urgent need of pushing local

communities and state governments to concentrate on assessing and managing flood risks following the socio-ecological systems approach (Schanze, 2006; Scott et al., 2013). As a result, flood risk has been characterized as a complex and dynamic phenomenon comprised of coevolving interdependencies between social-technical and natural systems. Constructivist thinking has stimulated a depth examination of the social and cultural context that influences the consequences of catastrophic events that lead to social and environmental injustice (Liao et al., 2019). Therefore, assessing and managing uncertainties of flood risk has become a central task in flood risk management.

Following constructivist thinking, the characteristics of the decision-making frameworks and management measures have transformed recently. As a result, diverse interpretations of resilience and vulnerability were evolved during the past decades (Birkmann, 2006; Hall & Solomatin, 2008; Sayers, Hall & Meadowcroft, 2002). However, actualizing the concept of flood resilience would be a major milestone (Moghadas et al., 2019). Still, there is a knowledge gap concerning the definitions, assessment, and operationalization of flood resilience (Mechler et al., 2014; Cutter et al., 2008). Moreover, the decision-makers have recognized the importance of the capacity of a decision-making framework not only regarding system maintenance but also for system change and system transformation.

Contemporary flood risk management research that has embraced FRM systems has accepted the constructivist's perspective. Currently, society is undergoing a paradigm shift from "fighting floods" towards "flood risk management" (McClymont, 2020). Therefore, reducing vulnerability and improving the adaptive capacities of the socio-ecological system began to be more highlighted than before. In these circumstances, making flood resilience operational includes the inclusion of spatially distributed land-use policies and strategies.

Such strategies and policies are considered a necessity for the management of floods. Therefore, the perception of stakeholders for managing spatial development has become a key aspect of flood risk management. This transformation has encouraged a

better accounting and appreciation of the human dimension in FRM (Plate, 2002; Schanze 2006; Hall et al. 2003; Hooijer et al., 2004; Liao et al., 2019). There is a plurality of views concerning the planning and designing of spatially distributed land-use policies and strategies. Risk-based flood management claims to mutually reinforce society's development objectives and management of extreme flood events (Keating et al., 2017). It has been found that the uncertainty associated with socio-economic development is greater than the uncertainties due to natural factors such as climate change (Klijn et al., 2012; Kok et al., 2016). Managing ambiguity uncertainties has become a dominant issue in flood risk management. Uncertainty management has become an integral aspect of operationalizing flood resilience.

It has been recognized that the uncertainty associated with flood risk management is related to stakeholders' limited knowledge and single stakeholder cannot fully understand the socio-spatial and temporal dynamics of the flood risk. Uncertainty is therefore a key parameter in decision making. The availability of a common planning process offers stakeholders the opportunity to define long-term adaptation strategies and pursue social, ecological, and economic development objectives.

In this context, decision-making models focusing on the best use of selected ecosystem services have been rejected (Nelson et al., 2008; Armitage et al., 2009). However, how to manage the socio-ecological systems trade-offs related to flood risk is still under discussion. Managing the uncertainty of flood risk management is still a debatable issue with the researchers as well as the practitioners in the face of rapid urban development (Keith Compton, 2009). The utilization of floodplains for urban development and conservation of floodplains for a long-term strategy for maintaining flood resilience has been argued among the stakeholders (Jager, 2003).

Flood risk management is not intrinsically bound to the physical characteristics of space. Society's wishes, needs, and appreciations play a greater role in determining spatial quality (Goethals & Schreurs, 2011; Davidoff, 1965). Flood risk management may be enhanced through wide stakeholder participation (Donnell et al., 2018). Moreover, the integration of stakeholders has become a key factor in flood risk

management (Kuhiliche et al., 2011). However, defining floodplain land uses, roles, and responsibilities of the stakeholders in flood risk management have become the key questions. Spatial planning can play a significant role as a collaborative decision-making process when managing the uncertainty incorporate with flood risk. Therefore, even though risk-based flood management has highlighted the integration between spatial planning and flood risk management, it has not yet been actualized. Hence, it becomes clear that the operationalization of flood resilience required a common framing among the stakeholders.

The operationalization and validity of the significance of the joint role of spatial planning and flood risk management with stakeholder acceptance persist to be unspoken and weak. It was revealed that flood risk management and spatial planning were confirmed as a collective discussion platform taking the concept of evolutionary resilience in policy and strategy-making concerning flood risk management into appreciation. ARMONIA project conducted in Europe has questioned that what extent spatial plan has to consider hazards. Accordingly, it is largely evident that spatial policies and techniques are failing in activating processes being effective in reducing the water risks. Moreover, Spatial planning presently plays only a minor role in risk management (ARMONIA, 2007). In this context, several hypotheses that were made can be seen as follows.

- Inadequateness of land use policy and strategy-making process
- Lack of specific policy, strategy, or tools
- Incompatibility between ecosystems and Institutional arrangement
- Ill consideration or involvement of water risk in spatial planning and plan-making
- Lack of communication between ‘technical ‘domains and political ‘domains
- Lack of cooperation between different levels of spatial and water management policymakers
- The gap between policy and practice in spatial planning and water management

Decision-makers have progressively recognized that the limitations of the traditional decision-making frameworks of flood management systems are mainly due to their incapability to manage the uncertainty incorporated with the flood risk.

- Data collection and data checking
- Analysis of flood risk
- Evaluation of management options
- Goal and strategy development
- Designing of governance mechanism (roles & responsibilities of the stakeholders)
- Monitoring system

Accordingly, the method of flood risk assessment, method of flood risk management, methods of operationalization have been recognized to be improved over the past years. Moreover, the theory has advanced over the years. However, there are visible shortcomings in operationalization concepts and methods mainly due to the Lack of a framework for clear recognition and understanding of the components of the flood risk management system

1.2 Problem Statement

How to develop a framework to recognize the components for the operationalization of flood risk management?

1.3 Objective

To identify the FRM system with its components and make appropriate recommendations for its operationalization.

1.4 Specific Objectives

1. To conduct the State-of-the-art literature review to recognize the present level of flood risk management system with its components.
2. To conceptualize the development of flood risk management systems and their associated frameworks.
3. To identify the critical components for successful operationalization.
4. To conceptualize and develop a solution model for critical elements of the system.
5. To identify the satisfactory solution with accepted criteria.
6. To validate the proposed solution for a Flood risk management system
7. To make recommendations for sustainable management of flood impacts.

1.5 Thesis Outline

Figure 1.1 presents the outline of the thesis.

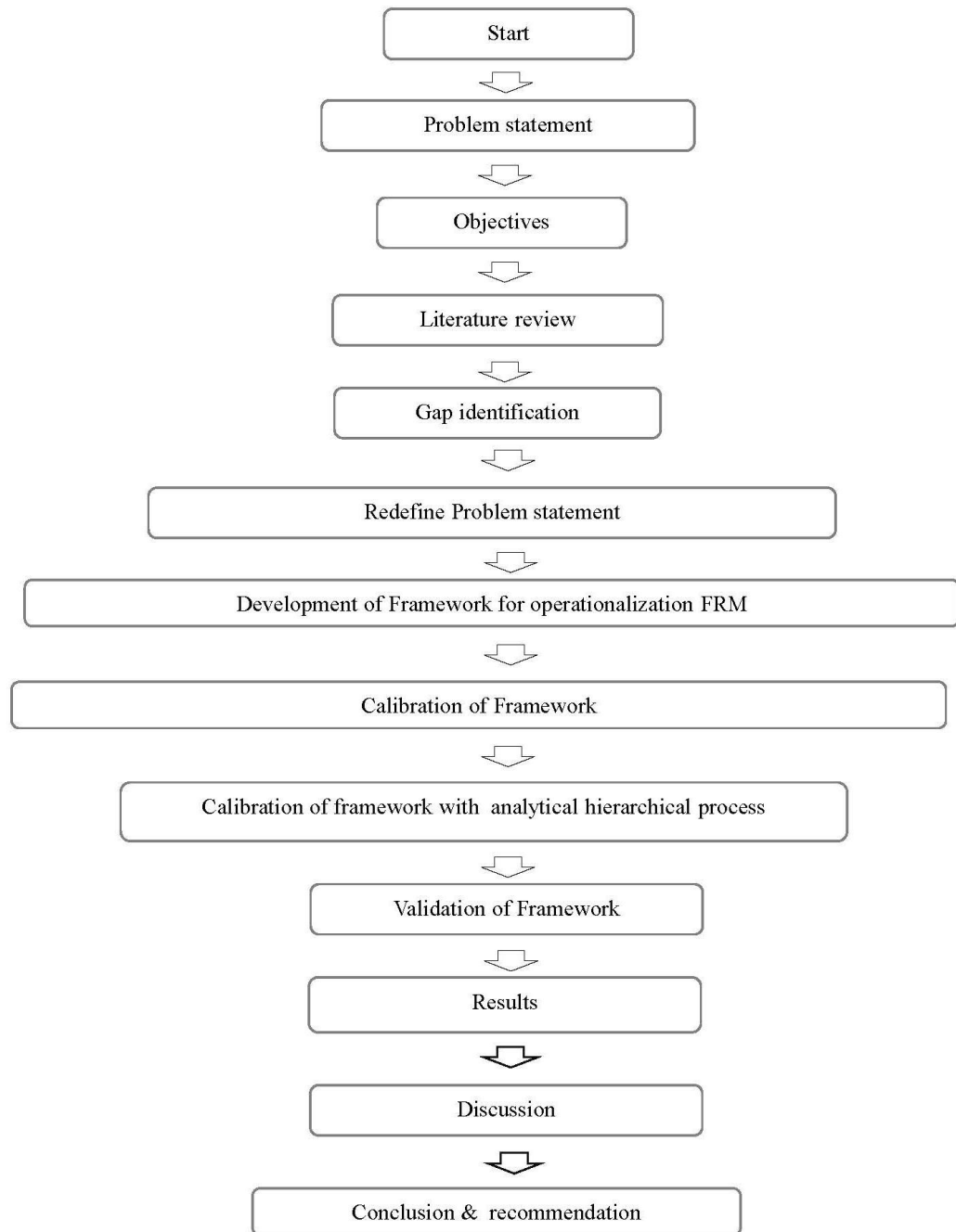


Figure 1.1 Research methodology

Figure 1.1 illustrates the schematic diagram of the thesis outline. Chapter 01 describes the background to initiate this research. It explains the research objectives and methodology of the research. Chapter 02 is the literature survey which is mainly focused to analyse how flood risk management has been conceptualized over time.

The arrangement of thinking in FRM which is used to recognize the practical complications which are related to flood risk management frameworks has been analyzed thoroughly in this context. The publications of approximately the period from 1950 – 2019 were examined for this evaluation. Key factors associated with the conceptualization of flood risk management were identified and evaluated by considering the characterizations, assumptions, and selection of alternatives for application. The outcomes of the assessments were then used to methodically identify the practical problems and constraints that should be viewed as imperative for maintaining sustainable FRM. The best alternative options as frameworks for flood risk management were identified by combining the present status and the identified gaps in this context. Chapter 03 explains the methodology of the research in detail.

Chapter 04 highlights the conceptualization and the calibration of the framework for the evaluation of flood risk management systems for planning and designing of the resilience flood risk management practices. The conceptual framework is comprised of variables that explain and evaluate the input, processing, and output variables. These variables have been converted to units of data collection and the scale of evaluations under each of the above categories following the literature review. This conceptualized framework has been calibrated with the assistance of experts in flood risk management considering the real ground experiences. Chapter 05 describes the Framework validation with a case study. Chapter 06 highlights the discussion and conclusion of the research as well as the future research requirements.

CHAPTER 2 - LITERATURE REVIEW

2.1 Decision Making Framework

Frames are described as “cognitive representations”. Framing is related to the perception of the problem and defines the bounds of what researchers examine and from which perspective. Problem framing governs mainly with two dimensions such as the prioritized values and the explanatory theories (Lele, 2018). Tversky and Kahneman (1981) describe framing as the concept of those who make decisions about the actions, outcomes, and contingencies associated with a particular choice. Flood management practices and the objectives of the flood management systems have been evolved in response to flood events throughout history. It is often possible to approach a particular decision problem in several ways. “The perception of problems and the assessment of probabilities and the consequences produce certain predictable shifts when the same problem is outlined in different ways” (Tversky & Kahneman, 1981). Therefore, problem framing can be understood as the process, by which the meaning of the situation is negotiated among the participants in the decision-making process. Thus, the framing of a problem situation and expected outcome are mainly determined by the core values and assumptions of the decision-makers.

Three main criteria are important to outline the problem framing. They are (1) elements at risk (2) stakeholders (3) roles and responsibilities of stakeholders (Brugnach et al., 2008). Decision frameworks are tools that refer to the principles that structure conceptual thinking and practices to start with information and desires to communicate actions and results. Decision-making frameworks are varied with the design and the purpose. National Research Council (2013) has highlighted the common elements of a decision-making framework. These elements can be cited as "problem identification and formulation, identification of clear objectives, clarification of key issues to help stakeholders understand the problem and management options, knowledge-building processes and analytical tools to evaluate options, connections of specific stakeholders making decisions about the problem make outcomes linked to those decisions”.

2.2 Decision-making Frameworks of Flood Risk Management (FRM)

Several transitions have taken place in the decision-making of flood risk management (Wutich, 2018). Conceptualization of flood risk, flood risk assessment, and flood risk management have been changed and modified during the past period with various viewpoints. The development process of decision-making of flood risk management was mainly based on understanding the dynamics of flood risk. As highlighted in Figure 2.1, the framing of flood risk management system can be broadly divided into two domains which include, rationalist and constructivist (Schanze, 2006; Samuels, 2010; Sayers et al., 2002; Sayers, 2015; Plate, 2002; Evans, 2006; Birkholz et al., 2014).

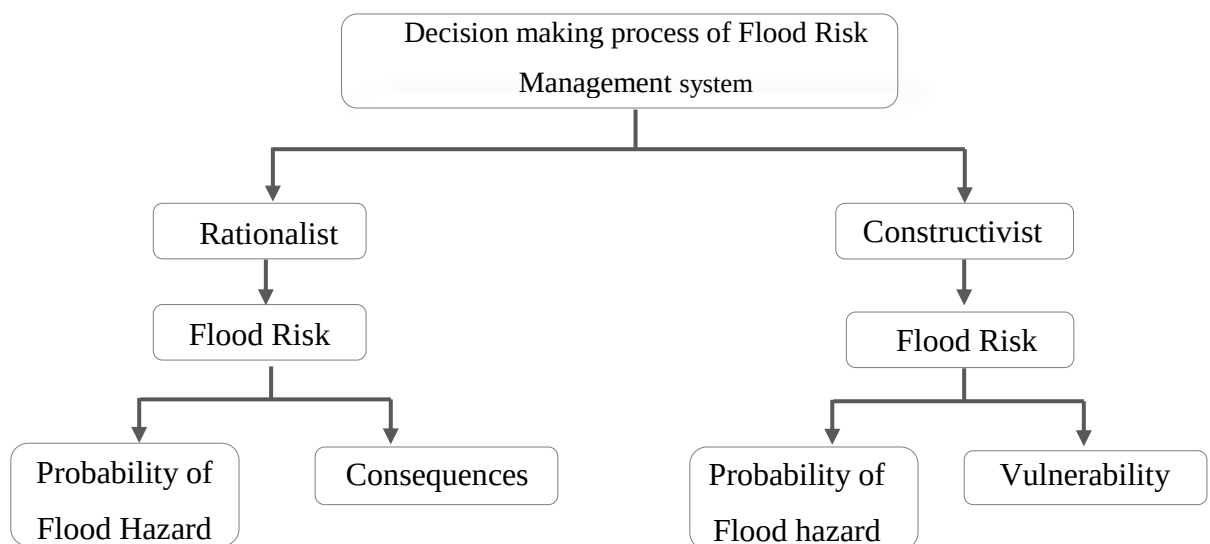


Figure 2.1 Decision making process of Flood Risk Management

2.3 Traditional Decision-making Frameworks of Flood Management

2.3.1. Conceptualization of flood risk

Traditionally, flood risk was characterized based on the probabilistic approach. Thus, the decision-making of flood management was based on assuming that flood hazards can be predicted based on the hazards that have occurred in the past. Flood risk was described as the interaction between the probability of occurrence of the phenomenon, its magnitude, and its consequences (Ciurean, 2013). Flood risk management in the past was largely subjected to rationalist thinking. Rationalist thinking has focused more on the study of physical processes such as hydrology, etc. associated with the occurrence of floods (Merz, 2014; Herath, 2020). Moreover, in the early days, flood risk was mainly described with hydrological and metrological characteristics and flood risk was described neglecting the interactions with the social system.

2.3.2 Assessment of flood risk

The flood frequency method is a technique used for the forecast of river flow patterns that will result from certain return periods. Flood frequency analysis is an estimate of how often a particular event will occur. Therefore, the observed historical streamflow records were analyzed to determine the future probabilities of exceedance. Flood frequency analysis involves fitting a probability model to the sample of the annual flood peak recorded over a time for a specific catchment area (Solomon, 2013; Bhagat, 2017).

The main focus of the flood frequency analysis is to construct the relationship between the scope and frequency of extreme floods (Chow, 1988). The understanding of flood risk was further modified by considering floods as multivariate events. Thus, the magnitudes of flood damage were considered to be affected by many factors such as depth of flood, time of flooding, the velocity of floodwaters, duration of flooding, sediment loads and warning time, etc. However, the depth of flooding is the factor that

has been considered in most historical risk assessments (McBean, 1986; Thieken et al., 2005). Expected Annual Damage (EAD) was calculated mainly with the following two steps (Aerts, 2013).

(1) The Annual Exceedance Probability-Loss (EPL) curve was established with the estimation of flood damage corresponding to different return periods

(2) Expected Annual Damage was calculated by estimating the area (i.e., the integral) under the EPL curve

The major element of understanding flood risk in the past was the estimation of future flood damages (Emanuelsson et al., 2014). Both the magnitude and frequency of the flood events are considered in the decision-making of flood risk. The main assumptions of probability-based risk assessments were that flood parameters must be static. Flood control structures of the probability-based risk assessment were designed based on the hydrological system's stationary behavior due to the assumption that flood events were fixed (Stedinger, 2011; Milly, 2008; Chow et al., 1988).

2.3.3. Flood management

The subsequent EAD measures had been used as a risk indicator to design flood control infrastructure measures (Penning-Rowsell, 2000; Merz, 2009; van Manen, 2005). Thus, these static and single numbers are embedded within decision-making frameworks of flood risk management in the past (Milly, 2008; Merz et al., 2010). As a result, flood control infrastructure measures were designed to resist the flood consequences from specific flood events (Cutter et al., 2013). Flood control infrastructure projects are designed assuming that the pattern of river variability will remain unchanged over time (Chow et al., 1988; Viessman, 2003; Bras, 1990; Clausen, 1995; Vogel, 2017; Milly et al., 2008; Zevenbergen & Gersonius, 2007). Flood control structural measures were designed to resist specific flood events (Cutter et al., 2013). Moreover, flood control infrastructure designs produce acceptable outcomes for a

limited number of hypothesized conditions. Therefore, flood control infrastructural measures are not reliable in the face of climate change.

The major focus of traditional flood controlling measures was to keep the water out of the landscape. Before the 1970s, the main emphasis was on managing flood risk by controlling the flood hazard (Kryžanowski et al., 2014). Hydrologists were the primary decision-makers providing information for decision-making in flood risk management. In the past, non-structural flood protection measures such as land use planning did not play an important role in flood risk management. Water was seen as a controllable and well-adaptable element. Therefore, traditional FRM solutions were confined to the boundaries of the water system. (Tempels & Hartmann, 2014).

2.3.4 Limitations of the rationalist approach in decision making

2.3.4.1 Estimation of total flood loss

The major drawback of the probability-based damage assessments was the ineffectiveness to facilitate the estimation of complete flood loss in the decision-making process. Probabilistic-based flood risk assessments mainly considered that flood damages can be certainly be measured in financial terms (Meyer, 2009; Ten Veldhuis, 2011; Apel et al., 2009; Nillesen, 2015). Many researchers have found that direct property damage alone cannot accurately describe the impacts of flooding. Flood damage assessment is required to include the intangible damage, in particular, the effects on health, the ecosystem, employment, etc. (Ohl, 2000; Tapsell & Tunstall, 2003; Defra, 2004; Fewtrell, 2008; Jahan, 2000). The direct impacts relate to the immediate area and at the time of the floods. The indirect impacts occur outside the flooded area and cause impacts on the economy, infrastructure services, environment, etc. However, indirect impacts spreads over a wider area (Okuyama, 2014; Apel, 2008; Jonkman & Vrijling, 2008; Thielen, 2008; Jonkman et al., 2008). Difficulties in applications due to insufficient data would also have caused problems in recording damage in monetary terms (Olesen et al., 2017).

2.3.4.2 Uncertainties of flood risk

The quantitative flood risk assessment is based on the flood frequency and the annual flood damage that is caused. This method has a considerable number of uncertainties. (Merz, & Thielen, 2005; Merz et al., 2009; Smith, 1994). Climatic change can affect the frequency as well as the magnitude of floods. As a result, climate change has altered the likelihood of a projected flood. The limitations of stochastic streamflow models in decision-making for flood risk management have been highlighted when the increase of impact of land use activities. Because these models could not recognize the nonstationary behavior of hydrologic systems due to land-use changes. Consequently, the assumption of stationary streamflow sequences was also questioned (Vogel, 2017). In addition to the above, it was also realized that the flood hydraulics changes are also due to the flood management measures such as dams and land use controls (Meyer, 1994). The importance of taking into account the uncertainties associated with hydrological and land-use changes in the assessment and management of flood risks was stressed.

Traditional flood management considered the reduction of uncertainty by a statistical grouping of flood occurrence and by quantifying their probabilities. In the beginning, flood management was interpreted as the actions undertaken to mitigate the risk with designing standards (Schanze, 2006). Flood management was mainly provided through government interventions. Traditional flood management frameworks mainly focused to keep water away from the land by building levees and raising them continuously (Kundzewicz, 1999). Then, the goal of flood management frameworks was to decrease the likelihood of a flood hazard rather than flood vulnerability. Decision-makers were assumed to have some form of control over extreme flood events.

2.3.4.3 Levee effect

In general, risk assessment is carried out to provide the basis for assessing acceptable losses, selecting decisions, and timing on which measures are to be implemented. Extreme flood events have been hypothesized to arise from an independent time series with a probability distribution pattern. Physically-based stochastic models were used assuming that the floods can be assimilated to random events. Flood risk management models were therefore based on established standards. These decision-making models presupposed a more certain image of the future. Moreover, the decision-making frameworks followed the performance-based engineering models which were aimed to provide efficient infrastructure services. Flood risk refers to situations in which probabilities and targets can be identified for possible results.

Flood management is traditionally based on technocratic decision-making processes. Conventional flood management was characterized by the authority of centralized institutions. Flood risk management depended heavily on technical experts trained in reductionist science. In the early periods, the central governments focused on using flood control infrastructure measures to control flood losses (Kryžanowski et al., 2014). Reducing the probability of flood risk with structural measures incorporated with rules of thumb designs was inadequate in the face of event uncertainties (Zevenbergen, 2007; Merz, 2010). The structural measures which could not reduce flood losses led to a false sense of security (Vis, 2003; Thampapillai, 1985). Urban waterways have been largely "improved" with an emphasis on removing water from urban areas as quickly as possible. Flood managers focused on increasing the efficiency of flood protection while ignoring the values and potentials of floodplain conservation.

Traditional Flood control structural measures were disapproved because the non-consideration of flood exposure was fuelled by the uncontrolled development of floodplains (Visser, 2014). The floodplain land use development mainly relies on flood control infrastructures that were poorly prepared in case of extreme floods. Therefore, traditional structural measures were criticized by decision-makers due to

the ill consideration of natural and social system dynamics. Decision-makers realized that the flood risk cannot be avoided by controlling the hazard. The lack of attention paid to the interdependencies of land and water in the past flood control measures was highlighted here.

An example of this is the "levee effect", which shows how the damage caused by floods worsens due to the increase in flood protection infrastructure (Baldassarre, et al., 2013; Collenteur, 2015; de Bruijn, 2019; Liao, 2012; Smits et al., 2006). Over-reliance on technical infrastructures was a highlighted issue even during the middle of the past century (White, 1945; Romali et al., 2015). Flood damage assessments which considered the probabilities of events were unable to deterministically forecast future damages of the flood (White, 1942). Concurrently, the understanding of flood risk management has advanced with the recognition of many limitations in its characterization as an objective phenomenon.

One of the major reasons that led to the non-surfacing of associated uncertainties and direct handling of the dynamic forces of flood risk with the use of statistical methods (Merz & Blöschl, 2008). Therefore, the focus has been moved on managing a certain extent of (socially acceptable) risk rather than on seeking comprehensive flood protection and safety. If the infrastructure object is a temporary solution, it may not be necessary to fully assess the long-term socio-economic impact of the investment. If a longer lifespan of flood management infrastructure is expected, the risks associated with the dynamics of climate change and socio-economic development need to be considered in the decision-making process. Moreover, the decision-making frames of flood management have been transformed towards a more holistic approach with the understanding of the limitations of the effectiveness of the traditional flood management systems for the longer term. When considering the effects of climate change on flood management infrastructure, it is important to understand the relevance and cost-effectiveness of the climate change adaptation activities to be carried out. As a result, the development of thinking from flood protection to flood risk management has been observed in the last half of the century. As a result, during the past half of the

century advancement in thinking from flood control to flood risk management could be observed (Sayers, 2013; Plate, 2002).

2.3.4.4 Fragmented approach

Around the 1950s, it was realized that structural measures were not fully effective in the face of flooding episodes. It was realized then that spatial planning controls should also be incorporated in flood management (Correia, 1999). Spatial planning regulations were also designed to reduce the flood hazards by changing the spatial characteristics of a floodplain, and the behavior of its community mainly restricting the development of floodplains. However, during the earlier period, the policies and regulations of the water sector and spatial planning sector functioned in a fragmented and disconnected government framework (White, 1945; Wiering, 2006). Hence, the designing of spatial planning measures was also based on static limits of floodplain development, and such measures could cope up with only certain flood events (Miller, 1999; Burby, 1998). Spatial planning practices were discouraged incompatible land uses in flood-prone areas by applying these controlling measures (White, 1945; Burby, 2000; Godschalk et al., 1998; White et al., 2002; Filatova, 2014). Flood management was with the responsibility of water managers who held a dominant position in the state water management administration (Neuvel, 2009; Neuvel, 2010). Very often the flood risk managers were equipped with their system of regulations, plans. Also, these dedicated water agencies owned taxation powers and geographic extents for jurisdictions (Wolsink, 2006).

2.4 Constructivist Approach to Flood Management

Flood risk was considered a product of the interactions between hazard and vulnerability (De Wrachien, 2011). Over time, the focus and understanding of the disaster damage that occurred among the decision-makers were increased. The most frequently discussed topics related to vulnerability to floods can be summarized as the type of communities affected, the nature of the potential strategies, the measures taken

to ensure the management and mitigation of the effects of floods (Pistrika, 2007). Decision-making and framing of the flood risk management system have changed with the understanding of the causative factors of flood disaster. The constructivist perspective of the flood risk thus underlines the importance of social processes as essential elements of disasters. This understanding has challenged the decision-making based on rationalist thinking. After the 1980s, most decision-makers presented the argument that flood disasters are socially constructed events (Aragon-Durand, 2009).

As a result, the conceptualization of flood risk management systems was reframed (Weichselgartner, 2001). Vulnerability-based decision-making frameworks accepted that the damage caused by flooding is largely caused by policy decisions and actions of the society. Understanding of flood vulnerability has greatly appreciated the human dimension in decision making of flood risk management (Plate, 2002; Hall, 2003; Hooijer, 2004; Schanze, 2006).

2.4.1 Flood vulnerability

Gradually, vulnerability became the key factor when determining whether a hazard had turned into a disaster (Cutter, 1996; Birkmann, 2006; Jonkman & Vrijling, 2008). Pluralistic conceptualizations of vulnerability to flooding have been developed. In general, vulnerability can be described as the extent to which a system is likely to experience damage due to exposure to a hazard. Accordingly, the importance of understanding the characteristics of flood exposure in research related to flood vulnerability was emphasized.

2.4.1.1 Flood Vulnerability and the characteristics of the physical system

The vulnerability has encountered a mixture of conceptualizations over time (Birkmann, 2006). In the early 1980s, researchers theorized vulnerability as a characteristic of the biophysical properties of exposed elements. Thus, vulnerability to flooding has been mainly considered about the proximity of rivers (Messner, 2006). In

this conceptualization, the physical properties of the exposure associated with the nature of the hazard are considered first-order effects. It has been found that the first-order effects are increased or decreased by the biological and social properties of the systems involved (Brooks, 2003). Therefore, the vulnerability was viewed as a function of three aspects such as (1) the type of physical event to which the human system was exposed, (2) the probability or frequency of occurrence of the event, (3) the degree of human exposure, and sensitivity of the system to the effects of the particular event (Brooks, 2003). Human population, land use, and investments in flood-prone areas were considered the main sources of flood risk (Parker, 2014). Therefore, the presence of susceptible land uses, infrastructure, etc. in flood-prone areas was considered as the main cause of greatest vulnerability (Cutter, 1996).

2.4.1.2. Flood vulnerability and the characteristics of the social system

In the 1980s, flood management models described vulnerability, taking into account both social system characteristics and physical factors. The characteristics of the social system have been perceived as factors responsible for vulnerability (Anderson, 1995). Therefore, the magnitude of the impact of the floods was considered a fundamental characteristic of the land uses of the floodplains. Further, it was considered that the value of flood-affected assets and the communities were assigned by the affected society (Sayers, 2013).

By the late 1980s, policymakers had taken into account that the social contexts of communities were the main factors contributing to vulnerability (Blaikie et al., 1994; Watts, 1993). The ability to cope with and respond appropriately to disasters is determined by historical, cultural, social, and economic factors as well as social processes (Cutter, 1996; Kelly, 1999). Thus, the vulnerability has been described taking into account the socio-economic factors of the society concerned (Cutter, 2010; Blaikie et al., 1994). The vulnerability has been highlighted as a collective measure of human wellbeing that takes into account environmental, social, economic, and political factors (Bohle, 1994; Bohle et al., 1994). In the early 1990s, it became clear to policymakers that vulnerability to floods was represented by two main factors, namely

the characteristics of the natural system and the social system of a given location (Cutter, 1996; Weichselgartner, 2001; Folke et al., 2002).

Consequently, the flood vulnerability of a community or a location was considered a multifaceted phenomenon. Further, it has also been recognized that the flood vulnerability is governed by diverse factors and processes, which are influenced at multiple scales and levels (Nirupama, 2012; Scheuer, 2011; Messner, 2006); (Turner, 2003; Turner, 2010). Therefore, the framing of flood risk management shifted towards managing the floods with a whole systems perspective (Schanze, 2006; Scott, et al., 2013).

Flood risk has been conceptualized using the attributes of coevolving natural and human systems their interdependencies, dynamic interdependencies, non-stationary interdependencies, and nonlinear interdependencies and path dependencies (Barendrecht, 2017; Collenteur, 2015; Van Walsum, 2005). Socio-ecological systems thinking has pointed out that the floodplains are not neutral containers. Floodplains are complex, interconnected socio-spatial systems. These complex floodplain systems are characterized by extensive and unpredictable feedback processes that take place on several spatial scales and time (Davoudi, 2012; Merz, 2015).

Further, vulnerability has been recognized as an intrinsic characteristic of a social system that is associated with space and time (Cutter, 1996; Cardona, 2004; Thywissen, 2006; Wisner, 2002). It has been interpreted that the impacts of the nonlinear interactions of land, water, and social systems vary to different social groups at diverse spatial and temporal scales (Zevenbergen, 2008). Therefore, it was also found that a single level of analysis is insufficient to understand the risk of flooding and that processes should be analysed that take place below and above the considered level (Walker, 2006). The flood risk management system encompasses not only the physical system but also includes the stakeholders that are impacted upon by flooding the response to flooding and the rules which structure and regulate the flood damages (De Bruijn, 2005). Further, it has been highlighted that the identification and

characterization of these interactions need to take its whole systems' complexity (Ostrom, 2009).

Socio-ecological system thinking has also explicitly emphasized the importance of understanding the tipping points, thresholds and recognizing that feedback mechanisms which cause the transformation for managing resilience (Folke, 2011; Moore, 2014; Rauter, 2019). The realization by policymakers that absolute flood protection is unattainable and has led to a shift in focus on flood risk management from a more holistic perspective, taking into account all potential interventions that could modify the flood (Sayers et al., 2002; Schanze, 2006; Scott et al., 2013). The overall behavior of the interrelationships between land, water, and social systems over the floodplains usually cannot be explained merely as the sum of individual parts. Therefore, it was recognized that the emergent properties of floodplains cannot be anticipated by knowing the individual aspects alone.

2.4.1.3 Flood Vulnerability and decision making frameworks

Flood vulnerability has been considered a characteristic that includes a combination of social and hydrological systems (Gallopín, 2006). At the start of the 21st century, vulnerability was viewed with a holistic approach within a human-environment system. The physical nature of flooding and socio-economic factors continued to influence the decisions of vulnerable populations (Hambati, 2015; Zischg, 2018; (Gallopín, 2006; Bogardi & Birkmann, 2004; Naess, 2006). Policymakers have recognized that the vulnerability of social systems to flooding rests on three factors at all levels. These three factors are exposure to flooding, vulnerability to flooding, and system stability (Balica, 2009; Hufschmidt, 2011; Scheuer et al., 2010; Willroth, 2011; Fuchs, 2017; Carreño et al., 2005; Turner, 2003; Smit, 2006; Bogardi & Birkmann, 2004). Therefore, the scholars recognized that the extent of vulnerability is not simply due to external natural hazards.

The internal factors of a social system such as social inequality, etc., are also required in determining the extent of the vulnerability (Naess, 2006). Flood vulnerability has

been considered as an inherent characteristic of the socio-ecological system. The latent nature of exposure exists in a social-ecological context independent of the flood hazard. Vulnerability is registered not only by exposure to hazards but also resides in the resilience of the system experiencing the hazard (Turner et al., 2003). Resilience was considered a counterpart of vulnerability (Herath, 2020).

Resilience was not seen as a way to cope with external changes or shocks, but as a function that actively and positively responded to floods (Giddens, 2009). As a result, the capacities of the flood control system were questioned, and it has explored the limitations of adaptive capacities of flood control measures to manage the dynamics of risk associated social, spatial, and temporal interactions of flood risk (Carreño et al., 2005; Bogardi et al., 2004). New flood risk management decision making frameworks evolved gradually with time due to the diverse interpretation of vulnerability (Birkmann, 2006; Hall and Solomatine., 2008; Sayers et al., 2002; Kuhiliche. et al., 2011; Plate, 2002; Schanze 2006; Hall et al. 2003; Hooijer et al., 2004). Meanwhile, it has been recognized that government interventions on flooding are inadequate for flood disaster management.

2.4.2 Flood vulnerability assessment

Flood vulnerability assessment is beginning to be considered to be much important around the world presently. It has been recognized that flood vulnerability is difficult to understand and model mainly due to the complex interactions of social, ecological, and physical processes in it. Moreover, the assessment of flood vulnerability for flood risk planning and management faces difficulties due to its multi-faceted and dynamic nature (Birkmann, 2006). Many of the proposed frameworks assessed vulnerability assuming that social vulnerability and coping capacity are homogeneous for the entire population.

Many of these vulnerability assessments have used the quantitative inhomogeneity of several attributes. The flood vulnerability assessment significantly prevents

researchers from making a reasonable assessment, as it neglects the high-dimensional, non-linear relationships between the various indices (Yang et al., 2018). It has been recognized that historical experiences and knowledge become less valuable when attempting to extrapolate those into the future because of the nonlinear and non-stationary interactions. The dynamics of natural and social systems, associated with a multiplicity of drivers of change combined with the stochastic nature of floods make it extremely difficult to quantify the changing of flood risk (Merz et al., 2010). Therefore, assessment of flood risk based on flood vulnerability has been recognized as a challenging task mainly in the face of rapid urbanization. Therefore, various scholars debated how to assess the risk and vulnerability of natural hazards (Bohle, 2001; Davidson, 1997; Turner et al., 2003; Blaikie et al., 2004; Cutter et al., 2000; Bogardi & Birkmann, 2004; Birkmann, 2013; Galderisi et al., 2014; Vojinovic et al., 2016; Jean-Baptiste et al., 2013).

Flood vulnerability assessment requires consideration of the simultaneous presence of multiple causative factors and processes associated with both social and physical systems (Fuchs, 2017; Cardona, 2013). Apart from this, due to the dynamic nature of flood vulnerability, it is necessary to carry out a continuous evaluation of vulnerability (Bogardi et al., 2004; Næss et al., 2006). However, the most critical factor is that very often the causes of vulnerability are quite remote from the initiating hazard event. Therefore, decision-making frameworks provide limited details about the structure of causative sequences, inclusion of nested scales of interactions, and feedback interactions beyond the system of analysis (Cutter, 1996).

The indicator-based method, curve method, and disaster loss data techniques are among the diverse practices that have been used for evaluating flood vulnerability (Dapeng Huang, 2012). Many researchers have considered vulnerability as a relative measure and not as something that can be expressed in absolute terms (Downing et al., 2001). Vulnerability is difficult to convert to a numerical value (Adger, 2006). Moreover, quantification of flood vulnerability is difficult. The subjective nature of vulnerability assessments raised many concerns regarding the evaluation of magnitude

and distribution of projected effects (Nasiri, 2016). The presence of uncertainty is another struggle with the effectiveness of flood vulnerability assessment.

In recent years, flood risk management work has increasingly focused on the ability of the affected society to recover with little or no outside help. It was recognized that the future conditions of the social and natural system could potentially change significantly compared to today. This has underlined that the decision-making need for a continuous process with monitoring and interventions (Schanze, 2006). Flood risk management has become a process of gathering data and information, assessing risks, evaluating options, and making, implementing, and reviewing decisions on managing flood risk (Hall, 2003). Instead, it is necessary to take into account what happens in the social context and the process of formulating and implementing strategies. As a result, the classic development cycle for data collection, decision making, response, and monitoring has been questioned (Hall, 2003).

This new paradigm was increasingly recognized in the state's inability to "keep water out". Besides, the importance of applying the principles of sustainable development in flood risk management was recognized. Consequently, it was stressed that a more balanced approach to flood risk management is needed between government and private sector and between the environmental, economic, and social objectives of the society (Johnson, 2008; Schanze, 2006; Hall, 2003). Further, the right balance between structural and non-structural in risk management systems is also highlighted. Therefore, the suitability of the current assessment, prioritization, and decision-making processes have been examined (Johnson, 2008). Thus, decision-making has been considered under uncertainty. Therefore, FRM enables the inherent conflicts as well as opportunities that characterize flood management choices to be openly debated, priorities to be set, and difficult investment choices to be made. The decision-making process has been characterized by deep uncertainty. Therefore, FRM allows for an open debate on inherent conflicts and opportunities that characterize flood management selection, prioritization, and selection of difficult investments.

Constructivist thinking sheds new light on the trade-offs between the individuals and collective benefits of society in the framing of flood risk management systems. The decision-making process has moved from a process of technical experts' authority to a process of stakeholder participation and government consultation to a division of responsibilities between the government and its citizens. Stakeholder engagement and public participation are seen as central aspects of the new paradigm (Becker, 2015). Consequently, the Flood Risk Management (FRM) system has been transformed into multiple learning processes. Multi-loop social learning is recognized as a crucial element to sustainable decision-making for land and water (Medema, 2014).

2.4.3 Limitations of assessment and management of flood risk

2.4.3.1 Interdependencies of land and water

Since 2000, the concept of the socio-ecological system had been increasingly used to capture the dynamics of flood risk (Zhou et al., 2010; Adger et al., 2005; Cutter et al., 2016; Morrison et al., 2018). It shows that there is an essential interdependency between land and water. Furthermore, the outside pressures on either water resources or the use of land result in chains of impacts and responses that are intertwined and interactive (Van Walsum, 2005; Osti, 2018). The concept of socio-ecological systems is reinforced to conceptualize that the flood risk management systems are complex and are constantly changing with space and time. The performance of flood risk management systems depends not only on the characteristics of the natural system such as topography and climate but also on changes in land uses. The flood risk system extends beyond the directly connected water system and flood protection. Accordingly, flood risk management systems include floodplain areas, land behind flood control, slope and elevation differences, land ownership, land use, institutional arrangements, political system, and population characteristics, etc. (de Bruijn, 2005). Therefore, it has been recognized that the management of spatial transformation is also closely linked to issues related to flood risk management.

2.4.3.2 Unpredictability of flood risk

It has been recognized that the future conditions of social, hydrological, climatic systems, etc., which are incorporated with flood risk in the past, maybe significantly vary from those that exist today. Therefore, it is quite difficult to predict the flood impacts over space and time. Even a small change in one variable of one system may lead to a non-proportional change in the dependent variables, or threshold effects occur due to the nonlinearity. The overall behavior of flooding systems usually cannot be explained merely as the sum of individual parts. The individual parts and their interactions often lead to emerge of patterns and cooperation in a complex system. Flooding has severe implications on functions of the social system before, during, and after the events. The impacts of the flood risk are more complex and unknown due to nonlinear and nonstationary that is processes (Merz et al., 2015). In a natural ecosystem, a regime shift occurs when there is a switch in the governing feedbacks. Regime change is often associated with rapid non-linear changes. As a result of non-linear changes, the system is reorganized into a different structure and function. Therefore, the decision-making framework of the flood risk management system is required to understand the consequences in long term. Flood damage assessment and vulnerability assessment methods of the past did not recognize the uncertain uncertainly risks which are associated with the flood. Therefore, consideration of nonlinear interactions among land and water, their feedback, and spatial-temporal relations became a necessity (Zevenbergen, 2008).

2.4.3.3 Assessment criteria

Cost-benefit analysis of traditional flood risk assessment was based on optimizing for individuals in flood-prone areas independently. The traditional cost-benefit analysis neglects downstream risk changes. Traditionally, it was checked whether the optimal risk management option was to minimize total costs. Total cost was defined as the sum of investment costs and the net present value of expected annual flood damage. Therefore, traditional cost-benefit analysis of the decision-making process often falls short in considering risk transfers and accounting for risk distribution. As a result,

many of the cost externalities has remained external to the developers in the past (Ward, 2013). Consequently, the flood management strategies could not accommodate the safeguard of the wellbeing of the urban poor (Dowall & Clark, 1996). Therefore, it is necessary to evaluate the impact of flood management strategies for both the long term as well as short term. Accordingly, the assessment criteria should not have focused solely on an economic basis but should have involved considerations of public safety, social equity, and environmental balance (Folke et al., 2011).

There is an irreducible uncertainty incorporated with the complex flooding systems (Döll, 2017). Adequately dealing with uncertainties has been considered as the primary concern in flood risk management (Mingers, 2004). This emphasis on resilient flood risk management is considered upon reducing harmful outcomes. Understanding uncertainty is a crucial condition that is necessary to reduce vulnerability and cope with changes occurring quickly and unexpectedly. The impact of flooding cannot be predicted by knowing the single components such as hydrology, etc., or a single system alone. Effective management of uncertainties would allow decision-makers to better understand the consequences of their decisions, especially regarding the different goals and actions of different stakeholders.

Accordingly, it has been suggested that the flood risk management systems are required to be designed based upon uncertainty rather than making a decision that is based on the estimation of the probability of flood damages as in the past (Emanuelsson et al., 2014). The uncertainty assessment determines the type and extent of a management strategy that does not influence the development objectives of stakeholders. Flood damage assessment and flood vulnerability assessments did not recognize the impacts of nonlinear interactions among land and water, their feedback, and spatial-temporal relations (Zevenbergen, 2008). However, the decision-makers could not foresee the feedbacks between floods and people in a dynamic way during the designing of flood control infrastructure measures (Menoni, 2012; Barendrecht et al., 2017; Baldassarre, 2013). Societies have undergone spatial transformations without improving the capacity to manage environmental feedbacks (Olsson & Galaz, 2014).

A common underlying assumption in the conventional approach to flood risk systems is that the natural and social systems are distinct from each other and that natural and hydrological systems are predictable and controllable. As a result, societies have undergone spatial transformations without improving the manage environmental feedbacks (Olsson & Galaz, 2014). Uncertainties and surprise are inherent due to the dynamics of the flooding system. It is necessary to assess uncertainties of hazard, impact (exposure), vulnerabilities, and resilience of the components of the flooding system at the decision making of flood risk management system. Therefore, the flood risk assessment should take into account not only the impact of floods due to the flood hazard and consequences for society but also the relative importance of the risks to a society based on the "long-term system-wide perspective ".

Conceptualization of flood risk management systems as social-ecological systems highlights the need for recognition of the coevolving dynamics and feedbacks inherent in coupled human-water systems. Therefore, risk assessment requires a full understanding of risk with a systems-based approach (Schanze, 2016). Socio-ecological system thinking is not only facilitated the presence of dynamics and foresight the social, hydrological, and ecological interactions but also their interdependencies, the spatial variability, and feedback loops (Shahid & Behrawan, 2008; Merz et al., 2015; Davidson et al., 2013; Dawson, 2015). Accordingly, it is necessary to understand the differences between uncertainties to adequately deal with the uncertainties (Zandvoort, 2018). Uncertainty determines what the type and extent of the precautionary action that is implemented might be, and the level and location of uncertainty are also important consideration factors here (Zandvoort, 2018).

2.4.3.4 Types of uncertainties

Ontic uncertainty resulting from the nonlinear behavior of a system. Ontic uncertainty is irreducible and inherently unpredictable. Ontic uncertainty is generally regarded as a property of the system independent of the knowledge of the observer. Therefore, ontic uncertainty is not simply resolved by additional research or empirical efforts (Brugnach et al., 2008; Walker et al., 2003). The reason for the epistemic uncertainty

is the lack of data to measure parameters that may be relevant to the current decision or policy (Zandvoort et al., 2017). The reasons that lead to epistemic uncertainty are technical problems such as errors in models or data and complications in translating a practical problem into a scientific problem (Bodde et al., 2018). Therefore, by increasing the quantity or quality of knowledge, epistemic uncertainty can be reduced. Ambiguity is the third type of uncertainty that can be viewed as a complex category of uncertainty due to the many societal frameworks that are not necessarily recognized by decision-makers (Zandvoort et al., 2017).

Multiple frames are usually caused due to different human values and interpretations of what the main problems are, what the stakes are what the goals to be achieved and what the likelihood of success of various measures are, etc. The existence of multiple frames of reference when understanding a certain phenomenon is also called ambiguity (Dewulf et al., 2005). Therefore, ambiguity is not about ‘not knowing enough, but about ‘knowing differently’ (Van den Hoek et al., 2014). Therefore, ambiguity arises from a lack of clarity about the problem structure, the variables involved, and their interrelationships between them (Wasson, 2016).

2.4.3.5. Management of uncertainties

Flood risk management and assessment are usually subjected to cognitive biases. This is due to the rare and uniqueness of extremes and the nature in which humans perceive risk (Merz et al., 2015). Interventions on flood risk problems will be in the face of incomplete knowledge about the problem. Objectives of flood risk management cannot be achieved as expected due to the ill recognition of uncertainties incorporated with flood risk. Therefore, uncertainties are required to be conceptualized more largely, relative to their role, meaning, and relationship with stakeholders in decision making. Two options have been recommended when confronted with multiple frames.

- 1) Choose the correct one (an epistemic strategy)
- 2) Accept the unchangeable fact (ontological strategy)

Uncertainties that are associated with flood risk cannot be removed but uncertainty can be managed by integration among stakeholders taking all potential trade-offs at different scales in space and time. As explained in Figure 2.2. Coping with uncertainties incorporated with flood risk management is a challenging task due to the availability of limited knowledge to understand these nonlinear interdependencies, thresholds, and spatial variations (Sayers et al.,2002; Evans, 2004; Schanze, 2006; Lechowska, 2018). Consequently, decision-makers have realized that there are no objective criteria for verifying possible solutions to complex problems. The choice of defining the appropriate solutions depend on the perspectives of the stakeholders rather than the use of objective criteria when it comes to decision-making related to floods (Allen & Gould, 1986). Moreover, it has been underscored that the experience and knowledge of an individual group of stakeholders become less valuable and are harder to extrapolate with time.

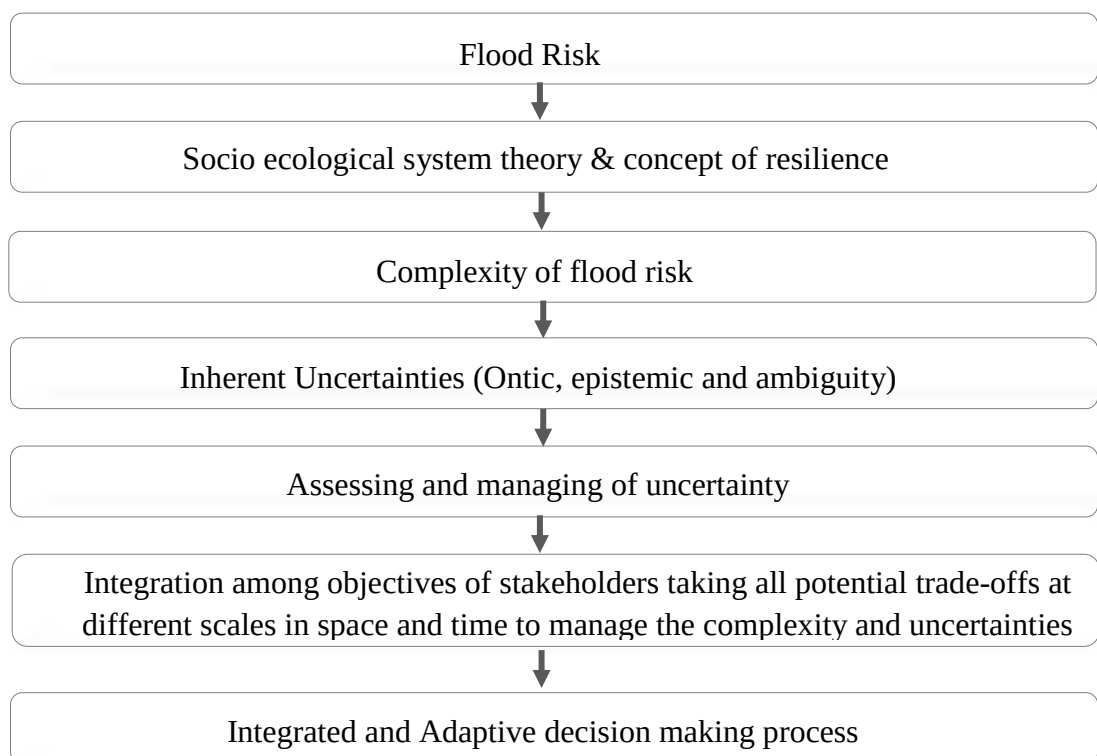


Figure 2.2 Transformation of decision-making process of FRM

2.5 Transformation of Flood Risk Management Towards an Adaptive and Integrated Process

The transformation of flood management towards Flood Risk Management (FRM) has been triggered by the impacts of catastrophic flood occurrence. Adverse impacts of extreme flooding events have provided new perspectives on the performance of past flood management practices and future needs. It was realized that the traditional flood control measures were not fully effective in the face of flooding episodes. The limitations of solely relying on flood defenses and disaster recovery programs have been identified. Therefore, the status of defining the resilience in flood risk management policy and strategy making of flood risk management system has been examined (Morrison et al., 2018). Flood risk management has been theorized with the non-stationary phenomenon. Therefore, the FRM system is focused to increase the adaptive capacity within the choices made and adopting a continuous process of monitoring and intervention (Sayers et al., 2012; Willows & Connell, 2003). Moreover, this situation has questioned the adaptive capacity of the planning process, components of the flood risk management system and characteristics, the knowledge generated among the stakeholders to appropriately evaluate flood hazards and then realistically determine the expected damage with careful identification of the stakeholder resilience.

The factors highlighted above have shifted the flood risk management decision-making process from more robust flood protection to more flexible and adaptable flood risk management that has been addressed in a holistic manner (Hartmann & Juepner, 2014). Also, the flood risk management system has undergone a transformation that takes into account the socio-spatial dynamics of flood risk for flood management decisions and can reduce the likelihood of flood risk. Flood and flood damage (Tempels & Hartmann, 2014). As flood risk management is a continuous process of adaptive management, new challenges arise for uncertainty analysis (Hutter & Schanze, 2008; Kuklicke, 2016; Sayers, 2013). In the sequential structuring of options, the definition of the problem is seen as critical. Incomplete formulation of a problem

can lead to inadequately formulated goals, which in turn can lead to incomplete or inadequate identification of management options.

2.6 Components of the Flood Risk Management System

The flood risk management system has become a process of 'holistic and continuous social analysis, flood risk assessment and reduction' (Schanze, 2006; Sayers et al., 2002; Evans et al., 2004; Schanze 2006; Link & Galloway, 2009; Samuels & Al, 2010; Pahl-Wostl et al., 2007). Figure 2.3 describes the components and their configuration.

The components of the FRM system are as follows.

1. Characterization of the complexity Flood Risk & FRM system
2. Flood risk assessment
3. Identification of the FRM objectives
4. Identification of Flood risk management options
5. Evaluation of the merits of flood risk management options
6. Identification of the FRM strategies
7. Evaluation of the merits of FRM strategies
8. Identification of Flood Risk Governance mechanism for operationalization flood risk management system
9. Evaluation of the merits of governance mechanism
10. Change the guidelines, Change the strategies & Change the objectives

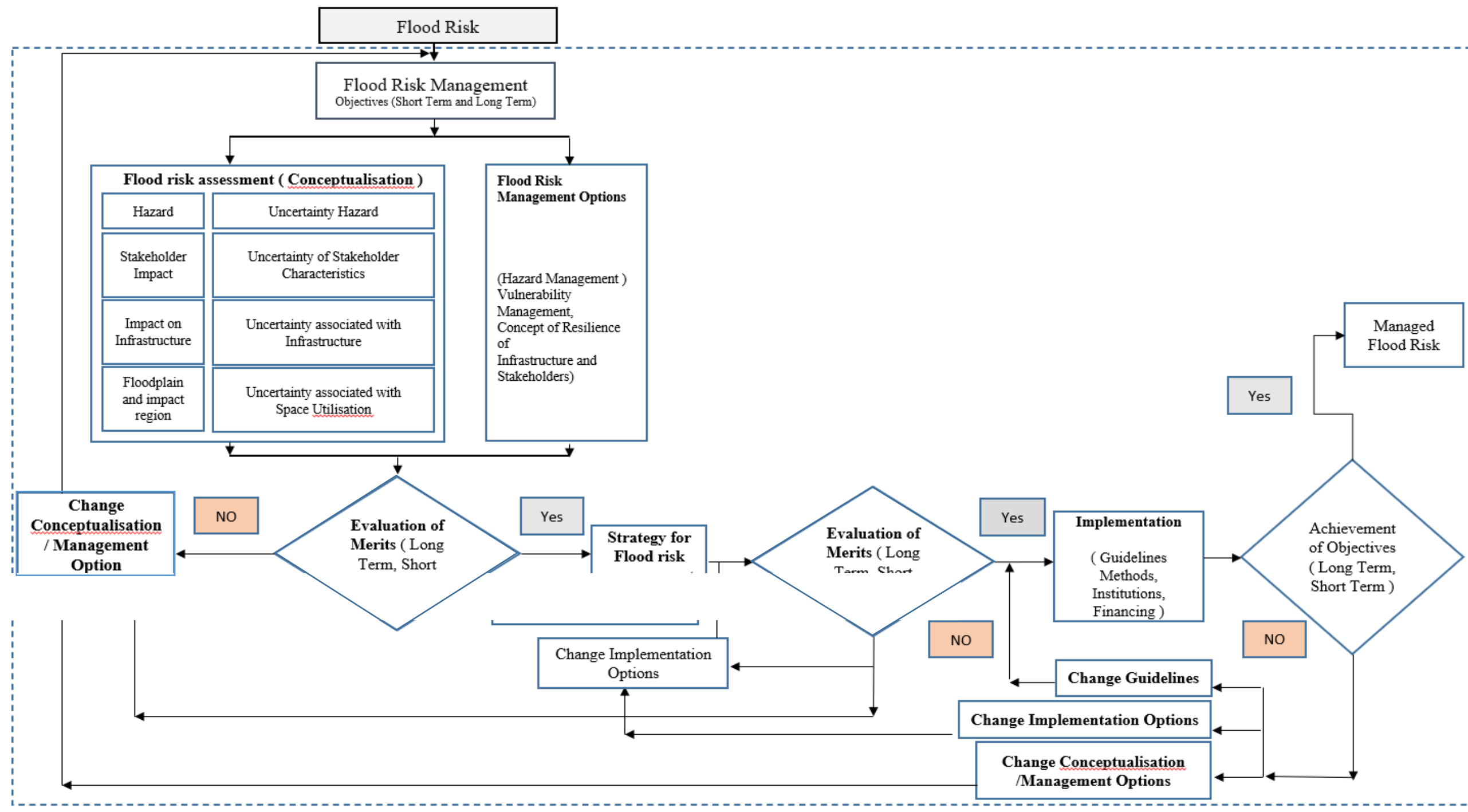


Figure 2. 3 Identification of flood risk management system

2.7 Current Status of Knowledge Related to the Components of the Flood Risk Management

The following part of this chapter explains the components of the FRM system. It also reviews how uncertainty has been characterized, assessed, and managed related to each of the components.

2.7.1 Flood risk

2.7.1.1 Characterization of uncertainty

Flood risk has been conceptualized as a coevolution phenomenon (Barendrecht, 2017; Collenteur et al., 2015; Van Walsum, 2005). Due to this factor, the consideration of the whole complex interdependencies of flood risk becomes very important (Zevenbergen, 2008; Ostrom, 2009; Samuels, 2010). It was pointed out that floodplains are required to study using a long time series of social and hydrological data and across multiple scales and cultures (Di Baldassarre et al., 2013). The dynamics of the complex flooding system are impossible to predict. This impossibility is due to the non-linear behavior and sensitivity to the original conditions of complex flood systems (Brugnach, 2008).

2.7.1.2 Assessment of uncertainty

The dynamic relationships of flood risk have been methodically discussed in the socio-hydrology literature (Linkov & Trump, 2019; Doroszkiewicz, 2017). However, the interactions and feedbacks between society and floods are not well understood (Sivapalan et al., 2012). For example, the social response to floods is different for cluster events and

random events. It is required to recognize two types of feedback to assess the flood risk (Mai, et al., 2020).

- (1) Governing feedback loops currently influencing flood risk
- (2) Dormant feedback loops that are likely to influence flood risk in the future

Stakeholders' knowledge of the dominant feedback loops, how they cause flood vulnerability, how they interact across different spatial scales is necessary to be understood when designing the flood resilience strategies (Zevenbergen, 2008). Therefore, dynamic models of coupled human-flood interactions are needed (Barendrecht, 2017).

2.7.1.3 Challenges and way forward

The high complexity of the hydrological and social processes in urbanized floodplains can be conceptualized using dynamic mathematical models (Simonovic, 2011; Di Baldassarre et al., 2013; Viglione et al., 2014). These models are required to explore a wider range of possible future scenarios (Barendrecht, 2017). For example, there is a growing demand for high-resolution spatial-temporal population estimates which allows accurate assessment of the population exposure to natural events (Smith et al., 2014; Merz, 2015). Tools of systems thinking such as Causal Loop Diagrams (CLD) can be used. CLD can unlock insights into the complex nature of the flood risk through visualizing the dynamics which are underlying the system structure (Zevenbergen, 2008; Andreas Paul Zischg, 2017). At present, methods to analyze and quantify environmental as socio-economic changes related to flood risk, both in space and time are not common (Andreas paul Zischg, 2019). The transition towards system-based approaches is still surrounded by many unknown factors (Zevenbergen, 2008).

2.7.2 Flood risk management objectives

2.7.2.1 Characterization of uncertainty

The concept of socio-ecological resilience has shifted attention towards managing flood risks from a more holistic perspective (Schanze, 2006; Scott et al., 2013). Hence, adaptiveness is a fundamental objective of any resilient system. It simply means the active management of any system to respond to changes (Walker et al. 2004). This understanding has highlighted the requirement of organization of the floodplain land uses according to the diverse hazards levels (Liao, 2012). Therefore, the primary objectives of the Flood risk management system should be the utilization of synergies between land and water (Bogardi & Birkmann, 2004; Cardona, 1999). This has highlighted the environmentally friendly concept of ‘learning to live with water instead of ‘fighting against the water’ (Restemeyer et al., 2015; Zandvoort, 2018; Kato & Ahern, 2008; Rauws et al., 2014; Balducci et al., 2011; Carpenter & Turner, 2000; Chapin et al., 2006; Walker et al., 2012; Martín-López et al., 2017; Olsson et al., 2015; De Bruijne, 2004; Douven et al., 2012; Restemeyer et al., 2015). As a result, the requirement of precautionary measures and coordinated action in governance processes was highlighted (Christmann, 2012; Brisley et al., 2016). However, in the past, most of the governments substantially spent more on the response to emergencies than on measures to anticipate and manage flood risk.

2.7.2.2. Assessment uncertainty

It has been further underlined that the objectives of flood risk management should not stand alone. The objectives of FRM are framed in broader socio-economic development (Sudmeier- Rieux et al., 2015) considering the context of river functions (Middlekoop et al., 2004; Biesbroek et al., 2009; Scott, 2013). Flood risk management (FRM) has highlighted the importance of integrated objectives that involve multiple stakeholders

across sectors and levels of decision-making (Samuels et al., 2010). Therefore, the objectives are focused on addressing all aspects of flood risk management including the reduction of potential adverse consequences of flooding for diverse human activities (Radulescu et al., 2016; Cumiskey et al., 2019). Combining different perspectives of the visioning of diverse stakeholders into singular and coherent perspectives considering their, multiple needs provides more effective responses (Radhakrishnan et al., 2017).

This change has already challenged the established governance boundaries between land and water (Tempels & Hartmann, 2014). Operationalization of flood risk management considers diverse objectives of diverse stakeholders included spatial planners, flood managers, affected communities, etc. However, the overall objectives of all these stakeholders are to improve spatial quality with better safety and higher environmental quality (White, 2010; Vis et al., 2003; Hooijer et al., 2004; Liao, 2014). Accordingly, the planning process should be able to understand the different stakeholder's perceptions for defining the objectives of the flood risk management system (Fuchs et al., 2017; Hutter, 2007; Zevenbergen, 2008; Doroszkiewicz, et al., 2017; Hamlet, 2011; Sayers et al., 2012).

2.7.2.3 Challenges and way forward

Flood risk cannot be solved by any single organization because a solution for one group of individuals often causes a new problem for another. Thus, it has been revealed that the flood risk cannot be managed in isolation at the local scale. A major setback of that is that local management actions are complicated by interlinked political, socio-economic, and environmental changes at different scales (Zevenbergen, 2008). The interrelations between social, physical, and spatial features of a particular place is depending on the risk perception of society. Therefore, it can be highlighted that flood risk management is a context-dependent phenomenon (Wiering & Immink, 2006). Flood risk management

involves many actors who have unique perspectives, objectives, and priorities. Due to this FRM depends upon the governance structures present (Samuels, 2010).

During the past decades, the concepts of flood risk management have been transferred into decision-making practice across many countries such as India, Australia, China, the United Kingdom, and the United States (Sayers et al., 2012; Jelena Batica, 2016; Chaffin et al., 2014; Folke et al., 2005; Pahl-Wostl et al., 2007; Restemeyer et al., 2018; Norberg & Cumming, 2008; Biggs et al., 2009; Berkers, 2007). However, mainstreaming integration in the practice is seen as a challenge, because diverse stakeholders are required to work cooperatively with the presence of fragmented policy territories (Cumiskey et al., 2019). Moreover, the introduction of a new and alternative concept to stakeholders is a challenge (Jelena Batica, 2016). This raises questions about how the participation of stakeholders, including local communities, can be put into practice successfully (When et al., 2015).

2.7.3 Flood risk management options

2.7.3.1 Conceptualization of uncertainty

Flood risk cannot be reduced solely by focusing on flood protection measures or keeping the water out of the urban areas. Flood risk management systems should provide diverse options for flood management to deal with hazards and vulnerability. Diverse, multifunctional, and flexible solutions are needed to cope up with the changing societal needs and dynamics of nature (Schulz et al., 2000). Flood management measures are required to be designed based on the scenario approach which allows a thorough examination of possible future conditions (Haasnoot & Middelkoop, 2012). There is a large range of potential future conditions, which are based on the climatic, socio-economic, and land-use changes, their priorities (Bhave et al., 2016; Haasnoot et al., 2012;

Haasnoot et al., 2013; Aerts et al., 2008; Wardekker et al., 2010; Innocenti & Albrito, 2011; van den Brink et al., 2011; Wesselink et al., 2015; Dieperink et al., 2016).

Literature supports that diversification of FRM leads to more resilience of flood hazards (Kundzewicz & Takeuchi, 1999). However, the operationalization of diverse flood risk management options is still lacking. Hence, flood protection standards are often formalized in law. These guidelines are not discussed with all stakeholders. As a result, flood defence has become depoliticized in many cases. Traditional flood risk management measures generally do not address the root cause of the flood risks, and many people and ecosystems are even more vulnerable in the long run (Depietri & Mcphearson, 2017). Flood control infrastructure measures are usually very specifically designed for one particular event (Hartmann, 2019). The flood risk management system is comprised of non-structural and structural measures, or a combination of both, depending on the location (Jones et al., 2012). The risk-based approach highlights that the floodplain should be primarily arranged to reduce flood vulnerability in different scenarios (Meijerink, 2008; Kumar et al., 2020). Therefore, the flood risk management system has highlighted the application of both technical measures and spatial planning policy interventions to manage both flood hazards and vulnerability (Klijn et al., 2015). However, diversification of management options is a challenging task due to the requirement of collaborative and participatory governance (Immink, 2005; Hegger, 2016).

2.7.3.2. Assessment uncertainty

Diversification does not only highlight the development of a single FRM system but also highlights the alignment of these strategies in area-specific integrated visions (Dieperink et al., 2016). Thus, the risk-based management option has recognized the interrelation between flood risk the other economic, political, environmental, technical, and social issues. The diverse strategies for flood risk management have been suggested for managing flood risk and the plural meanings of floodplains' land use of

stakeholders. Therefore, approaches to decision-making involve a combination of top-down and bottom-up approaches (Hallegatte, 2014).

2.7.3.3. Challenges and way forward

The diversification of FRM strategies has been widely discussed in the literature. However, the mechanism for implementing a diverse set of strategies is lacking. Even today, solutions such as dike reinforcement are the preferred option of stakeholders. Diverse strategies are required to practice cooperation between different policy areas such as disaster management, spatial planning, etc. The operationalization of flood risk management is therefore determined by collaborative and participatory governance (Dieperink et al., 2016). There is deep uncertainty about future socio-economic conditions and climate change, and it is difficult to identify adaptation strategies and requirements for the FRM system (Dessai et al., 2007; Brown, 2011; Refsgaard et al., 2013).

Various management options are derived based on a sound ex-ante uncertainty analysis that takes into account future considerations. Modern Portfolio Theory (MPT) has been used to develop flood management strategies. MPT aims to find a range of investments that diversify risk, thereby reducing the overall risk of the entire investment portfolio (Aerts et al., 2008). Aerts (2008) used a case study in the Netherlands to demonstrate this application of Modern Portfolio Theory (MPT) in flood risk management. They systematically identified the relationship between the return and risk of individual activities and the return and risk of entire portfolios. They also showed how the correlation of returns from different flood management activities will reduce the overall risk of the portfolio. Aerts (2008) highlighted the awareness of stakeholders in the Netherlands, including communities. Local communities, government, water management authorities, etc., remain strongly focused on total protection, and the highest economic returns.

2.7.4 Assessment of risk

2.7.4.1 Conceptualization of uncertainty

In the decision-making of complex issues, there are two types of uncertainties that can arise. One type of uncertainty is over the stakeholders' expected outcome and the other type of uncertainty is over the expected output (Mingers, 2004). The future is necessarily a combination of the known and the unknowable. Flood risk assessment should focus upon stakeholders' uncertainty rather than making a decision based on the estimation of the probability of flood damages as in the past (Emanuelsson et al., 2014). The potential for expanding stakeholder roles and the potential for creating a common decision-making framework to balance the costs and benefits of FRM among stakeholders also need to be assessed. (Bhave et al., 2016).

2.7.4.2 Assessment uncertainty

Who wins and who loses through the establishment of flood protection structures has become a question (Penning-Rowsell & Pardoe 2012). Flood risk is sensitive to deep uncertainties (Hu et al., 2019). The risk-reduction performance and cost-effectiveness of all possible solutions are required to be examined across different scenarios. Decision-making is needed to evaluate the performance of strategic alternatives in a very uncertain future. Therefore, flood risk management options are necessary to be developed by considering the following (Sayers et al., 2012).

- (1) Explore possible different future scenarios
- (2) Understand the future conditions
- (3) Performance of different decisions in those futures

The purpose of flood risk analysis is to define the adverse consequences to society caused by any flood event and design flood management strategies (Zhou, 2018). The selection of risk-based management options is based on an ex-ante assessment to separate reasonably acceptable from unacceptable outcomes when comparing the various costs and benefits (Yohe & Leichenko, 2010; Webb, 2011; Oels, 2013). Flood risk assessment is required to explore the cause-effect relationship as well as the conditions to specific human interventions that facilitate or inhibit such shifts in the desirable state (Walker & Meyers, 2004). Therefore, management options are developed to deal with the inherent uncertainty in complex flood risk management systems.

In the past, the tendency to remain passive in the face of uncertain climate fluctuations and "over-reliance on government flood control measures" have been stronger (Hallegatte et al., 2015). Decision-makers in developing countries may often give higher main concern and allocate public investments on poverty alleviation and economic growth. Moreover, they have neglected to give priorities for long-term risk from climate change in the planning process. As a result, they could neither not reduce flood vulnerabilities nor improve social welfare. After all, poverty alleviation and socio-economic development in developing countries are closely linked to climate. Therefore, this can only be addressed in an integrated manner (Hallegatte et al., 2015).

2.7.4.3. Challenges and way forward

Risk assessment should identify the possibilities of an adverse effect(s) occurring to different stakeholders of flood risk management. There are common questions that will be raised in the assessment process as "Who is responsible for adapting to climate change?" And "How can costs and benefits be distributed across generations?" (Termeer et al., 2011). It has been revealed that the uncertainty associated with the risk of flooding cannot be managed in isolation (Zevenbergen, 2008). This has highlighted the importance of jointly assessing the uncertainties of flood risk for long-term climate change adaptation

(Patt & Schröter, 2008; Conway & Mustelin, 2014). Uncertainty assessments have highlighted the heterogeneity and participation of stakeholders to open up a discussion about the goals, strategies, and standards of flood risk management (Leach et al., 2010; Armitage et al., 2011; Klinke & Renn, 2012). This new perspective demands a fundamental shift in perspectives, world views, and institutions (Folke, 2011). It is necessary to carefully consider these interdependencies among stakeholders to develop the sustainability of floodplain land uses. The assessment of the adequacy of communication mechanisms and distributional effects of flood management options on people, nature, landscape, and cultural heritage has been highlighted in the literature (Wiering & Driessen, 2001). Hutter and Schanze (2010) have highlighted that learning how to deal with uncertainty in long-term FRM comprises at least two phases.

- (1) Long-term analysis of flood risk uncertainty through scenario planning
- (2) Discussions on content and context from strategy development to the social learning process

Up to now, FRM research has paid less attention to exploring contents and contexts through social learning. Therefore, they have pointed out that the future research requirement for providing recommendations to planners to consider the social process of dealing with uncertainty. However, capabilities to deal with uncertainties are crucial for effective long-term planning (Hutter & Schanze, 2010). Therefore, stakeholders' views and the participation of stakeholders in decision-making is crucial aspect of flood risk assessment. Multi-criteria decision frameworks have been discussed in the literature for uncertainty assessment of flood risk management (Loos & Rogers, 2016). Successfully synthesized trade-off analysis of alternative flood management solutions under future deep uncertainty is bound to be a knowledge co-creation process of scientists, decision-makers, field experts, and other stakeholders (Hu et al., 2019). A successfully synthesized compromise analysis of alternative solutions for flood management in future deep uncertainties is inevitably a process of knowledge cooperation between stakeholders such

as scientists, policymakers, field experts, and other interest groups (Hu et al., 2019). Hence, the fuzzy theory and has recently been developed to evaluate uncertainty. Furthermore, the fuzzy set theory was developed to capture the uncertainty of judgment caused by a lack of knowledge.

2.7. 5 Evaluation of the merits long term and short term of flood management goals

2.7.5.1 Conceptualization of uncertainty

Flood risk management goals are framed focusing on long-term sustainability. The main goal of Flood risk management is to ensure that flood protection performs satisfactorily under a wide range of possible future flooding conditions (Simonovic, 2011). The urban flood risk cannot completely resolve strategies based on only structural interventions due to the strong interdependency of social and environmental systems and inherent uncertainty. Socio-ecological resilience thinking has highlighted the importance of dealing with the ontological uncertainties as a fundamental objective of the flood risk management system (Walker et al., 2003; Warmink et al., 2017; Wiering & Immink, 2006). Accordingly, the improvement of local and regional spatial qualities is the main objective of the integration of flood risk management with spatial planning (Nillesen & Kok, 2015; Waterman, 2016). Creating multifunctional land uses means creating space for the river while at the same time achieving the spatial quality and social benefits of floodplains (Juarez Lucas & Kibler, 2016; Potter, 2012).

Warner (2012) defined that spatial quality consists of restoring the original beauty of the river by combining economic values and water security with ecological, cultural, and historical values. Therefore, the aim of the flood risk management system is not only to reduce vulnerability to flooding but also to improve local and regional spatial qualities (Klijn et al., 2013). Flood risk management cannot be considered in isolation from other river functions such as nature, agriculture, inland navigation, and landscape values

(Middelkoop et al., 2004). Therefore, many governments are initiating long-term strategic planning processes to achieve more sustainable development of floodplains under different socio-economic circumstances (Bandudeltas, 2014). Integrated approaches lead to better outcomes for flood risk management (FRM) and society as a whole (Cumiskey, 2019).

2.7.5.2. Assessment of uncertainty

Recently, there are several initiatives for the establishment of the framework for the integration of stakeholders. One of the most widely acknowledged facts regarding successful FRM is the Integration of water management and spatial planning (Hartmann & Driessen, 2017; Pahl-Wostl, 2007; Warner et al., 2012; Wiering & Immink, 2006; Woltjer & Al, 2007). Different stakeholders' perceptions have been developed to define spatial quality

2.7.5.3. Challenges and way forward

The amalgamation of water management and spatial planning is widely acknowledged by decision-makers for a successful FRM system (Hartmann & Driessen, 2017; Pahl-Wostl, 2007; Warnerdelenbos & Buuren, 2012; Wiering & Immink, 2006; Woltjer & Al, 2007). The role of spatial planning has also been emphasized in managing flood risk by influencing urban structures (Fleischhauer, 2008). There is a growing recognition of the application of spatial planning in flood risk management (Jong et al., 2013). In the early periods, spatial planning measures were not adequately recognized for flood risk management (Wolsink, 2006).

Integration has been highlighted as alignment between policy domains, and to manage trade-offs and maximize synergies across management practices. However, achieving integration in practice is a challenging task because multiple stakeholders need to work

together across fragmented policy domains (Cumiskey, 2019). It was pointed out that there is a lack of research to show how spatial quality can be successfully achieved in practice by the combination of spatial planning and flood risk management (Busscher et al., 2017). However, there is an imperative need for research to address how spatial quality can be achieved through spatial planning (Dieperink et al., 2016; Hegger et al., 2014; Morrison et al., 2017). However, it has been recognized that these frameworks are sensitive to different geographical and institutional contexts (Cumiskey, 2019).

2.7.6 Evaluation of the merits long term and short term of flood management strategies

2.7.6.1 Conceptualization of uncertainty

The notion of resilience has been highlighted in three capacities. These capacities are “capacity to resist”, “capacity to absorb”, and “capacity to transform” (Hegger et al., 2016). For example, a resilience strategy is supposed to be able to better cope with uncertainties than a resistant strategy (Brujin, 2004). Flood protection strategies particularly engineering-based resistant structural measures will continue to place a significant burden on national budgets. Therefore, the flood management strategies are required to evaluate based on cost, risk reduction, economic impacts, social and environmental impacts in long term.

The flood risk strategies are required to evaluate, optimize multiple objectives, and adapt to different situations (Woodward et al., 2014). The core of the evaluation of strategies is to examine the ability to effectively manage the changes that can be occurred in all plausible future scenarios" of flood occurrence (Sayers et al., 2012; van der Pol et al., 2017). Therefore, they have highlighted the requirement of consideration of integrated scenarios that consider possible futures coherently and consistently. In addition to that, management strategies should not constrain future opportunities for development (Sayers

et al., 2012). Therefore, the strategies are designed to answer the two questions (1) what if a particular scenario becomes reality and (2) what happens to the outcome of the flood risk management. Strategies are evaluated for ‘how much climate change can the current strategy cope with?’ Therefore, the strategies are required to be evaluated by considering the cause-effect chain. This is followed by analyzing the cause-effect chain from pressures to impact (Kwadijk et al., 2010). The performance of flood risk management strategies is based on the level of flood resilience (Yazdandoost, 2008).

Flood risk management strategies can also reduce flood risk to levels acceptable to society as a whole (Eric, et al., 2018). Strategies of the Flood risk management system are defined based on risk acceptance of the stakeholders of a city concerning certain flood levels (Holcombe & Anderson, 2010). Flood risk management strategies are evaluated on their financial impacts (cost of flood damage) and their impacts on the economy, ecology, and landscape as well as their flexibility (Vis et al., 2003). Joint evaluation of hazard, exposure, and social vulnerability provides valuable information for the evaluation of FRM strategies (Koks & Jongman, 2015). Goals and strategies are evaluated for key vulnerabilities by looking for adaptation tipping points (Folke, 2011; Moore, 2014; Rauter, 2019). Moreover, integrated approaches have the potential to enable better outcomes for flood risk management and society as a whole (Cumiskey et al., 2019). It is therefore necessary to prepare urban communities to accept floods and create a favorable environment for flooding (Batista, 2016).

2.7.6.2 Assessment of uncertainty

It is necessary to assess the impacts of strategies for short-term and long-term as well as wider consequences (Barnett & O’Neill, 2010; Nyberg et al., 2014). Flood risk will be interpreted differently with diverse stakeholders due to their differences in experiences, needs, views and interests (Bormann et al., 2015). Therefore, the operationalization of flood risk management needs a framework to increase the common understanding of each of the

stakeholders. The evaluation process of the flood risk management system should consider the diverse spatial requirements of the stakeholders including the urban developers, communities, flood managers, hydrologists, and their interdependency with the dynamics of the flood risk (Carpenter, 2012; Driessen, 2012; Miguez, 2015). The evaluation process should be adaptive and integrated. This means that the evaluation process needs to support the negotiation of diverse aspirations of stakeholders to lean towards the implementation of strategies that fulfill multiple objectives of the stakeholders (Restemeyer, 2018). Flood risk management has focused on the content of the spatial planning process due to the connection between socio-economic development and flood risk management (Klijn et al., 2015; Prinsen, 2014). However, there were no frameworks to analyze the goals and the strategies at the interface of flood risk management and spatial planning as part of a longer-term development process and implementation (Seijger et al., 2016).

The selection of applicable flood management options is based on the stakeholders' knowledge system for imagining the outcome over the floodplain community at different scenarios and available resources, methods, tools, institutions, and flexibility of the planning process (Lane, 2011; Hutter, 2007). Therefore, the integration of stakeholders' knowledge systems, opportunities for social learning is underlined as the central methodological concern of the planning process for the operationalization of food risk management (Medema, 2014). The operationalization of flood risk management strategies has become an element of collective governance. Collective governance is different from the government, which consists of a single actor (Cosgrove, 2015). Spatial planning has been considered as a collaborative decision-making process to balance and integrate spatial claims of diverse stakeholders such as for water retention and residential development to achieve spatial quality (Healey, 2006; Biesbroek et al., 2009). Consequently, spatial planning, as a collaborative planning tool has been highlighted for providing opportunities to stakeholders to find out the integrated and adaptive strategies for the operationalization of flood risk management.

2.7.6.3 Challenges and way forward

It is necessary to integrate the knowledge systems of the stakeholders including the scientists, legal scholars into one coherent framework (Hegger et al., 2014). Fragmentation of governance structure is a barrier to the practice of adaptive management strategies (Marie Buijs et al., 2018). Integration of stakeholders' knowledge systems, opportunities for social learning are underlined as the central methodological concern of the planning process for operationalization of flood risk management (Medema, 2014). Therefore, the selection of management options of flood risk management systems depends on the adaptive and integrated capacities of its planning process. However, in literature, there is no evidence to describe the characteristics of such socially, politically, and resource efficiency coherent framework to operationalize flood resilience concepts (Allexander et al., 2016).

Implementing adaptive management strategies is difficult due to the relatively independent position of water authorities and the main epistemic community of civil engineers in this policy area. Besides, there are institutional barriers such as the requirement of legal certainty in the planning system, the expectation of protection against vulnerable communities, etc. (Lawrence et al., 2013). Multi-criteria models are developed to illustrate potential conflicts of interest and undesirable outcomes of planning strategies. It was proposed to use the multifunctionality of land use, trade-offs between stakeholders, added value, and the spatial distribution of benefits among all stakeholders except the property owner as criteria to assess the benefits. Flood risk management strategies (Hoang et al., 2016).

2.7.7 Development of guidelines

2.7.7.1 Conceptualization of uncertainty

A greater understanding of cross-sectoral relationships between land and water has been emphasized over time. It has been found that water can no longer be seen without considering other sectors and related issues affecting water management and vice versa (Biswas, 2008). Practicing of flood risk management was initiated in many European countries even at the beginning of 2000 (Thieken, 2016). Moreover, this has led to the systematic exploration and creation of retention space and rejection of purely protective measures. For example, the People's Republic of China has established the concept of 'Sponge City', in 2014, due to the rapid socio-economic development occurring, this concept deals with managing critical water issues.

The concept of 'Sponge City' is being developed to make use of the 'blue' and 'green' spaces in the urban environment for stormwater management and control. Until recently, grey infrastructure and hard engineering-based management practices have been adopted in Chinese cities (Chan, 2018). Hence, there are higher potentials for the implementation of integrated flood risk management (Thieken, 2016). Development and implementation of land-use guidance and assessment tools are recommended to achieve the dual goals of sustainable water use and better flood control. However, effective implementation is still heavily influenced by planning and implementing structural flood protection measures instead of taking flood risk management measures.

2.7.7.2 Assessment of uncertainty

Floods are an important function of the ecosystem. Society and the economy cannot always be protected from flooding (Sayers, 2017). The operationalization of flood risk management requires new governance rules for cooperation and an adaptation of existing

directives and regulations. For example, the implementation of the widening of the river is seen as a means of increasing flood safety and may require organizational changes (van Herk, 2015; Hooijer, 2004). The results linked to the implementation of new measures to widen the river constitute a new method of collaboration. This cooperation takes place between authorities, practical guidelines, new guidelines, and regulations as well as new government regulations and project management processes (van Herk, 2015). Therefore, it is important to involve stakeholders in the selection of acceptable flood risk levels. It was also pointed out that increasing stakeholder participation beyond consultation offers many benefits for operationalizing flood risk management practices, especially as the tasks are increasing. More transferred to the local level and that conflicts between stakeholders are reduced (Hooijer, 2004).

However, it is necessary to identify the stakeholders to define short-term and longer-term social benefits. It concludes that participatory modeling techniques can facilitate the identification of intervention options by a wide range of stakeholders, and prioritize a subset for further (Hooijer, 2004). They used Bayesian networks to create a conceptual model of the local flood risk system, with particular emphasis on how different interventions can achieve the goals of different participants (Hooijer, 2004).

2.7.7.3 Challenges and way forward

There are many challenges in the development of financial and implementation mechanisms across multiple stakeholders. For example, urban flood problems are handled by the institutions related to water Resources. Urban water pollution is handled by the institutions' related Environment. Deforestation issues are handled by the institutions' related forests. Accordingly, all of these interrelated institutions have their codes of practice and legislated practices and policies. However, managing all these issues simultaneously is a challenging task due to the rapid socio-economic development and the continuing climate change, particularly in the rapidly developing urban regions.

Therefore, it is necessary to develop a common framework in which all these objectives of different stakeholders can be interrelated if integrated flood risk management is to be implemented (Chan, 2018).

It has been further stressed that the flood management system needs to encompass integrated and flexible governance solutions that can respond to the complex feedbacks (Tendayi, 2011). As a result, the adaptiveness of the spatial planning process including the institutional structure was further questioned regarding its flood resilience (Carreno et al., 2007). Compartmentalization of spatial planning and flood management prevented the operationalization of flood risk management (Wiering & Immink., 2006; Wheeler & Evans, 2009; White, 2010).

It is largely evident that spatial planning measures are failing in activating processes that contribute to reducing the flood risks. Cooperation between water managers and spatial planners is not yet a day-to-day practice (Nijland & Menke et al., 2005). Presently, spatial planning plays only a minor role in flood risk management. It is largely evident that at present, the role of spatial planning in flood risk management remains inadequate mainly because of the absence of a common framework for the planning process (Herath & Wijesekera, 2019). The flood managers and spatial planners had become extremely demanding for integration at both policy-making and implementation levels. The transformation of policymaking dimensions towards action dimensions is a challenging task. However, in both levels of flood management and spatial planning, there is a need to define a common framework to be reciprocally influenced and effective.

2.7.8 Achievements of objectives

2.7.8.1 Conceptualization of uncertainty

Flood risk management of the system is conceptualized as a complex adaptive system with multiple equilibria. The concept of flood resilience can be valid when it can be quantified (Brujin, 2004). In recent decades, scholars have developed tools, ecological models, and indicators that can be used to measure resilience (Cumming et al., 2005; Bennett et al., 2005). Flood resilience has been defined as the capacity of an urban system to maintain its functions, organization, and structure to acceptable levels after being exposed to flooding (Brujin, 2004; Davoudi, 2012; De Bruijne, 2004; Folke, 2006). Flood Risk Management policies and strategies are focused to deliver a broader set of outcomes that are socially just, positively contribute to ecosystem services, and promote resilience outcomes rather than focus only on easily defined national economic impacts (Sayers, 2017).

Measuring resilience is a difficult task because flood resilience is a multidimensional property (Kotze & Meyers, 2016; Carpenter et al., 2005; Davidson et al., 2013; Marshall & Marshall, 2007; Cumming et al., 2005; Cutter et al., 2010; Shaw, 2009). Therefore, challenges remain to convert and quantify the concept of resilience into an operational tool. Resilience to flooding has been quantified using three parameters such as amplitude, graduality, and recovery rate (Brujin, 2004). Accordingly, the amplitude is defined as the severity of the effects of flooding and can be quantified as the expected average number of casualties per year. Graduality was defined as the increase in impact with the increasingly severe flood event showing disturbances in the relationship between runoff and damage that indicate the threshold and possible occurrence of disasters. The recovery rate is defined as the recovery capacity of the system, which is quite quantitative.

Gersonius (2008) has further developed the above framework. The indicators included in the modified framework are reaction threshold, amplitude, graduality, and recovery rate. Cumming et al., (2005) have also defined resilience as the capacity of the system to maintain its identity in the face of internal changes and external shocks and disturbances. Accordingly, three factors have been proposed to describe resilience as follows.

- (1) Components of the socio-ecological system
- (2) Relationships between components
- (3) The ability to maintain the relationships of components in space and time

Bennett et al., (2009) introduced a four-step approach. The first step is to identify the problem or analysis criteria. The second step was to look for important feedback processes. The third step is to map the system by defining its analytical limits. They also demonstrate that the key elements and the links between them, as well as the feedback process of a system, are contained in a resilient system. It is therefore important to identify the components and processes of the system to describe resilience. The fourth aspect is the quantification of resilience and they have suggested that this can be done by looking at changes in the slow variables that control the location and its thresholds.

Robustness is the ability of the system to remain functional during a disturbance despite the variables and uncertainties of the disturbance (Mens et al.,2011). Mens et al., (2011) presented a conceptual framework for analyzing the robustness of the system and suggested how robust the flood risk is the systems, this idea can be quantified and tested on the West Scheldt flood risk system in the Netherlands. The proposed system examines response and recovery over a range of disturbances and describes the response curve using the four characteristics: threshold of resistance, the severity of the response, Biggs et al., (2012) also identified seven criteria to describe the resilience of Socio-Ecological Systems (SES). Are diversity, connectivity, slow management of variables and feedback, understanding as complex adaptive systems, experimental, participatory, and polycentric.

Zurich Flood Resilience Alliance has put in place a framework based on a holistic approach to assessing the community's flood resilience (Keating, 2017).

2.7.8.2 Assessment uncertainty

Socio-ecological system highlights the capacity of a system to return to its original state before the disturbance. It also emphasizes the advancement of learning and adapting to such changes. (Adger et al., 2005; Folke, 2006). The main objective of the FRM is to reduce the consequences for the economy, human health, culture, and ecosystem. Achievements of flood risk management are to create ecologically, economically, and socially healthy communities, synergy among interdependent policy sectors, and clear responsibility division among the stakeholders (Dejan, 2018). Flood risk management strategies aim to manage flood risk by protecting and restoring the natural regulation of river basins, floodplains, and coasts. Consequently, the increase of spatial quality of the region due to the improvements of the local landscape and the ecology has also been emphasized as the achievement of flood risk management. Therefore, there will be potentials to create multiple ecosystem benefits of the watersheds with the operationalization of flood risk management (Hankin, 2017).

2.7.8.3 Challenges and way forward

There is a strong relationship between flood risk management and spatial quality. Therefore, achievements of spatial quality become a decisive ex-ante criterion of Flood risk management systems. The effectiveness of FRM measures and their assessment should be adjusted to fit into the local, geographical, and cultural values based on the location (Nillesen, 2015). Previous literature has highlighted the significance of co-design the management goals and the objectives to improve the spatial quality in flood risk management considering the local commitment and political commitments (Heeres et al., 2016; Lamers et al., 2010; Van Dijk, 2011; Von Korff et al., 2012). However, the

degree of resilience that is required has not been addressed yet (Brujin, 2004). Research has been largely ignored on how spatial quality can be successfully achieved in practice as part of flood risk management strategies (Busscher, 2019). Therefore, stakeholders in any government context should consider the acceptable level of risk and the variety of strategies that can be used to effectively achieve flood risk management and spatial quality.

2.8 Current Status of the Flood Risk Management

The current status of knowledge related to flood risk management has been analyzed under each component of the flood risk management under three aspects.

- Conceptualization of uncertainty – incorporation of uncertainty and how literature has been characterization the term
- Assessment – how stakeholder integration is used to assess the resilience associated with each component
- Management – current strategies for bringing socio-ecological resilience theory into practice

The understanding and application of flood resilience based on understanding the above three key areas were analyzed. The results highlights in Table 2.1.

Table 2.1 Critical Component of the Flood Risk Management

Component of the system		Conceptualizing of uncertainty	Assessment of uncertainty	Managing of uncertainty		
Consideration of impacts	Flood risk	Nonlinear effects	The socio-ecological systems analysis tool	Stakeholders Knowledge Participation of Stakeholders	Decision support tools(methodological framework for structure the decision-making process)	
	Objectives	Utilization of synergies between land and water.	Participatory assessment tools			
	Management options	Multifunctional and flexible solutions.	Modern Portfolio Theory (MPT)			
	Assessment of risk	Who gains and who loses of cost and benefits of the FRM	Multi-criteria decision framework and application of fuzzy theories			
Assess the impacts	Evaluation goals	Improving spatial quality & future development opportunities through strategic spatial planning	Optimization of synergies across management practices.	Frameworks for Participation of Stakeholders Fit the Local Values, Geographical and Cultural Context.		
	Evaluation strategies	Wide range of scenarios.	Joint evaluation of adaptation tipping points.			
Practice FRM	Development of guidelines	Dual goals of sustainable land use and better flood control	Participatory tools			
	Achievements of objectives	Spatial quality Adaptive governance	Participatory tools			

In light of socio-ecological system understanding, the decision-makers of flood risk management have recognized the need to deal with complex interdependencies between social and hydrological systems (Pahl-Wostl, 2007; Tempels, 2016). The focus of socio-ecological system thinking is on the system as a whole, and the scholars argued that all elements of the socio-ecological system evolve not only on their own but also through their interactions with one another (Berke P. R., 2000; Davoudi, 2012; Welsh, 2014). The concept of social-ecological systems highlights that the flood risk management systems are comprised of complex, non-linear, and constantly changing socio-ecological interactions and hence the conditions of a flood risk management system will change in the future. Understanding of the non-linearity and non-stationarity of flood risk management systems has stressed that the emergent is an inherent character and that cannot be easily predicted by looking at the constituent parts. Therefore, scholars have questioned how decision-making processes should take complexity into account in the planning process.

Achieving the objectives of flood risk management rests on an understanding of the non-linear dynamics of a system (Steen & Ferreira, 2020). The shift from structural flood protection to a risk-based approach followed by a more holistic system approach was triggered at the beginning of this century (Folke et al., 2010). Therefore, scholars have questioned how decision-making processes should take complexity into account in the planning process. It was debatable how to define the objective and the strategies of flood risk management due to the context of planning is changing at a very fast pace.

The context of planning is also involved by many stakeholders and defining the objectives and outcome of the flood risk management system are therefore uncertain. It has been recognized that there is a need for more flexible policies and strategies to be incorporated into the decision-making processes to deal with the complexity and the uncertainty inherent in changing physical and social components and the interactions of flood risk. In this way, quantifying and acknowledging the uncertainty associated with flood risk is a

guide aspect for decision-making of flood risk management (Sayers et al., 2015). Socio-ecological Resilience thinking has challenged the predictability of change, and the understanding that resisting change to maintain stability.

Therefore, resilience stresses the need for measures to cope up with a wide range of flood probabilities including frequent and rare flood events. Socio-ecological resilience has stressed that societies should adapt to live with floods and prepare for the disastrous consequences while do not seek to avoid them entirely (Pahl-Wostl, 2007). Moreover, it has been questioned how to increase the adaptive capacity of the social system to cope up with the uncertainty. The concept of the social-ecological system highlights the accept uncertainty and considers it as an opportunity for further development. Therefore, more consideration was paid for flexible strategies, diverse flood risk management measures, and measures for preparedness.

Resilience theory facilitates the development of multiple interpretations of change in a system. Therefore, the concept facilitates the identification of alternative narratives on equilibrium dynamics to maintain the stability of a system. Changes in the spatial form may influence the changes in both hazards, exposure, and vulnerabilities. The alternative narratives are required to assess for distribution of cost and benefits among the stakeholders. There was an urgent need to identify and implement cost-effective adaptation strategies in the urban context, including the use of no-regret measures with net social and economic benefits. Therefore, the main emphasis of operationalization of flood risk management is meant to increase the net welfare of a community.

Therefore, it is important to find the right balance of management measures and land uses of floodplains to avoid stakeholder conflicts at present and in the future. Further, the planning process of flood risk management has been recognized as a technical and political process. Therefore, the planning process of flood risk management has become a flexible framework that is based on the co-production of stakeholders' objectives rather

than a process based on fixing an end state. As highlighted in Table 2.1, the critical component was the determination of what are the objectives of the flood risk management system? who should be considered, and what are their roles? Therefore, identification and evaluation of objectives, strategies, and guidelines have become a critical aspect for implementation. Moreover, the practical meaning of the “flood risk management system” has been questioned.

2.9 Interplay between Spatial Planning and Flood Risk Management

2.9.1 Spatial planning and flood risk management in the early period

In early periods, the water became the determining element of spatial transformation (Woltjer, 2009). Water was considered technically controllable and adaptable after the industrial revolution. Flood control infrastructure measures were key factors that strongly contributed to the concerns of a built environment. In many countries, spatial planning was a component in the sector planning hierarchy. In the early periods, spatial planning measures were not adequately recognized for flood risk management (Wolsink, 2006). The interest in planning measures for flood management surfaced mainly after the 1950s. Traditionally, spatial planning discouraged incompatible land uses in flood risk-prone areas by applying controlling measures (Burby, 2000; Godschalk et al., 1999; Howe & White, 2002; Filatova, 2014). Spatial planners are also continued to assume that flood conditions with certainty. Hence, traditional spatial planning measures were also based on the engineering consideration of flood events and systems. The design of spatial planning measures was also based on static limits of floodplain development and such measures could cope up with only certain flood events (Miller, 1999; Burby et al., 1988). In the past, spatial planning was often narrowed down within flood risk management as a regulatory instrument which used to regulate land-use change in flood-prone areas (Hutter, 2007; Neuvel & Van Der Knaap, 2010).

2.9.2 Limitations of traditional spatial planning practices

Flood risk management measures were evaluated mainly using the economic criteria. Hence, very often priority was given to the economical uses of floodplains instead of reserving large areas for water retention and conservation. As a consequence, planning measures encouraged rent-seeking behavior among landowners and caused “windfalls and wipe out effect” (Mills, 1989). Many environmental costs remain external to developers and create tension between floodplain conservation and floodplain land-use development (Ward, 2013). Therefore, the planning policies and regulations did not accommodate the safeguarding of wellbeing of the urban poor and failed to break a vicious cycle of flood risks which is common in most cities in the global South (Dowall & Clark, 1996). Intensification of the flood risk particularly in urban areas will increase at a higher rate in the coming decades because the majority of population growth will take place in urban areas (United Nations, 2008). This rapid urban population growth will increase the development pressure and demand for the overuse of floodplains due to scarcity of land (Larsen, 2000; De Moel et al., 2011). Therefore, the planning process is needed to recognize the socio - spatial-temporal relations and their feedback loops of flood risk (Zevenbergen, 2008).

The traditional spatial planning measures also did not accommodate the dynamic and nonlinear and non-stationary nature of flood risk. Spatial planners have misconstrued the complex and dynamic nature of flood risk. Burby and French (1981) examined the performance of land use management programs to protect floodplains. They argued that the factors that encourage the adoption of floodplain management programs also stimulate interference with the flood hazardous area, which in turn limits the usefulness of the program. Therefore, they have proposed that the local context, relevant stakeholders, and their conflicts between development interests and regulatory restrictions should be taken into consideration in designing the floodplain land uses. Therefore, spatial planners and flood managers recognized that it is difficult to meet the increasing demands for flood risk

management only relying on structural and command and control measures. Flood risk planning systems are increasingly demanded integration mainly with spatial planning.

2.9.3 Integrating of flood risk management and spatial planning

2.9.3.1 Spatial planning for integration

Integration is one of the fundamental features of spatial planning. Integration has become a part of the orthodoxy of spatial planning. Spatial planning adopts a holistic and collaborative approach that tries to synchronize diverse spatial demands of different sectors such as economic, housing, recreational, conservation, etc. Spatial planning is a collaborative process that attempts to position the diverse land use activities such as housing, agriculture, recreation, or industry in the landscape considering the desired and undesired outcomes in the future. Accordingly, spatial planning became a process that controls the spatial transformation considering the concerns and objectives of diverse groups in society. Moreover, the integration of sectoral policies is frequently considered as one of the main objectives of contemporary spatial planning (Stead & Meijers, 2009). Also, spatial planning can manage the spatial transformation processes considering the multi-scalar drivers (Jean-Baptiste, et al., 2013).

2.9.3.2 Spatial quality

Spatial planning is coordinating spatially-oriented planning at all spatial scales—from the national down to the community level and seeks to influence the future distribution and pattern of activities based on their location. Therefore, spatial planning can balance and integrate spatial claims of diverse stakeholders such as water retention and residential development to achieve spatial quality (Healey, 2006). The role of the planning process is to find the best possible mutual adjustment of space and society, and the creation of multifunctional land uses and a high level of spatial quality (Van den Broeck, 2005;

Nijland & Menke et al., 2005). After the 1990s spatial planning, the process has also transformed its role. It has given a high emphasis on spatial integration, which means creating an added value or coherent outcome on a space by joining different spatial claims, land uses, and functions (Hillier, 2011; Albrechts et al., 1999).

2.9.3.3 Role of spatial planning in flood risk management

Flood risk management is about dealing with outcomes, which are the combination of the probabilities of an event and the impacts associated with that event (Sayers et al., 2002). This can be predominantly done through optimization of the functioning of the existing system, increasing transformative capacity leads to a situation in which the functioning of the system is improved by system innovation. Land and water are inextricably linked with each other (Defra, 2004; Neuvel & Van den Brink, 2009). Operationalization of flood risk management is required to maintain the balance between land and water.

Operationalization of flood risk management means designing the floodplains' land uses that minimize flood risk to an acceptable level and avoid adverse impacts elsewhere. Organization of floodplain land use is the most effective way to manage the flood risk. Therefore, spatial planning can be used to reduce flood vulnerability and exposure by managing the development of flood-prone areas, directing the migration of development to relatively fewer risk areas, re-zoning of land use activities, and promoting natural-based water detention (Porse, 2014; Cheong, 2011; World Bank, 2017). Flood risk management is highlighted in consideration of flood risk in coherence with other land use functions in urban areas which include housing, recreation, etc. (Scott et al., 2013).

Furthermore, it was recognized that flood management strategies should be integrated into spatial transformation to achieve the overall social development objectives. It has been further stressed that the flood management system needs to encompass integrated and flexible governance solutions that can respond to the complex feedbacks (Tendayi, 2011).

Spatial planning can lay a foundation for long-term forward-looking risk reduction primarily through reducing exposure to natural hazards. For example, floodplain's land uses are required to arrange to reduce the flood vulnerability in different scenarios (Meijerink, 2008). Moreover, spatial planning has been recognized as a tool to balance and integrate spatial claims of diverse stakeholders such as for water retention and residential development to achieve spatial quality (Healey, 2006). Spatial planning has become a tool to increase the coping capacity, recovery capacity as well as adaptive capacity of the socio-ecological system (Hutter, 2007; Neuvel & Van Der knap, 2010). Fleischhauer (2008) has been highlighted in managing flood risk by influencing urban structures. The urban structure is understood in three ways.

- 1) Physical/environmental structure
- 2) Socioeconomic structure
- 3) Institutional structure

Implications of flooding, as well as flood risk management measures, affect a broad range of sectors and stakeholders at different spatial scales (Galderisi et al., 2014). Therefore, flood risk management practices are also required to design equal distribution of cost and benefits of the management practices among stakeholders. It was recognized that the flood risk management strategies should be integrated into spatial transformation to achieve the overall social development objectives (Scott et al., 2013). Spatial planning has considered the flood risk encompassing the physical and socio-economic processes.

Also, above, Spatial planning, as a collaborative planning tool has been highlighted for providing opportunities to stakeholders to find out the integrated and adaptive strategies. Flood risk management became one of the key components of spatial planning (Biesbroek et al., 2009). Evolutionary resilience has pointed out the importance of spatial planning for managing the uncertainty incorporated with flood risk. Moreover, managing the uncertainty associated with flood risk has become a crucial aspect of flood resilience.

Assessment of the plural perceptions among stakeholders on co-evolved interdependencies between land and water and their spatial relations have been recognized as important factors for the operationalization of flood risk management. A greater understanding of cross-sectoral relationships between land and water has been emphasized over time. Hence, the consideration factors associated with traditional flood risk assessment have also been questioned. Spatial planning is also able to resolve disagreements among the stakeholders. For example, when ambiguous uncertainty is drawn into the planning situation, there is a possibility to reframe the problem situation through the interactive co-construction process or joint fact-finding (Abbott, 2005; Brugnach et al., 2008; Schenk et al., 2016; Susskind & Field, 1996). Integration of spatial planning has three dimensions such as territorial, policy, and institutions (Jing Ran, 2016). Therefore, the amalgamation of flood risk management and spatial planning is determined by the three generic factors such as planning process, planning context, and the planning outputs (Lyles, 2014).

2.9.3.4 Transformation of role of spatial planning in flood risk management

Currently, the use of land use planning in flood risk management is increasingly recognized (Jong & Margo van den Brink, 2013). In the context of climate change, the integration of land use planning into flood risk management as a flood risk reduction approach has gained in importance (Ran, 2016). With this understanding, the role of land use planning changed and became more important in terms of resilience to floods. As a result, flood management has become part of spatial planning (Biesbroek et al., 2009). As a result of this understanding, the role of land use planning has changed and has become increasingly important in dealing with resilience to floods. Spatial planning has greater potential to operationalize flood risk management, and the use of spatial planning in flood risk management is increasingly recognized (Jong & Margo van den Brink, 2013).

2.9.3.5 Operationalization of flood risk with spatial planning

The practice of flood risk management is the interpretation of the basic principles of governance into the flood risk planning system. This includes the complex network of stakeholders, policies, rules, methodological processes that deal with how relevant risk information is collected, analyzed, and communicated and decisions are made (Renn, 2011). Though adaptive management has not yet been widely integrated into applied spatial planning. Presently, spatial planning plays only a minor role in flood risk management. The flood managers and spatial planners had become extremely demanding for integration at both policy-making and implementation levels. The transformation of policymaking dimensions towards action dimensions is a challenging task. However, in both levels of flood management and spatial planning, there is a need to define a common framework to be reciprocally influenced and effective. Moreover, operationalizing flood resilience and the cooperation between water managers and spatial planners is still not a common practice.

It is largely evident that as at present, the role of spatial planning in flood risk management remains inadequate mainly because of the absence of a common framework for the planning process (Herath & Wijesekera, 2019). A greater understanding of cross-sectoral relationships between land and water has been emphasized over time. In this circumstance, it is questioned how to distribute the role and the responsibilities of the stakeholders' questions about the involvement of local stakeholders and their role in the policy-making process. In these circumstances, two questions have been raised. The first question is how to distribute the role and responsibilities of stakeholders such as spatial planners, water managers, etc. The second question is how to define the involvement of local stakeholders and their role in the decision-making process. As a result, the effectiveness of the spatial planning process including the institutional structure was further questioned for flood resilience (Carreno et al., 2007).

The compartmentalization of water managers and spatial planners has prevented the integration of spatial planning and flood management practices (Wiering & Immink, 2006; Wheeler & Evans, 2009; White, 2010). The effectiveness of resilience strategy making is sensitive to social context including socio-economic pressures, institutional capacities, and how resources and power get distributed within the stakeholders. However, the knowledge needed to design these collaborative planning tools is still lacking. Therefore, it is necessary to question the designing factors of multi-stakeholder governance for the legitimacy of flood resilience. Therefore, it is useful to identify criteria that are sensitive to the governance contexts that are aimed to improve the adaptive capacity of FRM. The absence of success criteria complicates not only for evaluation but also the designing of collaborative planning processes in this context. As a result of these changes, flood risk management also moved towards the recognition of the need to incorporate systematic spatial planning as a strategy in the management frameworks (Immink, 2005).

2.10 Challenges for Operationalization of the Flood Risk Management System

The risk of flooding must be accepted and adopted to develop a resilient strategy. By adaptation, researchers have highlighted any change in social systems in response to the actual or expected effects of flooding (Doroszkievicz, 2017). The adaptability of the planning process is presented in two ways (Li, 2016; De Bruijn, 2005). The practice of FRM includes content-oriented measures to find strategic alternatives for distant futures. The content focuses more on scenario analysis and finding strategic alternatives is an effective way to generate new ideas for long-term FRM. Process-oriented approaches include mobilizing a limited number of stakeholders and legitimizing the planning process (Hutter, 2007). The operationalization of flood risk management is determined by the conceptualization and assessment of flood risk management by stakeholders and the potential of the decision-making process and the context for developing integrated and adaptive management strategies.

2.10.1 Stakeholders' plural understanding on interdependencies of land and water

There is a fundamental difference in the perceptions of engineers and spatial planners in characterizing the interactions of flood risk management (Wiering, 2006; Lawrence, 2013). Accepting flood risk means breaking down stakeholders' perceptions of flood control. The idea of 'water as the guiding principle' in the spatial transformation process has been criticized by several spatial planners. They have argued that the focus is too much on the water in spatial transformation. Further, they have suggested water as 'one of the guiding principles in spatial transformation (Voulvoulis et al., 2017). There are plural views among the public as well as private stakeholders on flood risk, vulnerability, and resilience. As a result, there are diverse strategies and processes for risk management. Therefore, plural understanding of stakeholders on the interdependencies between land and water is one of the key challenges for the operationalization of flood risk management.

Understanding the plural perceptions among stakeholders based on the interdependencies between land and water and its spatial relation for flood resilience has been recognized as one of the key challenges. Therefore, stakeholders' understanding of land and water interdependencies associated with flood risk will enhance the successful implementation of diverse flood management measures. Therefore, flood resilience is a context-specific characteristic which generally depends on the aspirations of stakeholders and their identical values, core values, and worldviews (Folk, 2010; Driessen, 2016).

2.10.2 Public indifference to natural disasters

Public indifference to natural disasters is also another major challenge for the operationalization of flood risk management. Many local officials, communities, and politicians have often given low priority to collaborative planning as a strategy to reduce flood risk (Burby, 2003). Incorporation of hazard mitigation into the local planning is

determined mainly by state planning policy context and hence the local community, their capacities and potentials are inhibited in the planning process (Burby, 2003).

2.10.3 Territorial development

Flood risk management has focused to select options that optimize the multiple objectives of stakeholders (Giezen, 2015). Therefore, strategy-making is based on integrative concepts that encompass many stakeholders and ask for collaboration at local to regional levels which is aimed at an efficient and balanced territorial development (Tempels & Hartmann, 2014).

2.10. 4 Institution culture

Integration of stakeholders in decision making is varied greatly according to the aspirations of stakeholders, institutional culture, the level of political decentralization, and the fashion for public consultation (Sayers., 2013; Lyles, 2014; Harries, 2011).

2.10.5 Shared dilemmas in the planning process

One of the challenges of operationalizing the FRM system is common dilemmas (Berk, 1998). State governments often have more incentives to promote local mitigation planning than lower-level governments are required to participate in mitigation planning. However, the inclusion of risk reduction in local planning is primarily determined by the context of state planning policy, characteristics of the local community, and characteristics of the planning process (Burby, 2003). Excessive reliance on expert-led top-down planning, structural flood protection measures, and “hard” technical solutions is another challenge for operationalizing flood risk management practices. Moreover, it is recognized that fragmented approaches to risk management are not optimal and that integrated

management increasingly requires the operationalization of flood risk management (Merz, 2010).

2.10.6 Lack of political support

Lack of political support at the local level is also another major challenge for this (Wilson, 2006). Many local officials, communities, and politicians often give low priority to collaborative planning as a strategy to reduce flood risk. The cost of mitigation measures is immediate, but the benefits are long-term and uncertain and cannot occur during the term of elected officials. As a result, flood management has a weak public constituency (Burby, 2003). As a result, there are standalone hazard mitigation plans and the spatial plans at the local level do not often contribute to disaster management (Berke, 2014). The operationalization of flood resilience is based on the level of political decentralization and the fashion for public consultation (Harries, 2011).

Another limitation is the lack of government incentives for autonomous adaptation to the local community. Besides, individual communities and market forces can make land-use decisions that have collectively increased the risk of flooding, while the costs of adaptation and land scarcity are left to governments (Filatova, 2013). Socio-ecological systems thinking recognizes the limits of over-reliance on top-down, expert-led planning, and “hard” technical solutions for flood risk management. It is also recognized that fragmented governance approaches are not optimal for risk management. Integrated management therefore increasingly requires the operationalization of flood risk management (Merz., 2010).

2.10.7 Over-reliance on top-down planning

Implementation of a diversified set of flood risk management strategies in a certain area is only possible if these strategies and their coordination are seen as legitimate, effective,

and efficient in their physical and social context (Hegger, 2014). Many local officials, communities, and politicians often give low priority to collaborative planning as a strategy to reduce flood risk. The cost of mitigation measures is immediate. But the benefits are long-term and uncertain and cannot occur during the term of elected officials. As a result, flood management has a weak public constituency (Burby, 2003). As a result, there are stand-alone hazard mitigation plans and the spatial plans at the local level do not often contribute to disaster management (Berke, 2014).

2.10.8 Lack of flexibility of planning process

Flood risk management should take into account what is happening in a social context and when formulating and implementing strategies. Stakeholder engagement and public participation in the planning process have been observed as one of the central aspects of flood risk management (Huiteima, 2009). The capacity for transformation and organization is important for the operationalization of flood risk management. However, the level of exercise of FRM depends on the level of availability and how resources and power are exercised in the governance system (Davoudi, 2012; White & O'Hare, 2014). There should be potential for expanding the roles of stakeholders and creating a common governance framework. The flexibility of the planning process makes it possible to control the socio-spatial dynamics of the flood risk. The inclusion of the public and other interest groups in the FRM system will lead to increasing adaptability of socio-ecological systems. The inclusion of risk mitigation in local planning is mainly determined by the context of state planning policy and, therefore, the local community, its capacities, and potentials are inhibited in the planning process (Burby, 2003).

2.10.9 Planning context

Contextual factors, such as defining the local social relations in the planning process are also influenced by the operationalization of flood risk management (Healey, 2003; Healey,

1997). The involvement of private stakeholders with the public sector is strongly dependent on the political and constitutional tradition of a state (Keessen, 2013).

2.10.10 Flexibility of governance system

The presence of stakeholders' adaptive perception is insufficient to implement flood resilience strategies. It has been underlined flexibility of the governance system is also an important aspect for defining the adaptability of the planning process (Folke et al., 2010). Stakeholder engagement and public participation in the planning process are seen as one of the central aspects of flood risk management (Huiteima, 2009). Operation of this concept means translating the basic principles of governance into the flood risk planning system. Operationalization Flood risk management is recognized as an independent form of flood risk control. Flood risk governance arrangement represents the stakeholder networks, resources, discourses, and multilevel coordination mechanisms through which flood risk management is pursued (Alexander, 2016). Flood Risk Governance Arrangements (FRGA) has defined as an interplay between actors and actor coalitions involved in all policy areas relevant for flood risk management including water management, spatial planning, and disaster management; their dominant discourses; formal and informal rules of the game; and the power and resource the base of the actors involved (Hegger, 2013; Hegger, 2014; De Bruijn, 2005).

Management of flood risk is governed by the definition of institutional arrangements, their central interactions, and the power and resource base of decision-makers (Hegger et al., 2014; de Bruijn, 2005; Höllermann, 2019; Bodde, 2018). Therefore, lack of adaptive capacity of the institutional process became a central challenge for the operationalization of flood resilience (Chaffin et al., 2014; Folke et al., 2005; Pahl-Wostl et al., 2007; Restemeyer et al., 2018; Norberg & Cumming, 2008; Biggs et al., 2009). In particular, this alternative mode questions the prevailing hierarchical relationships and the legitimacy of the actions. Moreover, the network governance mode in particular is argued to offer the

potential to form horizontal and interdependent mutual stakeholder relationships for communication and knowledge exchange under conditions of uncertainty and complexity (Keast, 2016).

2.10.11 Lack of participatory governance tools

The implementation of a diverse set of flood risk management strategies in a given area is only possible if these strategies and their coordination are considered legitimate, effective, and efficient in their physical and social context (Hegger, 2014). The involvement of private actors in the public sector strongly depends on the political and constitutional tradition of a state (Keessen, 2013). The ability to transform and self-organize the FRM planning system depends on how resources and power are exercised in the governance system (Davoudi, 2012; White, 2016). The operationalization potential of flood risk management is determined by the configuration of actors (authorities, private and civil society), the distribution of power, and institutional structures (Driessen, 2012).

Consequently, it can be interpreted that the characteristics of the governance structures stakeholder groups, social learning, networks, organizations, institutions, incentives, political and power, or ethical relationships improve or undermine the operation of the risk management system (Folke, 2010; Alexander, 2016). Therefore, the operationalization of FRM is challenged due to the absence of stakeholder networks, rules, resources, discourses, and multi-level organization mechanisms through which FRM is pursued. There has been little research explicitly examining the role and implications of participatory decision-making in flood risk management (Buchecker, 2013; Pahl-Wostl, 2006). This change has questioned the established responsibilities of spatial planners and flood managers (Tempels & Hartmann, 2014). Another limitation is the absence of government incentives for autonomous adaptation to the local community. Moreover, this will allow individual communities and the market forces to make land-use decisions which

has collectively led to increasing the flood risk while leaving the costs of adaptation and land scarcity with governments (Filatova, 2013).

The potential for operationalization of flood risk management is determined by the configuration of actors (public authorities, private and civil society), distribution of power, and institutional structures (Driessen, 2012). Although the capacity for transformation and self-organization of the planning system of FRM depends on the way resources and power are exercised in the governance system (Davoudi, 2012; White, 2016). The involvement of the public and other stakeholders in the FRM system will cause the increasing adaptability of social-ecological systems. The involvement of private stakeholders with the public sector is strongly dependent on the political and constitutional tradition of a state (Keessen, 2013). Implementation of a diversified, resilient, set of FRM systems in a certain area is only possible if these strategies and their coordination are seen as legitimate, effective, and efficient in their physical and social context given the possibilities and limitations (Hegger, 2014).

There is little research that explicitly examines the role and effects of participatory decisions in flood risk management (Buchecker, 2013; Pahl-Wostl, 2006). The implementation of a diverse set and resiliency of FRMS in a certain area is only possible if these strategies and their coordination are considered legitimate (Hegger, 2014). The integration of flood risk management and land use planning is determined by the three generic factors such as the planning process, the planning context, and the planning results (Lyles, 2014; Hutter, 2007).

2.11 Gap of the Current Status of Operationalization of Flood Risk Management with Spatial Planning

2.11.1 Variety of stakeholders

Operationalizing flood resilience means developing planning guidelines so that the system can cope with changing circumstances. Flood resilience indicates that the system is

adaptable but essentially maintains the same system. It is generally recognized that the integration of water management and land use planning is necessary for the operationalization of flood risk management (Hartmann & Driessen, 2017; Pahl-Wostl, 2007; Wiering & Immink, 2006; Woltjer & Al, 2007). Different flood management strategies and stakeholder integration are considered central aspects of the framework for operationalizing flood risk management (Huiteima, 2009; Edelenbos, 2017; Ishiwatari, 2019). A central challenge for the operationalization of the FRM is to balance the many competing uses and users of floodplains to guarantee the needs of all the actors involved and at the same time guarantee a healthy and diverse ecosystem and security against floods (Basco-Carrera, 2017). The operationalization of the FRM system refers to the development of a common definition of problems, the establishment of common objectives, and the discussion of strategies based on the combined means and objectives of all parties involved through the exchange of information. Interests and also common learning (Van Herk, 2014). Therefore, FRM is a process that creates consensus among stakeholders when knowledge is incomplete. Strengthening the social skills of interest groups has been identified as an essential means of increasing the resilience of society to natural hazards (Adger, 2005).

2.11.2 Stakeholder participation

Stakeholder participation in water management can serve as a tool for achieving sustainable development (Abbott & Jonoski, 2001; Edelenbos, 2006). There is a lacking of research implementations to gain a better understanding of the required governance arrangements (Hegger, 2014). Moreover, there are no criteria to identify the stakeholders to be incorporated into the planning process (Becker, 2015). However, operationalizing flood resilience and the cooperation between water managers and spatial planners is still not a common practice.

Consequently, spatial planning, as a collaborative decision-making tool requires the providing of opportunities to stakeholders to find out the integrated and adaptive strategies for operationalization of flood resilience. It also shows the limits of spatial planning and calls for an integrated approach including a variety of authorities to dealing with multi-hazards. We are still a long way from putting integration into practice (Watson & Adams, 2010; DCLG, 2012). This change has already challenged the established governance. Some questions are still debatable such as what is to integrate and who the stakeholders are in the planning process (Biswas, 2004; Mostert Erik, 2006). Moreover, the decision-makers are questioning who and whose interests should be considered in the decision-making process (Tyler, 2012). As a result, developing an integrated framework to operationalize the concept of flood risk management would be a major development in FRM (Zevenbergen, 2016; Morrison et al., 2018). In this circumstance, it is questioned how to distribute the role and the responsibilities of the stakeholders' questions about the involvement of local actors and their role in the policy-making process.

2.11.3 Joint definition

Operationalization of flood risk management has required the provision of opportunities for stakeholders for collaborative and adaptive planning mechanisms which allow stakeholders to actively participate in the decision process and implementation considering the long-term impacts on them. The success of the operationalization of FRM relies on how management strategies are delivered, both in terms of the design of strategies and the implementation process. Interactive decision-making is expected to result in better-off flood management options that can be implemented more efficiently and thus raise the democratic legitimacy of the decisions (Farrelly, 2009). The operation of flood risk management strategies largely depends on the organization of the governance system and the decision-making process (den Boer et al., 2019; Meng, 2019).

2.11.4 Absence of a common framework

One of the major reasons is the ill understanding of the practical implementation of flood risk management by the stakeholders (Bruijn et al., 2017). Practical implementation of flood risk management is determined by how stakeholders conceptualize flood risk, the consideration factors of the planning process, the available potential for design and implementation of the collective and adaptive decisions in the planning system. Moreover, operationalization of flood risk management is depended on how do stakeholders evaluate the flood risk management options considering the impact they have on each of the stakeholders. The adaptive capacity of the flood risk management system is represented through the consideration factors of the planning process and the available institutions, methods, and financing tools for collaboration and learning for stakeholders of each context. Moreover, practicing flood risk management requires interactive planning and collaborative actor relations and institutions (Hartmann & Driesen, 2013). Moreover, the decision-makers are questioning who and whose interests should be considered in the decision-making process (Tyler, 2012). As a result, developing an integrated framework to operationalize the concept of flood risk management would be a major development in FRM (Zevenbergen, 2016; Morrison et al., 2018).

Consequently, the operationalization of flood risk management questions land and water governance. Accordingly, the decision-makers have questioned the process of interaction between spatial planners and the water managers and how do they integrate the spatial dimension of land use issues and the water issue for preparation of guidelines of flood resilience. It is largely evident that at present, the role of spatial planning in flood risk management remains inadequate mainly because of the absence of a common framework for the planning process (Herath & Wijesekera, 2019).

There is a research inadequacy in the operationalization of stakeholder resilience concerning flood risk management. Consequently, decision-makers have realized that there are no objective criteria for verifying that all possible solutions to complex flood

problems (Ran & Nedovic-Budic, 2016; Meng, 2019). Currently, there are no guidelines to evaluate the planning process for the operationalization of a flood risk management system. However, the choice of definition and the appropriateness of interventions depend on the perspectives of the stakeholders rather than the use of some objective criteria. Furthermore, there are no criteria for identifying the institutional arrangements, the characteristics of the actors and their speeches, their current state, and the desired design to better understand the different contexts and prescribe the constellations (Becker, 2015).

2.11.5 Reframing planning

A review of the flood risk management literature found that there are only a limited number of case studies between spatial planning and flood risk management that examine the planning process in detail and procedure (Meng et al., 2020). This overhaul of the process of designing and implementing flood risk management policies and strategies has been an obstacle to many challenges, in particular governance. We can therefore conclude that the reformulation of the decision-making process is mandatory (Waylen et al., 2018; Warner et al., 2012; Evans, 2012). There is a lack of implementation of research to better understand the governance rules required for flood risk management (Hegger, 2014). Beyond this, there are no criteria to identify the stakeholders who should be included in the planning process (Becker, 2015).

Although there is no uniform and agreed definition of a planning framework. Most publications describe a framework as a way to encourage collaboration, share knowledge, define roles and responsibilities, and create an arena for continuous learning and policy development and change (Pahl-Wostl et al., 2013; Clarvis et al., 2014; Cosens et al., 2014). Therefore, there is a need to explore an operational framework for flood risk management that can be used as a common framework for all stakeholders. First, the role of a framework for operationalizing flood risk management was analyzed. Second, the

main criteria of the framework have been established. Also, the sub-criteria of the framework has been defined.

The development of an integrated framework to operationalize the concept of flood risk management would be an important development in FRM (Zevenbergen, 2016; Morrison et al., 2018). A review of the literature on flood risk management revealed that there are only a limited number of case studies that examine in depth the planning process, procedural interactions between land use planning and flood risk management, and the mandates of each sector (Meng et al., 2020). The process of drafting and implementing flood risk management guidelines and strategies has posed many challenges, in particular governance. It can be therefore concluded that a reformulation of the decision-making process is mandatory (Waylen et al., 2018; Warner et al. 2010; Evans, 2012).

2.11.6 Governance arrangement and participation of stakeholders

There is little research that explicitly examines the role and effects of participatory decisions in flood risk management (Buchecker, 2013; Pahl-Wostl, 2006). The operationalization of flood risk management strategies (FRMS) refers to defining and delineating the problem in a manner consistent with existing administrative expertise and political responsibilities (Daviter, 2017; Molenveld, 2019). The governance regime is increasingly becoming more comprehensive as it also includes the role of stakeholders, resource allocation, and speeches, the operationalization of flood risk management depends on the governance structure of each context in a given place. Implementations to better understand the governance arrangements required (Hegger, 2014).

Understanding the relationships between mandated stakeholders and their governance arrangements has formed a central part of the integration theory. Moreover, there are no criteria to identify the stakeholders to be incorporated into the planning process (Becker, 2015). Moreover, the selection criteria of stakeholders, their networking, defining the roles and responsibilities have become the key aspects for operationalizing flood

resilience. Therefore, it is useful to identify criteria that are sensitive to the governance contexts that are aimed to improve the adaptive capacity of FRM. The absence of success criteria complicates not only the evaluation but also the design of collaborative planning processes in this context. As a result of these changes, flood risk management also moved towards the recognition of the need to incorporate systematic spatial planning as a strategy in the management frameworks (Immink, 2005).

A review of the literature related to flood risk management showed that there is only a limited number of case studies that explore the planning process in-depth, procedural interactions between spatial planning and flood risk management, and the mandates of each of those sectors (Meng et al., 2020). It is clear that this transformation of design and implementation process of the flood risk management policies and the strategies has been a barrier with many challenges particularly governance therefore it can be concluded that reframing the decision making process is compulsory (Waylen et al., 2018; Warner et al., 2012; Evans, 2012).

2.11.7 Absence of guidelines

Currently, there are no guidelines to evaluate the flood risk management system for the operationalization of flood resilience. Moreover, there are no criteria to identify the institutional arrangements, actors' characteristics and their discourses, their current status, and the desired design, to better understand the different contexts, prescription constellations (Becker, 2015). Consequently, decision-makers have realized that there are no objective criteria for verifying that all possible solutions to complex flood problems (Ran & Nedovic-Budic, 2016; Meng, 2019). However, the choice of definition and the appropriateness of interventions depend on the perspectives of the stakeholders rather than the use of some objective criteria.

2.11.8 Adaptive capacity

The relationships between mandatory stakeholders and their governance arrangements have formed a central part in the operationalization of flood risk management. The governance structure includes the role of stakeholders, their discourses, and how power and resources are distributed in each context. Scoping of the FRM system is determined by the existing administrative expertise or the knowledge system and policy responsibilities (Daviter, 2017). Therefore, practicing flood risk management relies on the integrated and adaptive capacities of the planning process and the governance context (Hutter, 2007).

The adaptive capacities of the decision-making process are determined by how stakeholders conceptualize flood risk, the consideration factors of the planning process, the available potential for design and implementation of the collective and adaptive decisions in the planning system. The adaptive capacity of the decision-making system is represented through stakeholders' expected outcome of the flood risk management systems, expected outcome of the planning systems, and the consideration factors of the planning process and the available institutions, methods, and financing tools for collaboration and learning for stakeholders of each context.

2.12 Need of Research

The definition of flood risk has changed during recent years with the understanding of the dynamics of social, spatial, and temporal dimensions of flood risk. During the past years, the determinants of flood risk characterization, flood risk assessment, and management measures have been questioned (Sayers, 2017 De Bruijn, 2007, Hutter, 2007). There are two contradictory concepts evolved to define flood risk. Several scholars determined flood risk by using natural factors such as hydrology and climate while other groups of scholars determined flood risk as a socially constructed phenomenon that is interdependent on

natural and social factors. Decision-making based on the constructivist approach has highlighted that the land use development over floodplains is a key factor for the increase of flood exposure and flood vulnerability. It has further highlighted that the changes in exposure and vulnerability can lead to variations in flood risk. Thus, flood risk and flood vulnerability are conceptually described differently over time, and in recent decades, flood risk has been described with non-linearity, non-stationarity of flood risk (Klijn, 2015; Brikholz, 2014).

Land and water systems are intensely connected. There are multiple stakeholders related to these complex interactions and they operate their decisions actively in an environment (Merz, 2010). The decision networks of all these stakeholders are interconnected with each other. The planning process of FRM is a complex process that involves multiple stakeholders each with their objectives. There are multiple interpretations for land and water relationships and therefore, uncertainties are inherent in the decision-making process. Moreover, the objectives and the outcomes of the decisions of FRM are being challenged by the absence of a common methodological framework for an effective influence on all stakeholders (Medema, 2014). The Analytic Hierarchy Process (AHP) is a multi-criteria analysis technique that can be applied for the structuring of complex decision-making problems involving multiple stakeholders and scenarios. Therefore, the Analytical Hierarchy process can be used as a tool to develop a solution model for structuring the complexity of flood risk management and increase the certainty of the objectives of stakeholders.

The concept of risk-based flood management is evolving and the literature review has highlighted that the operationalization of the FRM system is still not a common practice. The practice of flood risk management strategies largely depends on the decision-making process among mandated stakeholders as well as the organization of the governance system of the context (den Boer et al., 2019; Meng, 2019). After reviewing the literature, it became clear that there is currently little research available that allows for systematic

study on resilience frameworks and indicators. (Disse et al., 2020). Still, there is much more to understand about the conditions and factors which enable the Flood risk management system to be integrated and adaptive. There is no single, consensual definition of what constitutes a framework. The main objective of this research is to develop a systematic approach as an operational framework for the management of flood risks. In addition, this framework will be a methodological framework to be used as a common framework for all stakeholders to achieve flood resilience.

CHAPTER 3 - METHODOLOGY

3.1 Development of a Framework

Risk-based decision-making in FRM is a complex process. Frameworks provide a logical, analytical base to explore and structure the problem conditions. A framework is an elementary structure used to describe complex issues. Frameworks help decision-makers to have solutions for problems and better maintain those solutions. Frameworks of decision making are “cognitive representations of the problem situation by stakeholders”. A framework can be defined as a structure of rules or ideas (McMeekin, 2020).

Table 3.1 Classification framing of complex problems

		Uncertainty about scientific knowledge	
		Certain	Uncertain
Consensus	Agreement	Structured	Semi-structured
	Disagreement	Semi-structured	Unstructured

Source: Hommes (2008)

As shown in Table 3.1 above, complex issues can be classified as structured, semi-structured, and unstructured. Unstructured decisions are characterized by a lack of scientific knowledge and differences of opinion among stakeholders. Developing a framework for a complex, unstructured problem with many disagreements often requires multiple iterations. McMeekin et al., (2020) pointed out that the methodological frameworks were developed using a variety of approaches. They have been highlighted that there are eight different approaches used for developing a methodological framework and those approaches are summarized in Table 3.2. There is no formal definition or the finest pathway that should be used to develop a robust methodological framework (McMeekin et al., 2020). Although there are no prescribed guidelines on how to develop

a methodological framework, this scoping review found a consensus on the approaches used, which can generally be classified into three stages: (a) collection data to support the methodological framework; (b) development of the methodological framework; and (c) validate, test and refine the methodological framework. As highlighted in Table 3.2, some research works have been followed refining and validating approaches for the development of frameworks (McMeekin et al., 2020). These studies have used different techniques for refining and validating the framework, such as piloting the framework (Tappenden, 2012), Delphi technique, using case studies (Rodgers, 2016; Stremke, 2012; Reed, 2013).

Table 3.2 Approaches used for the development of methodological frameworks

Reported approaches	Percentage (%)
Based on existing methods and guidelines	66.7%
Refined and validated	33.0%
Experience and expertise	30.0%
Literature review	26.7%
Data synthesis and amalgamation	23.3%
Data extraction	10.0%
Iteratively developed	6.7%
Lab work results	3.3%

Source: McMeekin (2020)

3.2 Development of a Decision Making Framework in Flood Risk Management

Flood risk management is a complex process. This complex process is characterized by strong competition between different groups of stakeholders and the presence of different objectives. Increasing the complexity of flood risk management demands a decision-making process be integrated and adaptive. Participatory and collaborative modeling helps characterize the relationship between stakeholders in the planning process and manage the resulting ecological, economic, and social impacts that influence stakeholders. The literature has rarely examined the methodological approach of risk management and the building of social capacities and increasing societies' resilience towards natural hazards (Höppner, 2012). In flood risk management, the stakeholders are required a methodological framework to reach a common consensus regarding the evaluation of flood risk management options considering the socio-spatial and temporal dynamics of flood risk. Moreover, the adaptive and integrated planning process could manage conflicts among stakeholders as well as knowledge uncertainties associated with the planning process (Haasnoot, 2013). The conditions and processes of developing a methodological framework for the adaptive planning process in flood risk management are known insufficiently and remain largely unexplored (Österblom, 2013; Akamai, 2016). There is a need in the literature for a methodological approach to guide the adaptive and integrated decision-making process. The methodological framework of FRM provides a structured practical guide for understanding the elements of the planning process and for structuring a planning process to achieve a goal. A Methodological Framework for Operationalizing Flood Risk Management offers structured practical instructions for creating policies, strategies, and guidelines.

3.3 Application of Multi-Criteria Decision Making (MCDM)

Multi-criterion decision making (MCDM) is typically used to solve complex decision problems. MCDM is often used to structure, decision-making problems that involve multiple stakeholders, objectives, and alternatives. MCDM methods help decision-makers

make decisions based on several conflicting criteria (Waris, 2019). Additionally, MCDM enables decision-makers to compromise between the various options available (de Brito & Evers, 2016; Rogers, 2002). A review of the literature shows that MCDM is an important tool for structuring and analyzing complex decision problems, where inaccuracies and vague information are often present in the evaluation process (Malczewski, 2006). Multi-criteria decision-making has been successfully applied to optimize and distribute water resources among stakeholders (de Brito, 2016; Brouwer, 2004). The application of this method in the context of flood risk management is still rare. It is therefore still questionable how to assess flood risk and methodologically valid trade-offs included in cost-benefit assessments.

3.4 Development of Decision Making Framework with Analytic Hierarchical Process (AHP)

The analytic hierarchy process is also a type of MCDA. The Analytic Hierarchy Process (AHP) can be applied to manage complex decision-making problems involving multiple stakeholders, and scenarios (Dolan, 2008). The Analytical Hierarchy Process (AHP) developed by T. L. Satty (1980) aims to solve problems with a wide variety of variables. AHP helps in making judgments by decomposing a complex problem into a multi-level hierarchical structure, which includes objectives, criteria, sub-criteria, and alternatives. AHP shows excellent performance in dealing with interdependent criteria. AHP has several uses in different situations such as decision making, prioritization, and resource allocation. AHP systematically solves complex problems by breaking down the structure of a problem. AHP technique is used to structure a problem hierarchically on several levels with often contradictory and subjective criteria. One of the advantages of the AHP technique is to achieve consensus in the group decision-making process to obtain an optimum solution (Waris et al., 2019).

AHP offers the possibility to investigate and evaluate the causal relationships between goals, factors, sub-factors, and alternatives by deconstructing the problem. This technique can be particularly relevant in the planning process when different management measures lead to different outcomes. AHP evaluates the relative importance of each criterion and also generates an overall ranking of alternatives or the weight of factors. Clear and organized solution. Therefore, decision-makers can identify and prioritize the important factors that are taken into account when making decisions (Siddayao et al., 2014). Another important feature of AHP is the ability to reach a consensus on group decision-making. AHP can help decision-makers get the best possible judgment about their problem rather than getting “right” answers (Ouma, 2014). AHP is particularly good at quantifying expert opinions based on personal experience and knowledge to design a coherent decision-making framework. AHP is a useful tool to systematically channel and organize the knowledge of all experts to obtain a clear and organized solution.

Delphi technique is useful for framework building when human perception is subjective and there is incomplete knowledge about a problem or phenomenon (Skulmoski et al., 2007). The Delphi technique is a systematic and interactive method that relies on a panel of independent experts. Delphi method is an iterative process to collect and modify the judgment so f the experts. Therefore, quantitative and qualitative techniques were used in this study. The first phase includes the identification of important criteria and sub-criteria required for the operationalization of flood risk management via the studying of relevant literature. The structure of the problem has been developed by analyzing literature and brainstorming sessions with the experts. Delphi technique has been merged with AHP to systematically identify the criteria and the sub-criteria to structure the problem to set priorities among them. The proposed framework has been used to evaluate the existing practices of flood risk management. The following Figure 3.1 describes the schematic diagram of the development framework.

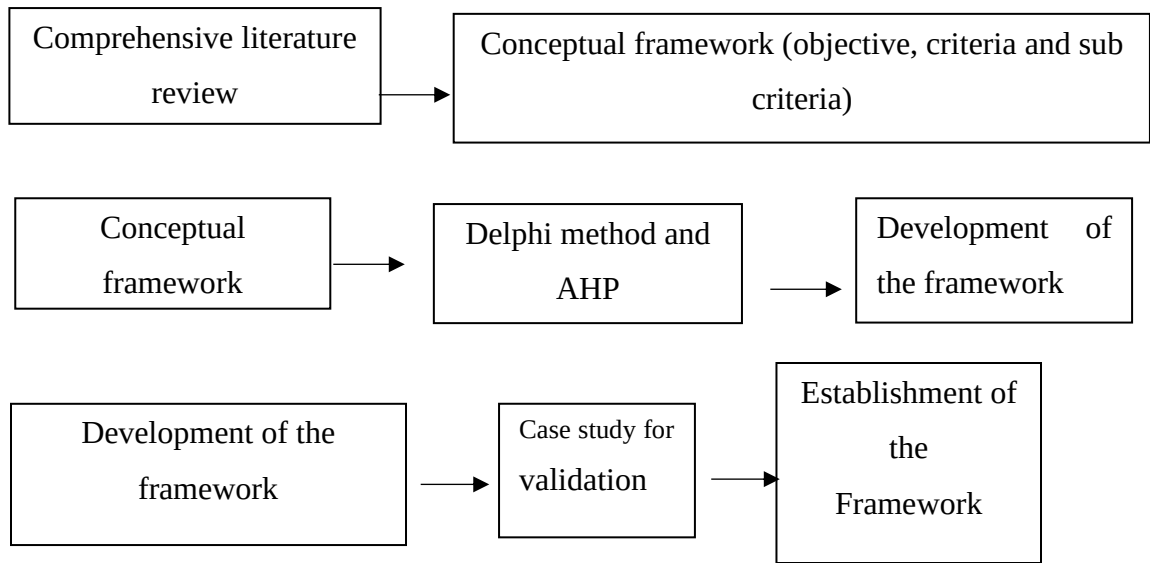


Figure 3.1 Schematic diagram of the framework development process

The following diagram Figure 3.2 illustrates the methodology applied to this research and the following part of this chapter describes it in detail.

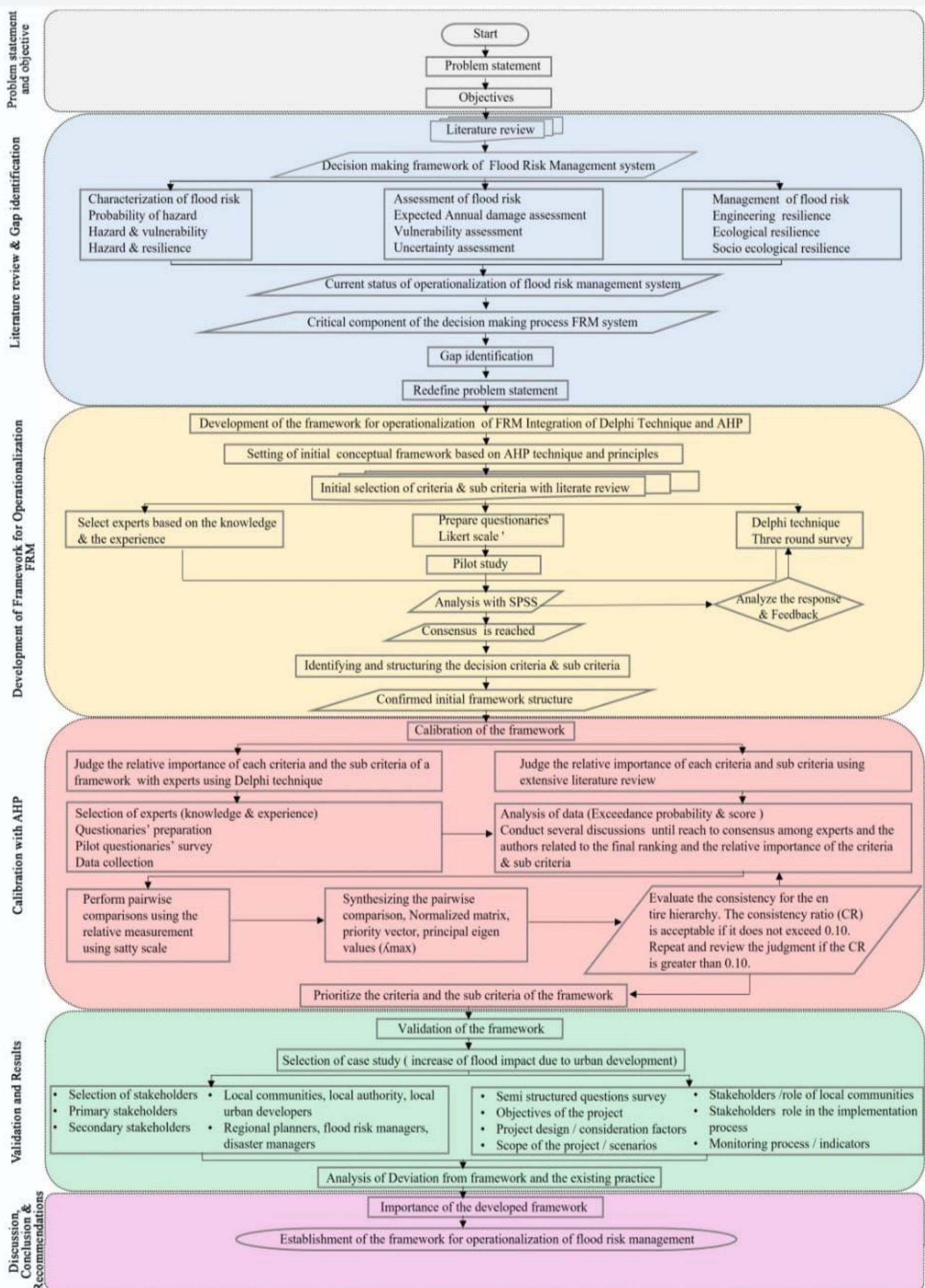


Figure 3.2 Methodology flow chart

3.5 Application of AHP in Flood Risk Management

According to the literature, the AHP method is often used to solve complex decision-making problems in water management (Wijitkosum, 2019). In the past, AHP has been used primarily for flood vulnerability and risk mapping in urban areas (Ouma & Tateishi, 2014). The planning process of the flood risk management system was not questioned based on AHP analysis (de Brito, 2016).

3.6 Methodology of the AHP

The AHP technique is based on the three principles of (1) decomposition, (2) comparative judgments, and (3) synthesis of priorities (Saaty 1986; Dyer & Forman 1992).

3.6.1 Develop a hierarchical structure of the problem

The hierarchical structure is a cornerstone of AHP. Decision-makers build a hierarchy to structure complex problems using multiple criteria. As shown in Figure 3.2, the hierarchical model of the decision problem is developed so that the goal is positioned at the highest level. The criteria and sub-criteria are found at the lower levels. The alternatives have positioned themselves at the bottom of the model (Saaty, 1987). The elements of a hierarchy are grouped into levels based on their homogeneity (Saaty, 1987). It has been further highlighted that extensive work is required for structuring the practical problem.

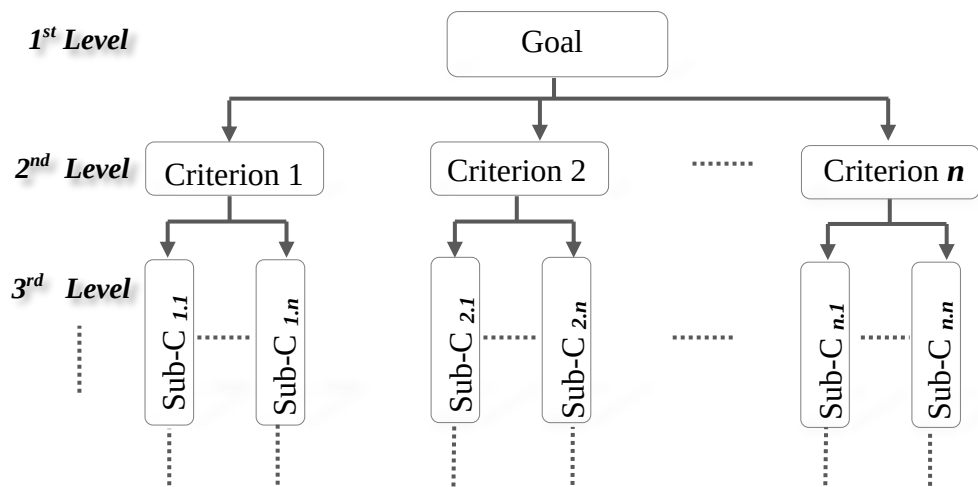


Figure 3.3 Hierarchical structure

3.6.2 Literature review to extract possible criteria and sub-criteria

The hierarchical structure of the concept was based on desktop research. It has considered existing literature as well as the results of current and finished research projects on flood risk management. The majority of relevant parameters for the operationalization of FRM were then determined. Initially, a systematic literature review has been conducted to select criteria, sub-criteria, and experts. The literature search included publications from the past decades on the topics of flood risk assessment, flood risk management, and land use planning.

3.6.3 Setting up the decision hierarchy using the Delphi technique and AHP

The Delphi technique was used to analyze the opinions of decision-makers. Delphi technique has been used successfully to explore new concepts within and outside the realm of knowledge systems. It is generally believed that the Delphi method has an advantage over other group decision-making methods in group interaction due to the anonymity of group experts and avoidance of the dominance of individual opinions (Okoli, 2004). The Delphi technique emphasizes the development of agreements between experts while avoiding drawing a dominant conclusion in the expert group (Huang, 2008). The Delphi Method uses a variety of techniques including brainstorming, semi-structured / structured questionnaires, interviews, interviews, and discussion workshops. The Delphi Method is a systematic and interactive qualitative research technique with an iterative process to reach a consensus within an expert group. The Delphi Process has three general stages (Grisham, 2009).

- (i) Brainstorming for relevant criteria
- (ii) Narrowing down the original list of criteria to a manageable number
- (iii) Final evaluation according to the ranking of important criteria

3.6.3.1 Brainstorm session

First, a brainstorming session with selected experts on the topic of flood risk management was held to convince the research objectives and introduce criteria and sub-criteria. The list of criteria and sub-criteria was narrowed down after brainstorming with the experts.

3.6.3.2 Pilot Questionnaires' survey

A pilot survey was conducted to ensure that the questionnaires met the survey objectives and to check the understanding of the questions.

3.6.3.3 Questioner survey

The questionnaire was distributed to all experts. The time allowed them to decide on the relevance of the criteria and sub-criteria provided. They were asked to rate their opinion on the importance of each criterion and sub-criteria to operationalize flood risk management. A series of Delphi questionnaires with a five-point Likert scale (1: strongly disagree, 2: strongly disagree, 3: neither agree nor disagree, 4: agree, 5: strongly agree). The arithmetic mean was calculated to understand trends in expert responses. This process was carried out until a consensus between experts and researchers was reached. The questions used for the development and prioritization of the framework have been attached as appendix A.

3.6.3.4 Experts selection

Experts from the following institutions were involved in the development of the framework. This study included experts from institutions on flood risk management in the context of Sri Lanka.

- Irrigation Department
- Sri Lanka Land Development Corporation

- Mahaweli Authority
- Lanka Hydraulics
- Water Supply & Drainage Board
- National Building Research Organization
- Urban Development Authority
- Disaster Management Center
- National Building Research Organization
- University of Moratuwa
- University of Sri Jayawardenapura
- Institute of Policy Studies of Sri Lanka

Experts' education level and professional practice have been considered as the major parameters for selection.

Working experience has been classified as follows

- More than 5 years
- 5 years to 10 years
- More than 10 years

Academic qualification

- Master in Water management, Urban planning, Environmental Management
- Ph.D. related to water management
- Ph.D. related to urban planning

3.6.3.5 Analysis of experts consensus

During this study, three cycles were performed to refine the criteria into a final series and to finalize the hierarchical structure. A final list of criteria and sub-criteria was then distributed to the experts. The elements selected from the final dataset can be seen as the most influential criteria for building the hierarchical structure. The final feedback of the questionnaires was analyzed using computer software packages, namely the Statistical Package for Social Sciences (SPSS) version 17.0.

3.6.4 Pairwise comparison

The second step is to determine the relative importance of the framework's criteria and sub-criteria. The impact of the elements of the hierarchy is assessed through pairwise comparisons made separately concerning each of the elements of the next higher level. First, a paired comparison of criteria and sub-criteria from the literature was performed. Secondly, a series of expert questionnaires were created to evaluate all criteria according to their categories. It served as a questionnaire to collect expert opinions on the relationship of importance between factors and thus to create an importance matrix.

3.6.2.1 Sample selection

As indicated in Table 3.3, Forty-two experts (42) have been selected considering their knowledge and the experience of the following institutions. These 42 professionals have participated in the prioritization of the criteria and the sub-criteria of the framework.

- Irrigation Department
- Sri Lanka Land Development Corporation
- Water Supply and Drainage Board
- Urban Development Authority
- Disaster Management
- National Building Research Organization
- University of Moratuwa
- University of Sri Jayawardenapura

Questionnaires have also been prepared for prioritization of the criteria and the sub-criteria of the framework. The selection of experts for the prioritization of the criteria and sub-criteria of the framework was also followed by the following parameters.

- Knowledge: knowledge of each expert bears related to the flood risk management
- Experience: practicing flood risk management

Table 3.3 Selection of experts

Knowledge		Relevance	Experience	Number of experts
Technical experts	Hydrologists, water resource planners	Master / PhD, Chartered	More than 10 years	22
Policy experts	Disaster management, Urban planning	Master / PhD, Chartered	More than 10 years	20

3.6.2.2 Collection of experts' opinions

Literature has highlighted that the AHP method can be used individually as well as in group decisions. However, this study has followed the group decision-making process instead of individual decision-making (Şahin, 2018). The Delphi Technique is a method of reaching the consensus of a group of experts. Hence, the Delphi technique is used for the pairwise comparison of criteria and sub-criteria. Experts were selected considering the understanding real situation in flood risk management operations. The questionnaire survey collected expert views on the important relationships between criteria and sub-criteria and thus created an importance matrix. Decision-makers receive pairwise comparisons based on their value judgments of items at the same level as an item at the next higher level. Expert judgments on the importance of the criteria and sub-criteria were based on 100. The criteria and sub-criteria were also prioritized based on the author's extensive literature. Finally, experts and research authors agreed on the important values of each criterion. The question used to collect experts' opinions has been attached as appendix B.

3.6.2.3 Sample size

The sample size is an important feature of any experimental study. Inadequate or excessive sample size affects research quality and accuracy. The selection of sample

size of experts in AHP has been discussed differently in the previous literature. Baby (2013) has highlighted that one of the main advantages of AHP is that it does not always require a statistically significant sample size for analysis. However, it was also pointed out that the sample size depends on the study objectives (Schmidt, 2015). The literature has shown that respondents must be high-level employees who regularly participate in decision-making. The competence of the AHP method depends on the quality of the subjective judgment of the experts. Therefore, to ensure a high quality of the scientific approach to this study, it was discussed with the experts from the field of flood risk management the experts who are currently practicing the FRM were used for this study.

3.6.2.4 Experts' scoring for criteria weights

The AHP method is a semi-quantitative approach in which the weight of the criteria is estimated based on an expert opinion on the relative importance of the criteria for the operation of flood risk management. As described in Table 3.2, this study has considered the judgments of 42 experts from the field of hydrology, urban planning, and disaster management.

3.6.2.5 Analysis of the experts' opinions

There is more of a comparison matrix when making group decisions. It has been pointed out in the literature that these comparison matrices must be reduced to a single matrix. The geometric mean is often used for this reduction (Saaty, 2008). In this study, the probability exceedance curves have been plotted to understand the distribution pattern of scores for the main criteria and the sub-criteria. The probability of exceeding is the probability that an uncertain parameter exceeds a certain threshold value. The classification was carried out by visually observing the breaks in the probability of exceedance curves. Relative weights of each criterion and the sub-criteria were collected till the experts reached a consensus. All Experts have reached a consensus after three cycles and the author's explanation. The distribution of each criterion and

sub-criteria have been tabulated and the average values have been calculated. Pairwise comparison tables that have been compiled based on their judgments. The final pairwise matrix was prepared by taking a round - off of the average score given by the experts. In this study, three series of sessions were implemented to culminate in negotiations between experts and research authors and to reach the ultimate meaning of each criterion and sub-criterion of the framework. The following Tables of 3.4, 3.5, 3.6, 3.7, and 3.8 highlight the relative importance of the main criteria and sub-criteria. The process of analysis of expert opinions and the reached consensus value has been illustrated in Appendix D.

Table 3.4 Priority values of the main criteria

Main criteria	Relative importance (negotiated average value)
Conceptualization	60
Place assessment	100
Discourse	25
Participatory tools	65

Table 3.5 Priority values of the sub-criteria of conceptualization

Sub criteria	Relative importance (negotiated average value)
Complexity	40
Multiscale	25
The unpredictability of flood risk	70
Social assessment and integration	100

Table 3. 6 Priority values of the sub-criteria of place assessment

Sub criteria	Relative importance (negotiated average value)
Adaptive capacity	85
Diverse scenarios	45
Hydrological integration	22
Social integration	15

Table 3. 7 Priority values of the sub-criteria of discourse

Sub criteria	Relative importance (negotiated average value)
Adaptive planning	85
Multi-level integration	15
Flexible governance / monitoring	60
Local communities participation	50

Table 3. 8 Priority values of the sub-criteria of participatory tools

Sub criteria	Relative importance (negotiated average value)
Land and water	65
Catchment scale	30
Flexibility	22
Local community	65

3.6.2.6 Pairwise comparison matrix

Pair-wise comparisons identify the interrelationships among the elements at each level of criteria and sub-criteria. Accordingly, the next step is to establish the relative importance of the main criteria and sub-criteria by comparing them in the form of pairs. Table 3.9 highlights an example of calculating pairwise comparison for the main and sub-criteria of the framework.

Table 3.9 Pairwise comparison matrix structure

Criteria	Criteria 1	Criteria 2	Criteria 3	Criteria 4
Criteria 1	-	Criteria 1: Criteria 2	Criteria 1: Criteria 3	Criteria 1: Criteria 4
Criteria 2	Criteria 2: Criteria 1	-	Criteria 1:Criteria 3	Criteria 2: Criteria 4
Criteria 3	Criteria 3: Criteria 1	Criteria 3: Criteria 2	-	Criteria 3: Criteria 4
Criteria 4	Criteria 4: Criteria 1	Criteria 4: Criteria 2	Criteria 1: Criteria 3	-

The relative importance values of criteria and sub-criteria derived from the Delphi method have translated into a Satty scale for subsequent analysis. It has been used the following algorithm which is highlighted in Table 3.10 to convert the relative importance of each criterion and the sub-criteria into the Satty scale (Reddy et al., 2015). Accordingly, it was assumed that if two criteria or sub-criteria were defined as significant to each other on an equal number of occasions (for example 50% for each), this would translate to “1” for both on the Satty scale, indicating equal importance (Reddy et al., 2015). Hence, 75% of the significance of any criteria corresponds to 5 on Saaty’s scale.

Table 3.10 Comparative Judgment Structure of Criteria

Formula used for $X \geq 0.5$	Ratio between the criteria	0.00	0.25	0.5	0.75	1.00
Linear approach $1 + 16 \times (x - 0.5)$	Satty scale	1/9	1/5	1	5	9

The final experts’ judgments are represented by numbers on the Satty scale. Table 3.11 highlights the summary of Saaty’s nine-point ratio scale. The reciprocal and diagonal elements are equal to one (Saaty, 1987).

Table 3.11 Saaty’s nine-point ratio scale (Saaty, 1987)

Numerical values	Verbal term	Explanation
1	Equally important	Two elements have equal importance
3	Moderately more important	Experience or judgment slightly favor one element
5	Strongly more important	Experience or judgment strongly favors one element
7	Very strongly more important	The dominance of one element proved in practice
9	Extremely more important	The highest order dominance one element over another
2,4,6,8	Important intermediate values	Compromise is needed

Pairwise comparison is required to compare all possible pairs of elements starting from the beginning of the hierarchical structure. A pairwise comparison in expert selection is the process of comparing the relative importance, preference, or likelihood of two main items to another item (the target) at the top level. Based on the pairwise comparisons, the relative importance (weighting) of the elements of the hierarchical structure is calculated. The diagonal elements take the value of one because each element is equally important to the same. The structure of the pairwise comparison matrix is applying the AHP highlighted as following Figure 3.3.

$$A = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} = \begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \dots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \dots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \dots & \frac{w_n}{w_n} \end{pmatrix} = \begin{pmatrix} 1 & \frac{w_1}{w_2} & \dots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \dots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \dots & 1 \end{pmatrix}$$

Figure 3.4 Pairwise comparison matrix

The calculation of the relative priorities for each decision element is performed through a series of numerical calculations.

3.6.5 Synthesis of priorities

The relative weights of the main criteria and sub-criteria have been calculated by normalizing the comparison matrix. Normalization has been done by dividing each value by the total value of the column. Subsequently, the contribution of each main criteria and sub-criterion to the main objective of the framework was determined through calculations performed using the priority vector (or eigenvector). The priority vector has been obtained as an approximation by calculating the mathematical average. The total of all priority vector values is one.

3.6.6 Checking the Consistency Ratio

As a pioneer of AHP, Saaty (1991) proposed the Eigenvector method, which is derived from matrix theory. In this method, the corresponding weights of the decision elements were determined by comparing the normalized eigenvalue with the principal eigenvalue. However, the eigenvector and logarithmic methods are commonly used to derive relative weights. An important aspect of AHP is the measurement of the "consistency ratio" (CR). Finally, the consistency of the subjective ratings is checked. If there is CR 0.10 for matrix A, the estimates of the relative importance of the criteria and therefore the prioritization of the alternatives are considered acceptable. In other cases, it is necessary to investigate why the inconsistency of the estimates is too high. A higher inconsistency index value, e.g. CR value greater than 0.10, should not be considered appropriate and these calculations should be reassessed. The CR must be equal to or less than 0.10. However, a revision of the pairwise comparison is mandatory if CR is greater than this limit value.

3.7 Validation of the Developed Framework

The final phase of the research includes the implementation and validation of the proposed framework through structured interviews with several stakeholders associated with the flood risk management project. The applicability of the framework is discussed with the stakeholders using structured interviews.

3.7.1 Validation with the case study

The applicability of the framework is discussed based on the case study. This framework offers an approach to assess the adaptive capacity of the planning process and identify the degree of operationalization of flood risk management. The developed framework can be used in different ways. It can be used to identify the overall degree of operationalization of flood risk management. For example, how the land-water relationships are considered in the planning process in practice. Therefore, this

framework can be useful to identify how the operationalization of flood risk can be improved, thus, validating results to ensure the reliability of the implementation of the framework is enabled. Validation is for judging a model's accuracy in making applicability to their decision. Validation can be seen as a demonstration process to provide stakeholders with proof of acceptance and ease of use of this new framework. However, validation is a process and depends on the information provided by the type of stakeholders.

The calibrated framework is based on a constructivist as well as an integrative perspective. The decision-making of this perspective is depended on the stakeholders' perceptions of the situations and issues being studied. Therefore, the establishment of this research is based on the context, and how actions are planned and taken by stakeholders. Moreover, this approach stresses seeing an appropriate solution for a problem situation and multiple objectives instead of formulation of the problem in terms of a single objective and optimization. Accordingly, it is necessary to study multiple case studies. The establishment of policy discourse is based on policy arrangement or how power, resources, and responsibilities are distributed among the stakeholders.

3.7.2 Selection of case study for validation

Panadura is one of the fastest developing coastal urban centres in the Colombo urban region. It is located in the wet zone of Sri Lanka which receives more than 2,500 mm annual rainfall. Rapid land use transformation and densified economic activities have modified the hydrological flow patterns over a period, which resulted in changing the stormwater movement patterns. Panadura urban area experiences flood annually. It has been noted change from low urbanization to a high urbanization pattern is the main driver for increasing the flood risk in the study area.

3.7.3 Stakeholders selection for validation of the decision model

A stakeholder can be any person, group, or organization that is affected by the topic. There are different definitions for describing stakeholders. The main actors are “those who can have a significant impact or who are important for the success of the project”. As highlighted in Table 3.12, stakeholders can be divided into two groups, eg. Primary stakeholders and secondary stakeholders.

Table 3.12 Stakeholders related to the flood risk management in Panadura

Definition	Primary stockholder	Secondary stakeholder
The European Commission (2003)	Group of individuals who are affected by the issues (victim, or gainer). They include all those who affect and/or are affected by the policies, decisions, and actions of the system.	Group of individual’s influence, knowledge or experience with the subject”
Macarthur (2011)	Those ultimately affected, either positively (beneficiaries) or negatively (for example, those involuntarily resettled)” by the implementation of the project.	Those are “the intermediaries in the aid delivery process”.
Clarkson (1994)	Those who are essential for the survival and the well-being of an organization.	Those who interact with the organization but are not essential to its survival.

Definition	Primary stockholder	Secondary stakeholder
Panadura case study	Local communities Local authority Local politicians	Irrigation Department (ID) Sri Lanka Land Development Corporation (SLLDC) Urban Development Authority (UDA) Disaster Management Centre (DMC) Central Environmental Authority (CEA) Department of Agrarian Development (DAD) District secretariat Department of Meteorology Coast conservation department

3.7.4 Preparation of questions for validation

Semi-structured interviews have been used with stakeholders for assessing the practical confirmation of the developed framework. Semi-structured interviews have been used because a semi-structured interview adopts both structured questions and a conversational approach that allows gathering information on complex issues. It is necessary to understand how flood risk management is understood, and what kind of actions are executed to make areas more resilient. The questionnaires that have been focused on for validation have been attached as Appendix C. In addition, it has also studied the following aspects to understand flood risk management in Panadura using literature, observation, and focal group discussions.

- (1) Flood damage during previous years
- (2) Existing planning policies, strategies, guidelines related to flood risk management

- (3) Present situation and level of consideration of criteria and sub-criteria to the selection of alternatives of goals, strategies, and guidelines
- (4) Limitations of the existing management practices such as drainage systems and zoning regulations
- (5) Alternatives management practices

CHAPTER 4 - ANALYSIS

4.1 Development of the Framework

4.1.1 Structure of the framework for operationalization of flood risk management

Water and land use are inextricably linked. Flood risk is characterized by nonlinear and non-stationary interactions. Flood risk is a multi-dimensional phenomenon that involves changes of physical as well as social dimensions such as political, institutional, economic, etc. Long-term planning and management of flood risk are challenged by uncertainty due to the changes of both physical as well as social dimensions. Flood risks indicate an inadequacy of existing policies and practices in flood risk management to conceptualize the socio-spatial and temporal dynamics of flood risk. Moreover, flood risk is due to the ill recognition and management of complexity and uncertainty due to socio-spatial-temporal interactions of flood risk. Probability-based flood damage assessment is inadequate for decision-making. A comprehensive understanding of flood risk requires a systems-based approach. Decision-makers of FRM have questioned that flood occurrence is an unavoidable phenomenon. They further questioned the method to manage the complexity and the uncertainty incorporated with flood risk. FRM is not a problem-solving process but rather the management of causative factors of the flood risk. Therefore, it is required to undertake uncertainty assessment for decision making. Accordingly, flood risk management requires adaptive flood risk management measures. Assessment and management of flood risk require a shared understanding of risk with the stakeholders. The decision-making process which is based on flood management is required to transform towards flood risk management to cope up with future uncertainties. The selection and evaluation of alternative goals and strategies in the planning process of flood risk management is a critical task due to the inherent uncertainty of flood risk. Therefore, the operationalization of flood risk management requires a common decision-making framework that recognizes the interdependency of stakeholders and hence optimizes the objectives of all stakeholders.

The flood risk management planning process involves many stakeholders, each with their priorities. Therefore, the process of flood risk management depends on the existing governance structures.

The operationalization of flood risk management depends on how stakeholders appreciate the adaptive and integrated planning process. The planning process is influenced by a dense network of relations, with stakeholders holding various powers, resources, and competencies. The operationalization of FRM depends mainly on the planning process as well as the governance network of relations, with stakeholders. In summary, the operationalization of flood risk management is determined mainly with two factors such as characteristics of the planning process and the governance context (Figure 4.1).

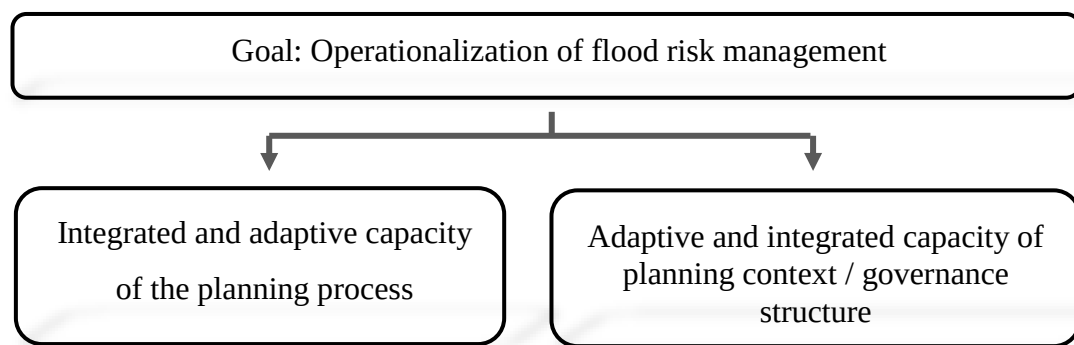


Figure 4.1 Framework for operationalization of flood risk management

4.1.1.1 Planning process

The planning process requires to have the ability to integrate diverse spatial demands of the floodplain as well as political visions (Van Herk et al., 2011; Friedmann, 2004). Therefore, the planning process of the FRM system requires a wider focus on the consideration of social and environmental impacts. The role of the planning process of FRM requires to be able to define the management strategies to fulfill the diverse stakeholder's objectives. Accordingly, the planning process aims to identify the common objectives and strategies which cater minimum impact of flood risk to the

public sector while concerning the long-term uncertainty. Thus, the planning process of flood risk management system aims to (1) explore jointly aligning objectives, (2) reduce duplication (3) manage trade-offs, and (4) promote synergy across interdependent stakeholders (Candel, 2016). Therefore, it is necessary to define the stakeholders who participate in establishing the facts jointly, to frame flood risk and the management options to provide the knowledge and resources which are needed for practice flood risk management (Davoudi, 2012). For that reason, the planning process of FRM is governed by mainly two aspects. First, how the objectives of the flood risk management system are conceptualized by the stakeholders of the planning process. Secondly, the consideration factors of the assessment of the flood risk for determination of the objectives flood management system.

4.1.2 Governance Context

Operationalization of flood risk management means the coexistence of the natural phenomenon of flooding and socio-economic development. Practicing of flood risk management system largely depends on the decision-making process among mandated stakeholders as well as the organization of the governance system of the context (den Boer et al., 2019; Meng, 2019). Designing and implementation of the adaptive and integrated goals and the strategies largely depend on the integration of multiple stakeholders such as housing, economic activities, spatial development, etc., at multiple policy levels and scales (Van Herk, 2014; Serra-Llobet et al., 2016). Moreover, the operationalization of FRM is a multilevel and multi-stakeholder governance practice (Van Herk et al., 2012). Operationalization of flood risk management depends on the provision of opportunities for the stakeholders to increase the adaptive capacity of the system through collaboration, by considering the long-term impacts of flood risk. Therefore, stakeholder integration is the central aspect of the operationalization framework of flood risk management when coping with the inherent uncertainty of flood risk (Huiteima, 2009; Edelenbos, 2017; Ishiwatari, 2019). Operationalization of FRM refers to the development of a joint definition of flood risk management goals and strategies based on the combined means and objectives of all stakeholders (Van Herk, 2014). Efficiency and the legitimacy of the decision

implementation are also expected to increase through a collaborative decision-making process (Farrelly, 2009). Therefore, the relationships between mandatory stakeholders and their governance arrangements have formed a central part in the operationalization of flood risk management.

A collaborative governance system is comprised of networks of structures that provide potentials for the integration of interdependent stakeholders with each other to achieve goals beyond their capacities (Gerlak & Heikkila, 2011; Evans, et al., 2004). The governance system includes the (1) role of stakeholders, (2) their discourses, and (3) how power and resources are distributed in each context. Hence, the governance structure refers to the body of knowledge system which describes the problem and ways to deal with it (Molenveld, 2019). Scoping of the FRM system is determined by the existing administrative knowledge system and policy responsibilities (Daviter, 2017). Therefore, practicing flood risk management relies on the integrated and adaptive capacities of the planning process and the governance context (Hutter, 2007). Past literature has highlighted that there is a lack of research done to get a better understanding of the government action required (Hegger, 2014). The characteristics of the planning process, as well as governance context, determine the operationalization of flood risk management. The flood risk governance structure can be broadly classified as its knowledge system and the available interaction mechanisms among stakeholders. Figure 4.2 describes the developed framework for the structure of this complex process and identifies the resilient measures. As explained in Figure 4.2, four main criteria characterize the operationalization of flood risk management. These main criteria are Conceptualization of flood risk management, Assessment of flood risk management, Knowledge system of stakeholders, and Participatory interactions mechanisms

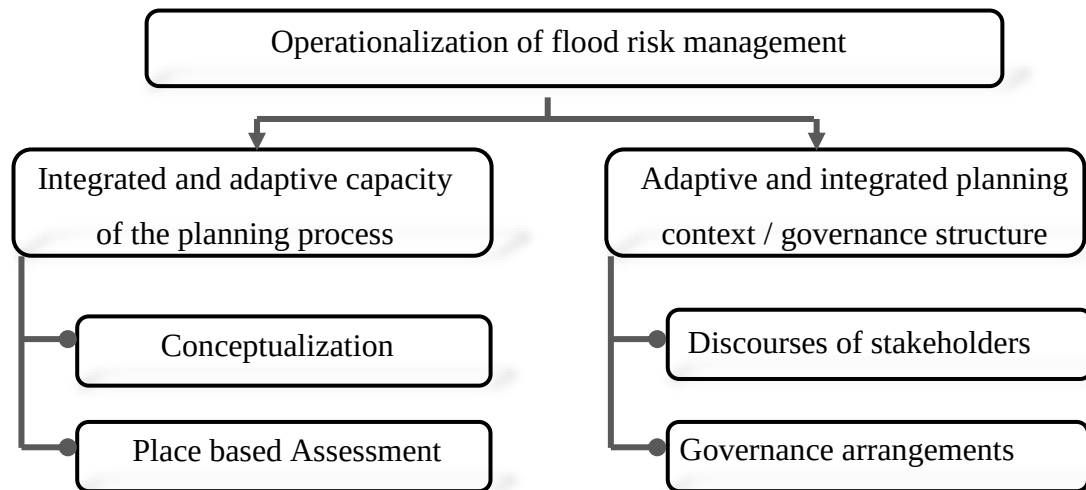


Figure 4.2: Main Criteria of the Framework for operationalization of flood risk management

4.2 Adaptive and Integrated Planning Process

4.2.1 Conceptualization of flood risk management (FRM)

The notion of socio-ecological systems has underlined that the socio and ecological systems are characterized as strongly intertwined, inherently complex unpredictable, and self-organizing interactions. It has also highlighted these systems to be permeated by uncertainty and discontinuities (Davoudi et al., 2012; Folke, 2016; Berkes, 1998). Recently, the decision-making of flood risk management has also adopted socio-ecological system thinking, which provides a wider and more comprehensive conceptualization of the FRM system (Davoudi, 2012; Linkov et al., 2014; Restemeyer, 2015). Accordingly, it is essential to recognize the impact of non-linear and non-stationary interactions of flood risk for the designing of flood risk management strategies.

The Planning process is required to characterize the components and the socio-spatial interconnections, as well as their dynamics for the operationalizing of flood risk management (De Bruijn, 2005; Linkov, 2014). Traditionally, the planning process

could not identify all the relevant stakeholders in the selection of management options due to the weak understanding of the nonlinear interactions of the flood risk (Merz, 2010). As a result, many of the countries practiced a sectoral approach for FRM (Davoudi, 2012; Linkov, 2014; Restemeyer, 2015). Therefore, one of the main barriers in the operationalization of flood risk management is the ill understanding of the interactions between the hydrological, social, and ecological dimensions of the flood risk by the stakeholders (Nicholls et al., 2015).

The knowledge system of the stakeholders who are in the planning process can recognize the following considering the scenario-based approach.

- (1) Long term dynamics of flooding
- (2) Floodplain Land uses
- (3) Impacts due to the implementation of flood management measures on people, infrastructure, economy, etc and the on the functions, processes, structure, and identity of floodplains

Stakeholders in the planning process can recognize the long-term impacts due to the non-stationary and nonlinear interactions of flood risk on people, infrastructure, economy, etc, and on the functions, processes, and identity of floodplains. Moreover, the decision-makers have recognized that the land use development and structures along the floodplains are the results of decision-making of the past (Zevenbergen, 2008; Barendrecht, 2017; Sayers, 2013; Liao, 2012; Jonkman, 2012). Therefore, the first step in operationalizing flood risk management is to characterize the components, interconnections among them, and the key stakeholders of the FRM system (De Bruijn, 2005; Linko., 2014).

4.2.2 Assessment of the planning process

The planning process is defining the goals and the strategies, basically answering two main questions such as ‘where do we want to go’ (what is the goal/objective) and ‘how do we get there’(what is the implementation strategies and guidelines) (Hutter, 2008).

The role of the planning process is to select the flood management options considering the social, spatial, and temporal interdependencies of flood risk. The planning process needs to evaluate the management options in terms of cost-effectiveness and equity with changing of social, economic, and environmental characteristics of a location in long term (Hall, 2003; Jonkman & Vrijling, 2008; Erdlenbruch, 2009; Ward, 2013; de Bruijn, 2017).

The concept of socio-ecological thinking provides a useful translation of strategy making in the planning process (de Bruijn et al., 2017). Two main questions are highlighted when analyzing human-environment interdependencies (Davoudi, 2012). First, what is the purpose or desired outcome of the management system, the second is whose desires are considered in the management system? Hence, assessment means identifying the common objectives and strategies which cater to wider benefits for all stakeholders considering the long-term impacts of the dynamics of flooding and human interactions.

The purpose of the planning process is to increase the adaptive capacity of floodplains to diverse scenarios of flood occurrence including extreme flood events. Therefore, it is necessary to select the management options to maintain the functions, structure, feedbacks, and identity of floodplains. The planning process of flood risk management should be able to develop spatially and socially integrated policies and strategies to cope up with the risk of diverse climatic scenarios. Therefore, the assessment of the planning process is to explore the opportunities to reduce flood risk through collective actions of stakeholders with the minimum impact to the public sector while concerning diverse scenarios of climatic change. Practicing flood risk management is an integrated and continuous process that takes broad perspectives of all potential trade-offs of different spatial scales and time into consideration (Faehnle, 2013; Renn, 2011; Alexander, 2016).

4.3 Adaptive and Integrated Governance System / Planning Context

There should be a potential for common identification and optimization of the collective knowledge of all those involved in the decision-making process. Second, it should be possible to create a broad base to support the newly generated knowledge for implementation. It should be clear how the views and interests of stakeholders are taken into account and how trade-offs between different interests are made during the planning process (Pettersson, 2017).

4.3.1 Discourses of Stakeholders

Consensus-building among the stakeholders is the key factor for practicing flood risk management. The operationalization of FRM needs to explain who should govern flood risk and how societal interventions should occur (Plummer, 2018). The discourse of stakeholders of risk management is required to facilitate of sharing of responsibilities between multiple stakeholders including the state and non-state sectors organizations. The discourse of the stakeholders is important to translate the fundamental principles of flood risk management into the planning process. Flood risk governance determines the relationship between many stakeholders and their policy principles (Dieperink et al., 2016). Operationalization of flood risk management depends on the discourse of all stakeholders of the flood risk management system and how they appreciate the adaptive and integrated planning practices (Driessen, 2012; Armitage, 2012; Hegger, 2013; Lawrence, 2013; Gersonius, 2016; Van Buuren, 2016). Therefore, the policy discourses of the stakeholders included their ideas, concepts, and vocabularies to determine the content of the plans of FRM (Wiering, 2018).

There are many obstacles to implementing flood risk management strategies (Lawrence, 2013). The integration of stakeholders into decision-making varies greatly depending on stakeholder objectives, institutional culture, degree of political decentralization, and the nature of public consultation (Sayers, 2013; Lyles, 2014; Harries, 2011). The operationalization of flood risk management, therefore, means an expansion of the responsibilities of public and private stakeholders. For example, FRM

initiated the inclusion of other policy areas such as spatial planning and disaster management and therefore the distribution of responsibilities among a wider range of stakeholders (Gilissen, 2016; Mees, 2014).

4.3.2 Participatory governance arrangements

Municipalities in different contexts of the world respond to flood risk management differently. This difference is not only due to the different effects of climate change in individual communities but also to the different conditions of the institutional framework (Vink et al., 2015; Pahl-Wostl, 2007).

The joint assessment and strategy development showed that stakeholders need to include different points of view, interests, and values to interpret and assess information differently and to mobilize different knowledge to underline the points of view (Koppenjan, 2004). Managing the trade-off between diverse stakeholders is controlled by the communication interconnection among them (Chan, 2012; Harrison-Atlas, 2016). Therefore, the communication interconnections among the stakeholders are also considered to be very important in the process of decision making. The institutional setting, rules, and regulations that enable actors to collaborate and address shared problems are generally referred to as institutional capacity (Rein, 1993; Healey, 2003; Healey, 1997).

Dynamic and flexible actor platforms allow diverse perspectives, interpretations, and negotiations of different dimensions of risk management to get integrated (Pahl-Wostl, 2007). Collaborative and adaptive planning contexts can provide opportunities for integrated strategy making. Implementation of the flood risk management system depends on the stakeholder's understanding of integration among multiple actors on multiple levels. The planning process of flood risk management requires dynamic and flexible actor platforms that allow diverse perspectives, interpretations, and negotiations of the different dimensions of risk management (Pahl-Wostl, 2007). The success of an adaptive planning process highly depends upon the political and

administrative traditions of a country. The following characteristics of Governance arrangement determine the operationalization of flood risk management enables or hinders the application of a more adaptive approach (van Buuren, Lawrence, Potter & Warner, 2018; Avoyan and Meijerink. 2019).

- Power relations between state and society
- Legal framework
- Integration science in the political field
- Assessment techniques used in the implementation of the guidelines
- Economic efficiency assessment and indicators

The planning process is influenced by a dense network of relations, with stakeholders holding various powers, resources, and competencies. Therefore, legitimacy becomes increasingly complex in the operationalization of flood risk management because due to multiple stakeholders' involvement in the planning process (Hegger, 2014; Avoyan & Meijerink., 2020). Moreover, it depends on the interrelation of stakeholders.

4.4 Conceptualization of flood risk

4.4.1 Flood risk as a complex phenomenon

Hydrological, social, and ecological systems related to flood risk are strongly intertwined (Davoudi, 2012; Folke, 2010). It is necessary to conceptualize that the flood risk is embedded in both the natural and social systems. Flood risk management should not have limited the consideration to the water system and flood defenses. Therefore, flood risk management systems are characterized by dynamic, feedback loops and hence require continuous attention (Schoon, 2015). Flood risk management includes the physical as well as socio-economic systems (De Bruijn, 2005; Zischg, 2018). Flood impacts are subjected to ill recognition of the inextricable link between land (socio-spatial) and water (natural–physical) systems (Folke, 2002; Tompkins, 2004; Hartmann, 2011; Gerrits, 2008). Consequently, the integration of socio-spatial

systems in flood risk management can lead to a wide consideration of the problem. Therefore, the flood risk management system has a broader scope than in the past. Understanding the multiple interactions, of flood risk is necessary to define the components of the risk management system (De Bruijn, 2014).

4.4.2 Scale sensitivity of flood vulnerability and risk

Flood risk is considered to be the result of the interaction between hazard, exposure, and vulnerability. Flood risk is determined by the exposure to extreme weather events, as well as their vulnerability to the event (Sayers, 2003; Apel, 2009). Flood vulnerability means the incapability of the social-economic system (physical, social, economic, political, etc.), to cope up with (prepare, manage, reduce) the flood risk (Barendrecht, 2017). In the earlier time, decision-makers considered that flood vulnerability is solely a function of exposure to external hazards such as climatic extremes. Subsequently, it has been conceptualized that each component of flood risk was controlled by multiple factors influencing at multiple scales. However, with time, decision-makers have recognized that the flood risk and vulnerability are due to dynamic interactions of multiple interdependent factors such as social, hydrological and ecological, etc related to flood risk at different scales (Mavhura, 2019; Hall et al., 2008). Further, the decision-makers have realized that changing one of these factors may influence the others due to feedback mechanisms in the system. Sometimes it may result in unexpected impacts to the region (Barendrecht, 2017).

Flood risk needs to be theorized as a co-evolving phenomenon that varied socially, spatially, and temporally due to the interaction of multiple factors influencing at multiple levels (Barendrecht, 2017; Mavhura, 2019; Tempels & Hartmann, 2014). Accordingly, it is suggested to understand the evolution of the floodplain land uses holistically. The planning process needs to be conceptualized not only on flood hazards but also on vulnerability and exposure. Therefore, it is necessary to recognize the inherent interdependencies of the complex landscape of flood risk. Moreover, recognizing the vulnerabilities, triggers, and consequences of flooding is required for the decision-making process (Ray-Bennett et al., 2015).

4.4.3 Inherent uncertainties associated with flood risk

Flooding is a natural process. Floodplains are used for urban development due to many reasons. However, if there are no exposure elements over the floodplains, there are no flood damages. The continuing expansion of urban settlement results in a higher degree of vulnerability in floodplains. All land uses along the floodplains cannot be protected by following the same flood protection standards due to economic and hydrological reasons (Fuchs, 2015). Nevertheless, diverse stakeholder of flood risk management has different values over floodplain land uses. Therefore, flood risk can be defined as a way of expressing the uncertainty associated with flood risk. Second flood risk occurs due to the absence of collection judgment over floodplain land uses among the stakeholders. Moreover, diverse stakeholders are involved in the process of flood risk management due to its multidimensional nature. There are diverse interpretations of flood risk management (Merz et al., 2015; Merz, et al., 2010).

Multiple decisions of diverse stakeholders are taken in the same environment and all their events and causalities are densely interconnected. As a result, there is inherent uncertainty in the decisions when there is no common goal for them. Therefore, flood risk will increase due to the absence of knowledge to understand the flood risk in a broader way (Díez-Herrero, 2020). Moreover, there is an incompleteness of the knowledge (scientific) or necessary information in decision making (Hommes, 2009; Rosenhead, 2001). Therefore, the wider ramification cannot be ignored, and hence uncertainty becomes another crucial element in the conception of flood risk management (Baroang, 2009; Raaijmakers, 2008).

There are uncertainties built upon decisions of all stakeholders, and their expected objectives (Rosenhead, 2001; Brugnach, 2011). It can be concluded that the planning process is required to conceptualize constant change of risk of flooding due to uncertainty incorporated with social and natural systems. Therefore, flood risk cannot be predicted. Also, flood risk cannot be solved by a single institute or with a single management strategy. It is highlighted that, flood protection infrastructure measures

are not reliable which is based on the climatic model cannot cope up with the flood risk due to future climatic changes. Because uncertainty in future climate change is also great (Aerts et al., 2008). Accordingly, many traditional approaches to designing infrastructure and other long-lived investments are ineffective (Hallegatte, 2009). Also, it has been increasingly questioned the floodplain land-use control which is based on the assuming that probability of certain future trends of flood risk (Burby et al., 1999).

4.4.4 Flood risk management as socially assesses, integrated and adaptive process

In the past, most of the flood risk management decisions were evaluated based on the classical cost-benefit analysis, and their effectiveness was questioned (Aerts et al., 2008). In recent years, the concept of the adaptive management process was introduced. This concept highlights the requirement of reducing the existing vulnerabilities rather than taking the decision based on the simulation of future vulnerabilities (O'Brien et al., 2004). Therefore, flood risk assessment requires a balance between the total costs due to flooding, including reduced economic development, the functioning of vital ecosystems, etc., and the costs of mitigating effects. It has been recognized that trade-off of certain aspects of outcome subjected to that particular location in the face of severe uncertainty (Merz et al., 2015). Therefore, it is necessary to identify all the stakeholders from a broad perspective and take all potential trade-offs at different scales in space and time (Pahl-Wostl, 2006). It has further been highlighted that understand the interdependency of each stakeholder in flood risk management. As a result, the integration of the knowledge system has become a central role in the conceptualization of flood risk (Pahl Wostl et al., 2005).

Also, it is required to continuously assess the risk when the fundamental uncertainty operates over a lifetime. Therefore, negotiation between the stakeholders regarding flood risk management policies and strategies is important. Accordingly, the change in the roles and responsibilities of the stakeholders has been recognized. Thus, FRM has been primarily regarded as a co-responsibility of all stakeholders who are affected rather than the responsibility of only public institutions. Therefore, the acceptance

level of risk of all stakeholders is a crucial determinant of the decision-making process. Besides, the scope of the integration includes three factors a space integration, social integration, and time integration (Samuels et al., 2008). Thus, flood risk management has transformed as a socially integrated and adaptive process that maintains the economic and societal uses of floodplains in the face of changing rapid urban development and climatic conditions. Reducing uncertainty has been conceptualized as a product of the integration of stakeholders' knowledge. As explained in Figure 4.3, the sub-criteria of conceptualization of flood risk management is a complex, multiscale, unpredictable, and socially constructed phenomenon.

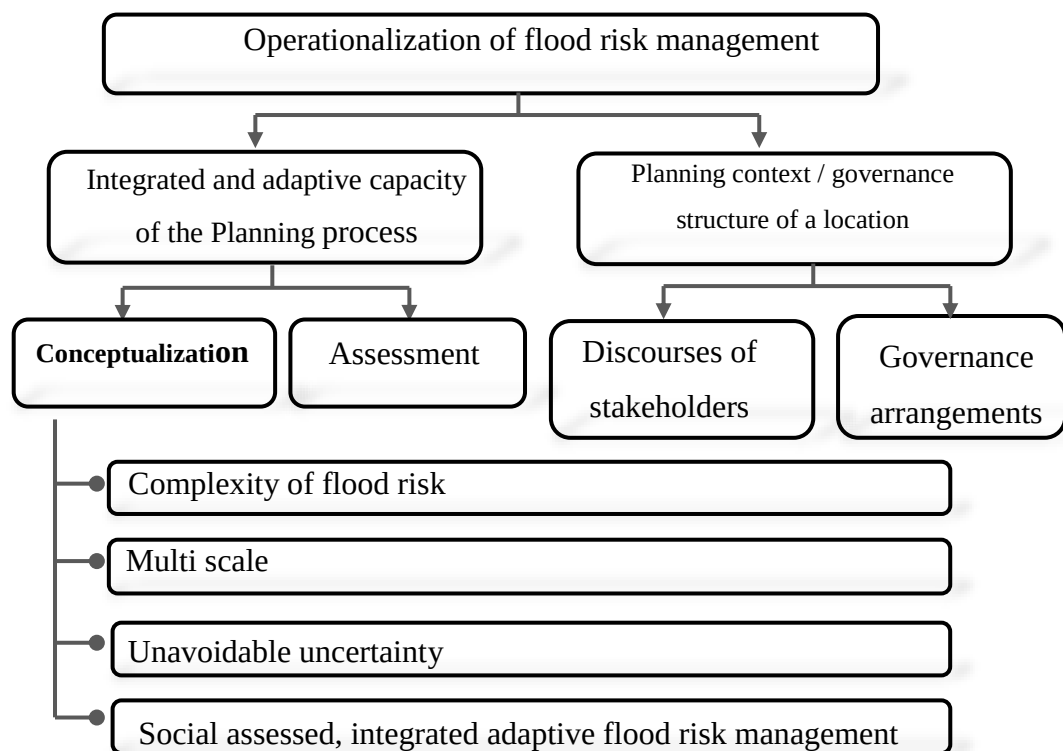


Figure 4.3 Sub criteria of conceptualization

4.5 Place-based Assessment

4.5.1 Adaptive capacities to maintain the ecological functions of the floodplains

Traditionally, the engineering management system focused on resisting an increasing number of more severe storms, rather than adapting to such changes in the floodplain

ecosystem. Thus, the design of flood-control infrastructure such as levees was followed by the probability thresholds. These traditional flood control infrastructure measures were established to prevent high water flows from reaching floodplains. Also, they reduced the natural flood storage capacity and the processes that maintain healthy forests and wetlands on the river. However, decision-makers continue to select flood control infrastructures. This reflects the in-built management paradigm of controlling nature (Birkland, 2003; Godschalk, 2003). Also, flood management infrastructural measures are often expensive (Castonguay, 2007). Despite the limitations of flood control, it still dominates the practice.

4.5.1.1 Natural floodplain and urban development

Natural floodplains are diverse and provide a range of ecosystem services (Tockner, 2002; Shilpakar, 2020). Floodplains can help attenuate flows by storing water in the system and releasing it gradually over time. Thereby, floodplains are used to reduce the intensity and likelihood of destructive flood events. Floodplain functions such as flood storage and conveyance, reducing flood velocities, reducing flood peaks, reducing sedimentation, etc., are often replaced with the increase of urban development (Kiedrzyńska, 2015). As a result, the urban floodplain becomes less tolerant of flooding, as there is less land available to transport and store floods and sediments (Opperman, 2009). There is no local or regional flood damage if there is adequate availability of lands for storing and conveying floodwater and sediments (Liao, 2012). Floodplains are natural ways of flood defense. Therefore, the presence of floodplains and wetlands is essential to manage the effects of flooding. The adaptability of floodplains depends on the availability of the floodplain (Hegger et al., 2016). Adequate availability of floodable land in urban areas is a crucial aspect of flood risk management.

4.5.1.2 Flood resilience

Resilience can be defined as a system's capacity to absorb change (Holling, 1973). Over time, the socio-ecological resilience concept characterizes floodplains from the viewpoint of complex adaptive systems (Zischg, 2018). Flood resilience is the ability of a floodplain to cope up with climatic disturbances, changes of flooding, or extreme weather events while still maintaining its basic structure, processes, feedbacks, and its functions. Adaptive systems can absorb greater disturbances without shifting into an alternate regime. A regime shift occurs when the dominant feedback changes, and it is often associated with a rapid non-linear change. Socio-ecological system restructures into different functions due to nonlinear changes that can occur. When the floodplains cross the adaptive threshold, the system may change its ecological functions (de Bruijn, 2017). If the thresholds of dominant feedbacks of a socio-ecological system are exceeded, the system can reorganize itself, which is characterized by different processes, feedbacks, and structures. Managing the adaptive threshold requires an understanding of two questions namely whether this system is approaching towards threshold or if it is time to avoid this threshold (Kelly et al., 2015). Accordingly, the development of adaptive strategies depends on the amount of information available, the degree of risk tolerance among stakeholders, and potentially significant social and economic benefits of avoiding the threshold (Christensen, 2012; Kelly., 2015).

4.5.1.3 Adaptive strategy making

Floodplains are the socio-ecological system. Regime shift change occurs when the threshold for the control variable is exceeded in a socio-ecological system (Walker et al., 2004). The threshold of the control variable of the considered floodplain can close or be far away from the important levels. The prospective management strategy making requires recognizing whether the socio-ecological system is approaching a threshold and if it is necessary to take timely actions to avoid it. It is, therefore, important to analyze what may happen to the whole system instead of one single element (Kerner, 2014). Hence, the goals and strategies of flood risk management are

suggested to withstand hazards to an acceptable level of the stakeholders (Linkov et al., 2014). Assessment of the planning process is, therefore, required to identify the adaptive thresholds for floodplains for different urban and climate change scenarios. The planning process is thus required to explore the management strategies which can provide high levels of desired productivity of floodplains instead of controlling the current hydrological and ecological functions of floodplains (Zevenbergen, 2008).

4.5.1.4 Strategy for Preparedness

Cities need a switch from engineering resilience-based flood management to flood risk management for long-term flood protection. Moreover, the objective of flood risk management is to maintain the adaptive thresholds within the current stable regime of floodplain functions, structure, and place identity (Liao, 2012). Therefore, flood resilience means the restoration of ecological functions of the floodplain (De Bruijn, 2005; Linkov, 2014; Pendall, 2010). Flood risk management has highlighted the integration between land and water management and structural and non-structural measures (Schneidergruber, 2004).

This adaptive management should provide economically and environmentally sustainable management measures for diverse flood events instead of controlling the impacts of certain flood events (Fuchs, 2017; Ahmed, 2018). Therefore, the planning system needs to look for ways to maintain the adaptive capacity of the floodplain ecosystem to cope with the dynamics of urban development & climate change scenarios. The adaptive strategy is focused to increase preparedness capacity for extreme flood events. Besides, the adaptive capacity means institutions are more prepared to deal with several kinds of uncertainties of external drivers such as climate change and urban development (Folke et al., 2005). Therefore, adaptive capacity is the presence of the collective action of stakeholders.

4.5.2 To develop diverse flood risk management options for different uncertain futures

4.5.2.1 Diverse scenarios of climatic changes

The risk-based planning process focuses on managing existing vulnerabilities in a system. Socio-ecological resilience thinking has highlighted the thresholds of adaptive capacity of a system accordingly they can be summarised as (1) linkages between biophysical properties and (2) acceptable levels of society (Berkes, 1998; Fuchs, 2017). The planning process needs to follow the adaptive pathway approaches. An adaptive approach is recommended to plan for a range of scenarios and to build the adaptive capacity of the flood risk management system for future scenarios. Planners can evaluate possible options and make trade-offs among stakeholder preferences of diverse floodplain management options following the pathway approach. Therefore, it is necessary to consider the co-evolving dynamics of interactions among the biological process of the watershed, climate change, and land use transformation in the selection of management strategies (Martín-López, 2017).

In the literature, the concept of the resilience of a socio-ecological system is described using dependent variables and independent variables (Walker, 2004). In general, climate change is regarded as a slower variable or independent variable of the socio-ecological system. The components of the watershed and their ecological functions such as regulatory functions, etc. Are mainly determined by climatic factors that operate globally. According to this understanding, climate change is the key factor that determines the properties of an ecosystem (Bailey, 2009). Further, land use transformation also influences the ecological processes of the watershed, floodplains, etc. It is required to understand the emergent properties of the above interactions in the assessment process and selection of strategies for flood risk management (González-Quintero, 2019).

Defining threshold values for flood management options means recognizing the specific boundary condition for ecological, technical, social, economic, etc systems

related to floodplains. Diverse flood management options are required to cope with the social, spatial, and temporal dynamics of the flood risk (Kerner, 2014). Accordingly, flood risk management strategies acknowledge the functioning of a system not only to be resilient to current disturbances but also to have resilience regarding the future dynamics of flood risk (Evans, 2006; Merz, 2010; Gersonius., 2010). Therefore, during the assessment process, trade-offs between vulnerability and adaptability due to different possible futures are required (Haasnoot, 2011).

Diversity is an important generic characteristic of flood risk management strategies (Biggs, 2012; De Bruijn., 2004; Restemeyer., 2015; Aerts., 2008; Klijn, 2010). Therefore, planning processes should assess the impact of diverse management options on flood risk management on the objectives of diverse stakeholders for different scenarios. To that end, flood-risk management options are evaluated based on an integrated risk assessment for efficient and equal decision-making. Therefore, more sophisticated decision-making processes such as social cost-benefit analysis, multi-criteria analysis, etc, can also support the planning process (Foudi, 2015).

4.5.3 Hydrological interactions of floodplains

The impacts of flood risk are diverse to stakeholders at different levels and sectors and the impacts of flood events do not stop at administrative borders. Flood risk management with river basin scale perspective has been discussed for a long time to respond to water-related issues (Evans, 2002; Nachtnebel, 2009; Hartmann, 2011). Effective flood risk management is necessary to consider the watershed scale (Sayers et al., 2015). The importance of designing flood risk management strategies based on a natural system with connecting upstream-downstream relations has been highlighted for flood resilience (González-Quintero, & Avila-Foucat 2019). Flood risk management strategies are required to be designed based on the whole system approach. Therefore, it will help to avoid or manage the conflicts between the upstream-downstream, cross the river, etc. (Quinn, 2019). Further, spatial integration has been identified as the integration of land and water, surface water and groundwater,

water quantity and quality, interests related to the upstream and downstream water, and the freshwater and coastal zone (Kidd, 2007; Clausen et al., 2001).

4.5.4 Socio-spatial interactions of floodplain

In the past, the main objective of the flood management strategies was very often to protect urban areas, industrial areas, etc from flood occurrences. Economic efficiency and profitability were the main criteria in the selection of management strategies in the past (Holland, 2017; Schlosberg, 2017). However, these flood control strategies could have had brought larger negative impacts for large communities particularly in long run (Holland, 2017; Schlosberg, 2017; Johnson, 2007). Some of the social groups were excluded from the planning and implementation process due to lack of empowerment, lack of resources or lack of knowledge, etc (Clausen et al., 2001). Also, the objectives of local stakeholders were not highlighted in the decision-making process of flood risk management. The traditional cost-benefit analysis was also used to assess flood risk which can hardly assess the impact of nonlinear and non-stationary interactions of the flood risk (Thaler, 2016). As a result, traditional flood management strategies focused on the physical separation of water and community (Böhm, 2004).

Each stakeholder in a community has its perspectives for flood risk management depending on their priorities and objectives over the floodplain. Managing the social equity of flood risk has been debated in past decades (Fielding, 2005; Johnson, 2007; Walker & Burningham 2011; Thaler, 2016). Therefore, the process of developing the flood risk management strategy should attempt to strike a balance between creating floodplains for diverse spatial demands. Therefore, compromising spatial claims over floodplains is required in the planning process (Pardoe, 2011). Accordingly, decision-makers have discussed the allocation principles of floodplain land uses, financing, distribution of liabilities of flood damage, etc. For that reason, it is also necessary to assess the coevolution between different stakeholders and land use development over the floodplain. Further, it is also necessary to explore the potential for the integration of objectives of the different stakeholders in the management of flood vulnerability.

Social integration highlights that, through the integration of stakeholders at all levels as local, regional, and state level. Strategies could be devised on the river basin scale, taking into account upstream and downstream linkages, spatial claims as well as the social demands of all stakeholders. Social integration leads to creating the socio-ecological system to be more robust for extreme flood events. Social integration increases the social capacity to tolerate flooding and to reorganize land uses of floodplains to maintain current socioeconomic identity. But still, implementation of multiple synergies between policies, sectors, scales is largely missing (Bouwma, 2018; Hartmann, 2012). This situation underlines the need for developing an integrated approach to water management, flood risk management, and nature conservation for rivers and floodplains. It can still be argued that giving up robust planning decisions and moving to a system based solely on flexibility is not an option both (Tempels & Hartmann, 2014). The sub-criteria of place-based assessment are highlighted as the factors considered for deciding the acceptable levels of risk and selecting of flood risk management option. The following Figure 4.4 highlights the sub-criteria are (1) capacity to maintain the ecological feedbacks of the floodplain, (2) capacity to cope with diverse climatic scenarios, (3) capacity to maintain the balance between territorial hydrological balance, and (4) the capacity to fulfill the local social-spatial demands.

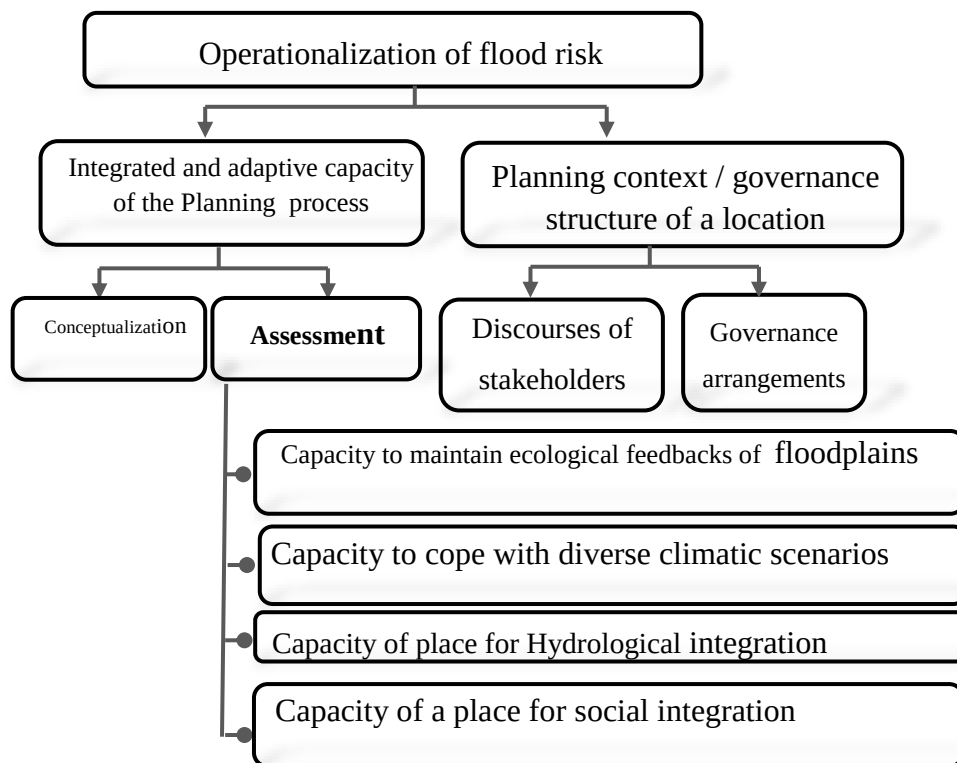


Figure 4.4: Sub criteria of the place-based Assessment

4.6 Discourses of Stakeholders

The institutionalized knowledge system explains the ability of interest groups and local authorities to respond flexibly to changes in flood risk over the long term. Traditionally, policymakers particularly hydrologists have assumed that uncertainty can be reduced through rational and regular cost-benefit analyses. However, the main purpose of cost-benefit analysis is to explore whether the flood risk management policies, strategies, and guidelines provide net benefits to society. The current practice of cost-benefit assessments is based on the linear cost and the damage function assessments. The backward-looking cost-benefit assessments are ineffective to capture the social cost due to the socio-ecological dynamics of flood risk in the future. The traditional cost-benefit analysis considers that the cost and the benefits of flood risk management practices such as infrastructure measures, zoning guidelines are distributed evenly among all the stakeholders. Hence, the existing evaluation process does not help to adequately address the social injustice of the local community (Hudson & Botzen, 2019). Hydrologists hold a strong position in the policy networks around flood risk management (van Buuren, 2018). Operationalization of flood risk management is restricted due to the understanding of stationary assumptions that are anchored in the existing institutional context of water management (Gersonius et al., 2016; Van Buuren, 2016). The knowledge system of governance is necessary to understand the limitations of existing practices of flood risk management and anticipate non-linear dynamics. These are important aspects of adaptation planning. Making flood risk management operational requires stakeholders to understand the importance of long-term planning, use of scenarios, and consideration of uncertainties rather than a shorter time frame (van Buuren, 2018).

A broad shift is required to realize the necessity to learn to live with floods. Therefore, the institutionalizing of adaptive planning requires well-tuned processes that address the preferences and values of the present and those representing future generations (Alexander, 2016; Offermans, 2011). The implementation of risk-based approaches in government guidelines promotes preventive consideration of the effects of climate

change (van Buuren, 2018). An important driving factor behind this change is the increasing recognition of the epistemic community that flood defense is not necessarily the most financially or environmentally sustainable strategy in the long term impacts are considered (Fournier., 2016). This understanding of the stakeholders might be more useful to try to accommodate water through flood mitigation and flood preparedness. In recent years, the strong long-term orientation and tradition of using scenarios to set flood risk management standards are also needed to provide fertile ground for long-term policy development (van Buuren et al., 2018). There is a timely requirement of institutionalizing the importance of adaptive and long-term planning.

4.6.1 Social Learning

In recent decades, social learning has been recognized to promote interaction among stakeholders to attain productive knowledge. The importance of social learning is highlighted when the stakeholders realize they are interdependent and individual action will yield lesser benefit than the collaborative effort. The main objective of the participation of stakeholders in FRM is learning and knowledge exchange (Lorenzoni, 2015). Social learning is important to effectively translate common goals into actions. Because social learning develops and maintains the capacity of various stakeholders to manage water resources (Pahl-Wostl, 2009; Armitage., 2008). Therefore, social learning is another key criterion for the operationalization of flood risk management.

4.6.2 Multilevel governance systems

More collaborations among stakeholders and the broadening of the responsibilities of stakeholders including government, community, and political groups are necessary for the operationalization of flood risk management. There are two separate dimensions of social integration that can be practiced such as integration of stakeholders among different sectors and the scales. Sectoral integration highlights the integration of different policy domains, ‘joining up’ of the priorities of different public policy domains and their associated stakeholders within a given territorial area. The role of a

multilevel governance system as opposed to closed and focused on sectoral implementation in decision making (van Buuren et al., 2018). Multi-level governance systems are needed to recognize the importance of an integrated knowledge system that fosters strong interdisciplinary and intersectoral networks. Further, multi-level governance systems promote greater public accountability and collaboration (van Buuren et al., 2018). Local community participation allows the inclusion of local knowledge and different values, interests, and perspectives in planning and management processes (Gooch, 2008; van Buuren et al., 2018).

4.6.3 Flexibility in governance arrangements for continuous learning and experimentation

Stakeholders need to recognize the importance of flexibility in governance arrangements for operationalizing FRM (Fournier, 2016; Molenveld & van Buuren, 2019). Decision-making is required to consider the FRM process as a continuous process that is comprised of feedback loops (Cosoveanu, 2019; Pahl-Wostl, 2009). Accordingly, there are three ways to manage the uncertainty in the decision making providing opportunities for governance arrangements for learning.

1. Single-loop learning is to expand the performance of established routines of flood risk management systems. (improvement of actions)
2. Double-loop learning to reframe the goal, the problem, and assumptions (cause-effect relationships)
3. Triple-loop learning is an alteration of the structural context and factors that determine the frame of reference and underlying values, beliefs, and world views of the stakeholders

Flexibility in governance arrangements facilitates continuous learning and experimentation. Further, the recognition of the importance of the flexibility of the related policies is also an important factor for different framing of the flood risk and strategies considering the socio, spatial and temporal dynamics. Further, policies are required to recognize the importance of available flexible mechanisms for the offering of opportunities to bring new stakeholders on board and help to align mindsets for plans and projects.

4.6.4 Local initiatives

In addition, local community participation in planning and implementation which includes local stakeholder initiatives, self-organization, and self-responsibility are important factors for operationalizing flood risk management. Stakeholders are also necessary to recognize the importance of legitimization of local initiatives and community participation in the decision-making process. Community participation is seen as a key element in minimizing the impact of flooding and adaptation measures need to be developed and implemented at the local level (CCRA, 2012; Wilson, 2006). Community participation allows to include the communities' interests, values, and culture, and therefore shape the interaction of stakeholders in decision making. Thereby the capacity to address flood risk as a joint problem framing will be also facilitated. Although climatic change is taken into account in many parts of the world, participatory decisions are still not considered an important tool in the process of reducing exposure and flood vulnerability. For example, spatial planning policies provide a legitimized platform to the stakeholders to frame of reference of floodplain land use development. Therefore, related policy discourse of flood risk management should recognize the importance of the participation of the local community in the decision-making process. As described in Figure 4.5, the important factors which characterized the discourse of the stakeholders are recognized the significance of social learning, multilevel governance flexibility in the governance process, and the participation of the local community in the decision-making process.

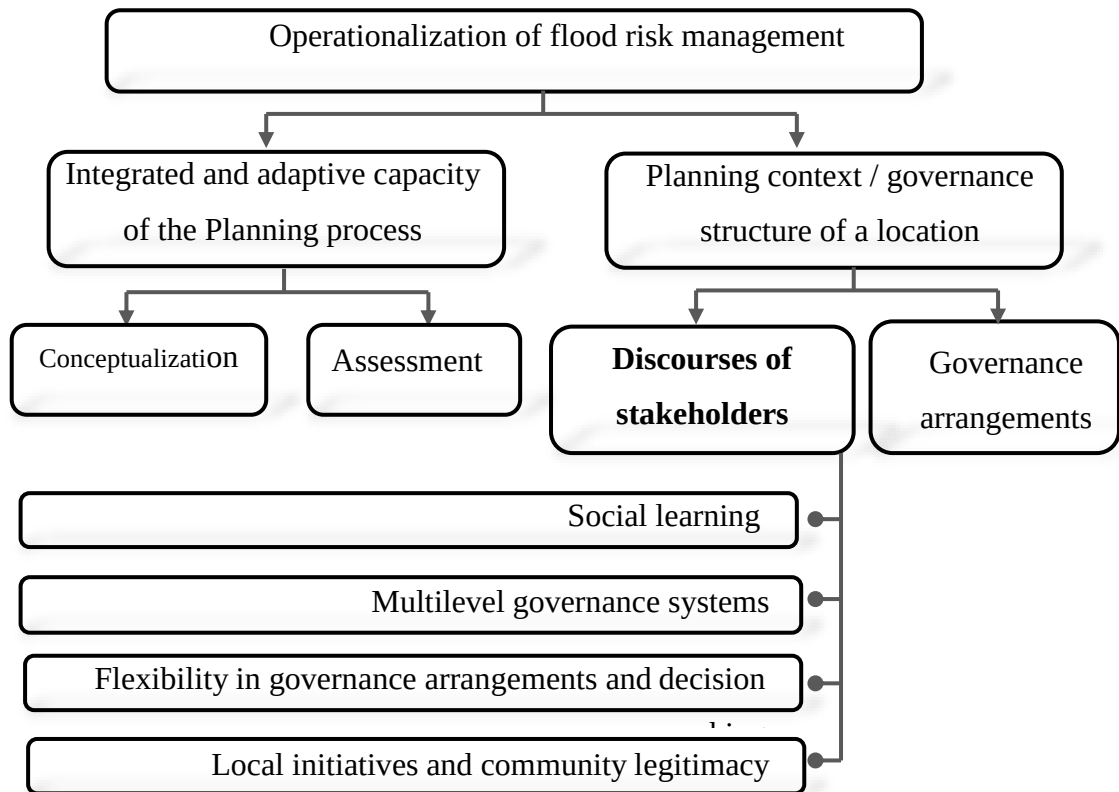


Figure 4.5 – Sub criteria of discourse of the stakeholders

4.7 Integrated and Adaptive Governance Mechanism

4.7.1 Integration among the land and water institutions at all scales and levels

A strong and autonomous position of the water authority, dominated by engineers, is an obstacle to the operationalization of the flood risk. The autonomous position of the water administration has resulted in fragmentation between planning and flood management. The autonomy of the regional water authorities allowed the system to remain on the command and control path and resist adopting more flexible approaches (Van Buuren, 2015). Further, the pressure of the local population on the housing and urban development market also poses a challenge for the implementation of risk management strategies. Land and water integrated tools are important for the implementation of flood risk management. In practice, there is a less coherent mechanism for integrating land use planning and flood risk management.

Consideration of the level of connectedness between land and water stakeholders' objectives in the planning process and availability and strength of mechanisms connecting actors, e.g., partnerships or regulations are important (Gilissen et al., 2016). Spatial planning and coordination of water management strategies are currently preferred in many countries in policy areas (Chan, 2018).

4.7.2 Integrated goal setting and catchment-scale approach

The management of water resources in river basins aims to ensure consistency between different aspects of water management, e.g. Flood issues, water quality, energy production, and agricultural objectives. There should be a strong territorial integration for the operationalization of the FRM (Kidd, 2007). The “watershed-based planning approach” indicated that government takeover of these private, public, and third-sector organizations should work more closely together. Central governments should view the risk of flooding as a matter of public concern and determine what to do to achieve the best result while being strictly required by law to protect the public (Kuklicke, 2016). Therefore, the river basin should be seen as a unit of assessment to understand the positive and negative influences of interventions that take into account the transboundary spatial and temporal complexities (Halle, 2006; van Herk, 2015). Further, territorial communication mechanisms facilitate trade-offs among the stakeholders at the upper and lower levels of the watershed.

The establishment of regional platforms, including provinces and water authorities, to achieve better alignment between water and planning to facilitate the implementation process is evidence of a basin-wide approach to flood risk management (van Buuren, et al., 2018). Local flood risk management strategies could better correspond to the regional planning level. This coherence mechanism is not yet fully developed (Benson, 2017). However, institutional mechanisms at the regional level are evolving, such as new laws like the England Water Act 2014.

4.7.3 Multiple Governance

There should be a strong functional link between each level of government and between levels of government to implement flood risk management practices (Lawrence, 2015). The implementation of flood risk management is reinforced by the internal organization and distribution of power at different levels and different scales (van Buuren et al., 2018). Multi-level governance structures allow everyone involved to jointly participate in complex flood risk management. However, it is not expressed in current institutional systems and requires various adaptations and articulations between the organization and, above all, between the powers of the different levels. It is also recognized that the production of knowledge or evidence shared between different actors is a critical step to help actors develop strategies and implement interventions (Newig, 2009; Evers, 2012; Challies et al., 2016). Fragmentation in the institutional setting can hinder the social adaptation to flooding and Multiple Governance mechanisms facilitate distribution and diversify responsibilities among stakeholders.

4.7.4 Local stakeholders for participation

Active involvement of the local population at every stage of the flood disaster risk management cycle, such as preparedness, response, recovery, and mitigation, is essential to increase community resilience to flood risk (Begg, 2015) and to reduce flood vulnerability (Butler, 2011). It is, therefore, necessary to transfer part of the responsibility for operationalizing flood risk management to individual stakeholders and local communities. Also, having a local agenda that inspires ecological aspects increases stakeholder participation in the planning process. As explained in Figure 4.6 the key characteristics of participatory mechanisms required to practice flood risk management are the presence of the resource and information distribution mechanism among the land and water-related stakeholders overall catchment scale stakeholders, multi-sectoral as well as the local communities.

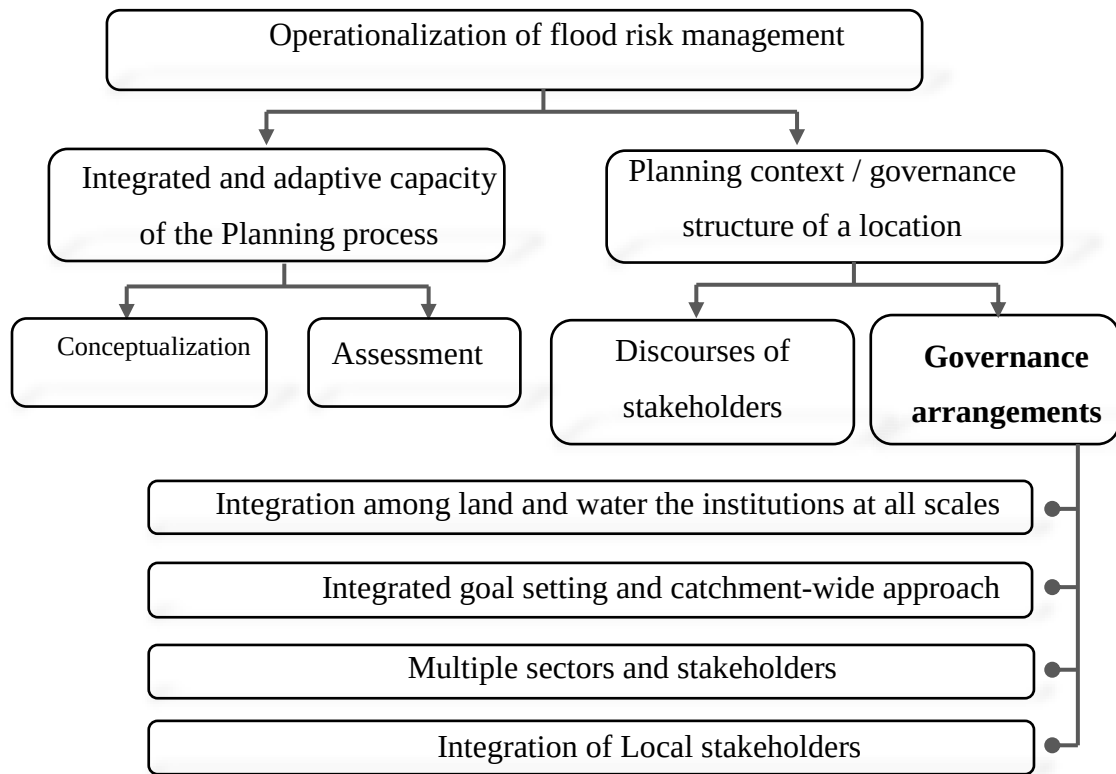


Figure 4.6: Sub criteria of Participatory governance context

4.8 Proposed Framework for Flood Risk Management

Rationalists consider that risk can be estimated in terms of probability and, provide some quantitative expectations about the future. It highlights that if decision-makers own complete knowledge there is no element of uncertainty and risk. However, it has been realized that the uncertainty incorporated with flood risk needs to be managed since it is not possible to be eliminated. Therefore, flood risk management has moved towards achieving an appropriate balance between realizing opportunities and minimizing losses. Traditional prescriptive flood risk management has transformed emphasizing the achievement rather than the means of achieving it (Aven, 2010). Flood risk can be described as a way of expressing uncertainty in the decision among processes (Raaijmakers et al., 2008). Therefore, flood risk management has been described as a decision-making process of collection of perceptions of stakeholders for analyzing uncertainty and exploring the potential for managing uncertainty.

Management of uncertainty is the core objective of the planning process for the operationalization of FRM. Moreover, adaptation and integration are the key characteristics of the decision-making process for the implementation of flood risk management.

The level of operationalization of flood risk management is determined by the characters of the planning process as well as the planning context. As indicated in Figure 4.7, operationalization of flood risk management system can be framed into four main dimensions such as (1) conceptualization of flood risk and (2) place-based assessment of flood risk in the planning process and the (3) discourses of stakeholders and the (4) power and the resource distribution pattern of the governance context.

Reducing uncertainty incorporated with flood risk management is assumed to be a product of the integration of stakeholders' knowledge. Conceptualization of the planning process describes the characteristics of the knowledge system of the mandatory stakeholders in the planning process. Stakeholders' conceptualization of FRM in the decision-making process determines the expected objectives/outcomes of the flood risk management system. Decision-makers in the planning process are required to conceptualize flood risk management as a complex, multiscale, unpredictable, and socially constructed phenomenon. The sub-criteria of the conceptualization of flood risk is (a) conceptualization of flood risk as a complex phenomenon, and interdependency between social, hydrological, ecological subsystems (b) conceptualization of scale sensitivity of flood vulnerability & flood risk in the planning process (c) conceptualization the inherent uncertainties incorporated with flood risk management system (d) conceptualization of Flood risk management as an integrated & adaptive process (Figure 4.7).

The place-based assessment describes the consideration factors of defining goals and strategies of flood risk management and increasing the adaptive capacity of the system. It describes the determinants of the planning process to achieve flood resilience. Stakeholders in the planning process can recognize the long-term impacts due to non-stationary and nonlinear interactions of flood risk on people, infrastructure, economy,

etc, and on the functions, processes, and identity of floodplains considering a scenario-based approach. The sub-criteria of the assessment of flood risk in the planning process are (a) identification the potentials/strategies to increase the adaptive capacities to maintain the ecological functions of the floodplains rather than design strategies based on probability thresholds (b) identification of diverse management measures to minimize flood hazard & vulnerability (structural & non-structural measures to increase flood resilient) to cope up with diverse climatic scenarios (c) identification of the potentials/strategies for maintenance of the Hydrological interactions of flood risk over the overall watershed and (d) identification of the potentials for multifunctional land uses over floodplains integrating the diverse spatial claims of stakeholders (trade-offs of multiple social interactions of flood risk). The role of the assessment of the planning process is to provide opportunities for stakeholders to produce the trade-offs considering the multiple criteria considering the location-specific. Therefore, the sub-criteria in the assessment process is consideration of floodplain natural functions, multiple climatic scenarios (extreme events), hydrological connectivity, and the consideration of the social hydrological interdependency for evaluation of flood risk management practices (Figure 4.7).

The planning context is characterized by the discourses of the stakeholders and the power and the resource distribution pattern among the stakeholders. Discourses of Governance structure describes the Policy discourses of the stakeholders which include the principles, concepts, and methodologies that determine the practicing of flood risk management. Adaptive and integrated policy discourses of the stakeholders facilitate the implementation of flood risk management which is characterized with Institutionalizing of social learning (b) Institutionalizing of Multilevel governance system (c) Flexibility in governance arrangements & decision making and (d) Legitimize Local initiatives and community participation.

Participatory Governance structure means the Power/resources distribution patterns of the governance system. Opportunities for joint fact-finding or optimizing the collective knowledge of all stakeholders can provide broad support for the construction of new knowledge. Participatory governance context is characterized by the Mechanisms

available for integration among the land and water-related institutions at all scales and levels (b) Mechanisms available for integrated goal setting & catchment-wide approach for decision making (c) Multiple regime Governance Tradition (d) Legitimized tools available for Empower local stakeholders in decision making & implementation of FRM system (Figure 4.7).

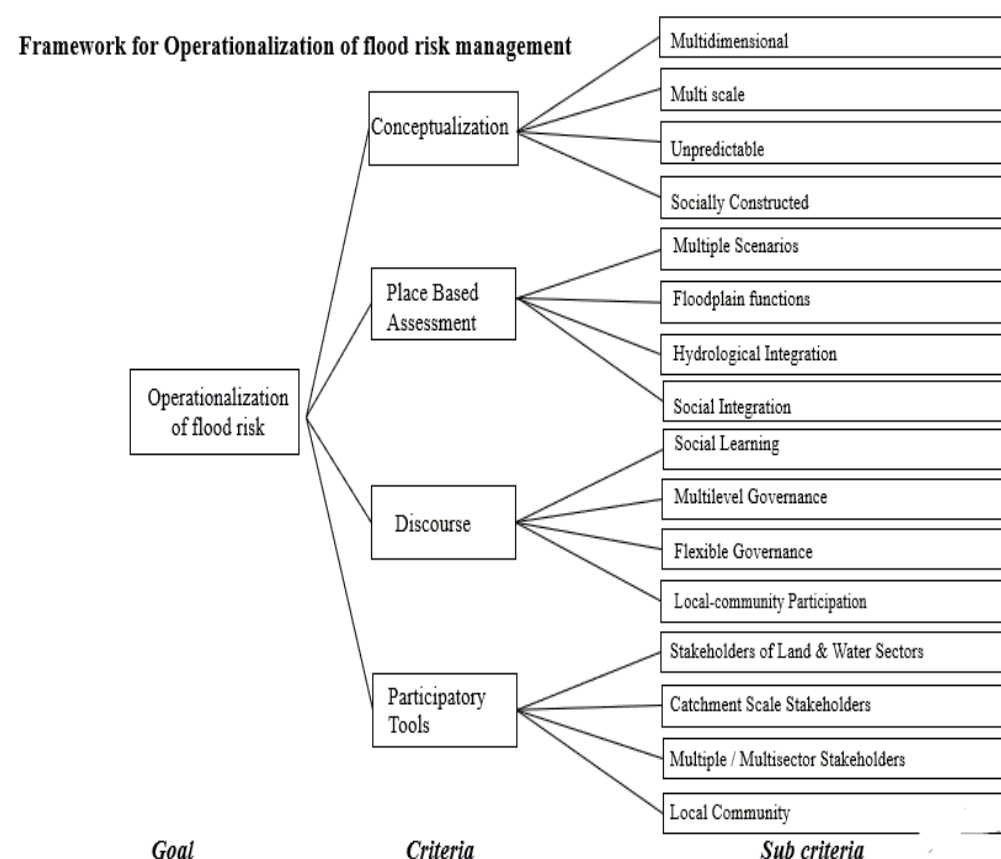


Figure 4.7 Criteria and Sub criteria of the framework for operationalization of FRM

4.9 Calibration of the Proposed Framework

In the initial calibration phase, the examiners assessed the relevance of the criteria and sub-criteria of the conceptual framework that defines the overall objective.

4.10 Experts Consensus on the Criteria and Sub-Criteria of the Framework

Table 4.1 presents the results of the evaluation of the main criteria and sub-criteria of the framework by all the experts. Tables 4.2 and 4.3 show the degree of agreement between engineers and planners on the main criteria and the sub-criteria separately.

Table 4.1: Results of Expert consensus (overall assessment)

Criteria and the sub-criteria of the framework	Percentage						
	Strongly agree 1	Agree 2	Neutral 3	Disagree 4	Strongly disagree 5	Mean	Standard deviation
Main criteria							
Conceptualization	42.86	54.76	2.38	0.00	0.00	1.60	0.54
Assessment	50.00	45.24	4.76	0.00	0.00	1.55	0.59
Discourse	40.48	57.14	2.38	0.00	0.00	1.62	0.54
Participatory	42.86	52.38	4.76	0.00	0.00	1.62	0.58
Sub criteria							
Conceptualization							
Complexity	59.52	35.71	4.76	0.00	0.00	1.45	0.59
Multiscale	54.76	38.10	7.14	0.00	0.00	1.52	0.63
Unpredictable	45.24	40.48	14.29	0.00	0.00	1.69	0.72
Integration	57.14	42.86	0.00	0.00	0.00	1.43	0.50
Assessment							
Adaptive capacity	38.10	47.62	9.52	4.76	0.00	1.81	0.80
Diverse scenarios	40.48	54.76	4.76	0.00	0.00	1.64	0.58
Spatial interdependency	42.86	50.00	7.14	0.00	0.00	1.64	0.62
Social interdependency	47.62	47.62	4.76	0.00	0.00	1.57	0.59
Discourse							
Adaptive Planning	45.24	47.62	7.14	0.00	0.00	1.62	0.62
Multilevel governance	30.95	57.14	9.52	2.38	0.00	1.83	0.70
Continuous & flexible system	33.33	54.76	9.52	2.38	0.00	1.81	0.71
Local community participation	50.00	40.48	9.52	0.00	0.00	1.60	0.66
Participatory							

Land & water	42.86	50.00	7.14	0.00	0.00	1.64	0.62
Multiple scales	30.95	61.90	4.76	2.38	0.00	1.79	0.65
Flexibility of the process	33.33	47.62	19.05	0.00	0.00	1.86	0.72
Legitimacy of Local communities	30.95	54.76	11.90	2.38	0.00	1.86	0.72

Table 4.2 Results of Expert consensus (Engineers)

Engineers	Percentage (%)						Standard deviation
	Strongly agree 1	Agree 2	Neutral 3	Disagree 4	Strongly disagree 5	Mean	
Main criteria							
Conceptualization	36.364	63.636	0.000	0.000	0.000	1.636	0.492
Assessment	50.000	45.455	4.545	0.000	0.000	1.545	0.596
Discourse	45.455	50.000	4.545	0.000	0.000	1.591	0.590
Participatory	40.909	50.000	9.091	0.000	0.000	1.682	0.646
Sub criteria							
Conceptualization							
Complexity	59.091	36.364	4.545	0.000	0.000	1.455	0.596
Multiscale	59.091	36.364	4.545	0.000	0.000	1.455	0.596
Unpredictable	31.818	50.000	18.18	0.000	0.000	1.864	0.710
Integration	40.909	59.091	0.000	0.000	0.000	1.591	0.503
				0.000			
Assessment							
Adaptive capacity	36.364	45.455	9.091	9.091	0.000	1.909	0.921
Diverse scenarios	36.364	59.091	4.545	0.000	0.000	1.682	0.568
Spatial interdependency	40.909	50.000	9.091	0.000	0.000	1.682	0.646
Social interdependency	40.909	50.000	9.091	0.000	0.000	1.682	0.646

Engineers	Percentage (%)						
	Strongly agree 1	Agree 2	Neutral 3	Disagree 4	Strongly disagree 5	Mean	Standard deviation
Discourse							
Adaptive planning	40.909	50.000	9.091	0.000	0.000	1.682	0.646
Multilevel governance	31.818	63.636	4.545	0.000	0.000	1.773	0.685
Continuous & flexible system	27.273	63.636	9.091	0.000	0.000	1.818	0.588
Local community participation	40.909	45.455	13.636	0.000	0.000	1.727	0.703
Participatory							
Land & water	45.455	50.000	4.545	0.000	0.000	1.591	0.590
Multiple scales	31.818	59.091	9.091	0.000	0.000	1.773	0.612
Multilevel & multisector	31.818	50.000	18.182	0.000	0.000	1.864	0.710
Legitimacy of Local communities	27.273	54.545	18.182	0.000	0.000	1.909	0.684

Table 4.3 Results of Expert consensus (Town Planners)

Town Planners	%						
Merge these two cells	Strongly agree 1	Agree 2	Neutral 3	Disagree 4	Strongly disagree 5	Mean	Standard deviation
Main criteria							
Conceptualization	50.000	45.000	5.000	0	0	1.55	0.604
Assessment	50.000	45.000	5.000	0	0	1.55	0.604
Discourse	35.000	65.000	0.000	0	0	1.65	0.489
Participatory	45.000	55.000	0.000	0	0	1.55	0.510
Sub criteria							
Conceptualization							
Complexity	60.000	35.000	5.000	0	0	1.45	0.604

Town Planners	%						
Merge these two cells	Strongly agree 1	Agree 2	Neutral 3	Disagree 4	Strongly disagree 5	Mean	Standard deviation
Multiscale	50.000	40.000	10.000	0	0	1.6	0.680
Unpredictable	60.000	30.000	10.000	0	0	1.5	0.688
Integration	75.000	25.000	0.000	0	0	1.25	0.444
Assessment							
Adaptive capacity	40.0000	50.0000	10.0000	0	0	1.7	0.656
Diverse scenarios	45.0000	50.0000	5.0000	0	0	1.6	0.598
Spatial interdependency	45.0000	50.0000	5.0000	0	0	1.6	0.598
Social interdependency	55.0000	45.0000	0.0000	0	0	1.45	0.510
Discourse							
Social Learning	50.000	45.000	5.000	0.000	0	1.55	0.604
Multilevel governance	30.000	50.000	20.000	0.000	0	1.9	0.718
Continuous & flexible system	40.000	45.000	10.000	5.000	0	1.8	0.833
Local community participation	60.000	35.000	5.000	0.000	0	1.45	0.604
Participatory							
Land & water	40.000	50.000	10.000	0.000	0	1.7	0.656
Multiple scales	30.000	65.000	5.000	0.000	0	1.8	0.695
Multilevel & multisector	35.000	45.000	20.000	0.000	0	1.85	0.745
Legitimacy of Local communities	35.000	55.000	5.000	5.000	0	1.8	0.767

The results highlight that the selected main criteria and the sub-criteria of the framework are strongly agreed or agreed upon by the experts.

4.10.1 Prioritization of the main criteria

A pair-wise comparison matrix was created with the help of a scale of relative importance. Each number in a column of the pairwise comparison matrix was divided by its column sum. Table 4.5 highlights the normalized pairwise matrix for the main criteria. Subsequently, the priority vector was developed by averaging each row of the normalized matrix and Table 4.6 Priority vector for main criteria. The consistency of the subjective input data in the pairwise comparison matrix can be assessed by calculating a Consistency Ratio (CR). When the consistency ratio is greater than 0.1 the subjective input is required to re-evaluate. Accordingly, it has been computed the consistency ratio CR after calculating of $\lambda_{\max}$, Consistency Index (CI), and Random Index (RI). Table 4.7 highlights the calculation of $\lambda_{\max}$ value. The following Table 4.8 presents the weights for the main criteria obtained from AHP. Figure 4.8 presents the prioritization values for the main criteria which affect the operationalization of FRM.

Table 4.4 Pairwise comparison matrix for main criteria

Main Criteria		Pairwise comparison	
Conceptualization	Assessment	1	3
Conceptualization	Participatory tools	1	2
Conceptualization	Integrated & adaptive policies	4	1
Assessment	Participatory tools	3	1
Assessment	Integrated & adaptive policies / discourse	7	1
Participatory tools	Integrated & adaptive policies / discourse	5	1

Main Criteria	Conceptualization of uncertainty	Assessment to manage uncertainty	Participatory tools	Integrated & adaptive policies
Conceptualization of uncertainty	1	1/3	1/2	4
Assessment	3	1	3	7
Participatory tools	2	1/3	1	5
Integrated & adaptive policies / discourse	1/4	1/7	1/5	1

Main Criteria	Conceptualization	Assessment	Legitimized tools for integration /	Integrated & adaptive policies / discourse
Conceptualization	1.00	0.3300	0.5	4
Assessment	3.00	1.0000	3.0	7
Participatory tools	2.00	0.3300	1.0	5
Integrated & adaptive policies / discourse	0.25	0.1428	0.2	1
Column sum	6.25	1.8028	4.7	17

Table 4.5 Normalized matrix for main criteria

Main Criteria	Conceptualization	Assessment	Legitimized tools for integration	Integrated & adaptive policies
Conceptualization	1.00	0.3300	0.5	4
Assessment	3.00	1.0000	3.0	7
Legitimized tools for integration	2.00	0.3300	1.0	5
Integrated & adaptive policies / discourse	0.25	0.1428	0.2	1
Column sum	6.25	1.8028	4.7	17

Main Criteria	Conceptualization		Assessment		Participatory tools		Integrated & adaptive policies	
Conceptualization	1/6.25	0.1600	0.33	0.1830	0.5	0.1063	4	0.2352
Assessment	3/6.25	0.4800	1.00	0.5548	3.0	0.6382	7	0.4117
Participatory tools	2/6.25	0.3200	0.33	0.1830	1.0	0.2127	5	0.2941
Integrated & adaptive policies / discourse	0.25/6.25	1.5625	0.1428	0.0792	0.2	0.0425	1	0.0588
Column sum	6.25		1.8028		4.7		17	

Table 4.6 Priority vector for main criteria

Main criteria	Conceptualization		Assessment		Participatory tools		Integrated policies			Average weight
Conceptualization	1/6.25	0.16	0.3300	0.1830	0.5	0.1063	4	0.2352	0.6845	0.1711
Assessment	3/6.25	0.48	1.0000	0.5548	3.0	0.6382	7	0.4117	2.0847	0.5211
Participatory	2/6.25	0.32	0.3300	0.1830	1.0	0.2127	5	0.2941	1.0098	0.2524
Integrated & adaptive policies / discourse	0.25/6.25	0.04	0.1428	0.0792	0.2	0.0425	1	0.0588	0.2200	0.0550
Column sum	6.25		1.8028		4.7		17			

Table 4.7 Principal Eigen-value calculation for main criteria

Main Criteria	Conceptualization of uncertainty		Assessment for manage uncertainty		Participatory tools		Integrated & adaptive policies			
	0.1711		0.5211		0.2524		0.055			
Conceptualization	1	0.1711	0.3300	0.1719	0.5	0.1262	4	0.220	0.6892	4.0280
Assessment	3	0.5133	1.0000	0.5211	3.0	0.7572	7	0.385	2.1766	4.1700
Participatory tools	2	0.3422	0.3300	0.1719	1.0	0.2524	5	0.275	1.0415	4.1260
Integrated & adaptive policies / discourse	0.25	0.0427	0.1428	0.0744	0.2	0.05048	1	0.055	0.2225	4.0469
Column sum	6.25		1.8028		4.7		17			16.3709/ 4
Principal Eigenvalue (λmax)										4.0927

Calculation of Consistency ratio for the main criteria

$$\begin{aligned}
 \text{Principal Eigen value} &= \lambda_{\max} \\
 \lambda_{\max} &= 4.0927 \\
 \text{Dimension of the matrix} &= n \\
 \text{Consistency index} &= \frac{\lambda_{\max} - n}{(n-1)} \\
 &= .0927/3 \\
 \text{CI} &= 0.03
 \end{aligned}$$

Random index

Size of the matrix	2	3	4	5	6	7	8	9	10
Random index (RI)	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

$$\begin{aligned}
 \text{Consistency ratio (CR)} &= \text{CI} / \text{RI} \\
 &= 0.03 / 0.9 \\
 &= 0.03
 \end{aligned}$$

CI= Consistency Index, n = size of the matrix,

$\lambda_{\max}$ = Eigen Value of the matrix,

RI= Random Index

(Saaty suggests that if that ratio exceeds 0.1 the set of judgments may be too inconsistent to be reliable)

Table 4.8: Main criteria weights obtained from AHP

Main criteria	Criteria weights
Conceptualization	0.1711
Assessment	0.5211
Integrated & adaptive policies / discourse	0.055
Participatory tools	0.2524

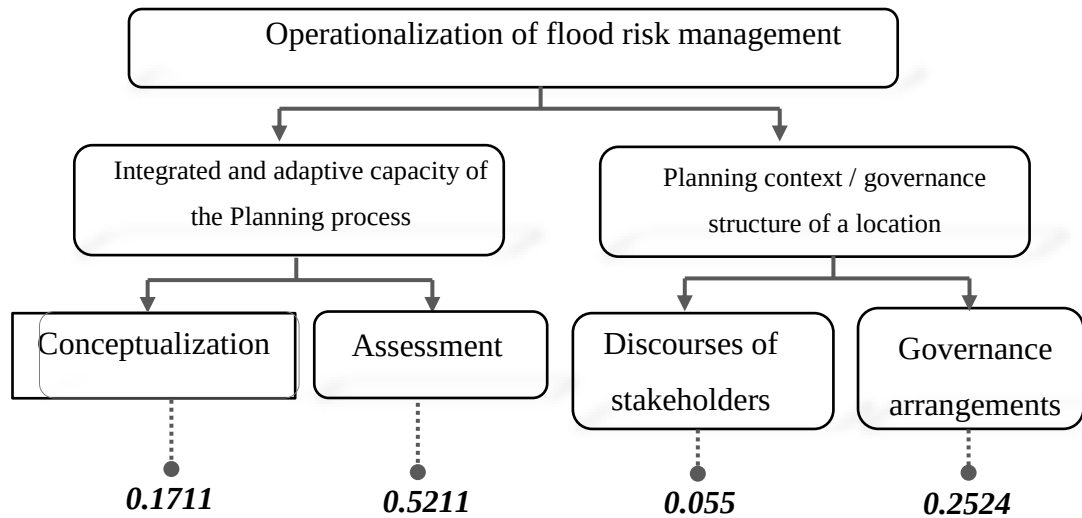


Figure 4.8: Prioritization of the main criteria

4.10.2 Prioritization of sub-criteria of conceptualization

Table 4.9 and Table 4.10 highlight the pairwise comparison matrix and normalized matrix for sub-criteria of conceptualization. Further, Table 4.11 demonstrates the priority vector determination for the sub-criteria of conceptualization. Consequently, the Consistency Ratio was calculated and Table 4.12 presents the principal Eigenvalue calculation for sub-criteria of conceptualization. Therefore, Table 4.13 presents the weight of sub-criteria of conceptualization obtained from AHP analysis, and Figure 4.9 presents the prioritization of the sub-criteria of Conceptualization.

Table 4.9 Pairwise comparison matrix for sub-criteria of conceptualization

Sub Criteria		Pairwise comparison	
Holistic	Scale sensitivity	3	1
Holistic	Non linearity/ Unpredictability	1	3
Holistic	Social assessment & integration	1	5
Scale sensitivity	Non linearity / Unpredictability	1	6
Scale sensitivity	Social assessment & integration	1	7
Non Linearity / Unpredictability	Social assessment & integration	1	3

Table 4.10 Normalized matrix for sub-criteria of conceptualization

	Holistic	Scale sensitivity	Unpredictability	Social assessment & integration
Holistic	1	3	1/3	1/5
Scale sensitivity	1/3	1	1/6	1/7
Non linearity / Unpredictability	3	6	1	1/3
Social assessment & integration	5	7	3	1

	Holistic		Scale sensitivity		Non linearity / Unpredictability	Social assessment		
Holistic	1.000/9.33	0.1071	3/17	0.1764	0.333/4.499	0.0740	0.200/1.675	0.1194
Scale sensitivity	0.333/9.33	0.0356	1/17	0.0588	0.166/4.499	0.0370	0.142 / 1.675	0.0847
Unpredictability	3.000/9.33	0.3215	6/17	0.3529	1.000/ 4.499	0.2227	0.330/ 1.675	0.1970
Social assessment	5.000/9.33	0.5350	7/17	0.4117	3.000 / 4.499	0.6668	1.000/ 1.675	0.5970
Total Colum	3.30		17		4.49		1.675	

Table 4.11 Priority vector for sub-criteria of conceptualization

	Holistic	Scale sensitivity	Unpredictability	Social assessment	Criteria weight	Average weight
Holistic	0.1071	0.1764	0.0740	0.1194	0.4769	0.1192
Scale sensitivity	0.0356	0.0588	0.0370	0.0847	0.2161	0.0540
Unpredictability	0.3215	0.3529	0.2227	0.1970	1.0941	0.2735
Social assessment	0.5350	0.4117	0.6668	0.5970	2.2105	0.5526

Table 4.12 Principal Eigenvalue calculation for sub-criteria of conceptualization

	Holistic	Scale sensitivity	Unpredictability	Social assessment	Criteria weight	Average weight
	0.1192	0.0540	0.2735	0.5526		
Holistic	0.1071	0.1764	0.0740	0.1194	0.4769	0.1192
Scale sensitivity	0.0356	0.0588	0.0370	0.0847	0.2161	0.0540
Unpredictability	0.3215	0.3529	0.2227	0.1970	1.0941	0.2735
Social assessment	0.5350	0.4117	0.6668	0.5970	2.2105	0.5526

	Holistic 0.1192		Scale sensitivity 0.0540		Unpredictability 0.2735		Social assessment 0.5526	
Holistic	1.000	0.1192	3.00	0.1620	0.333	0.0910	0.200	0.1105
Scale sensitivity	0.333	0.0396	1.00	0.0540	0.166	0.0454	0.142	0.0784
Unpredictability	3.000	0.3576	6.00	0.3240	1.000	0.2735	0.333	0.1840
Social assessment	5.000	0.5960	7.00	0.3780	3.000	0.8205	1.000	0.5526
Total Coolum	9.330		17.0		4.499		1.675	

	Holistic 0.1192		Scale sensitivity 0.0540		Unpredictability 0.2735		Social assessment 0.5526			
Holistic	1.000	0.1192	3.00	0.1620	0.333	0.0910	0.200	0.1105	0.4827/0.1192	4.0494
Scale sensitivity	0.333	0.0396	1.00	0.0540	0.166	0.0454	0.142	0.0784	0.2174/ 0.540	4.0250
Unpredictability	3.000	0.3576	6.00	0.3240	1.000	0.2735	0.333	0.1840	1.1391/0.2735	4.1648
Social assessment	5.000	0.5960	7.00	0.3780	3.000	0.8205	1.000	0.5526	2.3471/0.5526	4.2470
Total Colum	9.330		17.00		4.499		1.675			16.4865/4 4.1216
Principal Eigenvalue (λ_{max})										4.1216

Calculation of Consistency ratio for sub-criteria of conceptualization

$$\begin{aligned}\text{Principal Eigen value} &= \lambda_{\max} \\ \text{Consistency index} &= \frac{\lambda_{\max} - n}{(n-1)} \\ &= \frac{4.1216 - 4}{4-1} \\ &= 0.0405\end{aligned}$$

Random index

Size of the matrix	2	3	4	5	6	7	8	9	10
Random index (RI)	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

$$\text{Consistency ratio (CR)} = \text{CI} / \text{RI}$$

$$\begin{aligned}\text{Consistency ratio} &= .04 / 0.89 \\ &= 0.04\end{aligned}$$

It is less than 0.1

Where, CI= Consistency Index, n = size of the matrix, $\lambda_{\max}$ = Eigen Value of the matrix

RI= Random Index

(Saaty suggests that if that ratio exceeds 0.1 the set of judgments may be too inconsistent to be reliable)

Table 4.13 Weights of Sub criteria conceptualization obtained from AHP

Sub criteria of conceptualization	Criteria weight
Flood risk is a complex phenomenon	0.1192
Scale sensitivity of flood risk.	0.0540
There are inherent uncertainties in the flood risk management decision-making process	0.2735
Flood risk management has required the assessment and integration of the multiple objectives of all stakeholders / Social assessment & integration	0.5526

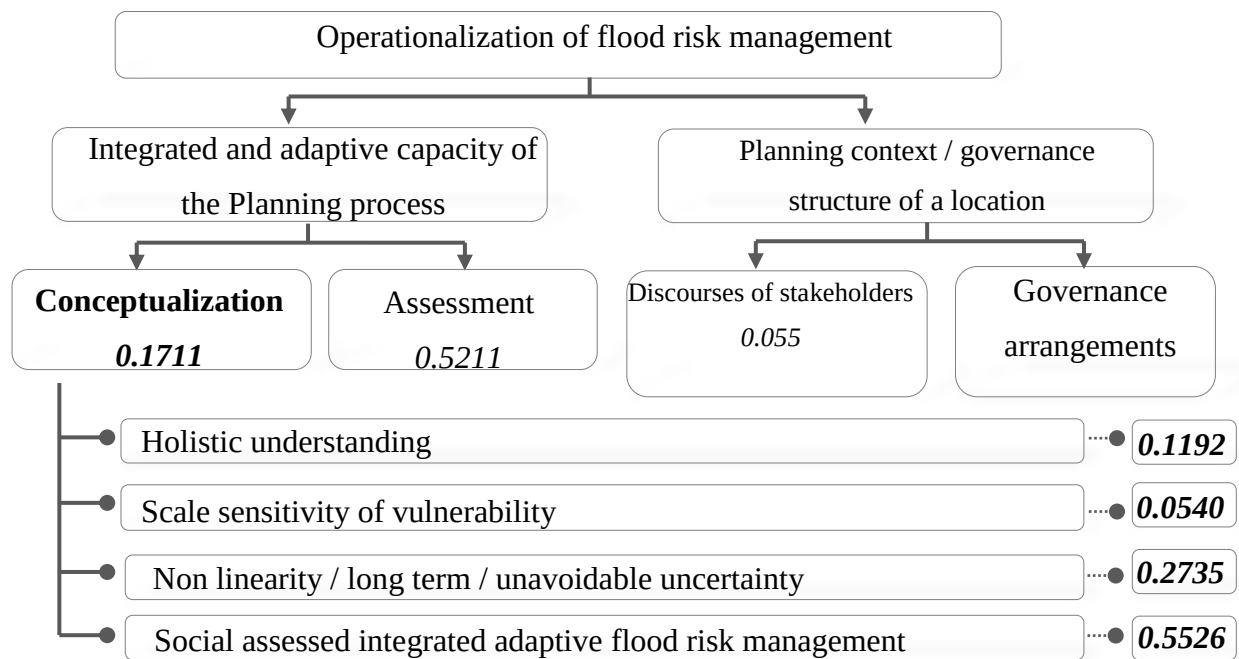


Figure 4.9 Prioritization of the sub criteria of Conceptualization

4.10.3 Prioritization of sub-criteria of place assessment

Table 4.14 shows the pairwise comparison matrix of four sub-criteria of place-based assessment. Table 4.15 and Table 4.16 demonstrate the normalized matrix and priority vector calculation for sub-criteria of place-based assessment. The next step is to calculate Consistency Ratio to determine the priority weights. Accordingly, Table 4.17 presents the principal Eigenvalue calculation for sub-criteria of Place assessment. Finally, Table 4.18 and Figure 4.10 show the weights and prioritization values obtained from AHP.

Table 4.14 Pairwise comparison matrix for sub-criteria of Place assessment

Sub - criteria		Pairwise comparison	
Climatic Scenario	Hydrological interconnectivity	3	1
Climatic Scenario	Social interconnectivity	5	1
Climatic Scenario	Floodplain functionality	1	3
Hydrological interconnectivity	Social interconnectivity	3	1
Hydrological interconnectivity	Floodplain functionality	1	6
Social interconnectivity	Floodplain functionality	1	7

Table 4.15 Normalized matrix for sub-criteria of Place assessment

	Scenario	Hydrological interconnectivity	Social interconnectivity	Floodplain functionality
Climatic Scenario	1	3	5	1/3
Hydrological interconnectivity	1/3	1	3	1/6
Social interconnectivity	1/5	1/3	1	1/7
Floodplain functionality	3	6	7	1

	Scenario	Hydrological interconnectivity	Social interconnectivity	Place functionality
Climatic Scenario	1.00	3.00	5	0.3300
Hydrological interconnectivity	0.33	1.00	3	0.1660
Social interconnectivity	0.20	0.33	1	0.1428
Floodplain functionality	3.00	6.00	7	1.0000

Table 4.16 Priority vector for sub-criteria of Place assessment

	Scenario		Hydrological interconnectivity	Social interconnectivity	Floodplain functionality				Criteria weight
Scenario	1.0/4.533	0.2206	3.00/ 10.333	0.2904	5/16	0.3125	0.3330 /1.6424	0.2027	0.2565
Spatial interconnectivity	0.333/ 4.533	0.0734	1.000/10.333	0.0968	3/16	0.1875	0.1666 /1.6424	0.1014	0.1147
Social interconnectivity	0.200/ 4.533	0.0441	0.333/10.333	0.0322	1/16	0.0625	0.1428/1.6424	0.0869	0.0564
Floodplain functionality	3.00/ 4.533	0.6618	6.000/10.333	0.5806	7/16	0.4375	1/1.6424	0.6088	0.5721
Colum sum	4.533		10.333	16	1.6424				

Table 4.17 Principal Eigenvalue calculation for sub-criteria of Place assessment

	Scenario			Hydrological interconnectivity			Social interconnectivity			Floodplain functionality				
	0.2565			0.1147			0.0564				0.5721			
Scenario	1	0.2565	0.2565	3	0.1147	0.3441	5	0.0564	0.2820	1/3	0.5721	0.1905	1.0731	4.183
Hydrological interconnectivity	1/3	0.2565	0.0855	1	0.1147	0.1147	3	0.0564	0.1692	1/6	0.5721	0.0953	0.4647	4.051
Social interconnectivity	1/5	0.2565	0.0513	1/3	0.1147	0.0382	1	0.0564	0.0564	1/7	0.5721	0.0817	0.2276	4.035
Floodplain functionality	3	0.2565	0.7695	6	0.1147	0.6882	7	0.0564	0.3948	1	0.5721	0.5721	2.4246	4.238
Principal Eigenvalue ($\lambda_{\max}$)	$16.507 / 4$ 4.1267													

Calculation of Consistency ratio for sub criteria of Place assessment

Consistency index = $\lambda_{\max} - n / (n-1)$

$\lambda_{\max}$ = $4.1267 - 4 / 4 - 1$

= 0.0422

Random index

Size of the matrix	2	3	4	5	6	7	8	9	10
Random index (RI)	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Consistency ratio (CR) = CI / RI

Consistency ratio = .0794 /0.89

Consistency ratio = 0.0422 /0.89

=0.047

It is less than 0.1

Where, CI= Consistency Index, n = size of the matrix, $\lambda_{\max}$ = Eigen Value of the matrix,

RI= Random Index,

(Saaty suggests that if that ratio exceeds 0.1 the set of judgments may be too inconsistent to be reliable)

Table 4.18 Weights of Sub Criteria Place assessment obtained from AHP

Sub Criteria Place Assessment	Average Weight
Scenario	0.2565
Hydrological interconnectivity	0.1147
Social interconnectivity	0.0564
Floodplain functions	0.5721

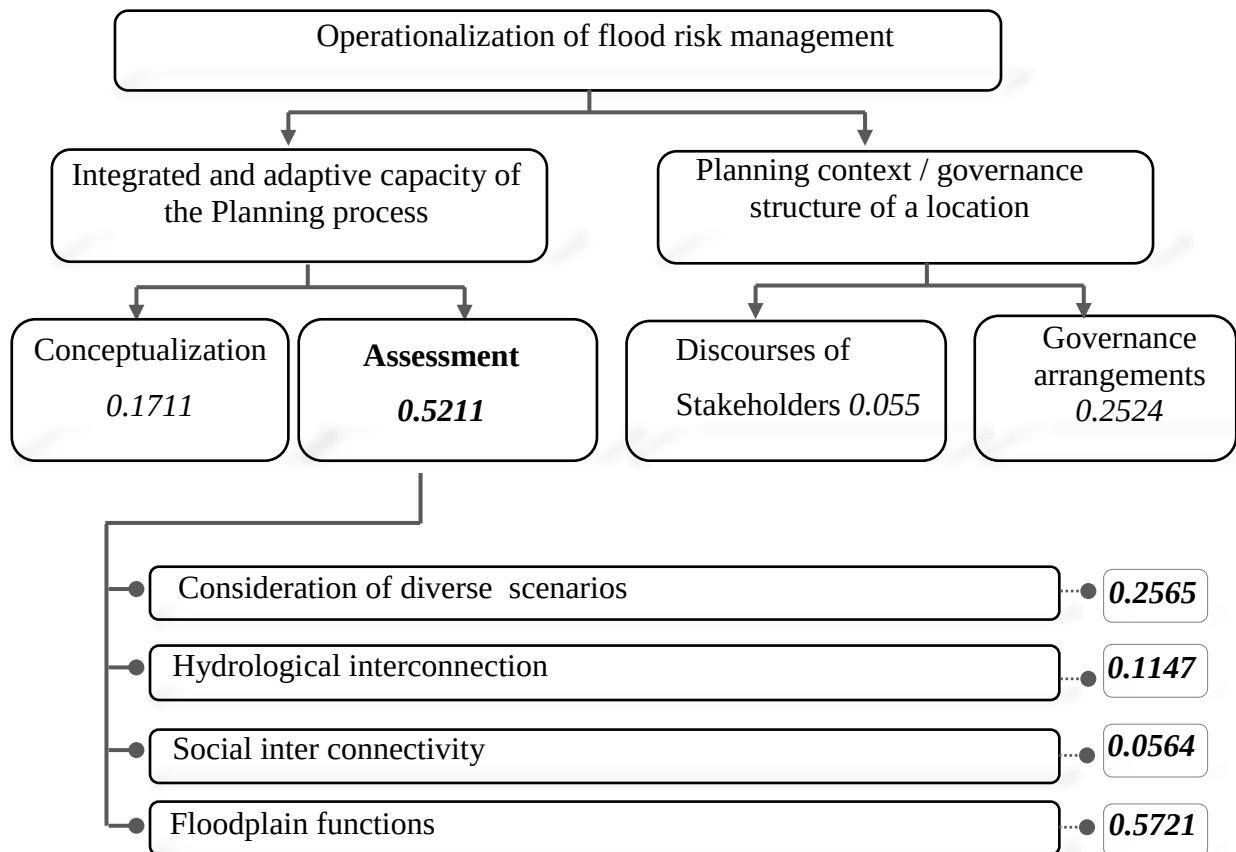


Figure 4.10 Prioritization of the sub criteria of Place assessment

4.10.4 Prioritization of sub-criteria of discourse

Each step of computation the weights of sub-criteria of discourse are described in detail with Table 4.19, Table 4.20, Table 4.21, Table 4.22, and Table 4.23. Figure 4.11 demonstrates the Prioritization of the sub-criteria of discourse.

Table 4.19 Pairwise comparison matrix for sub-criteria of Discourse

Sub -criteria		Pairwise comparison	
Social learning	Multi-level governance	7	1
Social learning	Continuous process	3	1
Social learning	Local initiatives	4	1
Multi-level governance	Continuous process	1	2
Multi-level governance	Local initiatives	1	3
Continuous process	Local initiatives	2	1

Table 4.20 Normalized matrix for sub-criteria of discourse

	Social learning		Multilevel governance		Continuous process		Local community	
Social learning	1	1.0000	7	7	3	3.0	4	4.00
Multilevel governance	1/7	0.1428	1	1	1/2	0.5	1/3	0.33
Continuous process	1/3	0.3300	2	2	1	1.0	2	2.00
Local community	1/4	0.2500	3	3	1/2	0.5	1	1.00

	Social learning		Multilevel governance		Continuous process		Local community	
Social learning	1	1.0000	7	7	3	3.0	4	4.00
Multilevel governance	1/7	0.1428	1	1	1/2	0.5	1/3	0.33
Continuous process	1/3	0.3300	2	2	1	1.0	2	2.00
Local community	1/4	0.2500	3	3	1/2	0.5	1	1.00
	1.7228		13		5		7.33	

Table 4.21 Priority vector for sub-criteria of discourse

	Social learning		Multilevel governance		Continuous process		Local community			
Social learning	1.0000/1.7228	0.5804	7/13	0.5384	3.0/5.0	0.6	4.00/7.33	0.5457	2.2645	0.5661
Multilevel governance	0.1428/ 1.722	0.0829	1/13	0.0769	0.5/5.0	0.1	0.33/7.33	0.0450	0.3048	0.0762
Continuous process	0.3300/1.7228	0.1915	2/ 13	0.1538	1.0/5.0	0.2	2.00/ 7.33	0.2728	0.8181	0.2045
Local community	0.2500/ 1.7228	0.1451	3/13	0.2307	0.5/5.0	0.1	1.00/7.33	0.1364	0.6122	0.1530
	1.7228		13		5		7.33			

	Social learning	Multilevel governance	Continuous process	Local community	Average weight
Social learning	0.5804	0.5384	0.6	0.5457	0.5661
Multilevel governance	0.0829	0.0769	0.1	0.0450	0.0762
Continuous process	0.1915	0.1538	0.2	0.2728	0.2045
Local community	0.1451	0.2307	0.1	0.1364	0.1530
	1.7228	13	5	7.3300	0.9998

Table 4.22 Principal Eigenvalue calculation for sub-criteria of discourse

	Social learning		Multilevel governance		Continuous process		Local community			
	0.5661		0.0762		0.2045		0.1530			
Social learning	1.000	0.5661	7	0.5334	3.0	0.6135	4.00	0.6120	2.3250	4.1070
Multilevel governance	0.1428	0.0808	1	0.0762	0.5	0.1022	0.33	0.0504	0.3096	4.0629
Continuous process	0.3300	0.1868	2	0.1524	1.0	0.2045	2.00	0.3060	0.8497	4.1550
Local community	0.2500	0.1415	3	0.2286	0.5	0.1022	1.00	0.1530	0.6253	4.0860
Principal Eigen value (λ_{max})										4.1029

Calculation of Consistency ratio for sub criteria of discourse

$$\begin{aligned}
 \text{Principal Eigen value} &= \lambda_{\max} \\
 \text{Consistency index} &= \lambda_{\max} - n / (n-1) \\
 \lambda_{\max} &= 4.1029 - 4 / 4 - 1 \\
 &= 0.1029/3 \\
 &= .0343
 \end{aligned}$$

Random index

Size of the matrix	2	3	4	5	6	7	8	9	10
Random index (RI)	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Consistency ratio (CR) = CI / RI

$$= .0343 / .9$$

$$= 0.038$$

It is less than 0.1

Where, CI= Consistency Index, n = size of the matrix, $\lambda_{\max}$ = Eigen Value of the particular matrix, RI= Random Index (Saaty suggests that if that ratio exceeds 0.1 the set of judgments may be too inconsistent to be reliable)

Table 4.23 Weights of Sub criteria discourse obtained from AHP

Sub criteria	Weightage
Social learning	0.5661
Multilevel governance	0.0762
Continuous process	0.2045
Local community	0.1530

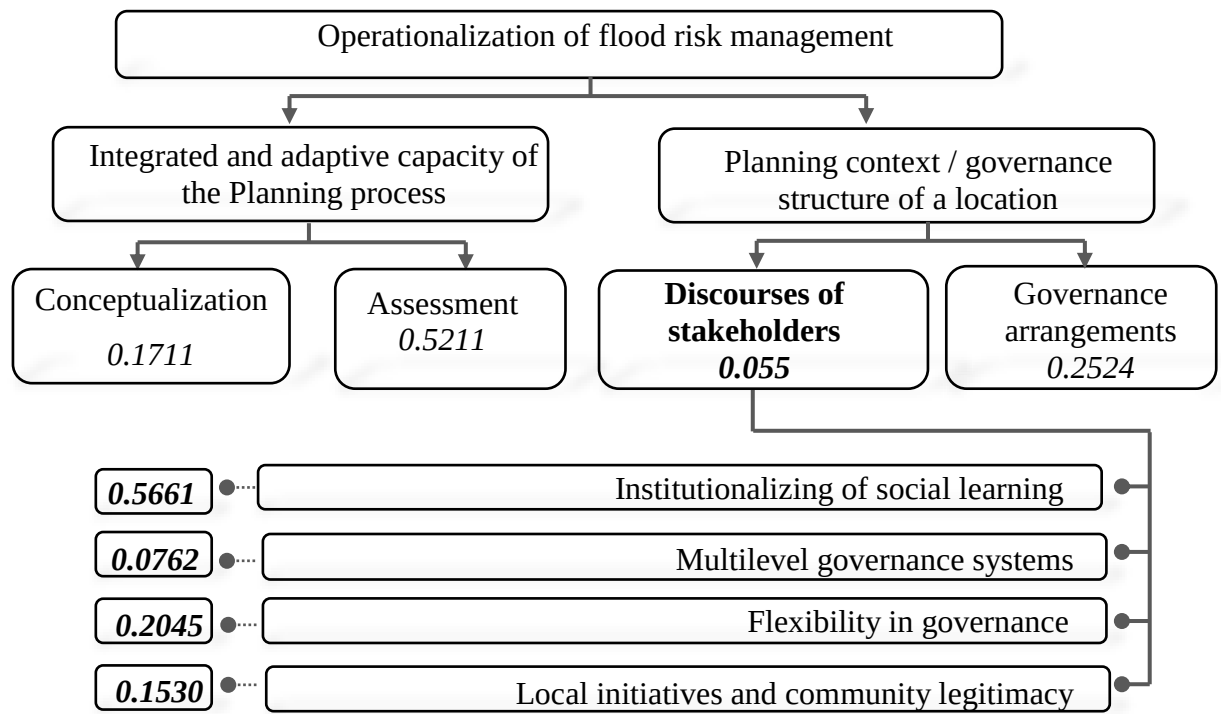


Figure 4.11 Prioritization of the sub criteria of Discourse

4.10.5 Prioritization of sub-criteria of participatory tools

Table 4.24 and Table 4.25 demonstrate the pairwise comparison matrix and normalized matrix for sub-criteria of participatory tools. Further, Table 4.26 highlights the computation of priority vector for sub-criteria of participatory tools. Table 4.27 highlights the Principal Eigenvalue calculation for sub-criteria of participatory tools. Table 4.28 and Figure 4.12 show the weights of Sub criteria of participatory tools obtained from AHP.

Table 4.24 Pairwise comparison matrix for sub-criteria of participatory tools

Sub Criteria		Pairwise comparison	
Land water	Territorial scale	3	1
Land water	Multi-sectoral	5	1
Land water	Local community	1	1
Territorial scale	Multi Sectoral	2	1
Territorial scale	Local community	1	3
Multi Sectoral	Local community	1	5

Table 4.25 Normalized matrix for sub-criteria of participatory tools

	Land water	Territorial	Sectoral	Local initiatives
Land water	1	3	5	1
Territorial	1 /3	1	2	1/3
Sectoral	1 /5	1/2	1	1/5
Local initiatives	1	3	5	1

	Land water	Territorial	Sectoral	Local initiatives
Land water	1.000	3.0	5	1.000
Territorial	0.333	1.0	2	0.333
Sectoral	0.200	0.5	1	0.200
Local initiatives	1.000	3.0	5	1.000
Column total	2.530	7.5	13	2.530

	Land water	Territorial	Sectoral	Local initiatives.
Land water	1.000/ 2.53	3.0 /7.5	5 / 13	1.000 /2.53
Territorial	0.333 / 2.53	1.0/7.5	2 /13	0.333 /2.53
Sectoral	0.200 / 2.53	0.5 /7.5	1 /13	0.200/2.53
Local initiatives.	1.000 /2.53	3.0 /7.5	5 /13	1.000 /2.53
Column total	2.530	7.5 /7.5	13	2.530

Table 4.26 Priority vector for sub-criteria of participatory tools

	Land water		Territorial		Sectoral		Local initiatives.			Average weight
Land water	1.000	0.3952	3.000	0.4000	5.000	0.3846	1.000	0.3952	1.5750/4	0.3937
Territorial	0.333	0.1316	1.000	0.1330	2.000	0.1538	0.333	0.1316	0.5500/4	0.1375
Sectoral	0.200	0.0790	0.500	0.0666	1.000	0.0769	0.200	0.0790	0.3015/4	0.0753
Local initiatives	1.000	0.3952	3.000	0.4000	5.000	0.3846	1.000	0.3952	1.575/4	0.3937
Column total	2.530		7.500		13.000		2.530			

Table 4.27 Principal Eigenvalue calculation for sub-criteria of participatory tools

	Land water 0.3937		Territorial 0.1375		Sectoral 0.0753		Local initiatives 0.3937			
Land water	1.000	0.3937	3.000	0.4125	5.000	0.3765	1.000	0.3937	1.5764/ 0.3937	4.004
Territorial	0.333	0.1299	1.000	0.1375	2.000	0.1506	0.333	0.1311	0.5491/.1375	3.993
Sectoral	0.200	0.0787	0.500	0.0687	1.000	0.0753	0.200	0.0787	0.3014/.0753	4.002
Local initiatives	1.000	0.3937	3.000	0.4125	5.000	0.3765	1.000	0.3937	1.5764/.3937	4.004
Column total	2.53		7.5		13		2.53			4.0075
Principal Eigenvalue (λ_{max})										4.0075

Calculation of Consistency ratio for sub criteria of participatory tools

Principal Eigen value = $\lambda_{\max}$

Consistency index = $\lambda_{\max} - n / (n-1)$
= $4.00075 - 4 / 4-1$
= 0.00025

Random index (RI)

Size of the matrix	2	3	4	5	6	7	8	9	10
Random index (RI)	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Consistency ratio = $0.00025/9$
= 0.0002

It is less than 0.1

Where, CI= Consistency Index, n = size of the matrix, $\lambda_{\max}$ = Eigen Value of the matrix,

RI= Random Index,

(Saaty suggests that if that ratio exceeds 0.1 the set of judgments may be too inconsistent to be reliable)

Table 4.28 Weights of Sub criteria of participatory tools obtained from AHP

Sub criteria of participatory tools	Sub criteria weightage
Land water	0.3937
Territorial	0.1375
Sectoral	0.0753
Local initiatives	0.3937

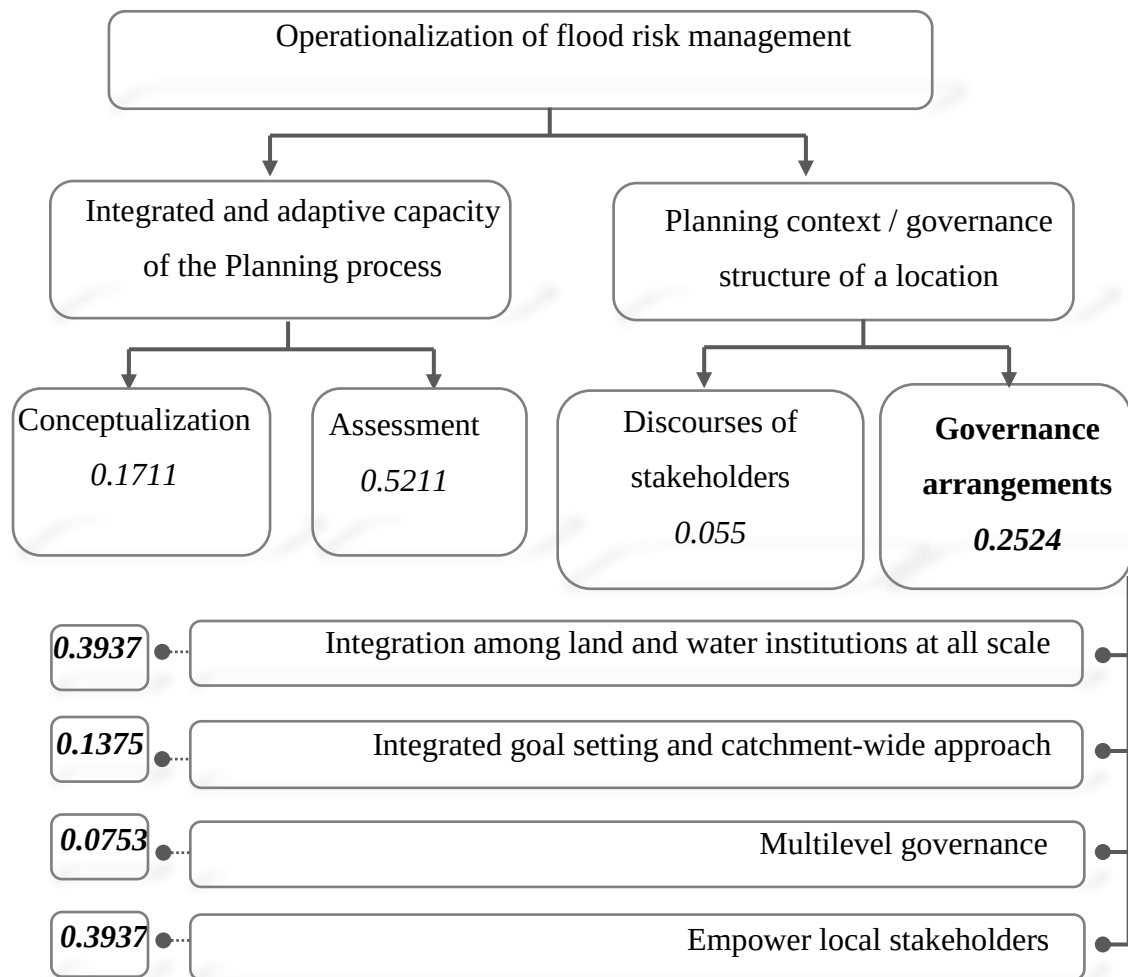


Figure 4.12: Prioritization of the sub criteria of Participatory tools

4.11 Ranking of Sub criteria

The relative importance of each main criterion and the sub-criterion have been calculated as demonstrated in the text. The following Table 4.29 highlights the weights of the main criteria and the local and global weights of the sub-criteria that are affected for the operationalization of flood risk management.

Table 4.29 Relative importance of criteria and the sub-criteria of the planning process

Criteria	Weight	Sub criteria	Local weight	Global weight	Rank
Conceptualization of flood risk management process is the identification of the multiple stakeholders and their objectives to define the outcome/ impacts.	0.1711	Interdependencies of the social and natural systems	0.1192	0.0203	11
		Multi-Scale sensitivity of flood risk.	0.0540	0.0092	14
		Feedback loops and inherent uncertainties in the flood risk management	0.2735	0.0467	7
		Trade-off analysis of multiple objectives of all stakeholders.	0.5526	0.0945	5
Place-based Assessment- consideration factors for selection of the objective/trade-offs among the stakeholders. (multifunctional floodplains)	0.5211	Scenarios of flood risk	0.2565	0.1336	2
		Hydrological interconnectivity	0.1147	0.0577	6
		Social interconnectivity / interdependency	0.0564	0.0293	10
		Functionality of floodplain	0.5721	0.2981	1
The discourse of the stakeholders recognizing the	0.055	Social learning	0.5661	0.0311	9
		Multilevel governance	0.0762	0.0041	16

importance of integration and adaptation.		Continuous process and flexibility	0.2045	0.0112	13
		Local community	0.1530	0.0084	15
Participatory tools are available for integration and adaptive decision-making.	0.2524	Land & water integration	0.3937	0.0993	3
		Territorial governance / regional planning/ watershed	0.1375	0.0347	8
		Sectoral / levels integration	0.0753	0.0190	12
		Local initiatives	0.3937	0.0993	3

4.12 Relative Importance of the Criteria and the Sub-Criteria for Implementation of FRM

The result of the study has highlighted the importance of main criteria and the sub-criteria to structure the complexity of the planning process for the operationalization of flood risk management. The main criteria of the framework for operationalization of flood risk management are (1) conceptualization (2) assessment of the planning process (3) the discourse of the stakeholders in the governance context as well as the (4) available interaction mechanism of stakeholders for participatory decision making. AHP has been applied to obtain the relative weights of the main criteria and the results of each step are shown in Table 4.4, Table 4.5, Table 4.6 Table 4.7, and Table 4.8. Figure 4.8 illustrates the criteria weight of each of the above four main criteria which are important to practice flood risk management are 0.1711, 0.5211, 0.055, and 0.2524, respectively.

Four sub-criteria are required to evaluate the conceptualization of the planning process of flood risk management are (a) Flood risk considered as a complex phenomenon. There are interdependencies between social, hydrological, ecological, etc subsystems. Therefore, FRM includes multiple stakeholders from multiple sectors, (b) Flood risk management is influenced by multiple factors at diverse spatial scales. Scale sensitivity of flood risk and therefore, the importance of assessing/managing flood risk at a different scale. Therefore, analysis and management of flood risk are required based on the scales. (c) There are inherent uncertainties in the flood risk management decision-making process due to diverse stakeholders with multiple knowledge and interpretations of flood risk management are involved in the process of decision making, (d) Decision-making process is to be continuous and based on the social learning process and has required the integration of the multiple objectives of all stakeholders. The AHP has been applied to determine the relative weights of each of the above sub-criteria and the result of each step is illustrated in Table 4.9 – 4.13. Figure 4.9, the importance of these sub-criteria for the conceptualization of flood risk management is as 0.1192, 0.0540, 0.2735, and 0.5526, respectively.

Sub criteria to evaluate the assessment of the planning process are (a) Identification of the potential strategies to increase the adaptive capacities to maintain the ecological functions, processes, feedback, etc. of the floodplains adaptation with uncertainty, (b) Identification of diverse flood management measures including measures to increase resistance capacity, recovering capacity, the transformative capacity to manage the uncertainty and vulnerability with different and range of climatic scenarios (including extreme events) rather than design strategies of flood control measures based on probability thresholds of flood events, (c) Identification of the potentials flood management strategies for Maintenance of Hydrological integration over the watershed/ spatial integration to manage uncertainties of different climatic scenarios, (d) Identification of the potentials flood management strategies to increase social integration / multifunctional land uses over floodplains by identifying commonly acceptable thresholds integrating the diverse spatial claims of stakeholders/ social integration (trade-offs of multiple social interactions of flood risk) to cope up with different climatic scenarios. The sub-criteria weights have been calculated

following the step of AHP and the results of each step are exhibited in Table 4.14-4.18. Figure 4.10 illustrates the relative importance values of these sub-criteria are 0.5721, 0.2565, 0.1147, and 0.0564, respectively.

Adaptive and integrated planning is required to be recognized in the knowledge system of governance structure to practice flood resilience in any given context. Sub-required to characterize the Knowledge system of stakeholders are (a) recognition of the importance of social learning and knowledge sharing (b) recognition of the importance of common decision-making process and multilevel governance for sharing of resources and information, (c) recognition of the importance of flexibility of decision and create opportunities for changes of decisions (d) recognition the participation of local level (local communities) in the decision making and implementation process. Therefore, it is necessary to incorporate and mainstream the above four factors into the governance policy structure for practicing flood resilience. The relative importance of each of the sub-criteria is also calculated following the steps of AHP and the results are highlighted in Table 4.19 - 4.23. Figure 4.11 shows the importance values of these sub-criteria areas 0.5661, 0.0762, 0.2045, and 0.1530 respectively.

The implementation of objectives and outcomes of flood risk management requires the establishment of a platform and streamlining the adaptive and integrated planning in the governance structure. In addition, it is needed meaningful tools with legal authority to translate policies into practice. A participatory mechanism or governance tools to power and resource distribution patterns among stakeholders of the governance systems is characterized through the following sub-criteria which are (a) Mechanisms available for Integration among the land and water institutions at all scales and levels (b) Mechanisms available for Integrated goal setting and catchment-wide approach for decision making (c) Mechanism available for Multiple Regime Governance Traditions (top-down + bottom-up) and (d) Mechanism available / Legitimized tool availability for Empowering local stakeholders in decision making and implementation of FRM system (spatial planning). The relative weights have been determined following steps of AHP and the results are illustrated in Table 4.24 – Table 4.28. Figure 4.12 describes the relative importance values of these sub-criteria are 0.3937, 0.1375, 0.0753, and

0.3937, respectively. The developed framework demonstrates how to structure the planning process and governance context to achieve flood risk management. Therefore, this framework can be used to assess the level of adaptive capacity of the planning process of a given context and it has provided recommendations to improve the flood resilience of that context.

The relative importance of sub-criteria for the operationalization of flood risk management. Four main criteria are important for structuring the complex decision-making process to operation flood risk management. Among that four main criteria, the most important main which influenced the operationalization of flood risk management is the consideration factors of the assessment process rather than the other factors. Consideration of functions of the natural floodplain, consideration of multiple possible scenarios including the extreme events in the assessment process and the presence of mechanisms for local community participation in planning and implementation of flood risk management and mechanisms available for integration of land and water management related stakeholders have been identified as the most important factors which determine the operationalization of the flood risk management of any given context.

Table 4.29 highlights the relative importance of sub-criteria for the operationalization of flood risk management. Among that four main criteria, the most important main which influenced the operationalization of flood risk management is the consideration.

factors of the assessment process. The global values of each sub-criteria have been ranked and the Table 4.29 shows the rank of each sub-criterion. Accordingly, the most important sub-criteria which indicate the operation of flood resilience are (1) explore the opportunities for strengthening the functions, structure, processes, and the feedbacks of the natural floodplain in the assessment of the planning process and (2) maintain the stability of floodplains in the face of the diverse range of climatic conditions including extreme events in the assessment process. In addition, it has been highlighted that the (3) presence of participatory tools to integrate the spatial claims of land and water stakeholders and (4) presence of participatory tools for local communities are also important criteria to implement flood resilience.

CHAPTER 5 - VALIDATION OF FRAMEWORK

5.1 Increasing of Flood Damage

Sri Lanka is a tropical island situated in the Indian Ocean. The country has a strong seasonal variation in the rainfall pattern (Jayawardene, 2005). Due to the location of Sri Lanka near the equator and due to the monsoonal circulations in the South Asian region, the dynamics of the atmosphere of the country face extreme variables (Punyawardena, 2004). The monsoon winds blow in a South-Westerly direction (SW monsoon) from May to September, while the winds blow in a North-Easterly direction (NE monsoon) from December to February. The SW winds bring rainfall to Sri Lanka's SW quadrant or the wet zone while the NE winds bring rainfall to the rest of the country covering most of the dry zone. Rainfall patterns of Sri Lanka are associated with the meteorology of the Inter-Tropical Convergence Zone (ITCZ). The ITCZ plays an important role in the climate variability of the South Asian monsoons (Ranasinghe, 2001). The northward and southward migrations of the ITCZ during the year also govern the rainfall pattern of the country during the two Inter-Monsoon (IM) periods of March - April (1st IM months) and October – November (2nd IM months). Generally, the rainfall received during the first IM months is less than the rainfall received during the second IM month. In addition, the rainfall pattern is influenced by cyclones occurring in the Bay of Bengal.

Sri Lanka Climate Resilience Multi Phased Programmatic Approach initiated in 2019 by World Bank has highlighted that a significant threat is posed to the economic and social development of the country by the climate-related hazards. Sri Lanka was ranked the second among countries facing extreme events of weather by the global climate risk index report which was launched in the climate summit Katowice (COP 24). Sri Lanka is routinely affected by recurring disasters. The most frequent type of disaster occurring in Sri Lanka is floods. Moreover, the rate of flooding has depicted an increasing trend in recent years. Flooding which occurred in the years between 1990-2018 has caused massive damages of over US 2 billion dollars. The damage coast

by the tsunami of 2004 was estimated as US 1 billion dollars of damages according to the Preliminary Needs Assessment (ADB, JBIC, and the World Bank, 2005). According to the database managed by National disaster relief service centre, in any year, the relief cost for flood disasters accounts for about 80% to 90% of the annual expenditure (JICA, 2017).

5.2 Urban Flood Disasters

Floods have highly influenced those areas mainly distributed in the plain areas close to the coast. In recent years, particularly in the districts of Colombo, Gampaha, Kalutara, Matara, and Galle, urban flooding is beginning to pose a severe threat. Presently, the frequent urban flood problem has gone up to a more vulnerable level causing several socio-economic interruptions. These major flooding seasons are interrelated to the two monsoonal seasons. The western region often gets trapped due to floods especially during the southwest monsoons. The rainfall pattern of this region fluctuates throughout the year and it experiences the highest monthly rainfall during May and October which is about 350 mm. Furthermore, considering the extreme daily rainfall of each year, there is also a slight increase in the maximum rainfall recorded each year. According to the National adaptation plan for climate change impacts in Sri Lanka; 2016-2025 (Climate Change Secretariat, Ministry of Mahaweli Development and Environment) has reported that increased intensity of rainfall in the wet zone of Sri Lanka. There is a significant increase in total annual and monthly rainfall and extreme rainy days have been recorded over the last fifty years in this region. During the recent past decades, the urban regions have been expanded without considering the retention and detention capacities of marsh areas of the region.

Figure 5.1 shows the change in population in the flooded area from 2000 to 2015 around Metropolitan Colombo Area. The population in the flooded area increased from 2000 to 2015. Figure 5.1 clearly shows the intensification of flood disaster risk.

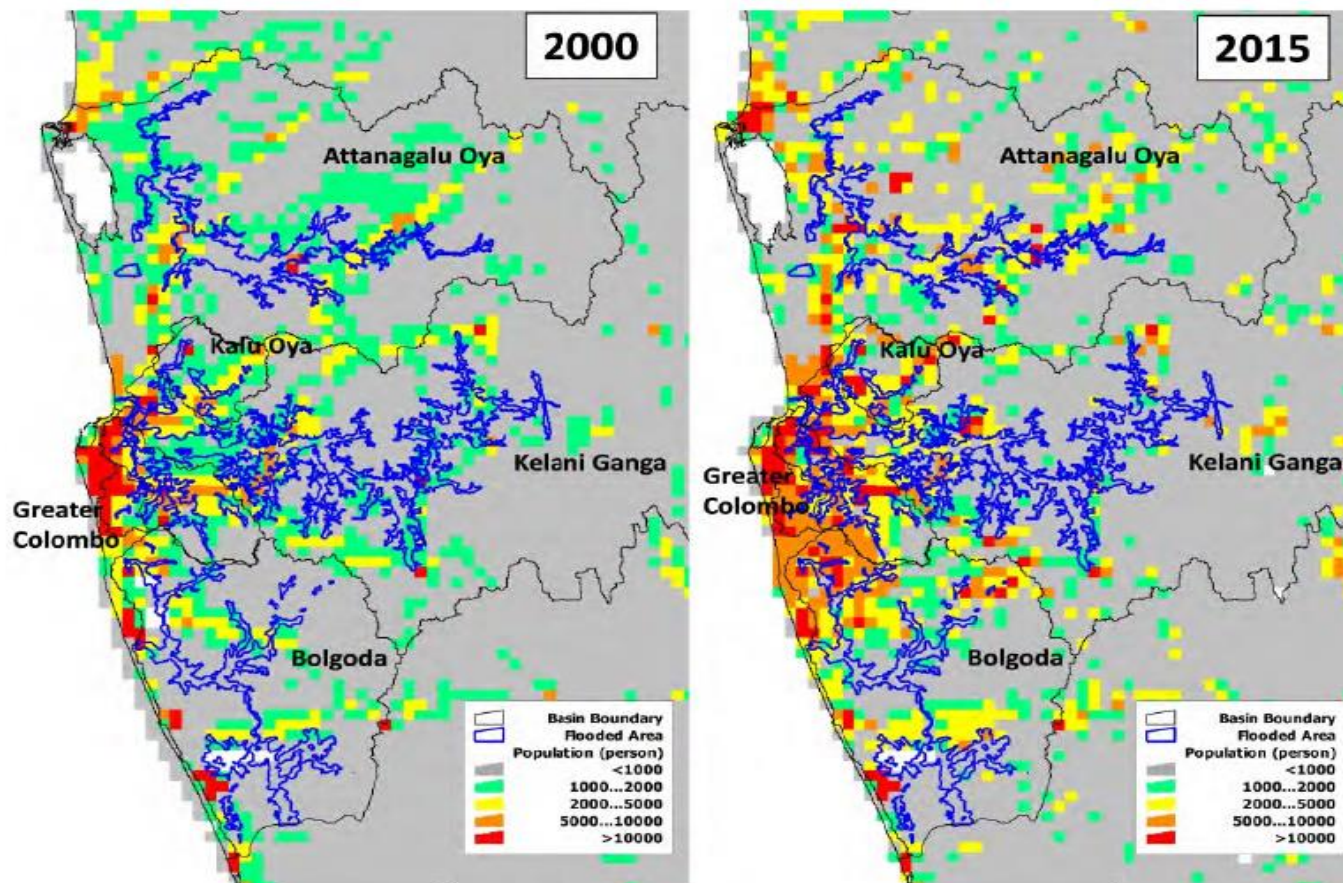


Figure 5.1 Flooded areas around Metropolitan Colombo Area

Source: Prepared by JICA Survey Team based on Land Scan data and Comprehensive Study on Disaster Management in Sri Lanka (2009) by Japan International Cooperation Agency (JICA), Earth System Science Co., Ltd. and CTI Engineering International Co., Ltd
Source: <https://openjicareport.jica.go.jp/pdf/12291944.pdf>

5.3 Increasing of Urban Flood Risk in the Colombo Metropolitan Region (CMR)

The population in urban areas has increased especially after the independence from British rule in 1948. The highest percentage (51%) of the urban population covers the western province, relating to the districts of Colombo, Gampaha, and Kalutara. Moreover, the annual growth rate of the western region was 3.1 percent per year during the years from 2005-2015. One of the major reasons for this rapid population expansion in the past few decades is the increase in urban development and industrial development. Thereby, the need for land has increased and drainage capacities have become inadequate and climate change impacts which increase the occurrence of sudden rainfall intensities have subsequently led to acute flood damages in high-density urban areas. Further, flood impacts are tending to increase particularly in urban areas in the coastal region where the elevation is less than six meters (6m) above sea level. Urban flooding is a severe issue and a challenge to socio-economic development (Moufar, 2018).

The western region of Sri Lanka which consists of the highest population holding, 28% of the total population of the country, is the region that is most affected by floods. The impacts of the floods are increasing recently due to significant urban growth of this region as well as the reduction of the extensive network of wetlands, which acts as flood retention areas. The main drainage basins of this region that are highly affected by recurrent flooding are the Ja Ela basin, Kalu Oya basin, Greater Colombo basin, and Bolgoda basin (Figure 5.2). The estimated flood damage of each sub-basin is highlighted in the following Table 5.1.

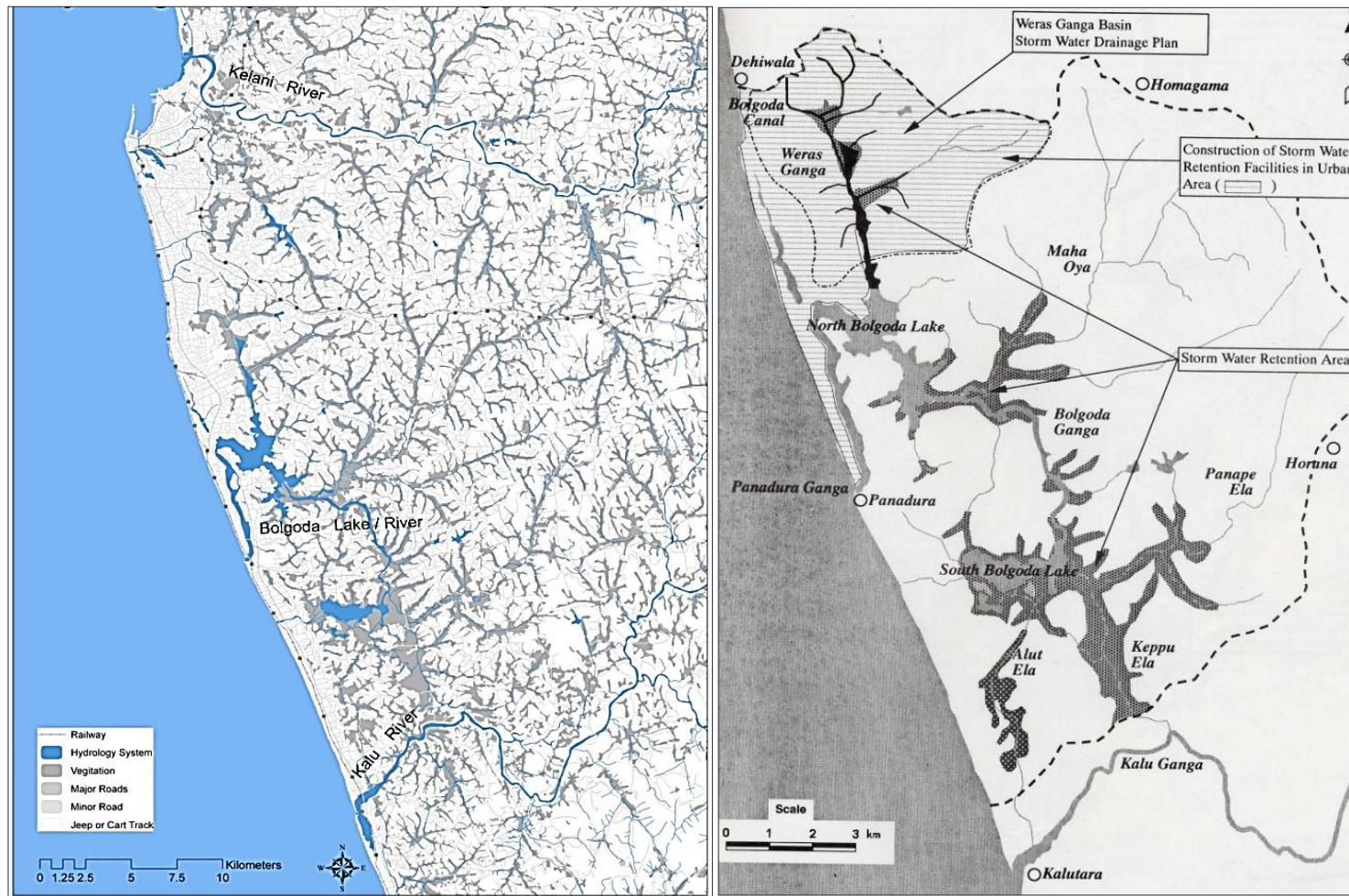


Figure 5.2: Hydrological pattern of the Colombo metropolitan region (**Source:** The Study on Storm Water Drainage Plan for the Colombo Metropolitan Region in the Democratic Socialist Republic of Sri Lanka (Japan International Cooperation Agency); https://openjicareport.jica.go.jp/pdf/11716586_22.pdf)

5.1 Estimated flood damage

Sub-basin	Estimated extent of inundation area by return period (ha)					Annual flood damage (Million Rs.)
	2- year	5- year	10- year	25- year	50- year	
Ja ela	1113	1609	1938	2755	3390	509
Kalu Oya	283	384	449	496	558	329
Greater Colombo	153	288	408	581	774	549
Bolgoda	2419	2929	3278	3645	3913	370

5.4 Increasing Flood Risk in Bolgoda River Basin

The Bolgoda basin is characterized by a unique water system and is comprising the two major lakes with incoming and outgoing waterways. The Bolgoda basin can be categorized into three regions as northern, southern, and northeastern, as follows.

- (1) The northern region of the basin includes the area in and around the Weras Ganga catchment. The land use of this area is covered by the highly urbanized areas of Nugegoda, Dehiwela-Mount Lavinia, Moratuwa, and Kesbewa.
- (2) The southern region of Bolgoda basin covering the towns of Panadura, Kalutara, Bandaragama and Horana areas.
- (3) The Bolgoda basin's northeastern portion includes semi-urbanized, with a mix of urban and rural settlements.

There are two large lakes in the Bolgoda Lake system, namely the North Bolgoda Lake and South Bolgoda Lake. Both lakes are interconnected by Bolgoda Ganga (River). The Bolgoda North Lake discharges into the sea through the Panadura estuary. Figure 5.3 indicates the natural streams with drainage pattern distribution of the Bolgoda basin.

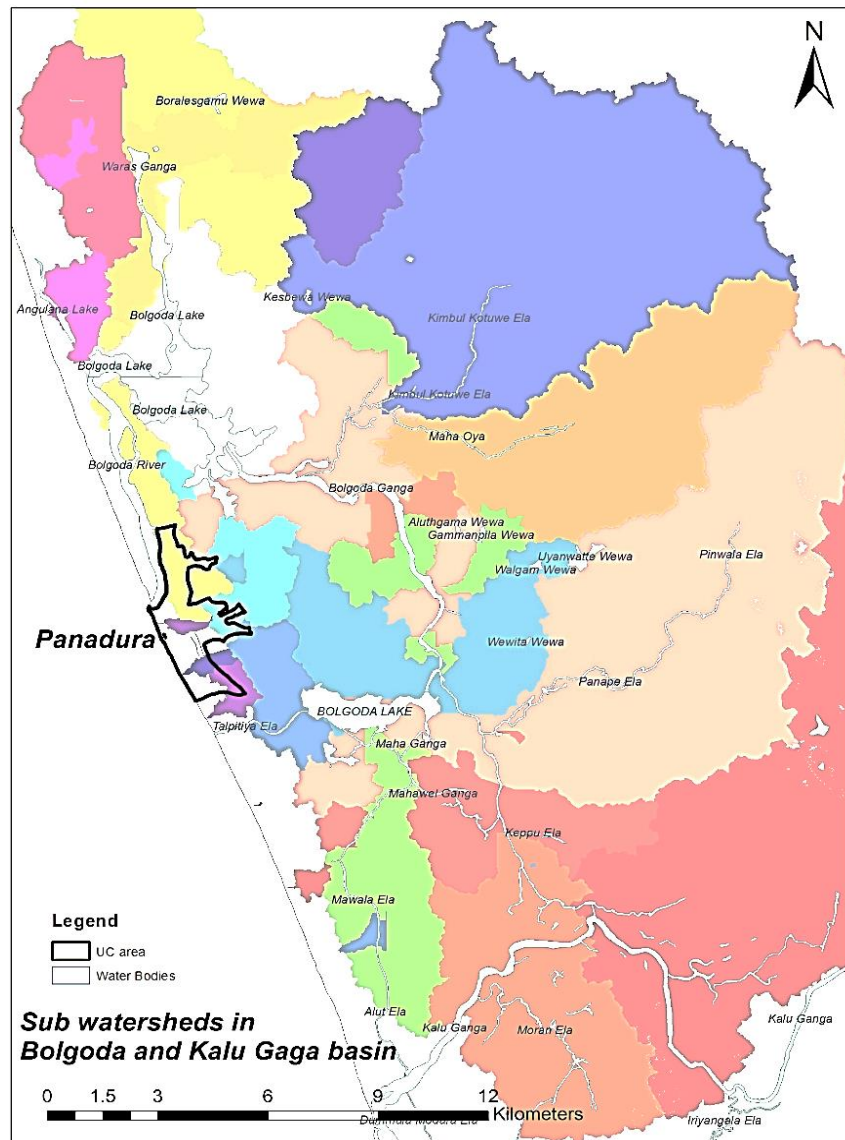


Figure 5.3 Urban areas in Bolgoda river basin

As explained in the Figure 5.3, the Panape Ela feeds the South Lake which is situated in the Kalutara district and South Bolgoda Lake is connected to the sea via Thalpitiya Ela. Bolgoda South Lake drains into the sea at Talpitiya and is also connected to the Kalu Ganga basin through a manmade canal. The lake system is comprised of fresh and brackish water. Legal and illegal reclamations reduce the floodplain areas of the lake and trigger frequent flooding during monsoon rain periods (Environmental Management Plan of Bolgoda, 2014). For example, the Panadura area was not affected by floods earlier. However, floods have become a repeated threat to this area in recent

years. Marshlands and abandoned paddy lands spread all over the basin while many are now filled or reclaimed for urban settlements. It is essential to specify that abandoning paddy lands were aggravated by saltwater intrusion resulting in a high salinity level of the lake.

5.5. Selection of Case Study

5.5.1. Panadura Urban area in the Bolgoda Basin

During recent years, with the increase of wetland reduction and climate change, floods are expected to get worse in the Panadura urban area. Several infrastructural interventions are proposed to tackle that problem. Panadura is highly affected by the southwest monsoon and inter-monsoon rainfall. High rainfall during these periods and inadequate drainage measures are the major cause to make flash floods. As per the 2012 census, the total population of the Panadura Urban Council was 45, 136 and the population density was 7,339 per square kilometer. In the 1981 – 2001 period, in the Panadura Urban Council area, the population growth rate was recorded as 0.70% and it has been increased up to 2.41% in 2012.

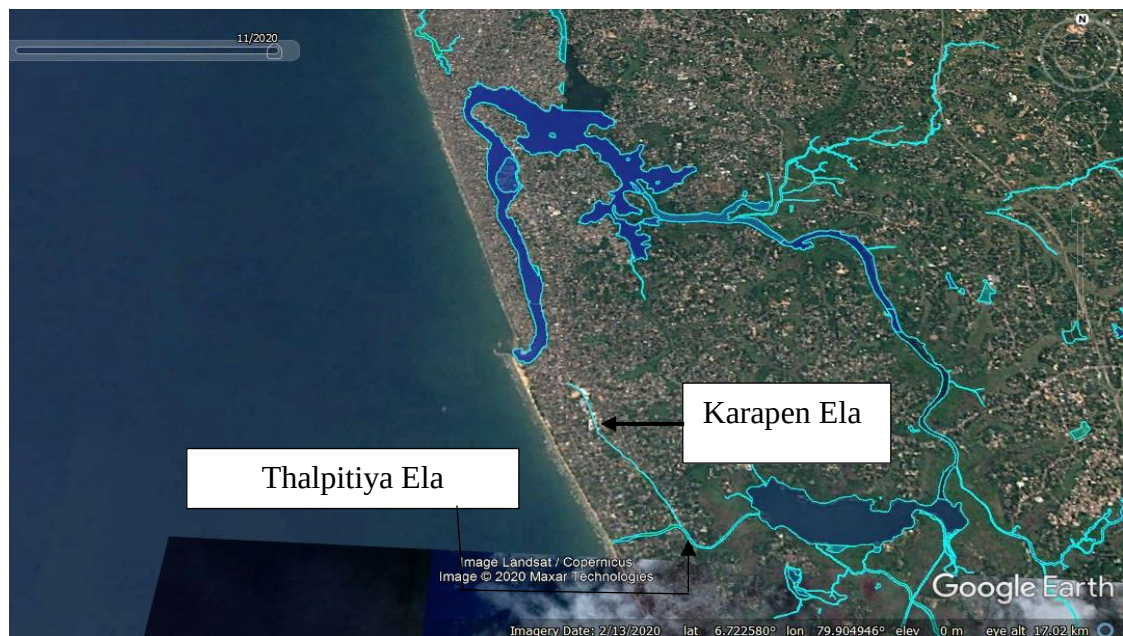


Figure 5.4 Distribution of human settlement over the Bolgoda river basin

The reasons for the population increase in this area are due to the increase of direct access to the Colombo, the possible road and transport network for ease approach to other cities, development of other infrastructure facilities, the establishment of famous schools with better facilities, and establishment of the Modarawila Industrial Estate. The population has been increasing in Panaduara during the past decades further due to the establishment of the Modarawila Industrial Estate and the presence of many infrastructure facilities. More than 6,000 job opportunities were generated from this industrial estate whereby a significant number of job opportunities have been offered to the people of the other areas of the Kalutara District. Furthermore, due to the presence of infrastructure facilities such as the Southern Expressway, which runs for 12 kilometers, there is a high tendency for commercial and industrial activities and hence there is a high demand for land. There is a tendency to extend out tourism and fishery sector within the area due to the existence of natural resources such as Bolgoda Lake and the sea beach. Figure 5.4 illustrates the distribution pattern of the built environment with the natural environment.

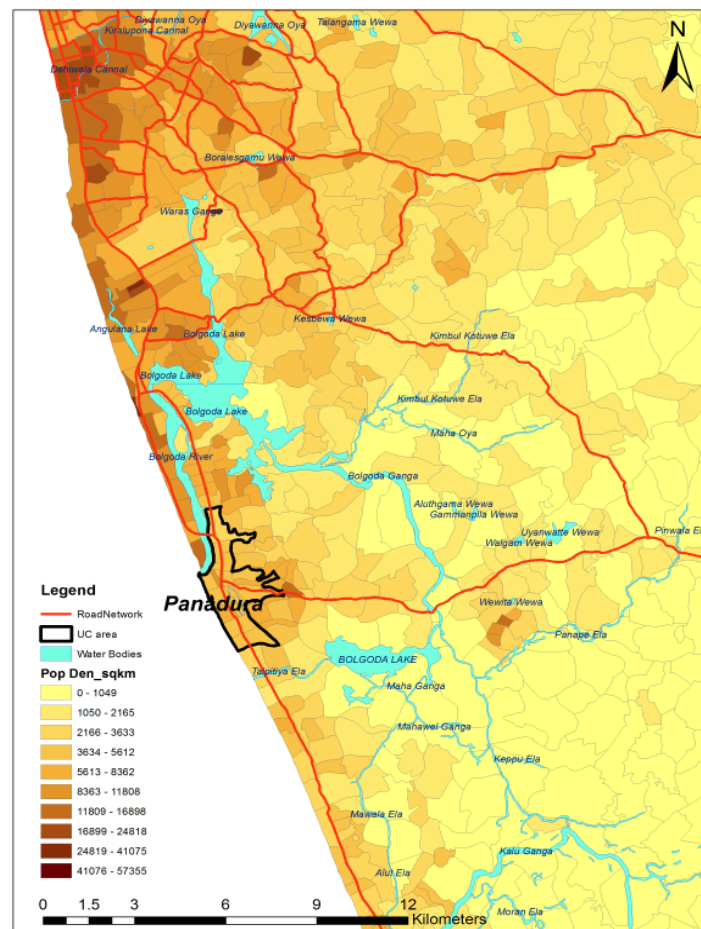


Figure 5.5 Population Density of the Bolgoda river basin (Source : Census,2012)

The Bolgoda Basin can be mainly divided into three regions such as the north, northeast, and south. The northern region, in and around the Weras Ganga watershed, is covered by the heavily urbanized areas of Nugegoda, Dehiwela-Mount Lavinia, Moratuwa, and Kesbewa. Many low-lying lands of this part of the basin are currently being reclaimed for urban development. The northeast region around Homagama, which occupies the upper watershed of Maha Oya, is semi-urbanized with a mixture of urban centers and rural areas. The southern region includes Panadura, Kalutara, Bandaragama, and Horana, which includes rural, semi-urban, and urban settlements. Figure 5.5 shows the spatial distribution pattern of the population in the Bolgoda Basin according to the 2012 census data. As shown in Figure 5.5, the population density in the Panadura region is higher than in other parts of the Bolgoda Basin.

5.5.2 Land use changes over the period in Panadura

Panadura urban area consists of 6.1 km² of land. The Panadura region which is located in the coastal plain of Sri Lanka is a topographically flat, low elevated area. The elevation varies from 0 m to 15.91m, MSL. Figure 5.6 indicates the topography of the study areas.

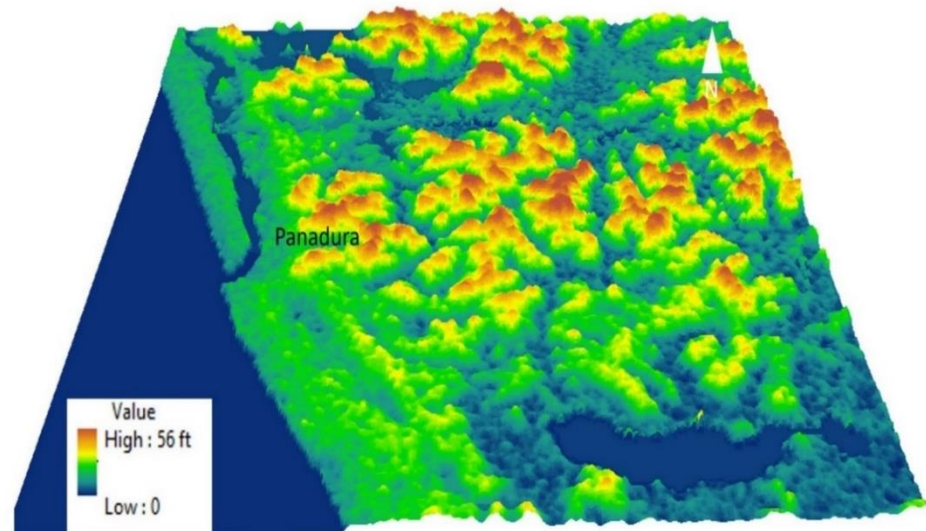


Figure 5.6 Elevation of the area (feet), MSL

More than 95% of the land is used for urban development activities such as residential, commercial, industrial, and agricultural activities. There is a high demand for the lands on both sides of the main roads of Galle (A002) and Horana (A008) roads. The marshy lands and the paddy fields of the area support keeping the environmental balance of the area. Rapid urban expansion, on the other hand, has resulted in issues like flooding, pollution, etc. and as well as a significant influence on the environment's balance and natural beauty. At present, the extent of the marshy lands is about 0.9 hectares and as a percentage, it accounts for 0.14%. These marshy lands of the Panadura Urban Area are significant and it is very useful to smoothen water flow during the rainy season. These marshy lands are subscribing to protect the ecological balance of the area and they cannot be used as a potential site for another development activity. Panadura urban area consists of several waterways. These waterways are Karapan Ela, Moda, Ela, Thalpitiya canal, and Bolgoda Lake.

According to the geographical location of the Panadura urban area, these waterways are important to drain the excess water during the heavy rainy season. But these waterways are not maintained regularly. As a result, flooding is a recurrent phenomenon in recent years. Due to the high rainfall intensities in the Bolgoda region, flooding can be seen as a very common disaster. Annually, the Panadura town area has been increasingly threatened by urban floods due to the low elevation of the town and lack of proper drainage facilities. Further, this condition aggregates due to improper functioning of the drainage system. Floods are mainly affected by residential activities as well as industrial and commercial activities of the area. Figure 5.8 indicates the areas where floods have occurred, especially Modharavila industrial zone. According to the 2016 May floods, the flood depth levels in the Panadura urban area was varied from 3 feet - 2 feet.

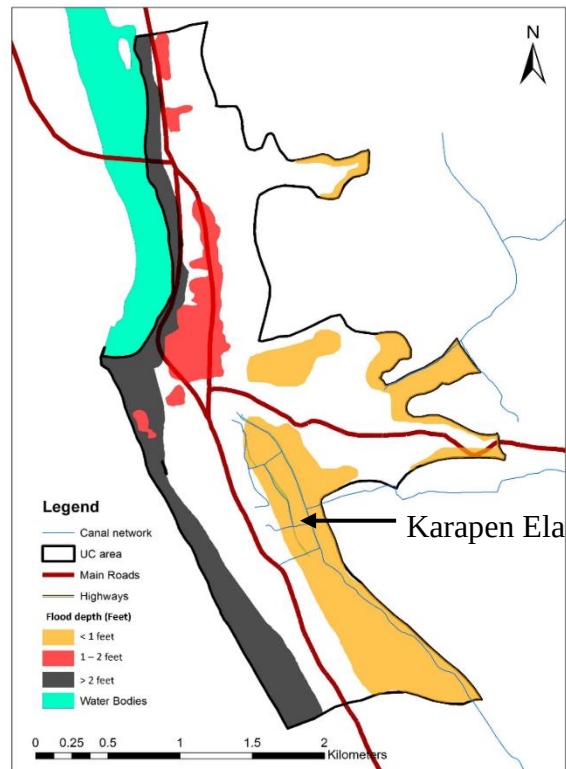


Figure 5.7 Flood damage in 2016 May (Field survey)

5.5.3 Karapen Ela

The length of the Kerapen Ela which starts from the Modarwila area and drains into the Thalpititiya canal is 3.5 km. ‘Moderawila’ was a small pond, distributed over 90 acres in extent, and was reclaimed by the Sri Lanka Land Development Corporation in 1979 for industrial development. During the rainy periods, water flows from the Panadura town center and left-hand side town area to this canal. Karpen Ela experienced floods even after a minor shower earlier and there are many reasons for this situation.

- Canals are blocked due to the dumping of municipal solid waste
- Canal banks are encroached by low-income settlements
- Unauthorized construction in low-lying areas and road reservations also further blocking stormwater drains and canals

Fig 5.8 and Fig 5.9 show the flood-affected areas and the built pattern of inundation areas.

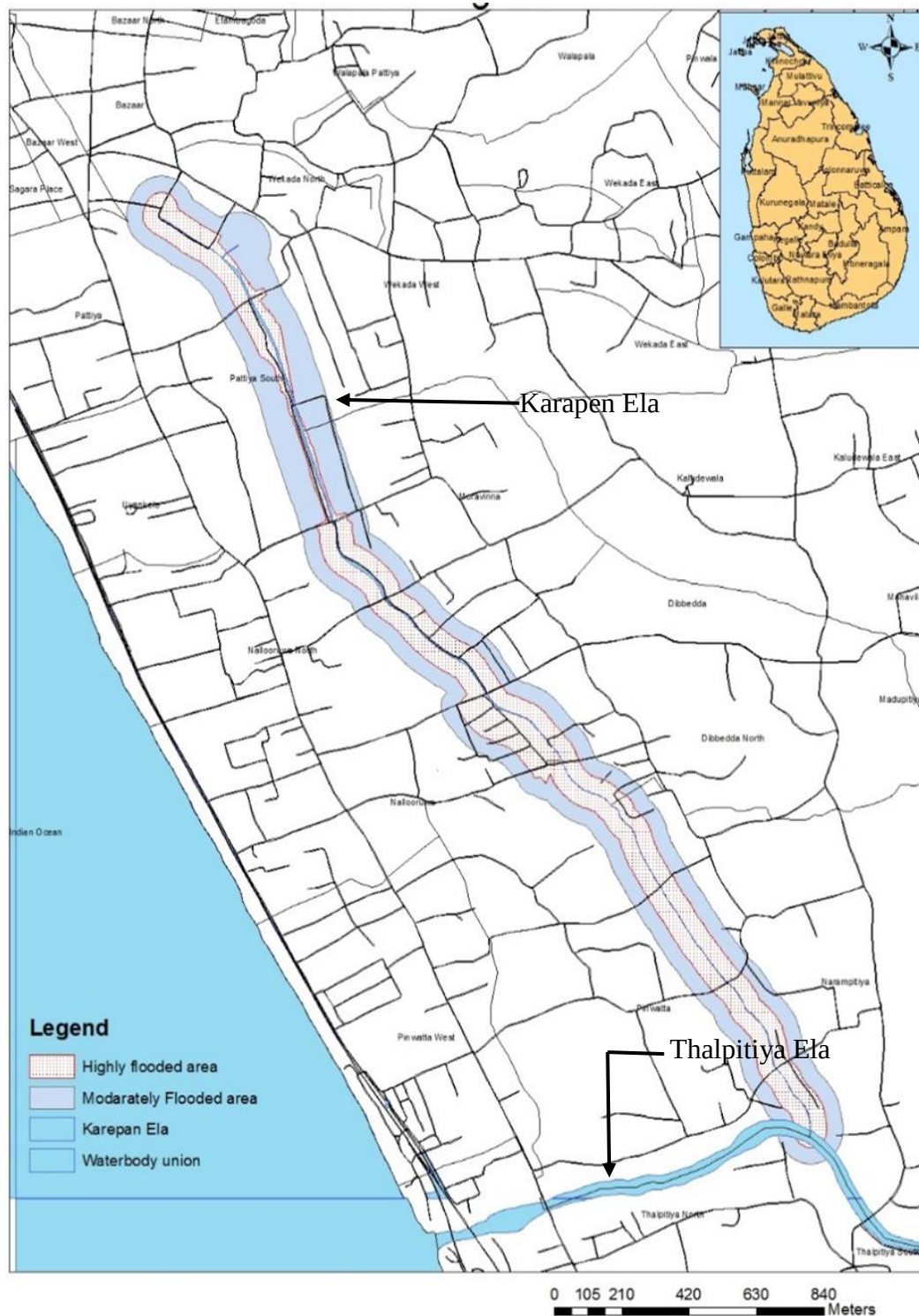


Figure 5.8: Flood affected areas of Karepen Ela

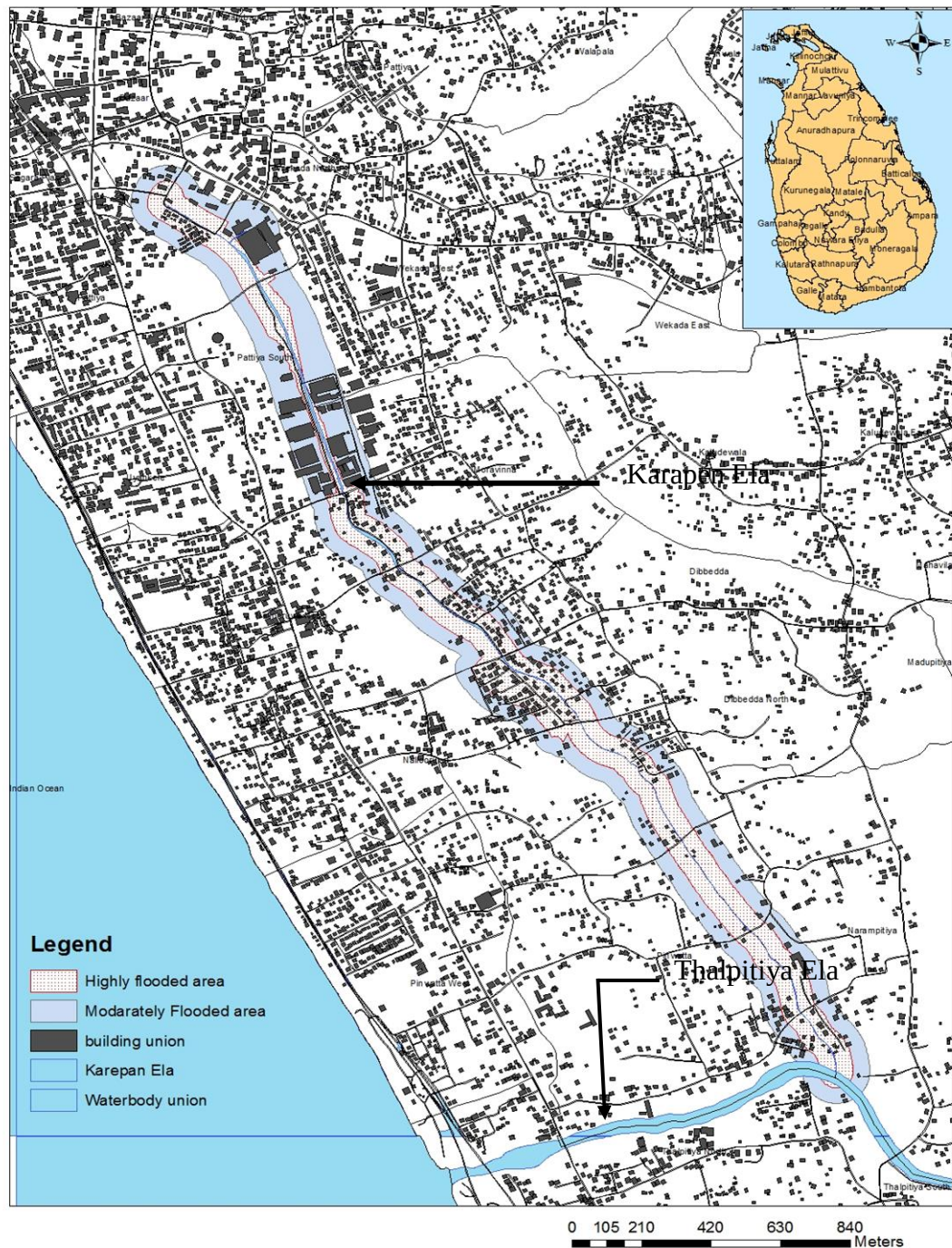


Figure 5.9 Flood damage in the vicinity of the Karepen Ela

Before 2000, there were no flood damages, however, after 2000, this area is affected by floods. Water levels are varied from 1 foot – 5 feet and usually remained for more than three days at locations very close to the canal (Figure 5.8 and Figure 5.9). Flood-affected areas are Finance Watta, Wadupasal Mawatha, and low-lying areas located on both sides of the Canal. The channel bed elevation of Karepen Ela is higher than

that of Thalpitiya Ela. Therefore, when the water level of the Karepen Ela increases, the water is not drained into the Thalpitiya Ela. As a result, the surrounding areas of the Karepen Ela get inundated. Communities have requested to increase the depth levels of the canal and widen the canal at the latter part. In addition, it is observed that industrial effluents from the Moderawila Industrial area and surface runoff of adjoining land uses are discharged into this canal and it is connected to Thalpitiya Ela.

Earlier there was a certain amount of paddy lands and undeveloped lands such as coconut, etc in the Panadura urban area. But nowadays all of these paddy lands are reclaimed for urban land uses. Panadura area experiences frequent flooding problems due to the disturbance to the stormwater flow pattern.

Thalpitiya Ela is part of Bolgoda Lake. The sea outfall of the Thalpitiya canal is blocked by the sand bar formations. Therefore, Thalpitiya Ela does not flow into the sea continuously. Before the construction of the industrial zone, there were no records of flood occurrences. Reclamation of wetlands results in water stagnation which leads to many environmental problems and public health issues. Water pollution, for example, is a common environmental issue in this region.

Figure 5.10, Figure 5.11, and Figure 5.12 illustrate the land use transformation in the catchment area of the Karepen Ela during 1990, 2004, and 2020, respectively.

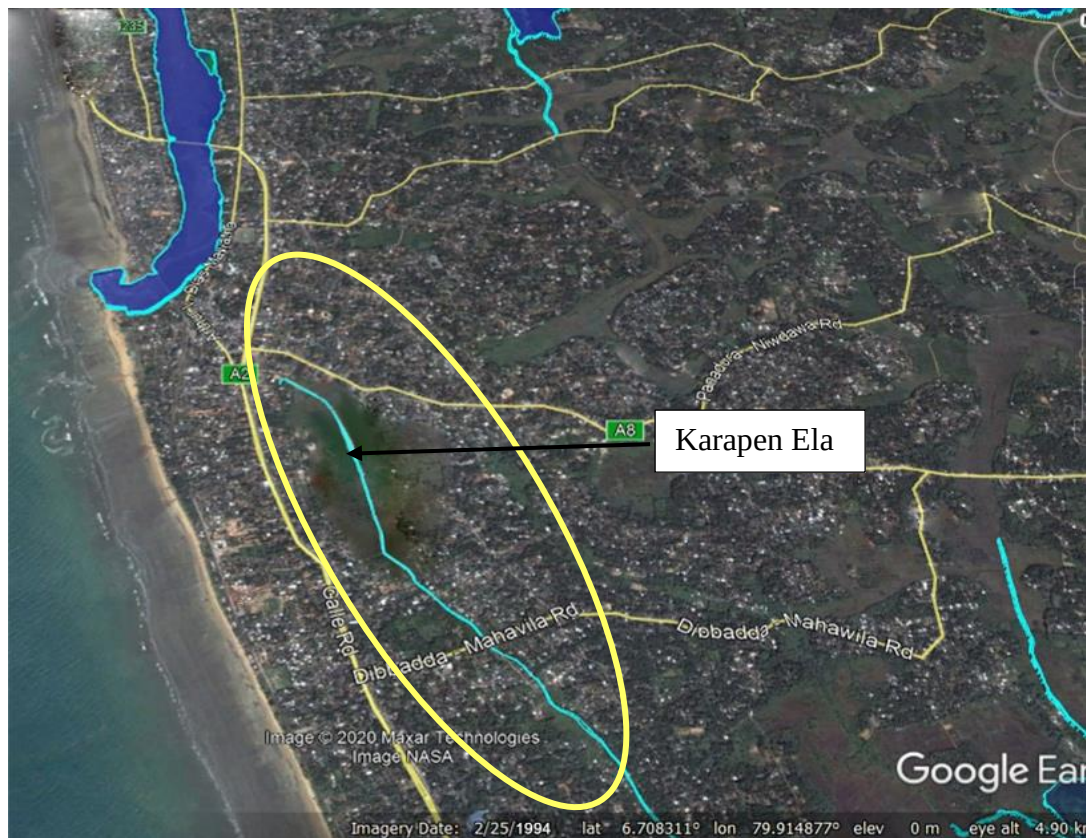


Figure 5.10: Land use changes in the catchment area of Karepen Ela in 1994

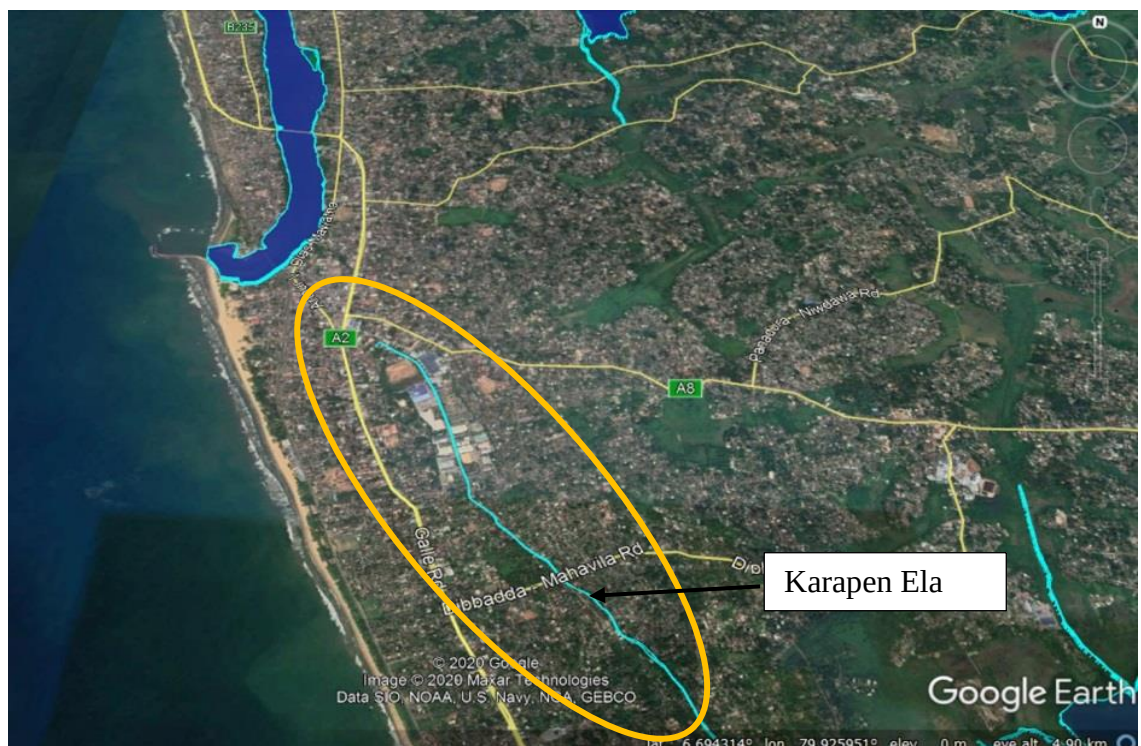


Figure 5.11: Land use changes in the catchment area of Karepen Ela in 2004



Figure 5.12 Land use changes in the catchment area of Karepen Ela in 2020

The above figures highlight the increase of built-up area and reduction of wetlands in the catchment of the Karepan Ela particularly the establishment of the Modarawil industrial area and related land use development during recent decades.

5.5.4 Flood risk management measures in Panadura

Considering the flood situation, a flood mitigation project was proposed for the Panadura urban area. The drainage Improvement Project at Panadura was initiated during the 2012-2014 period and the total estimated cost of the Drainage Improvement Project was Rs 139Mn. Moderawila development project was implemented under the first stage of the Panadura flood mitigation project. Four culverts and minor channels have been rehabilitated for the smooth flow of rainwater. The reconstruction of three culverts has been completed under the second stage of the project. Cleaning activities Karapen channel, construction work of retaining walls, and gabion wall of the end of Thalpitiya outfalls have been started with the implementation of the second stage of

the project. The client of this project is District Secretary, Kalutara. The project has been designed by the Sri Lanka Land Development Cooperation.

5.6. Land-Use Regulations in the Panadura Area

There is a 60m zone surrounding the Bolgoda water system as Bolgoda Environmental protection Area which has been declared by the Central Environmental Authority under the gazette notification No. 1634/23 on 30th December 2009 under the National Environmental Act no. 47 of 1980. The protected area is highlighted in Figure 5.13. The rest of the canals and waterways of this are adhering to the Special 04 Gazette Notice No. 1662/17 dated 14th July 2010 published by the Sri Lanka Land Development Corporation.

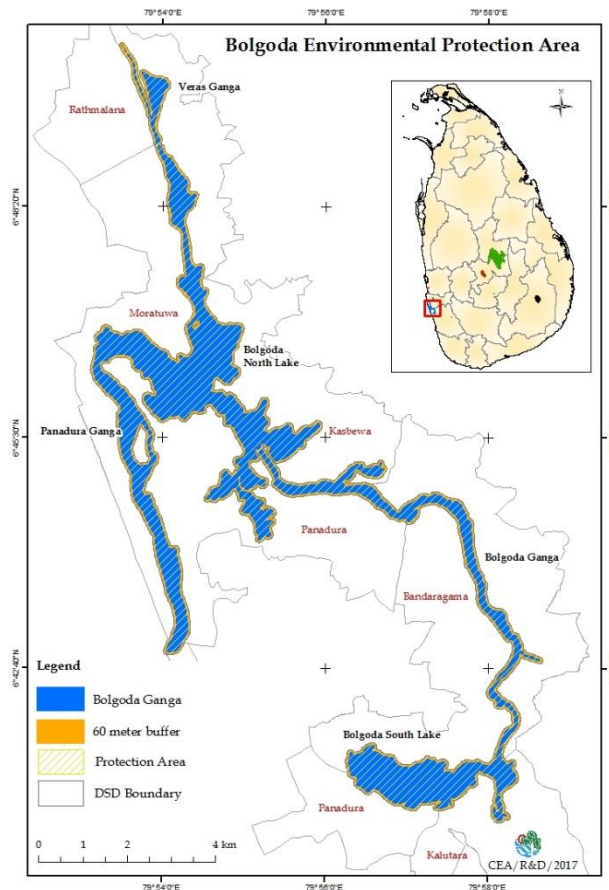


Figure 5.13 Bolgoda Environmental Protection Area (EPA)

(Source:http://www.cea.lk/web/?option=com_content&view=article&layout=edit&id=1162)

2A I කොටස : (I) ඡේදය - ශ්‍රී ලංකා ප්‍රජාතාන්ත්‍රික සමාජවාදී ජනරජයේ අති විශේෂ ගැසට් පත්‍රය - 2010.07.14
PART I : Sec. (I) - GAZETTE EXTRAORDINARY OF THE DEMOCRATIC SOCIALIST REPUBLIC OF SRI LANKA - 14.07.2010

Surface width of the canal (meters)	Reservation from the canal bank	
	for open canals (meters)	For surface covered canal (meters)
1.0 — 1.2	1.0	0.3
1.3 — 3.0	2.0	1.0
3.1 — 4.5	2.75	1.0
4.6 — 6.0	3.5	1.5
6.1 — 9.0	4.5	1.5
More than 9.0	6.5	2.0

In case where lengths declared by the Urban Development Authority, Irrigation Department, Central Environment Authority, Agrarian Services Department and Local Government Institutions regarding the reservations mentioned above exceed the lengths given in this statement, the lengths declared by the said institutions shall be accepted.

Figure 5.14: Floodplain guidelines (Source: Gazette Notification 2010.07.14)

Figure 5.14 describes the reservation of canals accordingly to the gazette notification. The reservation areas of the canals are varied according to the width of the canals. Land use planning regulations are framed following the guidelines of the Sri Lanka Land Development Corporation. Sri Lanka Land Development Corporation highlights the reservation of canals mainly considering the surface width of the canals. However, land-use zoning regulations do not consider the impacts on existing hydrological patterns and their significance in designing the land uses, the intensity of development, and the spatial distribution. Figure 5.15 illustrates the land use zoning regulations of the Pandura Urban area. It highlights the ill attention paid to the hydrological connectivity of the area.

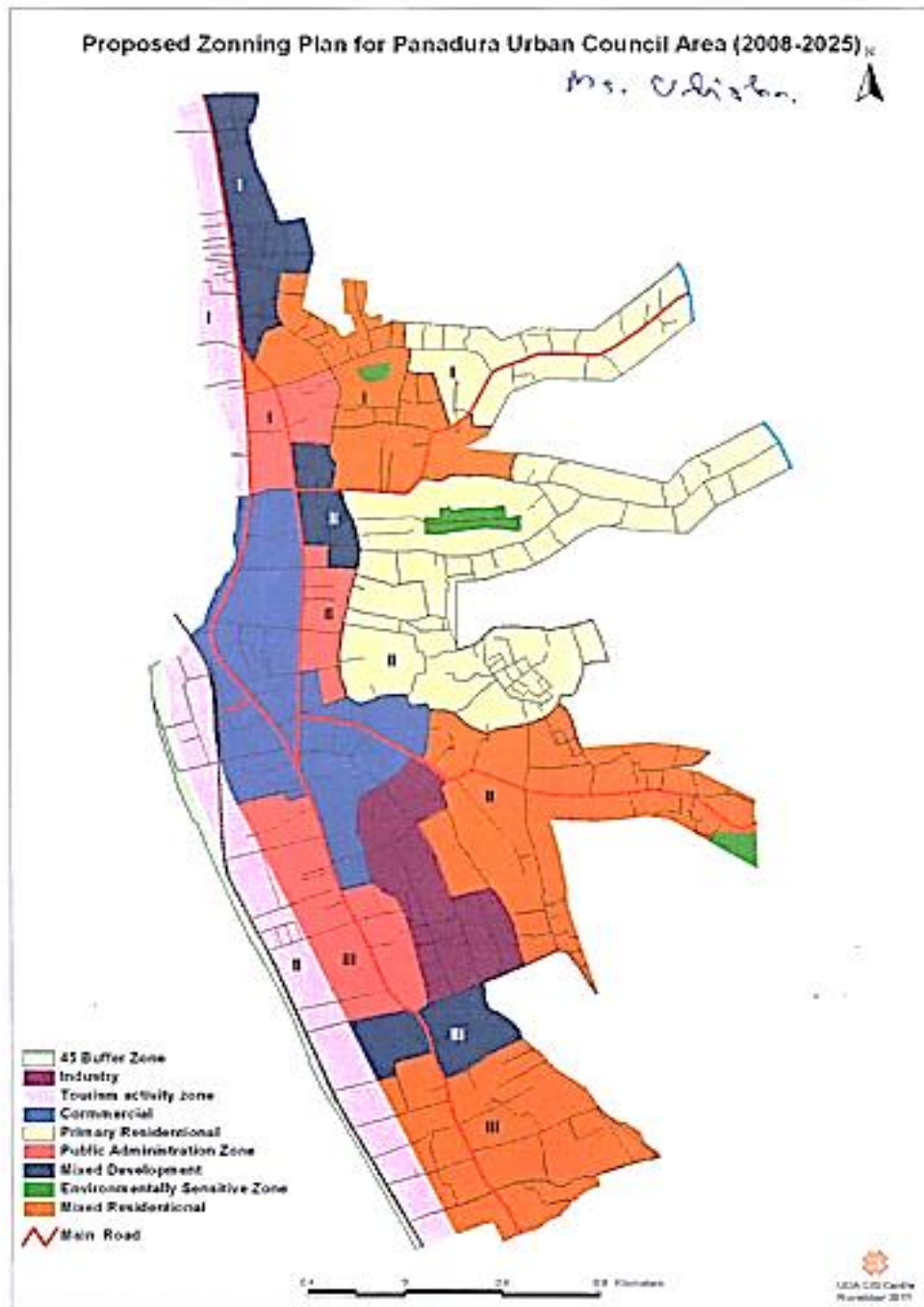


Figure 5.15: Land use zoning plan of Panadura Urban council area

(Source: Urban Development Authority, <https://www.uda.gov.lk/development-plans.html>)

5.7 Role of Different Stakeholders in the Flood Risk Management

The following Table 5.2 highlights the role of stakeholders in flood risk management in the Panadura area.

Table 5.2 Role of stakeholders in flood risk management

Stakeholders	Current status of responsibilities sharing among stakeholders
Panadura Urban Council	Part of the catchment area of Karepen Ela is under the urban council and the rest of the water catchment area of Karepen Ela is under the pradeshiya saba
Panadura Pradeshiya Saba (PS)	PS doesn't own the financial capacity to maintain and construct the drainage system
Divisional District Secretariat	Allocate financial sources for drainage construction
Disaster Management Center (DMC)	Relief distribution after flood damage Coordination of funds for relief program Involve in the discussions with communities for the improvement of the drainage system and management practices
Sri Lanka Land Development Corporation (SLLDC)	Design and construction of drainage system
Urban Development Authority (UDA)	Not very much involved in the flood risk management
Central Environmental Authority (CEA)	Concern the water pollution from Moderawila industrial zone
Department of Agrarian Development	Not much involvement of flood risk management practices
Coast Conservation Department (CCD)	Not involved in flood management

Meteorology Department	Not involved in flood management
Community organization	Improve their drainage system
Individuals of local communities	Increase the elevation of individual lands to prevent flood damage
Local politicians	Immediately after flood damage, they assist local communities

It has been evaluated the existing decision-making framework of flood risk management using the developed framework for making recommendations for sustainable and resilient urban development. The data and information gathered from the literature review, observations, and questionnaire surveys with the stakeholder have been analyzed using the developed framework.

5.8 Evaluation of the Existing Decision-Making Process for Operationalization of Flood Risk Management

The developed framework has been used to evaluate the existing flood risk management decision-making in the Sri Lankan context. Table 5.3 and the following part of the thesis discusses the level of operationalization of flood risk management in selected cases study. Table 5.3, explains the indicators to describe each sub-criteria of the framework in a detailed way. The developed framework contains sixteen sub-criteria to evaluate the decision-making approach under four main criteria such as conceptualization, assessment, discourse, and the participatory mechanism.

Table 5.3 Evaluation of existing approach for flood risk management

Criteria	Level of consideration/remarks			
	1	2	3	4
1 Conceptualization 1.1 Flood risk is defined as a complex phenomenon and identification of the socio-ecological components of the FRM system.	Characteristics of the Hydrological system	Characteristics of the Climatic pattern	Characteristics of the Ecological system (ecosystem functions)	Characteristics of the Social system Decision-making process, decisions, decision-makers
1.2 There are dynamic interdependencies between social, hydrological, ecological, etc subsystems (evolutionary interdependencies). The dynamics of flood risk and flood risk management are influenced by multiple factors at diverse spatial scales. There is an importance of assessing and	Local-scale dynamics / pressures	Regional-scale dynamics / pressures	National scale dynamics / pressures	Global-scale dynamics / pressures

Criteria	Level of consideration/remarks			
	1	2	3	4
managing flood risk at a different scale due to the scale sensitivity of flood risk. It is vital to characterize, analyze, and manage flood risk based on scales.				
1.3 Flood risk is characterized by socio-spatial and temporal dynamics. There are nonlinear interactions related to flood risk. As a result, there are inherent uncertainties in the flood risk management decision-making process due to diverse stakeholders with multiple knowledge and interpretations of flood risk management are	Unpredictability Flood hazard occurrence	The unpredictability exposure / of land uses changes	The unpredictability of vulnerability/policies	Unpredictability decision making process /policy changes

Criteria	Level of consideration/remarks			
	1	2	3	4
involved in the process of decision making. Therefore, the interactions incorporated with flood risk are unpredictable. Thus, a single agency cannot solve the problem.				
1.4 Decision-making process of flood risk management has required the social assessment and integration of the multiple objectives of all stakeholders.	Hydrologists and stakeholders related to water resources	Stakeholders related to ecological landscape / agrarian department / coastal conservation, etc	Stakeholders related to land use development such as communities, real state developers	Stakeholders related decision Policymakers
2 Assessment 2.1 The objectives of the FRM system are to manage the flood damage due to extreme events and maintain the ecological functions of the	Improve the adaptive capacity by maintaining the regulatory functions	Improve the adaptive capacity by maintaining the supportive functions of the floodplains	Improve the adaptive capacity by maintaining the cultural functions	Improve the adaptive capacity by maintaining the Provisional functions of the floodplain.

Criteria	Level of consideration/remarks			
	1	2	3	4
floodplains with different climatic scenarios and the wellbeing of the society in long term. Therefore, the role of the decision-making process is to identify the potential strategies to increase the adaptive capacities of the floodplain rather than design strategies of flood control measures based on probability thresholds of flood events.	of floodplains		of the floodplains .	
2.2 The objectives of the FRM system are to identify the diverse flood management measures (including measures to increase resistance	Consideration of selected scenarios and more focused towards increasing	Consideration of a certain range of scenarios and more focused towards increasing the	Consideration of broader set of scenarios and more focused towards	Consideration of extreme scenarios and more focused towards increasing the floodplain land uses capacity to

Criteria	Level of consideration/remarks			
	1	2	3	4
capacity, recovering capacity, the transformative capacity to manage the uncertainty of flood risk of different scenarios) to manage flood vulnerability with different climatic scenarios. Annual floods, Less than 25year recurrence 50- 100-year recurrence, Extreme / rare flood occurrence	the capacity of floodplains land uses to resist the flood occurrence.	floodplain land uses capacity to response the flood occurrence.	increasing the floodplains land uses capacity to recover from flood occurrence .	transform towards better situation after flood occurrence
2.3 Every floodplain has its specific function concerning its location. The objective of the FRM system is to identify the potentials of the location to maintain	Hydrologic al connectivity and balance between Upper and lower catchment.	Hydrological connectivity and balance between Groundwater and surface water	Hydrologi cal connectivity and balance between freshwater and coastal zone	Overall water balance of the catchment; Surface runoff, baseflow, precipitation, etc

Criteria	Level of consideration/remarks			
	1	2	3	4
the Hydrological integration over the watershed. Restoring the hydrological functions is one of the main factors for reforming decision-making.				
2.4 Every floodplain has its unique ecological and social interactions. The objectives of the FRM system is to identify the potential flood management strategies to increase social integration / multifunctional land uses over floodplains by identifying commonly acceptable thresholds integrati	FRM & local communities, real estate developers, (residential land uses)	FRM & ecologists (agriculture, fisheries, coast conservation, tourism sectors)	FRM & urban developer (UDA, local authority)	FRM & policymakers (politicians, disaster managers, regional development agencies)

Criteria	Level of consideration/remarks			
	1	2	3	4
ng the diverse spatial claims of stakeholders/ social integration (trade-offs of multiple social interactions of flood risk) to cope up with different climatic scenarios.				
3 Discourse	1	2	3	4
3.1 Recognize the importance of Institutionalizing adaptive planning and social learning among stakeholders in the FRM system.	Integration and knowledge sharing among water-related agencies in the decision-making process.	Integration and knowledge sharing among land development agencies in the decision-making process.	Integration and knowledge sharing among local communities in the decision-making process.	Integration and knowledge sharing among the politicians, etc in the decision-making process.
3.2 Recognize the importance of Institutionalizing of Multilevel governance	Integration for sharing information, resources,	Integration for sharing information, resources, power	Integration for sharing information, resources,	Integration for sharing information, resources, power Global-scale

Criteria	Level of consideration/remarks			
	1	2	3	4
mechanism in the FRM system.	power available for Top-down interaction s among the stakeholder s in the decision-making process	bottom-up interactions among the stakeholders in the decision-making process.	power Multisector interaction s among the stakeholder s in the decision-making process.	interactions among the stakeholders in the decision-making process.
3.3 Recognize the importance of Institutionalizing flexibility in governance arrangements and decision making and implementation.	Monitoring mechanism s are available.	Results of the monitoring can be used to improve the Guidelines.	Results of the monitoring can be used to improve the Strategies.	Results of the monitoring can be used to improve the Objectives of the plan/ contingency policies/plans instead of static policies.
3.4 Recognize the importance of Institutionalizing /Legitimization of Local initiatives and community participation for	Policy provision for Community participation in decision	Policy provision for Community participation in goal/strategy defining	Policy provision for Community participation in	Policy provision for Community participation in local and regional scales at decision-making process and

Criteria	Level of consideration/remarks			
	1	2	3	4
decision making & implementation.	making in risk assessment		guideline / action/ projects defining	implementation process / multiple scales
4 Participatory tools	1	2	3	4
4.1 Mechanisms available for Integration of objectives among the land and water institutions at all scales and levels	Local level	Regional level	National level	Global scale
4.2 Mechanisms available for Integrated goal setting and catchment-wide approach for decision making	Presence of decision-making tools at project scale/action level.	Presence of decision-making tools at the local scale	Presence of decision-making tools at regional scale	Presence of decision-making tools at policy scale
4.3 Flexible Mechanism available for Multiple Regime Governance Traditions (top-down + bottom-up)	Monitoring scheme	Monitoring revising of projects/guidelines	Monitoring revising of strategies	Monitoring revising of policies

Criteria	Level of consideration/remarks			
	1	2	3	4
4.4 Mechanism available / Legitimized tool availability for Empowering local stakeholders in decision making and implementation of FRM system (spatial planning)	Local-level	Regional level	National level	Global scale

5.9 Assessment of the Existing Decision-Making Process for Operationalization of Flood Risk Management

The existing flood management practices in Panadura have been evaluated using the developed framework. The results of the evaluation are highlighted in Table 5.4

Table 5.4 Assessment of existing flood risk management practices in Panadura

Conceptualization of FRM system	Level of consideration			
	1	2	3	4
1.1 Flood risk as a complex phenomenon				
1.2 Multiscale sensitivity				
1.3 Unpredictability of Flood Risk				
1.4 Social assessment and integration				

Conceptualization of FRM system	Level of consideration			
	1	2	3	4
Assessment	1	2	3	4
2.1 Adaptive capacities of the floodplain				
2.2 Diverse scenarios of climate change				
2.3 Hydrological integration				
2.4 Social integration among all stakeholders				
Discourse	1	2	3	4
3.1 Social learning in the FRM system.				
3.2 Multilevel governance in FRM system.				
3.3 Flexibility in decision making & implementation				
3.4 Legitimization of Local initiatives.				
Participatory tools	1	2	3	4
4.1 Integration of land and water institutions				
4.2 Integrated goal and catchment-wide				
4.3 Multiple Regime (top-down + bottom-up)				
4.4 Legitimized local stakeholders				

Above Tables 5.3 and 5.4 highlight the present status of practicing risk-based decision making in the considered case study.

5.10 Review of Flood Risk Management (FRM) Practices in Panadura

The following part of this chapter is focused to evaluate the existing practices of FRM with the developed framework and identifying the challenges and potentials for operationalization of FRM in the Sri Lanka context.

5.10.1 Conceptualization of flood risk

5.10.1.1 Complexity of flood risk

Flooding occurs with the overflow of the banks of rivers, canals, etc. Flooding can result in large damages to neighboring properties, assets, and land use activities. Floodplains are relatively flat lands adjoining the waterways. They may get flooded during the high discharges of water flows which occur yearly or once every few years. Although, floodplains can be used for many land-use activities such as agriculture, residences, and industries, etc. Floodplains and coastal deltas may directly flood from high rainfall intensities. Flooding can be a disastrous event when floodplains are intensively developed. After 2000, flooding has become a recurrent issue, and the highly affected areas are the town centre, surrounding areas of Karepen Ela, etc. Flood risk is increasing in the Panadura urban areas and multiple factors contribute towards this increase. Bolgoda basin experiences heavy annual rainfall and the following Table 5.5 shows the probable annual maximum daily rainfalls estimated for the Bolgoda basin and return period.

Table 5.5 Rainfall analysis

Return Period (years)	Probable 1-Day Rainfall (mm)
2	103.2
5	137.0
10	159.7
25	188.3
50	209.6

Source: https://openjicareport.jica.go.jp/pdf/11716578_01.pdf.

Panadura is a coastal town located in the Kalutara District. It is a flat terrain that is bounded by the sea. Panadura River and the Thalpitiya Ela both are parts of the Bolgoda basin that connects to the sea at the two locations of Panadura town (Figure 5.16 shows the natural hydrological system of this area). One of the causative factors for flood occurrence in the Bolgoda basin is the lack of a stormwater drainage system for draining stormwater runoff to the main streams. Further the natural drainage difficulty in the lowland surrounding the downstream aggregates this situation.

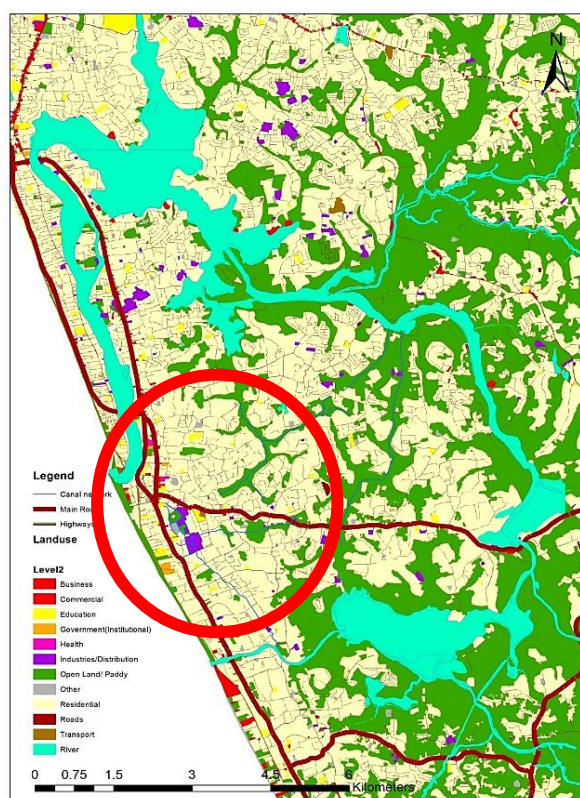


Figure 5.16: Hydrological pattern of the study area

After the 1980s, many of the low-lying paddy lands and marshy lands of this area were used for commercial, residential, or industrial uses. Due to recent unplanned urban development activities in Panadura, a significant reduction of paddy lands and marshy lands of the floodplains have been recorded. Moreover, the main causative factor for the increase of floods that occurred during the last few years was the reduction of water retention capacities of floodplains and land modification of catchment areas. Consequently, the water flow pattern and the volume of water flow particularly in the vicinity of the canal network (Karepen Ela) has been changed.

Panadura is a commercial as well as an industrial town. There is a higher land demand for urban development in the Panadura area because of its proximity to Colombo, and the availability of infrastructure facilities, etc. Therefore, rapid population growth has taken place in recent years. Low-income settlements have been established very close to waterways and canals due to the higher land values. As a result, unauthorized construction encroaching on wetlands and floodplains have occurred. This resulted in the reduction of the capacity of water retention areas. This situation will aggregate since Panadura is a coastal town where certain areas are below the mean sea level. The Bolgoda basin is characterized by a limited capacity for the natural outfall drainage system. Moreover, the elevation of the Thalpitaya canal is higher than the mean sea level and it is locked by a heavy sand bar at the sea outfall.

The water level of the Bolgoda lake system becomes a vital factor for the increase of floods in Panadura. Water flow patterns of the Bolgoda basin have changed significantly due to rapid land-use transformations of the Colombo metropolitan region such as the establishment of the southern expressway. Bolgoda water system connects to the sea at the Thalpitaya Ela. Karapen Ela connects to the Thalpitaya Ela and Thalpitaya Ela which is part of the south Bolgoda Lake. It does not flow into the sea continuously because of the sand bar formation at the sea outfall of the Thalpitaya canal. Therefore, there are bottlenecks for water flowing during the southwest monsoons. Natural drainage difficulties due to elevation differences and haphazard urban development aggregate the flood damage during recent years. These factors are (1) the increase of urban development along the coast and the proximity to the outfall,

(2) an inadequate connection between the tertiary and secondary drainage systems, (3) the blocking of water canals of the area due to the non-availability of proper solid waste management systems, (4) lack of support from the general public to flood risk management, (5) reclamation of lands and modification of lands, lack of coordination among relevant agencies such as local authority, Urban Development Authority, Sri Lanka Land Development Cooperation, etc., and (6) high expectation from structural flood risk management measures by the public community. Moreover, the community lays an extreme trust in the structural measures for flood damage protection. The illegal developments in canal reservations cannot control following the existing land use control and have caused difficulties in canal maintenance.

As described above, flood risk is no longer a hydrological phenomenon. Urban development in floodplains is a vital component of flood exposure, and changes made in this component can lead to variations in flood risk. Therefore, changing of flood exposure influences two main factors such as the occurrence of floods and the increase of the vulnerability to floods. Land-use changes in urban areas increase stormwater runoff volume, decrease infiltration and groundwater recharge and increase water pollution. The main objective of an establishment of a drainage system is to collect and dispose of stormwater runoff as fast as possible from urban areas to nearby receiving water bodies to avoid flooding. The design of drainage structures requires the estimation of flood water levels corresponding to a given probability of exceedance, or return period. According to the present practice, the flood risk has been mainly defined considering rainfall analysis. Decision-making is based on the probabilistic models which are used to simulate flood flows on floodplains. Furthermore, Damage maps at different return periods are used to calculate Expected Annual Damage (EAD). Designing structural measures particularly the capacity of the drainage network is based on the estimation of peak flows and inundation area. The return period is used to identify the flood hazard probability mapping. According to the existing practice, a 50-year return period (or 25 - year return period) is considered for designing the major streams based on the significance of the urban development, and a 5 -10 year return period is considered for the designing of urban drainage with small catchments.

The current practice is based on keeping hazards away from the communities and adopting infrastructural measures. Hydrologists have designed the capacity of the drainage channel by studying the historical rainfall intensities and the peak runoff analysis of the catchment. Therefore, the magnitude of peak discharge to defining flood protection levels of the small tributaries such as Karepen Ela is considered a 5year probability of flow capacity. Flood mitigation structures were normally designed to control up to a certain, predefined design flood, i.e. Return period of the design rainfall. However, at present, there is no specific criteria/guideline to define the appropriate or target scale of protection level (planning scale) existing in Sri Lanka (JICA, 2009). According to the developed framework it has been pointed out that the requirement and significance of understanding the flood risk following socio-ecological systems perspectives. Also, the decision-making process of the present practice does not consider the co-evolutionary interactions between society and the hydrological system. The framework highlights the consideration of bi-directional relationships among the flood occurrence, floodplain land use development in the assessment of flood risk. The independencies between social and hydrological systems related to the catchment and the stakeholders' interpretation of these interdependencies were not considered in the decision-making process. Flooding is a product of complex interactions among hydrology, meteorology, and socio-economy which are linked among themselves in a nonlinear manner with many feedback processes. The developed framework has highlighted the decision-making of flood risk management should not be based on the hazard probability but also the local spatial demands. Because, the inhabitants of the floodplains have complex reasons for living with this flood risk, such as population growth, land scarcity, land tenure issues, poverty, housing policy, etc.

5.10.1.2 Multiscale of flood risk

Sri Lanka Land Development Corporation has designed and constructed a drainage system to overcome the flood risk in Panadura. The current practice of flood risk is assessed mainly based on the rainfall pattern and Flood management systems have considered that the occurrence of extreme events arises from a serially independent

time series with a probability distribution pattern. Flood damage assessment is used to estimate the impacts associated with floods that might occur in the future. Flood damage assessment provides information for decision-making to flood risk managers. Moreover, flood damage assessment is used to estimate the cost of reducing damage caused by different flood frequencies. The components of the flood risk are subjected to change over the period due to multiple reasons which are influenced at different spatial scales, such as local, regional, and global. For example, the population growth has increased in Panadura in recent decades mainly due to the proximity to the city of Colombo.

Damage assessment considers the land-use changes of the local catchment scale. However, the land-use changes due to future urban growth in a regional context are not able to be considered in decision making. Moreover, flood risk management is required to be conceptualized with a socio-hydrological approach considering the socio-spatial and temporal dynamics. At present, the cost-benefit assessments of feasibility studies of flood risk management projects are often considered the linear cost and damage function assessments. Flood damage assessments are given less priority to proactive human responses' and thereby analyses are reduced to a few parameters or scenarios. Uncertainty incorporated with human responses is not considered in the current flood risk assessment. This narrow framing of flood risk could not recognize the socio-spatial-temporal dynamics related to flood risk influencing at different levels.

5.10.1.3 Unpredictability of flood risk

In current practice, the risk of flooding is defined based on static and narrow framing. The risk of flooding is currently defined as the product of the probability of occurrence of a hazard and its consequences. At present, the occurrence of flooding is considered to arise from a serially independent time series with a probability distribution pattern. Therefore, the hydrological parameters of flood events are considered fixed over the design life of a project. Climate change has eliminated assumptions of the past, relatively stationary hazard occurrence to a non-stationary condition. Therefore,

a new dimension has been added to the uncertainty associated with flood hazard predictions. Moreover, it is difficult to assess the uncertainty associated with the hazard due to the non-stationary nature of climate change.

Existing flood risk management is not focused on managing the vulnerabilities of society/regions. The estimation of flood damages also depends on several assumptions and the hydrological parameters are also not distributed homogeneously. Therefore, unpredictability poses a significant challenge to the implementation of flood risk management practices and the achievement of the effectiveness of flood risk management measures. However, at present, there are many limitations to the cost-benefit analysis applied in decision-making for flood risk management. The assessment of flood damage should include physical and social costs. Social costs are more difficult to quantify than physical costs. And in current practice, however, all effects are generally grouped into a single variable. Another disadvantage of the existing cost-benefit assessment is the combination of costs and benefits under the assumption of interpersonal aggregation. The existing cost-benefit analysis assumes that the disadvantage of one group of stakeholders can be completely offset and corrected by the advantage of another stakeholder. Further, costs and benefits are considered independent of each other. Therefore, this framework has highlighted the limitations of decisions based on existing cost-benefit assessments.

5.10.1.4 Social assessment and integration

Rapid urbanization in the Bolgoda basin in recent years has led to uncontrolled developments in flood-prone areas. Urban development activities without maintaining the flood retention function in the upper basin will result in increased flood damage in the lower basins. This rapid urban development over the upper part of the basin has increased the flood vulnerability in the coastal region. Further, rapid land use development of the coastal region and lowland areas has made coastal communities more vulnerable to flooding and will lead to increased flood damage. The developed framework has highlighted that conceptualizing flood risk in the present decision-making model is inappropriate to socio-spatial dynamics of Flood risk. Therefore,

flood risk management is not seen as a socially constructed, socially assessed, and socially integrated process. Therefore, decision-making processes and the choice of flood risk management measures are necessary to identify stakeholders' risk perception and knowledge system as a key factor in shaping human responses, e.g. land use development in floodplains.

Many of the low-income urban dwellers are established their settlements over the floodplains and the low lands due to an increase in land values, unemployment, poverty as well as due to the weakness of the housing, transportation, and urban development policies and poverty. In the current practice, flood risk management measures are selected based on economic evaluation. In general, reduction of flood damage and improvement of lands of the floodplain, free from flood damage is mainly considered as the benefits. Cost-benefit analysis is used to compare the cost of structural measures with the reduction in predicted future flood damage that management measure is like to cause. However, the current practice of flood risk management safety cannot be considered for low-income settlements, etc. Not only the risks but also the benefits of flood management measures may be perceived differently by individuals. Therefore, there should be a trade-off between different stakeholders when determining the acceptable risk for flood risk management measures. However, in current practice, the risk of flooding (desired flood risk, the capacity of the drainage system, and regulations to control land use in floodplains) is measured based on facts rather than consideration of impacts on diverse communities, and flood risk managers are determined the. In these circumstances, a multi-criteria analysis is better suited to analyze stakeholder preferences for risks and benefits. Thus, the framework highlights the selection of flood risk management measures is required to be determined based on the value judgments of all stakeholders because the main objective of flood risk management is to bring a net benefit to society in the long term. Table 5.6 highlights the recommendations for improving the existing practice of FRM.

Table 5.6 Recommendations to improve the conceptualization of FRM in the present decision making

Conceptualization of FRM system	Recommendation
1.1. Characterization of flood risk management	Flood risk is defined as a complex phenomenon and Identification of the socio- hydrological ecological components of the FRM system. It is necessary to recognize the nonstationary and nonlinear interactions related to floodplains in the study areas
1.2 There are dynamic interdependencies between social, hydrological, ecological, etc subsystems	Multi-dimension factors influence multi-scale determine the flood risk and there is a requirement of analysis of flood impacts at multiple scales and societies/ communities/ sectors with time scale rather local catchment level. Eg; urban development in Colombo metropolitan region
1.3 Unpredictability of FR Flood risk is characterized by socio-spatial and temporal dynamics.	Social spatial-temporal dynamics of flood risk are difficult to predict. It is impossible to predict the flood risk due to the inherent uncertainties of flood risk management. Therefore, the level of certainty of probability assessment is depended on the knowledge of the stakeholders. Thus, the knowledge of a single institution (Sri Lanka Land Development Cooperation) cannot be decided on an acceptable level of flood risk.
1.4 Decision-making process of Flood risk management has required the social assessment and integration of the multiple objectives of all stakeholders.	Flood risk is a socially constructed phenomenon. Therefore, the determination of the objectives of the FRM system is necessary to consider the acceptable levels of flood risk of all the stakeholders as well as their needs and diverse objectives. Therefore, the FRM has become a subjective process specific to location. Therefore, the selection of flood risk management strategies is necessary to take into account interdependent stakeholders (different spatial demands) in the long term.

5.10.2 Place-based assessment

Natural floodplains provide several benefits to society such as regulatory functions, supportive functions, cultural functions, and provisional functions. The floodplain functions include the provision of goods (agriculture, fish) and services (flood control, water quality regulation, and food chain support) while processing attributes such as biodiversity and cultural heritage. The appreciation of these functions is dependent on the actual perception of stakeholders. Implementation of structural flood control measures adversely impacts the ecosystem - dependent livelihoods and economy. However, these measures can create new environmental risks such as flooding, pollution, and biodiversity decrease. Further, problems like reduction of fishery activities, an increase in water pollution, and abandoning agricultural activities in the floodplain can arise. Such impacts have been recorded in the Panadura urban area in recent years. Therefore, the evaluation of flood management measures requires the consideration of the possible outcomes in the long term of the projects rather than an economic cost-benefit assessment. This developed framework has been highlighted the importance of assessing the flood risk considering the multiple impacts based on the whole systems approach and all stakeholder objectives.

Flood defenses may encourage urban development in risk areas, and recovery mechanisms might also provide a disincentive for flood-risk preparedness. The current cost-benefit analysis doesn't distribute the cost and the benefits of flood risk management measures evenly. Therefore, the evaluation of FRM measures in the decision-making process is required to consider gaining social benefits in the long run. Accordingly, the objective of the flood risk assessment is to explore the potential ways to improve the stability of the location by maintaining its ecological functions. This framework highlights that the objectives of Flood risk management are broad and mainly aimed to reduce potential negative impacts on society, economy, and ecology.

5.10.2.1 Analysis of different scenarios of flood risk

Flood damage estimations are usually associated with significant uncertainty. These uncertainties can be listed as follows.

- Changes in the precipitation pattern due to climate change
- Changes of the elements on a floodplain that were subjected to harm from the hazard
- Changes the pathways through which the impact of the hazard is exerted on the receptors

Floodplain land use development can be changed in the future due to many factors related to the area such as the level of urban development in Panadura. Besides, land use patterns will be changed due to population growth policy and economic development policies, etc. water flowing pathways can also be changed due to unauthorized reclamation of marshy lands, etc. The factors affecting the change of pathway and receptors are more or less the same. It is a challenging task to predict the socio-economic conditions and associated land-use changes over the catchment and the floodplains in the future. Also, the worsening of floods due to climate change will bring an additional burden to inland coastal communities. The current practice considers only a single future scenario rather than the multiple future scenarios of climatic change. Also, it does not consider the worst-case scenarios of climate change and urban development. At present, the main flood risk management measures, mainly implemented in the Panadura region, are only structural solutions, although policy documents keep on stressing the importance of non-structural and structural options in dealing with uncertainties.

5.10.2.2 Territorial hydrological integration

A fundamental factor of any flood risk management system is to smoothen the function of natural water flow patterns considering the basin scale. According to the study conducted by JICA, 2003, it has pointed out the Bolgoda Basin is characterized by

difficulties in the natural draining of stormwater. This situation is further challenged by climate change and the reduction of retention areas due to the rapid urban development of this region recently. However, if flood risk management mainly focuses only on channel improvements it requires a huge cost. Further, this solution is not socially and environmentally feasible. Therefore, it is important to maintain the existing marshes, lowlands, and paddy lands as stormwater retention areas. Secondly, it is necessary to consider the entire cascade factors and follow a model of floodplains as components of a single ecosystem. Unfortunately, at present, reclamation is conducted legally as well as illegally throughout the basin due to the absence of a clear common framework for land development. Besides, the current practice of the FRM is more localized, reactive, and isolated rather than being proactive and hydrologically integrated. Reconnecting the retention areas of floodplains will be economically feasible to face stronger storms in the future. According to the developed framework, it has been stressed that the planning process is required to pay attention to exploring the potentials to design the Bolgoda river basin landscape while identifying the protected areas of the trade-off of hydrological connectivity. However, all of these hydrological interconnections are weak considering the existing regional and local spatial planning practices.

5.10.2.3 Social integration

According to the present practice, the present safety level of the main canal system was evaluated in the range of a 5-year to 25-year return period. However, if the urbanization rates are increasing intensively, these safety factors would not be sufficient to protect land uses along with the floodplains and particularly the low-income settlements. Moreover, with the increase of climate change and socio-economic development, flood risks are increasing. However, increasing the safety levels of the structural measures will bring negative impacts to the local fishermen communities, farmers, as well as residents. For example, the objective of the Karapen Ela is to discharge the rainwater to the adjoining waterways as soon as possible. There is a minimum capacity of water Karepen Ela canal during the dry periods and it affects biodiversity, aesthetic quality, spatial quality in the vicinity, etc. Therefore, the

implementation of flood control measures would not improve the living conditions, housing quality, environmental quality, and economy of the local community.

Every community has different interest and their capacities for implementation are also varied on different management measures such as nature-based solutions, etc. Practicing risk-based management measures is subjective and cannot be tailor-made. The majority of the local communities in the Panadura area have not recognized the importance of wetland conservation and they still prefer flood control structural measures. This framework has highlighted the necessity for the consideration of socio-economic interdependencies with floodplains concerning each local context. Moreover, it highlights and assesses the potential for collaborative objectives which lead to multiple objectives of the stakeholders. Therefore, multi-functional land uses are required to be designed considering the trade-off of diverse objectives such as urban development, flood risk management, poverty, etc. Table 5.7 shows the recommendations for improving the current practice of FRM.

Table 5.7 Recommendations to improve the assessment of FRM in the present decision making

Assessment	Recommendation
2.1 Maintain the ecological functions of the floodplains with different climatic and social-economic scenarios and the wellbeing of the society in long term.	Identification of management options considering their contribution to the restoration of the ecological functions of Karepen Ela to face such rare events
2.2 Maintain the stability of floodplains in coping with different scenarios and extreme scenarios.	Identification of multiple management measures including the structural and the non-structural measures (wetlands as retention area) to cope with the diverse scenarios).

Assessment	Recommendation
2.3 Maintain the hydrological integration and balance in the territory.	Identification of strategies to maintain the local and regional hydrological connectivity in the Bolgoda basin and the adjoining basins particularly the Kalu river basin as well as the sea level rising also designing the flood management measures.
2.4 Maintain the multifunctional land uses over the Floodplain based on Trade-offs of considering social integration.	Identification of strategies to integrate the objectives of diverse stakeholders (creation of trade-off) in the Panadura urban areas such as flood managers, industries developers, urban developers, farmers, fishermen, local communities, etc.

5.10.3 Discourse of the stakeholders

5.10.3.1 Social learning

The Irrigation Department of Sri Lanka has been sanctioned to control river floods according to the Flood Ordinance No. 22 of 1955. Under the Colombo District (Low Lying Areas) Reclamation & Development Board Act No. 15 of 1968, Sri Lanka Land Development Corporation was established in 1968. The act was amended by Law No. 27 of 1976, Act No. 52 of 1982 and Act. No. 35 of 2006 and the authority to take legal actions against unauthorized land reclamation and water pollution was granted. The Sri Lanka Land Development Corporation is responsible for urban drainage. Sri Lanka Land Development Corporation is the main agency that is engaging in the planning and implementation of regulations related to the development and maintenance of wetlands and urban drainage systems. The Urban Development Authority defines the floodplains in urban areas following the given guidelines mainly by Irrigation Department and the Sri Lanka Land Development Corporation.

Flood risk management is currently being operationalized under the direction of technical experts. The flood risk management discourse and legal provision (laws) of Sri Lanka have been given priority to hard infrastructural measures. Further, flood risk management, climate change, and urban development are not considered as separate subjects. Flood risk management law facilitates flood protection rather than risk-based decision-making. A sectoral approach to flood risk management focuses on controlling flood risk rather than social learning. Therefore, when considering the flood risk characterization, the assessment strictly follows the technical flood risk examination method. Its consequences are strongly viewed as a physical event rather than a social judgment. Spatial planning requires a strategic view of the physical and social landscape management instead of a regulatory instrument of land uses. This developed framework recommends transformation of discourses based on flood management towards flood risk management which focused more on anticipating the future and facilitates collaborative decision making. This will help to create synergy between urban development, flood risk management, and ecosystem functions.

5.10.3.2 Multi-level governance

Flood risk management is a cross-cutting aspect in many different sectors of development. However, at present, Sri Lanka Land Development Corporation is responsible for the overall flood management in urban areas. Therefore, it can be seen that Sri Lanka's flood risk management is governed by a centralized system. The central government is responsible for flood risk management. Multilevel governance mechanism has outlined macroscopic policy levels but implementation and enforcement remain unclear at the local level. There is a lack of cross-sectoral coordination as well as a bottom-up approach. Therefore it is difficult to implement preparedness and flood mitigatory measures. Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR) (UNISDR, 2015), has highlighted the importance of multilevel governance for flood risk management. The existing stand-alone approaches reduce the effectiveness of investments in flood risk management. State departments and agencies often act independently in the decision-making process. The development of common meanings and values and the understanding of flood risk

through the multiple interactions of interest groups form the basis for future joint action. “Better relations between stakeholders” increase trust between stakeholders. In addition, this integration will allow stakeholders to share knowledge and resource base to operationalize flood risk management practices. However, the operationalization of the FRM requires the integration of strategies related to sustainable development and climate change. Unfortunately, this is not the practice at any level in Sri Lanka. Therefore, the developed framework highlights the presence of strong governance coordination for implementing flood risk management practices.

5.10.3.3 Flexibility in decision making

Flood Risk Management (FRM) encompasses both structural and non-structural measures to avoid (prevent) or limit (mitigate and prevent) the adverse effects of flood risks. Sri Lanka's flood management practices are very often reactionary. The Flood Ordinance No. 22 of 1955 does not contain any non-structural food risk management measures. Top-down, engineering approaches on flood control are based on building centralized hydraulic infrastructures. Currently, there is no monitoring mechanism to evaluate the effectiveness of the management measures implemented. Also, the division of responsibilities between agencies in terms of flood risk management is not evident. Currently, land use planning practices have not well recognized the relationship between poverty, low-income settlements, and flooding. Further, the role of land use planning for flood risk management is not legitimized. The developed framework has highlighted the need for diverse strategies and the policies and laws required to recognize the nature-based management measures at national, regional, and local levels.

5.10.3.4 Legitimacy of local community participation

In the current practice, flood management is predominantly centred on controlling the floods through engineering structural measures, mainly channelling the floodwater. Local communities do not participate in flood risk management. Both local community participation and adaptive capacities of local communities are not well recognized in

practicing flood risk management in the Sri Lankan context. Local community involvement in decision-making is required for effective risk reduction or preparedness activities. Living with flood risk would require local communities' adjustment to floods. Full protection from floods is not possible. Hence, the land uses of floodplains are required to be adjusted by diverse stakeholders' interests.

The Sendai 2015-2030 Disaster Risk Reduction Framework stresses the importance of stakeholder participation and sharing of local knowledge systems in the management process. The involvement of stakeholders raises many questions. These include the identification of legitimate stakeholders, identifying their roles, etc. Legitimacy becomes increasingly complex in the context of current flood risk management, as the scope is broad and diffuse. However, we are not yet operationalizing the Sendai framework. Therefore, this framework highlights the policies' recognition of the importance of the participation of local communities and the active involvement of the local community in framing the objective in the decision-making process. Table 5.7 shows the recommendations for improving the current practice of FRM.

Table 5.8 Recommendations to improve the discourses related to FRM in the present decision making

Discourse	Recommendation
3.1 Recognize the importance of Institutionalizing social learning, adaptive and integrated planning approaches for operationalizing flood risk management.	Existing laws and regulations are inadequate for risk-based land-use decisions and therefore, this research showed the importance of new legislation for strengthening social learning in flood risk management.
3.2 Recognize the importance of Institutionalizing the Multilevel governance mechanism.	Improve the legal provision to strengthen the role of spatial planning to coordinate different

Discourse	Recommendation
	stakeholders, policy directions, and monitor and implement decisions to balance the natural landscape and society (balance spatial development)
3.3 Recognize the importance of Institutionalizing Flexibility in governance.	Periodical monitoring of the achievement of social justice.is required to ensure through the administrative procedures and the legal background.
3.4 Recognize the importance of Legitimization of Local initiatives and participation.	Legalize Local community participation and encourage the practicing of preparedness strategies.

5.10.4 Participatory Tools

5.10.4.1 Land and water integration

Sri Lanka disaster management Act, no. 13 of 2005 demands a comprehensive risk-based flood management framework. Therefore, the Act aims to transform away from emergency response toward preparedness. However, in the Sri Lankan context, water engineers are usually responsible for the provision of flood protection facilities based on modeled flood scenarios (5 years, 20-year-flood). Accordingly, the Irrigation Department and SLLDC are the main responsible agencies for managing flood risk. The Urban Development Authority Act No. 41 of 1978 and amendments have provided a platform for the operationalization of integrated planning and implementation of economic, social, and physical development of the declared urban areas. In the current practice, spatial planning and flood risk management function as

two separate domains. Moreover, in the present context, spatial planning has relied on infrastructural solutions to manage flood risk. Incorporating measures to manage flood risk and increase the adaptive capacities of floodplains is not among the key priorities of spatial planning practices at the regional and local levels (see Figure 5.17).

Risk-based urban development guidelines are developed by considering the performances of the ecological systems (floodplains, streams, etc.) their functions, and feedbacks. For example, the thresholds of impervious cover determine the consideration of the impacts on the ecological system of the area. Water issues such as pollution, flood damages are evidence for poor coordination in land use development. For example, the presence of chronic flood damage, water quality degradation, etc. reflects the degree of coherence of land uses with water in a watershed. The main reason is the uncleanness between the interdependencies of spatial development patterns and the functions of the hydrological system. The responsibility sharing, power-sharing, resource sharing related to Disaster Risk Reduction (DRR), and climate change are not clear even at the national level. Nature-based solutions improve the adaptive capacities of regions, localities to cope up with extreme flood events. However, nature-based solutions require larger areas of land. Moreover, implementation of projects of room for the river, water sensitive urban design, waterfront urban development, green infrastructure, etc., also require more land. However, integration between land and water institutions is the cornerstone of practicing risk-based land use management. Therefore, this framework has highlighted that there are no interactive tools for sharing the property rights, integration, and development of trade-off mechanisms with land and water sectors.

5.10.4.2 Catchment scale planning

Climate change is expected to increase flood occurrence with more frequency and heavy precipitation. Climate change together with urban sprawling will aggregate the pressure on flood control measures. Therefore, flood resilience and the importance of improving the adaptive capacities of the places and regions have been highlighted.

Flood risk is increasing in Panadura is due to the land-use changes of the upper catchment of the Bolgoda basin. The causative factors for flood disasters often go beyond the administrative boundaries. Several local authorities have suffered from one flood event. Natural drainage difficulty is a salient characteristic of the Bolgoda water basin. As a result, the lowland surrounding the downstream water system has many ecologic as well as socio-economic issues. Therefore, it is important to consider the hydrological balance of the overall regional context when determining spatial development policies and guidelines. However, it is not operated as highlighted in this developed framework in the present context. Further, it is required to assess and manage the flood risk at different scales to manage the uncertainties associated with it. Therefore, a holistic catchment scale strategy covering the entire Bolgoda basin beyond administration boundaries is important to harness the potential of integration. Managing the interrelations between upstream and downstream riparian areas in flood risk management is a necessity. Moreover, a basin-scale management plan can be utilized to provide more opportunities to implement non-structural measures, cost-effective measures, and improve preparedness. Both regional and local stakeholders are required to be integrated to implement the catchment scale decision-making.

Accordingly, nature-based solutions provide multiple benefits to the economy, society, etc. However, these benefits are not clear at city scales. Basin-wide decision-making provides a platform for coordination of the objectives of various stakeholders for the integrated management of water and land resources. The involvement of a wide range of stakeholders in flood risk management is considered necessary to effectively reduce flood damage. It is important for managing the interrelationships between upstream and downstream riverbank areas, water retention areas, etc. In current practice, however, decision-making tools for the watershed scale are not available due to the lack of a framework. Moreover, there are no instruments to maintain the trade-offs between economic growth and environmental sustainability in the watershed.

5.10.4.3 Flexibility of tools

Current spatial planning policies and regulations are designed following the flood hazard maps. Therefore, land use planning zoning is not effective for extreme events and is the only effective for a certain threshold of flood occurrence. The current decision-making process is characterized by technically competent and economically streamlined decision-making processes. Technical experts from flood risk management authorities reserve a stronger position in the decision-making process. Current flood risk management and land use planning aim to maximize economic development. In addition, massive investments are being made in structural flood protection. Flood risk management strategies are needed to account for future uncertainties. In addition, this homogenous set of zoning regulations increases the stress on low-income settlements in urban areas. Moreover, there is a rigid boundary between land development and floodplains. Therefore, current flood risk management policies and strategies do not focus on vulnerability management. However, at present, there are no monitoring mechanisms for assessing the achievement of the objectives of policies and projects. If there are mechanisms for monitoring the effectiveness of the projects many of the social conflicts could be minimized. However, at present, there are no monitoring mechanisms for assessing the achievement of the objectives of policies and projects. Moreover, if there are mechanisms for monitoring the effectiveness of the projects many of the social conflicts could be minimized.

Floodplains are dynamic and are ecologically important. However, floodplains are socially, economically, and culturally important as well. The creation of a greener waterfront will become more resilient for climate change as well as attractive for urban development. Implementation of riverfront development projects or waterfront development projects, etc. depends on the relationships among water, land, community, and spatial planning. This is contradictory to the traditional spatial planning practices which were very often not considered the value of ecological functions. Therefore, this framework has highlighted the significance of maintaining the less rigid boundary between the land and water. It is crucial to have monitoring mechanisms to assess the achievement of the objectives. Risk-based flood

management highlights the adjustment of the spatial development over floodplains' considering overall community goals. Therefore, the flexibility in planning tools helps to reorganize the spatial development while minimizing the adverse impacts on the ecological function of each locality. Moreover, this helps to conserve many of the ecological functions of floodplains and wetlands, etc. However, during the last decades, the wetlands and the floodplains in the Panadura area have been decreased rapidly. This indicates that the ill flexibility of the existing spatial planning process and tools.

5.10.4.4 Local community participation

It was observed in the results of the case study that the local community considers the FRM as a responsibility of the state government. Land reclamation is a common practice in this area and flood occurrence, pollution, etc., have become critical issues. Moreover, many opportunities for sustainable urban development have been lost due to unawareness of these socio-hydrological dynamic interdependencies by the local community. Flood resilience practices offer many positive benefits for local communities, private property developers, etc. Selection and implementation of non-structural measures to minimize the risk of flooding require a shared understanding between local communities and the central government.

The result of the questionnaire survey conducted among local communities in the Panadura area showed that many communities that have recently suffered damage from flooding and they do not consider the FRM as their responsibility. Many local communities refused to leave the flood-prone areas, mainly due to the locational value of Panadura town. In addition, communities that lived for long periods were also reluctant to leave their hometowns. Furthermore, many local communities did not believe their actions could make a difference in reducing flood damage. Therefore, the implementation of flood risk management is determined by understanding the best outcomes for local communities. However, currently, there is no mechanism in place to actively involve local communities in the operationalization of flood risk management. Current decision-making is dominated by experts and top-down

planning processes which restrict local stakeholder involvement in the decision-making processes. There are no opportunities for local stakeholders' involvement in planning-related decisions.

The National Disaster Management Coordination Committee was established in the year 2007 for the improvement of the Hyogo framework. Furthermore, in the year of 2010, the National Disaster Management policy was established to perform as the major governing mechanism for the management of disasters. It includes important concepts such as the participation of local-level authorities, supporting multi-stakeholder approaches, and determining standards for response and relief. The government of Sri Lanka has begun developing the National Disaster Risk Management Plan for 2018-2030. This new plan has highlighted the participation of stakeholders representing various sectors related to disaster as well as development. The developed framework has highlighted the importance of mainstreaming the local community participation in visioning, strategy, and guidelines formation of flood risk management. Table 5.9 shows the recommendations for improving the current practice of FRM.

Table 5.9 Review the existing governance tools of stakeholders of existing decision making of flood risk management

Sub criteria	Recommendation
4.1 Integration of objectives among the land and water institutions at all scales and levels	There is a requirement for tools to manage the interplay between flood risk and urban development. Spatial planning is required to act as an integrated spatial development tool that coordinated multiple objectives of urban development and flood risk management. Moreover, there is the requirement for reconsideration of the role and scope of spatial planning at all levels

Sub criteria	Recommendation
	strengthening the integration of land and water sectors.
4.2 Mechanisms available for Integrated goal setting and catchment-wide approach for decision making	Flood risk management emphasizes managing hazard, exposure, and vulnerability rather than simply controlling hazards. Moreover, resilience to floods underlines the balance between the dynamics of climatic conditions and the land use development objectives of the stakeholders. The cumulative effects of spatial development should be coordinated and reorganized at the landscape level instead of focusing on the local scale. Therefore, there is a need for management tools at the watershed scale to manage the impact of cross-scale feedbacks and cross-sector feedbacks. Currently, the scope of spatial planning is more focused on as a regulatory instrument at a local scale. Therefore, this framework highlights the transformation of existing spatial planning as a proactive instrument that strategically coordinates policies and measures that affect spatial development at the regional and local levels.
4.3 Flexibility of tools	Mechanisms and opportunities are required to upgrade plans and actions with more negotiation and more conceptualization of outcomes. Thereby,

Sub criteria	Recommendation
	spatial planning becomes a more flexible tool for practicing flood resilience.
4.4 Mechanism available / Legitimized tool availability for Empowering local stakeholders in decision making and implementation of FRM system (spatial planning)	Spatial planning is required to be enabled as a tool that provides opportunities for negotiation among local communities to implement flood resilient projects.

5.11 Validation of the Framework

Validation of the developed framework has examined whether the conceptual decision model is acceptable with the real situation. A case study was used to validate the developed decision model. Accordingly, it was questioned and the similarities and the differences between the existing practice and the developed framework were compared. However, many of the respondents (state and local stakeholders) involved in the questionnaire survey were not properly aware of the relation between the decision-making process of flood risk management and the increasing of flood risk. The case study has revealed that the existing practices are more focused on flood management rather than flood risk management. Flood risk assessment is more grounded on quantifying the likelihood of flooding. The Decision-making process of FRM is more focused only on hydrological studies. The safety levels of the flood management structural measures are determined based on the linear rational models.

Application of this framework to the existing situation of Sri Lanka has revealed that the flood management practice is still response-driven. However, many of the stakeholders including the local communities have not yet recognized the importance of risk-based flood management and risk-based land-use planning. Further, the objectives of the flood management projects are not integrated with other associated land use development activities such as urban development, agriculture, etc. Therefore, the sectoral approach remains, and hydrologists have dominated the decision-making. Therefore, the planning process of FRM is not able to integrate the diverse objectives of the multiple stakeholders in the face increasing impact of climate change. Defining FRM practices has not concentrated to improve the adaptive capacity

of urban / regions considering the hydrological and social interactions. Therefore, flood risk has become a chronic issue with the increase of urban development, particularly in the coastal urban areas in the wet zone of Sri Lanka

The analysis of the case study shows the gap between the available policies and tools for the implementation of flood risk management. The outcome of the existing planning and flood risk management practice is required to be questioned. The developed framework is sensitive to the governance context. Therefore, more case studies in various governance contexts are needed to further strengthen the framework for further improvements.

CHAPTER 6 - DISCUSSION

This research is aimed to highlight the significance of risk-based decision-making and the role of spatial planning for flood risk management. This chapter discusses the limitations of the methodology of this developed framework. Further, this chapter presents the applicability of the developed framework referring to the local context and the recommendations for achieving flood resilience in the selected case study area and future research needs.

6.1 Uncertainty of Flood Risk

Flood risk is not a single problem. It is an outcome of a complex system. Rapid urban development and climate change have increased enormous pressures not only on land but also on water and infrastructure systems. Pressures on water or land will have an impact on both as these two systems and are closely related and interactive with each other. However, flood risk management has a strong engineering tradition which was characterized by solving clearly defined problems. As a result, during the earlier period, both flood management and land use planning strategies emphasized that stormwater should be withdrawn from urban areas as soon as possible. In the past, decision models were based on a rationalistic approach and largely failed to manage the flood risk. Those decision models were unable to understand or manage the nonlinear and non-stationary interactions of flood risk.

6.2 Risk-based Flood Management

From the year 2000 onwards, the concepts of complexity, socio-ecological systems, and socio-ecological resilience had enlightened the flood risk characterization, assessment, and management. Socio-ecological system resilience describes the stability of the systems with multiple stable states. Further, it has emphasized that the traditional decision-making processes often failed to take the complex socio-spatial and temporal dynamic nature of the flood risk into account. Characterization,

assessment, and management of uncertainties have become the core concern in the decision-making of flood risk management systems. In recent years, the incorporation of socially and spatially integrated policies and strategies to manage the uncertainties due to socio-spatial and temporal dynamics of flood risk has been emphasized. Moreover, it has been stressed that FRM policies and strategies need to encompass integrated and flexible governance solutions that respond to complex feedback.

Accordingly, the characterization of floodplains as complex adaptive systems and hence understanding the interactions and interdependencies of land and water systems in the decision-making process (for example the dynamic boundaries between land and water) has been underlined. The uncertainty which is incorporated with flood risk management cannot be reduced, and hence the importance of increasing the adaptive capacity of floodplains regions / urban areas and societies should be highlighted. It is acknowledged that future conditions of floodplains could potentially change significantly compared to those that exist today. Therefore, it has been underlined that decision-making should be transformed as a continuous and social process while stressing the need for flexible strategies for FRM. Moreover, flood resilience has been considered as a process and outcome, and the researchers and policymakers have pointed the importance of performance-based planning (process) rather than standards-based master plans. Therefore, socio-ecological system perspectives advocated a comprehensive exploration of hydrological, climatological, ecological, socio-economic, cultural, etc. characteristics of the context that influences the outcomes of the disastrous situations of flood occurrence.

Flood risk exists mainly due to the ill understanding of the interdependencies of stakeholders in the decision-making processes at different spatial scales and the broader socio-development. The difference between understanding the realities in flood-prone areas and what is perceived by those who do not live in flood-prone areas has increased vulnerability and unintended disasters. Traditional flood management has paid ill attention to floods. The notion of a socio-ecological system facilitates the identification of alternative narratives on equilibrium dynamics to maintain the stability of a system. Accordingly, diverse interpretations of land and water system

have been developed. Further, it has been recognized that the changes in land use, spatial pattern, and urban infrastructure layout may influence the changes in both hazards and vulnerabilities. In recent years, flood risk management has been defined as the subjective value judgment of land and water interrelationship by the stakeholders rather than statistical fact.

6.3 Socio-Spatial Integration for Risk-based Flood Management

Multiple interpretations of the land uses of floodplains and alternative flood risk management measures have been discussed due to the dynamic nature of the system. The alternative and diverse narratives required to assess for distribution of cost and benefits among the stakeholders have also been stressed. However, risk-based decision-making has highlighted that evaluation of the risk and benefits of flood risk management strategies should be based on the positive impacts on social wellbeing in long term. Therefore, an amalgamation of multiple objectives of stakeholders has been emphasized in the decision-making of FRM. Flood risk management is a multidimensional concept and the framing of the complex planning process of flood risk management is a challenging task. Moreover, identification and evaluation of objectives, strategies, and guidelines of FRM have become critical tasks.

Practicing flood risk management depends on the stakeholders' understanding of the impacts and envisioning the outcome of land use development over floodplains in the longer term. Thus, the operationalization of flood risk management depends on the assessment of strengths, weaknesses, and opportunities for redistributing the risk and benefits of FRM options among all stakeholders to achieve the net social benefits and achievement of social justice. Framing of multiple interpretations of stakeholders has become a critical task due to the presence of multiple knowledge systems, plural views, assessment criteria of flood risk and, shared dilemmas, etc. Therefore, 'stakeholder integration' and 'spatial integration' have become the fundamental tasks of the decision-making process. Spatial integration means creating an added value or coherent outcome on a space by joining different stakeholders' objectives and the ecosystem functions (Albrechts et al., 1999).

6.4 Operationalization of Flood Risk Management with Spatial Planning

The different spatial claims voiced by different stakeholders at different spatial scales have become a pressing challenge in spatial planning and flood risk management. However, the order of this acceptable spatial organization is determined by both the government and the society (Wiering & Immink, 2006). The relationship between flood risk, the planning process, and the governance context was underlined for the operationalization of flood risk management. The literature review has highlighted that the characteristics of the planning process and governance context are determined by the practice of risk-based decision-making.

In each country, the type of spatial planning system is developed according to the country's legal system and institutional framework. Spatial planning takes place on various levels of government. At the highest administrative levels such as federal or national levels in form of spatial policy or strategic plans specify general aims, objectives, and measures for future land use that are binding for all development authorities. At the district or local authority level, it works in the form of plans specifying development ambitions and required land uses under its jurisdictions. Despite the differences in planning systems the forefront of planning efforts is to manage the social-economic development, well-being of urban dwellers, protect and improve the environment (Polat, 2009).

Besides, the local land use plans, depending on the stage of the development and its political priorities, various other sectoral development plans are implemented at the local level. There is an obvious disparity among these plans and their objectives because they are prepared to aim of different jurisdictions levels or scale; national level, municipal level, or river basin level. For example, flood risk management plans mainly focus on a single objective in the reduction of the susceptibility of the flood rather than a common goal of urban development. The sectoral plans largely ignore the development potentials of floodplain areas. But, the land use plans pursue a common goal with multiple objectives as the provision of public services; natural

resource conservation, economic development, flood risk reduction, etc. Moreover, the ultimate goal of these two plans is to create healthy living conditions for urban dwellers through proper management of activities in space. Therefore, the role of spatial planning techniques is to find the best possible mutual adjustment of space and society (Van den Broeck, 2005).

Practically, integrated management of land use activities is a questionable task, because it will bring social and legal repercussions especially due to the prevailing system of property rights. That is why many water resource management plans have been challenged on various grounds and hampered the implementation processes. The requirement of integration of horizontal and vertical aspects (institutions) in the water resources management has been voiced over decades but, is still not practiced in many places because water agencies possess limited means of legal and political power influencing land uses. On the other hand, land use plans at the local level face many constraints due to limited capacities of financial and technical resources. Therefore, there is a potential for coordination of these two organizations at the local land-use level. Integration between water management and spatial planning at the local level would be able to seek complementary means of financial, technical, legal, and political aspects. Finally, this will lead to sustainable and efficient use of land and water resources.

6.5 Transformation of Spatial Planning for Stakeholder Integration

Until the middle of the 20th century, planning developed exclusively as a subset of architecture. Urban plans focused only on the physical layout and morphological views of the cities. Meanwhile, planners were more concerned with the planning process than plans. There are also many ideologies, concepts, and planning procedures that have been developed. However, the process of developing planning theories and concepts is not linear, and there is an accumulation of theories rather than an evolution of theories and concepts. Although widely accepted principles are closely aligned with community character, little attention was paid to environmental protection, social justice, and local economic development.

Spatial planning underwent a revival with highlighting sustainability in both social and physical terms and giving more sensitivity towards integration of multiple stakeholders and long-term perspectives after the 1990s. Sustainability has guided the spatial planning agenda at the end of the twentieth century. Sustainable development highlights the importance of integration among the economy, society, and natural environment. Further, 'resilience' has also highlighted how urban systems withstand the unexpected circumstances of environments. These ideologies have fuelled the emergence of strategic spatial planning after the 1990s. Therefore after the 1990s spatial planning also highly emphasized integration, flexibility, and learning as key principles of the spatial policy-making process (Hillier, 2011). In recent years, it has been recognized that integrating flood risk management into spatial planning is more important to cope with increasing pressures on floodplains (Andersson, 2012).

However, water in spatial planning has changed towards the creation of an identity for urban development, quality of life, and attractiveness (AL, 2004). As a result, new spatial strategic capacities have developed, focusing on water and water as a vehicle for attractive living and working conditions (Woltjer, 2009). According to the new water culture approach, the key objective of water was as an element of social coherence and social participants. In this context, spatial planning has become a very important legitimized tool because it organizes involved different levels and organizing of space considering the diverse requirement of stakeholders at different scales. Flood risk management and spatial planning domains have begun to share a more similar perspective. In both cases, it is evident that the policy level emerged from the making in the practices, and at both levels (policy-making and practices) flood risk management and spatial planning need to define a common framework to be reciprocally influenced and effective. Moreover, it explains how floodplain land uses are organized to cope up with the uncertainties associated with flood risk.

Integrated Water Resource Management (IWRM) following the Dublin principles highly considers the relationships and interactions among many aspects such as human and natural systems, land and water systems, and key stakeholder agencies and groups,

etc. However, in the real world, the concept will be exceedingly difficult to be made operational (Biswas, 2004). The concept of adaptive water management has been developed as complementary to IWRM. Adaptive management can be defined as a systematic process for continually improving management policies and practices by learning from the outcomes of implemented management strategies (Pahl Wostl, et al, 2005). Recently, there has been a trend to merge these two concepts to address the growing complexity of stressors shaping water management (Engle et al., 2011). However, they have underlined that it is often a challenging task to reconcile such changes with previous and ongoing management transitions. For example, implementation of Water Framework Directives, IWRM, Sendai framework, River Basin Management, etc, is also a challenging task because achieving perfect spatial integration has proved an elusive task in practice. Spatial planning as a collaborative planning tool has become vital when managing the uncertainty incorporated with flood risk management. In this context, the role of spatial planning as a collaborative planning tool has become a very important tool for the operationalization of flood risk management and achieve of resilience.

6.6 Managing of Flood Risk with Spatial Planning

Risk-based decision-making has received significant attention all over the world in recent years. Risk-based decision-making frameworks are required to equally distribute cost and benefits among the multiple stakeholders and favor some interests and expectations at the expense of others. Operationalization of flood risk management is designing floodplain-land uses of floodplains to minimize the flood impact while considering the acceptable level of all stakeholders. However, fixed return period-based flood management is still common despite the significance of risk-based decision-making. Risk-based decision-making has been highly recognized though; the operationalization of flood risk management is still under discussion due to the absence of a framework to define how social and spatial integration can be successfully achieved in practice considering future scenarios. The practice of flood risk management mainly depends on the integration and adaption capacity of the decision-making process as well as the implementation. Though spatial planning has become a

significant tool for the operationalization of flood risk management it presently plays only a minor role.

The assessment of risk and benefits of alternative management options and the involvement of the stakeholders in the planning process have a debatable issue. Defining flood risk, assessment of flood risk, defining, defining objectives, strategies, and guidelines, and evaluating the impact of alternative flood risk management options are central parts of the risk-based decision-making process, which is generally described with the interactions of stakeholders. Management of uncertainty is embedded in the flood risk management decision. However, though the importance of this process has been stressed, the implementation is only partially successful, and the application of the concept of socio-ecological resilience in flood risk management practices is still at the conceptual stage. In recent years, consideration of factors in the planning process of flood risk management has been questioned by policymakers as well as practitioners.

However, conflicts may arise due to disagreements between stakeholders regarding, who has the right to use the floodplain, the right to participate in the process, consideration factors for defining objectives, and who has to suffer the impact of using the floodplain for urban development. Moreover, who decides and how it is decided are the two main concerns in the decision-making process. The theory of flood risk management has been developed during past decades but the evaluation of flood risk management objectives, strategies, and guidelines are critical due to the absence of a common framework to structure the complexity and uncertainty. Integration of different knowledge of stakeholders or the combination of technical views together with social and political views in flood risk assessment and management has been questionable. At present, policymakers, many local officials, politicians, and the community often give a low priority to spatial planning as a strategy to achieve flood resilience. Public unresponsiveness to natural disasters is another major obstruction to achieving flood resilience. Further, the cost of mitigation measures is immediate, but the benefits are long-term and uncertain and cannot occur during the term of elected

officials. Moreover, the physical manifestations of increased public security are not visible. As a result, flood risk management has a weak public constituency.

6.7 Framing of Complex Decision Making with AHP

Policy, strategy, and guidelines of flood risk management are determined by the conceptualization of flood risk and assessment of the outcomes of diverse options and establishment of negotiations among the stakeholders. The results of the literature review highlight a need for a solution model for structuring the complexity of flood risk management and managing the uncertainty of the multiple objectives of stakeholders. The Analytic Hierarchy Process (AHP) is a multi-criteria technique that can be applied for the structuring of complex decision-making problems involving multiple stakeholders, multiple objectives, and multiple scenarios. The AHP can be used in making decisions that contain multiple criteria that may have interactions and correlations among different objectives. The analytic hierarchy process (AHP) is a Multi-Criteria Decision-Making (MCDM) approach that is applied to solve complex problems that can have multiple objectives and potentially conflicting objectives that affect decision-making. AHP is considered an influential tool for complex problems that involve interrelated objectives. The AHP allows a complex problem situation to be “systematically broken down into individual parts, the relationships of which can then be analyzed”.

The AHP technique provides a comprehensive framework for structuring a decision problem, representing and quantifying decision criteria, relate to overall goals. Moreover, AHP guides decision-makers through a series of pairwise comparative judgments to express the relative impact of items in the hierarchy. These judgments are then converted into numbers. AHP uses a pair-wise comparison of the criteria importance concerning the goal and it assumes interdependence of the criteria. Therefore, the pair-wise comparison allows finding the relative weight of the criteria concerning the main goal. AHP is considered an influential tool for complex problems that involve interrelated objectives. AHP does not provide an “exact” solution, but this technique allows those involved to interactively explore the option that best fits their

understanding of the problem and the requirements of its solution. Accordingly, solutions can be proposed to combine individual results and develop consensus frameworks. AHP has been recorded as a powerful tool for decision-making in flood risk management.

Integrated Delphi technique with AHP has been used to structure the decision-making process for the operationalization of flood risk management. Delphi techniques have been used as a technique for gathering expert opinions and reaching consensus. The Delphi technique is a systematic and interactive method that relies on a panel of independent experts that can be used to identify the fundamental elements of the phenomenon. Literature has highlighted that the Delphi technique is useful for framework building when human perception is subjective and there is incomplete knowledge about a problem situation. Accordingly, the Delphi method is suitable to explore new concepts within and outside of the system of Knowledge. In the initial phase of the research, open discussions were held with the experts to describe the current status of FRM, the importance of risk-based decision making, and the limitations of existing flood risk management practices. Forty-two experts in flood risk management have been selected for a detailed study. Hence, this research used qualitative and quantitative techniques for data collection and analysis.

6.8 Conceptualization and Calibration of the Framework

The conceptual framework has been developed following an extensive literature search. The criteria and sub-criteria of the conceptual framework and calibration of the framework have been done based on the depth literature review. The conceptual framework has been redefined and re-calibrated with experts who have real ground experience in flood risk management. The Integrated Delphi method with AHP has been adopted to calibrate the conceptual framework. The Integrated Delphi method with AHP was adopted to provide a logical backbone for the model. Delphi method is a structured process, which obtains the opinions among experts through an iterative procedure of multiple questionnaires. In this study, three rounds of questionnaires were conducted with professionals during the two phases of the research such as redefining

the structure of the framework and the pairwise comparison of the criteria and the sub-criteria. Delphi technique collects data with multiple iterations to reach a consensus among experts. Delphi technique has been integrated with AHP to facilitate the aggregating of experts' judgments and hence it could increase the efficiency of the decision making. The calibrated decision-making framework has been used to evaluate the case study. The developed decision-making framework was demonstrated through a case study and evaluate the existing decision-making framework for operationalization of flood risk management.

6.9 Validation of the Framework

The key issue in the decision-making of flood risk management is the evaluation of management alternatives to achieve flood resilience. The Decision-making framework contains simplifications and abstractions which represent the complex real-world decision-making process of flood risk management. The developed framework is useful to develop flood risk management policies strategies and guidelines at regional, provincial, and city levels. For example, it can assess whether the results of the developed framework are sufficiently accurate to make confident decisions. Validation has been defined as "the process" which ensures that the defined process is achieved or whether the proposed framework and its concepts make sense not only to the researcher but also to other practitioners. Validation is a process of comparing correspondence between developed model outputs and real-world system behavior. It involves the use of an experimental design to demonstrate that the framework can produce acceptable results within its intended use. Further, it establishes method performance values that are appropriate for the intended use. Validation provides feedback to the researcher for further development.

Validation of the decision model aims to show how the proposed model can be used to facilitate decision-making regarding the implementation of the theoretical framework of flood risk management. Validation of a new decision-making framework is a matter of social conversation. The change to a new paradigm cannot be based on strictly logical reasons. Moreover, relativist validation is in contrast to

logical empiricist validation and is a communicative process. The establishment of new knowledge is depended on social, cultural, and historical, etc characteristics. Therefore, it is an ongoing process of building confidence in the usefulness of the new knowledge concerning a purpose. Constructivists believe that knowledge is a flow and socially constructing and hence highlight the pluralistic, sensitive to local context and situation perspectives for confirmation of new policy frames. Wider participation of stakeholders (including those who know and experience the system well) in the validation is necessary when deciding the benchmark solutions (Molinari et al., 2019).

6.10 Selection of Case Study for Validation

The developed framework has been tested with a case study to demonstrate the uses of the framework. The selected study area was the Panadura urban area which is downstream of Bolgoda Basin. Panadura urban area is experiencing increasing flood risk due to rapid urban development in recent years. It has reviewed the flood risk management measures and the perceptions of the stakeholders on FRM. A small urban canal named Karapen Ela has been selected to evaluate the existing decision-making process and the consideration factors for the selection of the flood risk management options. Moreover, the flood risk management measures of Karepen Ela have been selected for detailed analysis. The information was collected from the past project reports, questionnaire surveys with stakeholders, focus group discussions, and field observations. It has used the stakeholders' knowledge to check the reliability of the developed decision-making framework. Stakeholders were invited to talk freely on the existing practices of flood risk management, their discourse and communication, networks, the content of the developed framework, and the challenges and the opportunities for implementation of the developed framework. Finally, the interviews were recorded and analyzed by the researcher based on the developed framework. This case study shows how the proposed decision-making model can be used to facilitate the decision-making process for achieving flood resilience when multiple criteria and alternative management measures are presented.

Many of the participants in the validation process highlighted the challenges for the achievement of the expected outcome of the model and the operationalization of flood risk management. However, the stakeholders of the selected case study area did not actively respond to this transformation. Further, they underlined the challenges for the implementation of the developed new framework.

The developed framework is focused on managing uncertainty incorporated with flood risk in the selection, evaluation, and implementation of flood risk management measures. According to the developed framework, flood-risk management should be viewed as a collective and public responsibility rather than a sectoral or individual responsibility. Therefore, the developed framework is sensitive to the governance context of decision-making. Statutory requirements are needed to provide a robust foundation for the decision-making process, enabling local stakeholders to implement FRM. However, at present, the spatial planning process and tools are not a recognized opportunity window for managing flood risk with spatial planning.

Historically, FRM was the sole responsibility of the central government. Understanding of flood risk phenomenon in the planning process and fitting it with governance context are the crucial factors that determine the operationalization of FRM. Therefore, central government statutory directions are important enabling local stakeholders to practice FRM. Discourses and management tools of water management and spatial planning are needed to highlight the interdependency of Flood risk and urban development. Validation highlights the satisfying level of achieving the intended use of the decision-making framework. Validation is a process and depends on the information provides by the type of stakeholders. Moreover, the local level stakeholders were not very knowledgeable about flood risk and the need for strategic interventions for flood risk management

Determination of the credibility of the developed framework can be achieved by the lens of the researcher as well as stakeholders of the project. The potential for researcher bias might be reduced by actively involving the research participant in checking and confirming the results.

6.11 Applicability of the Developed Framework for Operationalization of Flood Risk Management

The developed framework supports the implementation of FRM. It highlights the factors to be considered in the planning process as well as characteristics of the planning context to achieve flood resilience. Therefore, it indicates the gaps of the existing flood management practices and guides to redesign the FRM system. Socio-spatial integration has become a crucial aspect for operationalizing flood risk management which is governed through the planning process as well as the governance mechanism of any context. Integration of the stakeholders is governed by the governance mechanism of each context. The research has concluded that the consideration factors in the planning process as well as the institutional configuration including the discourses and participatory tools which facilitate the operationalization of flood risk management. Therefore, the operationalization of the flood risk management framework can be structured into four main criteria. These criteria are, ‘the conceptualization of FRM system’ ‘assessment of flood risk in the decision-making process, ‘knowledge base of the dominant discourses of stakeholders’, and ‘the mechanism of power and the resource exercised in the governance context’.

‘Conceptualization’ of Flood Risk Management (FRM) means the decision-makers have recognized the impact of flood risk in long term and have identified the stakeholders and their objectives in the decision-making process. The sub-criteria of conceptualization underline characterization of flood risk following the holistic approach including the non-linear interactions. Accordingly, the assessment of flood risk and the evaluation of alternative management measures are based on the multiple objectives of these stakeholders at multiple scales as well as multiple scenarios and focusing on long-term social wellbeing. Therefore, the conceptualization of the planning process means that the stakeholders considered that flood risk is a socially constructed phenomenon and hence flood management to be a continuous, integrated, socially analyzed, and socially evaluated process. Moreover, the scope of the decision-making is focused to manage uncertainty. The sub-criteria are characterization complexity of flood risk, characterization scale sensitivity of flood risk,

characterization of the inherent uncertainty of flood risk and characterization of flood risk assessment as a social assessment, and social integration process. This sub-criteria is important to identify the composition of stakeholders in the planning process and to evaluate the multiple objectives in the planning process. Conceptualization describes the planning process of flood risk management system includes integrated and adaptive objectives, strategies, guidelines, and lead to the sustainable development of the community. Conceptualization describes the common objective (outcome) considering the complex spatial needs of stakeholders and overall social benefits.

Assessment of the planning process is required to be more focused to increase the adaptive capacity of society/place by managing the uncertainties of flood risk. 'Place-based assessment' means to explore the potentials for increasing the adaptive capacity of the region/ urban areas by assessing the social, spatial, and temporal interdependencies of the stakeholders over floodplains. Accordingly, flood risk assessment is more focused on the restoration and reinforcing ecological functions, feedbacks, and structure of the floodplains, wetlands, waterways. Therefore, the assessment process aims to examine the transformation mechanism of floodplains as a strategic element of urban development.

Further, assessment of the planning process means the understanding of the uncontrollable nature of flood occurrence. Therefore, the role of the planning process is the identification of flood risk management measures to increase the adaptive capacities in the face of diverse climatic scenarios. In addition, maintaining regional hydrological balance and decision making based on the socio-cultural needs of the particular society are also other two sub-criteria to be considered in the assessment process. The developed framework has highlighted that assessment of diverse flood risk management options is necessary to base on the contribution of restoration of ecological functions/structure, processes, and feedbacks of floodplains, cope up with diverse climate scenarios, maintain regional and local hydrological balance, and fulfill of location-specific social demands to achieve flood resilience.

Flood risk management can be practiced by creating a synergy between multiple objectives of multiple stakeholders at different scales while considering the integration

of the knowledge and the interactions of stakeholders. Stakeholders have been required to recognize the significance of integrated and adaptive goals and strategies for FRM as well as the consideration of the social and spatial independencies of flood risk for the long-term wellbeing of the society. Therefore, the Knowledge system of the stakeholders has been recognized to be of utmost importance in the participatory decision-making and implementation process in the operationalization of flood risk management. The sub-criteria are recognition of social learning, recognition of multilevel governance, recognition of flexibility in decisions, and recognition of active local community participation in decision making and implementation.

‘Participatory mechanism’ means the availability of collaborative tools to share information, knowledge, resources, and power among the stakeholders for the integration of social-spatial and temporal interactions of the flood risk. Sub criteria are tools for consensus-building among the land and water stakeholders, collaboration among stakeholders at multiple levels and sectors, tools for performance-based decision making, and tools for local community participation. Moreover, these sub-criteria describe the requirement and the characteristics of available tools for achieving flood resilience. It has emphasized the capacity of the spatial planning tool for stakeholder integration. The calibration of the framework was carried out using the integrated Delphi technology with AHP. The AHP technique was integrated into the Delphi method to achieve consensus among the experts. In addition, several rounds of discussions with experts were held to reach a consensus among all on the relative importance of the selection of the criteria, the organization of the criteria, the prioritization of the criteria, and the sub-criteria of the framework.

6.12 Gaps of Existing Practices of FRM

Structural measures are often used to manage the existing flood risk in Sri Lanka. Future flood risk can be mitigated by land-use planning instruments such as zoning, building and development controls, etc. for example, floodplains, wetlands, etc, should not approve for incompatible development, such as new housing areas and industry, but may include green and recreational areas. However, increasing the demands of the

urban development many of the wetlands are reclaimed for new housing and industrial, etc development in Colombo and its suburbs. As a result, downstream of the Bolgoda basin area particularly Panadura urban area has experienced increases in flood damage during recent years.

The framework highlights that the role of the planning process is required to explore the means of balancing the costs and benefits of the floodplain land-use development. The research has concluded that the role of the planning process is to provide opportunities for synthesizing the trade-offs considering the multiple objectives of stakeholders being location-specific. However, the case study revealed that the existing practices are more focused on flood management rather than flood risk management. Hence, the still fixed return period-based infrastructural measures are common in the Sri Lankan context. Moreover, the sectoral approach for risk management is dominated by the decision-making process. Flood risk has been increasing in Panadura and rapidly urbanizing areas during recent years and these situations bring evidence of the absence of integrated decision making. However, many of the stakeholders including the local communities have not yet recognized the importance of risk-based flood management. Present flood risk management systems include strong top-down decision-making practices, where experts from public administration design new flood risk management plans and analyze strategies in terms of their effectiveness, and arrive at the economically optimal level of safety. Therefore, the objectives of present flood management policies and the practices are not integrated with other related spatial development activities such as urban development, housing, agriculture, industrial development, coast conservation, etc.

The presence of rivers, streams, floodplains, and wetlands in urban areas brings extraordinary value to the landscape and hence identity to the urban development. However, floodplains have become hazardous zones in the Sri Lankan context due to an ill understanding of the inter-relationship between the flood risk and the social and physical systems. Moreover, the case study shows that the planning process has neglected the strengths and potentials of the existing wetlands and waterways in urban development. The main challenge for practicing flood resilience or water-based urban

development in the Sri Lankan context is the lack of knowledge on the interdependency of water, urban development, and flood risk management. Moreover, the weak monitoring and weak assessment of the achievement of the outcomes of the existing policies and regulations have led to this situation. The case study has highlighted that spatial planning does not play a significant role in flood risk management in the current practice. The case study result has highlighted there is ill confidence and less awareness of outcomes, of the risk-based flood risk management among many of the stakeholders. Further, it has been emphasized that there is no opportunity or mechanism to practice flood resilience projects at the local level. However, it is necessary to validate the framework with more case studies for strengthening the recommendations of this research. Many of the stakeholders involved in the validation were unaware of the differences between the outcomes of flood management and flood risk management. In addition, they have hardly analyzed the limitations of the existing practices of FRM. It would be better to discuss the results and findings using the framework at the validation stage with the expert used in the calibration phase.

6.13 Recommendations for Sustainable Management of Flood Risk

Flood risk is required to be framed as a socially constructed problem rather than a technical problem. Decision-making of the current flood risk management system is required to address the complexity of the flood risk to increase flood resilience. It is necessary to identify the objectives of all the stakeholders at each spatial level particularly settlements at downstream of the Bolgoda basin. Secondly understanding the interdependencies of each stakeholder at different sectors and the spatial level considering the long term is important. Therefore, the flood risk management objective is required to be defined based on the impact of nonlinear and non-stationary interaction at the various stakeholders' levels and the spatial levels. Flood risk management objectives are required to transform towards the reduction of vulnerability and hence increase flood resilience of place/society rather than to control flood hazards. Therefore, it is necessary to consider the potential adverse consequences of flooding on human health, the environment, cultural heritage, and economic

activity. Moreover, flood risk management strategies and implementations should be addressed to the most vulnerable people, and the objectives need to be focused to increase the overall benefits of the society. Flood risk management objectives are required to transform towards reduction of potential adverse consequences of flooding on human health, the environment, cultural heritage, and economic activity rather than control flood hazards.

Flood risk assessment is required to focus on deciding the acceptable level of risk for the stakeholders rather than based on the numerical number derived from the damage assessment. Moreover, it is required to understand that the significance of land-use alteration of floodplains in the assessment process. In addition, this research recommends evaluating the performance of previously implemented flood management projects and the floodplain land-use planning regulations in the risk assessment. Flood risk assessment is required to explore the ways to increase the adaptive capacity of each location along the floodplain with diverse scenarios of climatic change. Accordingly, it is important to strengthen the role of spatial planning measures to evaluate and prioritize the flood risk management options to strengthen the ecological functions of the floodplain. In addition, it is required to increase the hydrological connectivity and the social-spatial demands (housing) of each location. Therefore, it is necessary to assess the flood risk following a place-based, assessment process while focusing on the long-term social impacts.

Framing of flood risk management through the lens of multiple objectives is the core factor for managing the uncertainties which incorporate flood risk management. The discourse of the stakeholders is required to highlight the importance of social learning, multiple governances, flexible governance as well as the local stakeholders' participation in the decision among and the implementation. Moreover, the existing institutionalized framework needs to transform stakeholder interactions towards decision-making for attaining a shared set of objectives. Multi-criteria consideration place-based assessment in decision making and implementation depends on the Stakeholder interaction, resource, and power distribution as a baseline condition of the institutional framework. The presence of the participatory tools reinforces joint actions

and legitimizes the institutional arrangement. Therefore there is a timely requirement to develop a tool for the integration of land and water, territorial scale, multisector and local community.

Flood risk, which is defined using damage assessment and flood risk management is under sectoral interventions. Increasing flood risk indicates the gap between water management and spatial planning. Flood risk management is the domain of state institutions and under the direction of technical experts and is still the territory of hydrologists. The Sri Lanka Land Development Corporation is responsible for the management of urban drainage. There is a high expectation of structural flood risk management measures by the public community. Urban Development Authority (UDA) defines the floodplains in urban areas following the given guidelines by technical experts. Low-lying land reclamation is a common practice and indicates the complex interest between local communities and government agencies. Narrow framing of flood risk could not recognize the socio-spatial-temporal dynamics of flood risk. As a result, the current practices do not recognize the stakeholders to define the objectives of the system. Current spatial planning practice is not able to reduce exposure and vulnerability to flooding risk and the factors that increase flood risk in the case-study area. As a result, the risk of flood risk is not evenly distributed among all stakeholders involved. There is ill coordination among relevant agencies such as local authority, Urban Development Authority, Sri Lanka Land Development Corporation, etc.

A case study demonstrates that the decision-making process has a weak ability to balance economic interests with long-term flood risk management objectives. The evaluation of the flood risk management options does not consider the possible outcomes in the long term and mainly considered the short-term economic benefits. The risk-based flood management system is focused to provide a means to lower the flood damage while harmonizing the land use activities with floodplain ecological functions. This case study indicates that flood risk management practices are more localized, reactive, and isolated rather than being proactive and hydrologically integrated. It further highlights that the decision-making of flood risk management is

more focused on controlling flood hazards rather than management of flood vulnerability. The Flood Ordinance No. 22 of 1955 does not highlight non-structural flood risk management measures for risk management. The existing policy framework does not facilitate the cooperatively sharing of responsibilities among the stakeholders including the state agencies to trade off the risk and the benefit. At present, state departments and agencies often act independently in the decision-making process of flood risk management. Therefore, flood risk management is mainly governed by a centralized system. The role of spatial planning for the operation of flood risk management is also not legitimized at local and well as territorial scales.

There are no interactive mechanisms, tools, etc for spatial integration among stakeholders to increase socio-ecological functions of regions, and local areas. There is no guideline to urban land use transformation and managing of the long-term impacts on the water resources at regional and local scales. As a result, water-related issues such as flooding are not among the key priorities of spatial planning practices. Responsibility sharing, power-sharing, resource sharing related to flood risk reduction are not clear even at the national level. In the current practice, spatial planning and flood risk management function as two separate domains.

The research recommends transforming flood management towards flood risk management. In addition, it highlights the weakness of the existing spatial planning policy and strategy-making process in the face of increasing flood risk. This developed framework can be used as a guide to the planning process to practice FRM and achieve flood resilience. The established framework can be used to provide recommendations for the operationalization of the flood risk management of any given context and the provide recommendation for further improvement. However, the developed framework is more sensitive to the governance structure (discourse and participatory tools) of the planning context, therefore, extensive research for further improvement of the framework applied in the diverse governance context is recommended.

The results of the questionnaire survey conducted for validation have highlighted, institutional fragmentation and the absence of the understanding of the

interdependency between land use development and flood risk management. Further, the discussion has highlighted the effects of the fragmented approach of decision making which does not recognize the interdependency between coastal management, fisheries, urban development, agriculture, biodiversity conservation, domestic wastewater management, and stormwater management. It has further highlighted the incompatibility between ecosystem management and Institutional arrangement. In addition, there is no cooperation between the different levels of spatial and water management policymakers. Accordingly, it has been underlined the requirement of the watershed as the unit for decision making and hence the development of the policies and the strategies to cope up with the climate change stresses.

The opportunities of using the floodplains, wetlands for urban development are not highlighted due to the inadequateness of spatial policy and strategy-making process and communication tools. At present practice there is no cooperation between spatial planning and flood risk management and flood is not a critical factor that determines the spatial development policies, strategies, and guidelines. Moreover, the watershed provides multiple ecological and hydrological functions. Risk-based decision-making highlights the green infrastructure for flood management which is common and attracted attention from local governments in many parts of the world. However, at present all the decision-makers as well as local stakeholders, politicians, etc are not considered important in the value of ecosystem functions and the services in the policy and strategy making at the spatial scales. It is better to develop strategic projects for incremental change and then new guidelines would be implemented slowly over some time during several phases. Therefore, the existing governance structure challenges the practice of flood risk management.

6.14 Future Research Needs

This research has highlighted the transformation of FRM from a reductionist approach towards a holistic approach for flood risk management. Therefore new researches are needed to study and the dynamic complexity of flood risk. Flood risk management requires spatially as well as socially integrated solutions. Therefore, integrated and flexible governance mechanisms are needed at the regional as well as local level. In this context, the most important aspect of increasing flood resilience is to increase the level of understanding of the interdependencies of each of the stakeholders at multiple spatial scales and the establishment of negotiations. Future researches are required to question 1) how stakeholders are being selected, 2) how to establish shared visions with diverse stakeholders to create resilient urban / regions, 3) how to make the trade-off among different spatial claims over floodplains, 4) designing of social learning networks, and 5) how to develop the participatory tools to share the resources and 6) establish negotiations to increase the adaptive capacity of urban areas and regions in the face of climate change and urban development.

CHAPTER 7 - CONCLUSIONS

Characterization of the inherent uncertainties that are incorporated with flood risk has highlighted the need for the transformation of flood management towards risk-based decision making. The planning process of flood risk management has transformed into an adaptive process that is based on the co-production of stakeholders' objectives rather than a process based on fixing an end state. Further, collective decision-making with a common objective and the negotiation of stakeholders has become an important factor in risk-based flood management. In these circumstances, spatial planning has become an important decision-making tool for the operationalization of flood risk management.

The planning process of flood risk management is unstructured and hence characterization of flood risk, flood risk assessment, selection of flood risk management options, and evaluation of flood risk management objectives, strategies, guidelines, and outcomes are still questionable. The absence of a common decision-making framework for all stakeholders has challenged the operation of flood risk management. The Analytic Hierarchy Process (AHP) has been used while integrated with the Delphi technique to identify and calibrate the criteria and the sub-criteria of the framework.

This research has concluded a methodological framework that includes a set of structured criteria and sub-criteria to guide and practice flood risk management. The methodological framework includes four main criteria and sixteen sub-criteria to frame the planning process and hence evaluate the alternative options of flood risk management. This developed framework will help to structure the complexity of flood risk management decision-making and provide recommendations. This developed framework can be used as a guide to the planning process to define the objectives and selections of strategies to achieve flood resilience. The established framework can be used to provide recommendations for the operationalization of the flood risk

management of any given context and also provide recommendations for further improvement.

The main criteria which determine the operationalization of FRM are the conceptualization of FRM in the planning process, consideration factors in the assessment process, the discourses of the stakeholders, and available participatory tools. Conceptualization highlights the factors that should be considered for the identification of stakeholders who are required to participate in the design of an acceptable level of risk. The assessment of the planning process highlights the consideration of factors for the selection of the flood risk management policies, strategies, and guidelines. Maintenance of ecological functions, place stability with a diverse range of climatic situations, regional hydrological balance, and local spatial demand are the sub-criteria that should be considered in the assessment of the planning process.

Discourse highlights the key policy principles of the stakeholders. Therefore, policies of the governance structure are required to recognize the importance of social learning, multilevel governance, flexibility in planning and implementation, and local community participation. The participatory tool describes the characteristics of the resource and power-sharing tools which determine the operation of FRM. It is necessary to have legitimized tools for land and water integration, watershed-based integration, flexible tool, and the ensuring of local community participation for practicing FRM. Consideration of criteria in the planning process is relatively more important to determine risk-based decision-making.

This research has concluded that the evaluation process based on contributing towards the restoration of ecological function, structure, feedbacks, etc., is the more important sub-criteria in determining the implementation of risk-based flood management. Prioritizing the ecological functions of floodplains in the assessment of the planning process contributes significantly to the practice of FRM compared to all sub-criteria.

The application of the framework further emphasizes the limitations of the existing decision-making of flood risk management in the Sri Lankan context. Floods cannot be managed in isolation and with a single solution because the potential flood impacts have become complicated by interlinked political, socio-economic, climatic, and environmental change. Flood risk management which is mainly focused on hazard control is unsustainable because due to the socio- hydrological interdependencies which are specific to each location. Therefore, the scope of the existing planning process is recommended to be transformed towards the framing of a common objective of all stakeholders in the FRM and identification of flood risk management options considering the range of economic and environmental performances.

Policies and institutional governance structures are also recommended to be transformed to facilitate risk-based decision-making. Hence, the spatial planning tools have to be reorganized as an adaptive and collaborative planning process that facilitates stakeholder integration in flood risk management. Transforming of conceptualization and the assessment of the planning process of the present practice of spatial planning to explore the opportunities of water-sensitive spatial planning and achieve flood resilience and sustainable urban development is suggested.

Therefore, this framework can be used to integrate flood risk management and spatial planning in the current practice. This established framework can be used for the evaluation of existing flood risk management practices and to identify recommendations for further improvement. In addition, the established framework helps to identify flood risk management objectives, strategies, tools, and guidelines in a given context. Further, this framework highlights the gap between flood risk management and spatial planning.

REFERENCES

- Adger, W. N. (2005). Successful adaptation to climate change across scales. . *Global environmental change*, 15(2), 77-86.
- Aerts, J. C. (2008). Dealing with uncertainty in flood management through diversification. . *Ecology and Society*, 13(1).
- Aerts, J. C. (2013). Cost estimates for flood resilience and protection strategies in New York City. . *Annals of the New York Academy of Sciences*, 1294(1), 1-104.
- Ahmed, F. K. (2018). Integrated adaptation tipping points (IATPs) for urban flood resilience. . *Environment and Urbanization*, 30(2), 575-596.
- Akamani, K. (2016). Adaptive water governance: Integrating the human dimensions into water resource governance. . *Journal of Contemporary Water Research & Education*, 158(1), 2-18.
- Akamani, K. H. (2016). Managing wicked environmental problems as complex social-ecological systems: The promise of adaptive governance. . In *Landscape dynamics, soils and hydrological processes in varied climates* (pp. 7.
- Alexander, M. P. (2016). A framework for evaluating flood risk governance. *Environmental Science & Policy*. *Environmental Science & Policy*, 38-47.
- Anderson, M. B. (1995). Vulnerability to disaster and sustainable development: A general framework for assessing vulnerability. Disaster Prevention for Sustainable Development. *Economic and Policy Issues*.
- Apel, H. A. (2009). Flood risk analyses—how detailed do we need to be?. . *Natural Hazards*, 49(1), 79-98.
- Apel, H. M. (2008). Quantification of uncertainties in flood risk assessments. *International Journal of River Basin Management*, 6(2), 149-162.
- Apel, H., Aronica, G. T., Kreibich, H., & Thieken, A. H. (2009). Flood risk analyses—how detailed do we need to be? *Natural Hazards*, 49(1), 79-98.
- AragOn-Durand, F. D. (2009). Unpacking the social construction of natural disaster through policy discourses and institutional responses in Mexico: the case of Chalco Valley's floods, State of Mexico.

- Armitage, D. D. (2012). Environmental governance and its implications for conservation practice. *Conservation Letters*, 5(4), 245-255.
- Armitage, D. M. (2008). Adaptive co-management and the paradox of learning. Global environmental change. *Global environmental change*, 18(1), 86-98.
- Armitage, D. R.-H. (2009). Armitage, D. R., Plummer, R., Berkes, F., Arthur, R. I., Charles, A. T., Davidson-Hunt, I. J., Adaptive co - management for social-ecological complexity. *Frontiers in Ecology and the Environment*, 7(2), 95-102.
- ARMONIA. (2007). *Assessing and mapping multiple risks for spatial planning—approaches, methodologies, and tools in Europe*. European Union.
- Baby, S. (2013). AHP modeling for multicriteria decision-making and to optimize strategies for protecting coastal landscape resources. *International Journal of Innovation. Management and Technology*, 4(2), 218.
- Bailey, R. G. (2009). The scale of ecosystem units. In *Ecosystem Geography*. (pp. pp. 25-28). New York, NY: Springer.
- Baldassarre, G. D., Viglione, A., Carr, G., Kuil, L., Salinas, J. L., & Blöschl, G. (2013). Socio-hydrology: conceptualizing human-flood interactions. *Hydrology and Earth System Sciences*, 17(8), 3295-3303.
- Balica, S. F. (2009). Flood vulnerability indices at varying spatial scales. *Water science and technology*, 60(10), 2571-2580.
- Barendrecht, M. H. (2017). A dynamic framework for flood risk. *Water Security*, 3-11.
- Baroang, K. M. (2009). Identifying uncertainty and defining risk in the context of the WWDR-4. Perugia, Italy.
- Basco-Carrera, L. W. (2017). Collaborative modeling or participatory modeling? A framework for water resources management. . *Environmental Modelling & Software*, 91, 95-110.
- Becker, G. H. (2015). Becker, G., Huitema, D., & Prescriptions for adaptive co-management: the case of flood management in the German Rhine basin. *Ecology and Society* 20(3):.

- Begg, C. W. (2015). Localism and flood risk management in England: the Environment and Planning C: Government and Policy, 33(4), 685-702.
- Benson, D. L. (2016). Evaluating social learning in England flood risk management: an 'individual-community interaction perspective. *Environmental Science & Policy*, 55, 326-334.
- Berke, P. R. (1998). Reducing natural hazard risks through state growth management. . *Journal of the American Planning Association*, 64(1), 76-87.
- Berke, P. R. (2000). Are we planning for sustainable development? An evaluation of 30 comprehensive plans. . *Journal of the American planning association*, 66(1), 21-33.
- Berke, P. R. (2014). Impacts of federal and state hazard mitigation policies on local land use policy. *Journal of Planning Education and Research*, 60-76.
- Berkes, F. &. (1998). Linking social and ecological systems for resilience and sustainability.
- Berkes, F. (2004). Rethinking community - based conservation. . *Conservation biology*, 18(3), 621-630.
- Bhagat, N. (2017). Flood Frequency Analysis Using Gumbel's Distribution Method: A Case Study of Lower Mahi Basin, India. . *Journal of Water Resources and Ocean Science*, 6(4), 51-54.
- Biggs, R. S. (2012). Toward principles for enhancing the resilience of ecosystem services. *Annual review of environment and resources*, 37, 421-448.
- Birkholz, S., Muro, M., Jeffrey, P., & Smith, H. M. . (2014). Rethinking the relationship between flood risk perception and flood management. *Science of the total environment*, 12-20.
- Birkland, T. A. (2003). River ecology and flood hazard mitigation. *Natural Hazards Review*, 4(1), 46-54.
- Birkmann, J. (2006). Measuring vulnerability to promote disaster-resilient societies: conceptual frameworks and definitions. Measuring vulnerability to natural hazards. *Towards disaster resilient societies*, 1, 9-54.
- Biswas, A. K. (2008). Integrated water resources management: is it working?. . *International Journal of Water Resources Development*, 24(1), 5-22.

- Blaikie, P., Cannon, T., Davis, I., & Wisner, B. otros. (1994). Natural Hazards, People's Vulnerability, and Disasters. In *At Risk*.
- Bodde, M. V. (2018) Strategies for dealing with uncertainties in strategic environmental assessment: An analytical framework illustrated with case studies from The Netherlands. Strategies for dealing with uncertainties in strategic environmental assessment Sustainability.
- Bogardi, J., & Birkmann, J. (2004). Vulnerability assessment: the first step towards sustainable risk reduction. . In *Disaster and Society From Hazard Assessment to Risk Reduction*, (pp. 75-82). Logos Verlag Berlin, Berlin, 1.
- Bohle, H. G. (1994). Climate change and social vulnerability: toward a sociology and geography of food insecurity. *Global environmental change*, 4(1), 37-48.
- Böhm, H. R. (2004). Implementation of flood risk management measures into spatial plans and policies. *River research and applications*, 20(3), 255-267.
- Bouwma, I. S. (2018). Adoption of the ecosystem services concept in EU policies. *Ecosystem Services*, 29, 213-222.
- Brooks, G. R. (2003). Geoscientific Insights into Red River Flood Hazards in Manitoba. Geological Survey of Canada.
- Brouwer, R. &. (2004). Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. . *Ecological economics*, 50(1-2), 1-21.
- Brouwer, R. &. (2004). Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. . *Ecological economics*, 50(1-2), 1-21.
- Brugnach, M. a. (2012). Ambiguity: the challenge of knowing and deciding together. . *Environmental science & policy*, 15(1)., pp.60-71.1.
- Brugnach, M. D. (2011). More is not always better: coping with ambiguity in natural resources management. . *Journal of environmental management*, 92(10), 78-8
- Brugnach, M., Dewulf, A., Pahl-Wostl, C., & Taillieu, T. (2008). Toward a relational concept of uncertainty: about knowing too little, knowing too differently, and accepting not to know. *Ecology and society*.
- Buchecker, M. S. (2013). The role of risk perception in making flood risk management more effective. *Natural Hazards & Earth System Sciences*.

- Burby, R. a. (1981). Coping with floods: the land use management paradox. *Burby, R.J. and French, S.P., 1981. Coping with floods: journal of the American Planning Association, 47(3), pp.289-300.*
- Burby, R. J. (2000). Land use planning for flood hazard reduction: the United States experience. In *Floods, 2* (pp. 6-18).
- Burby, R. J. (1998). *Cooperating with nature: Confronting natural hazards with land-use planning for sustainable communities*. Joseph Henry Press.
- Burby, R. J. (2003). Making plans that matter: Citizen involvement and government action. . *Journal of the American Planning Association, 33-49.*
- Busscher, T. v. (2019). Strategies for integrating water management and spatial planning: Organising for spatial quality in the Dutch “Room for the River” program. . *Journal of Flood Risk Management, 12(1), e12448.*
- Butler, C. &. (2011). From ‘flood defense to ‘flood risk management: exploring governance, responsibility, and blame. . *Environment and Planning C: Government and Policy, 29(3), 533-547.*
- Candel, J. J. (2016). Toward a processual understanding of policy integration. *Policy Sciences, 49(3), 211-231.*
- Cardona, O. D. (n.d.). The need for rethinking the concepts of vulnerability and risk from a holistic perspective: a necessary review and criticism for effective risk management. Mapping vulnerability. *Disasters, development and people, 17, 37-51.*
- Carpenter, S. R. (2012). General resilience to cope with extreme events. *Sustainability, 4(12), 3248-3259.*
- Carpenter, S. R. (2012). General resilience to cope with extreme events. *Sustainability, 4(12), 3248-3259.*
- Carreño, M.L., Cardona, O.D. and Barbat, A.H. (2005). Evaluation of the risk management performance.
- Castonguay, S. (2007). The production of the flood as a natural catastrophe: extreme events and the construction of vulnerability in the drainage basin of the St. Francis River (Quebec), mid-nineteenth to mid-twentieth century. *Environmental history, 12(4), 87.*

- CCRA, U. (2012). *The UK Climate Change Risk Assessment 2012 Evidence Report*. London : Department for Environment, Food and Rural Affairs.
- Challies, E., Newig, J., Thaler, T., Kochskämper, E., & Levin-Keitel, M. (2016). Participatory and collaborative governance for sustainable flood risk management: An emerging research agenda. . *Environmental Science and Policy* 55 , 275-280.
- Chan, F. K. (2012). Flood risk in Asia's urban mega-deltas: Drivers, impacts and response. 1. *Environment and Urbanization ASIA*, 3(1), 41-6.
- Chan, F. K. (2018). Sponge City” in China—a breakthrough of planning and flood risk management in the urban context. . *Land use policy*, 76, 772-778.
- Chapin III, F. S., Mark, A. F., Mitchell, R. A., & Dickinson, K. J. (2012). Chapin III, F. S., Mark, A. F., Mitchell, R. A., & Dickin Design principles for social - ecological transformation toward sustainability: lessons from New Zealand sense of place. *Chapin III, F. S., Mark, A. F., Mitchell, R. A., & Dickinson, K. J. (2012). Design principles for social - ecological Ecosphere*, 3(5), 1-22.
- Chen, Y. R. (2011). Integrated application of the analytic hierarchy process and the geographic information system for flood risk assessment and flood plain management in Taiwan. . *Natural Hazards*, 59(3), 1261-1276.
- Chow, T.V., Maidment, D.R., Mays, L.W., 1988. (1988). *Applied Hydrology*. New York: McGraw-Hill,
- Christensen, L. &. (2012). Christensen, L., & Kr Social thresholds and their translation into social-ecological management practices. *Ecology and Society*, 17(1).
- Christmann, G. B. (2012). Vulnerability and resilience in a socio-spatial perspective. *Raumforschung und Raumordnung*, 70(4), 259-272.
- Ciurean, R. L. (2013). Conceptual frameworks of vulnerability assessments for natural disasters reduction. In *Approaches to disaster management-Examining the implications of Hazard, emergencies, and disasters*. IntechOpen.
- Clausen, B. &. (1995). Regional frequency analysis of annual maximum streamflow drought. *Journal of Hydrology*, 173(1-4), 111-130.
- Collenteur, R. A. (2015). The failed-levee effect: Do societies learn from flood disasters?. . *Natural Hazards*, 76(1), 373-388.

- Collenteur, R.A., De Moel, H., Jongman, B. and Di Baldassarre, G. (2015). The failed-levée effect: Do societies learn from flood disasters?. *Natural Hazards*, pp.373-388.
- Correia, F. N. (1999). Floodplain management in urban developing areas. Part II. GIS-based flood analysis and urban growth modeling. *Water Resources Management*, 13(1), 23-37.
- Cosgrove, W. J. (2015). Water management: Current and future challenges and research directions. *Water Resources Research*, 4823-4839.
- Cosoveanu, F. S. (2019). Adaptive Capacities for Diversified Flood Risk Management Strategies: Learning from Pilot Projects. *Water*, 11(12), 2643.
- Cumiskey, L. P. (2019). A framework to assess integration in flood risk management: implications for governance, policy, and practice. . *Ecology and Society*, 24(4).
- Cutter, S. (1996). Vulnerability to environmental hazards. *Progress in human geography*, pp.529-539.
- Cutter, S. L. (2010). Disaster resilience indicators for benchmarking baseline conditions. . *Journal of homeland security and emergency management*, 7(1).
- Cutter, S.L., Emrich, C.T., Morath, D.P., and Dunning, C.M. (2013). Integrating social vulnerability into federal flood risk management planning. *Journal of Flood Risk Management*.
- Dash, P. &. (2020). Identification and validation of potential flood hazard area using GIS - based multi - criteria analysis and satellite data - derived water index. . *Journal of Flood Risk Management*.
- Daviter, F. (2017). Coping, taming or solving: alternative approaches to the governance of wicked problems. *Policy Studies*, 38(6), 571-588.
- Davoudi, S. (2012). Resilience: a bridging concept or a dead end?“. *Planning theory & practice*, 13(no. 2), 299-333.
- de Brito, M. M. (2016). Multi-criteria decision-making for flood risk management: a survey of the current state of the art. . *Natural Hazards and Earth System Sciences*, 16(4), 1019-1033.
- De Bruijn, K. (2005). Resilience and flood risk management: a systems approach applied to lowland rivers.

- de Bruijn, K. B. (2017). Resilience in practice: Five principles to enable societies to cope with extreme weather events. *de Bruijn, K., Buurman, J., Mens, M., Dahm, R., & Klijn, F. (2017). Resilience in practice: Five principles Environmental Science & Policy, 21-30.*
- De Bruijn, K. M. (2004). Resilience and flood risk management. *Water Policy, 6(1)* , 53-66.
- De Bruijn, K. M. (2014). An advanced method for flood risk analysis in river deltas, applied to societal flood fatality risk in the Netherlands. . *Natural Hazards and Earth System Sciences, 14(10)*, 2767.
- de Bruijn, K. M. (2019). Flood resilience of critical infrastructure: Approach and method applied to Fort Lauderdale, Florida. . *Water, 11(3)*, 517.
- de Bruijn, K., Buurman, J., Mens, M., Dahm, R., & Klijn, F. (2017). Resilience in practice: Five principles to enable societies to cope with extreme weather events. *Environmental Science & Policy, 70*, 21-30.
- De Wrachien, D. M. (2011). Flood management and risk assessment in flood - prone areas: Measures and solutions. *Irrigation and Drainage, 60(2)*, 229-240.
- den Boer, J., Dieperink, C., & Mukhtarov, F. (2019). den Boer, J., Dieperink, C., Social learning in multilevel flood risk governance: Lessons from the Dutch Room for the River Program. *Water*, 2032.
- Dewan, A. (2013). Floods in a megacity: geospatial techniques in assessing hazards, risk and vulnerability. Dordrecht: Springer.
- Dewulf, A. C.-W. (2005). Dewulf, A., Craps, M., Bouwen, R., Taillieu, T., & Pahl Integrated management of natural resources: dealing with ambiguous issues, multiple actors and diverging frames. . *Water science and technology, 52(6)*, 115-124.
- Díez-Herrero, A. &. (2020). Flood Risk Assessments: Applications and Uncertainties.
- Dolan, J. G. (2008). Shared decision-making–transferring research into practice: the Analytic Hierarchy Process (AHP). *Patient education and counseling, 73(3)*, 418-425.

- Döll, P. & L. (2017). How to embrace uncertainty in participatory climate change risk management—A roadmap. . *Earth's Future*, 18-36.
- Doroszkiwicz, J. &. (2017). Guidelines for the adaptation to floods in changing climate. . *Acta Geophysica*, 849-861.
- Driessen, P. P. (2012). Driessen, P. P., Dieperink, C., van Laerhoven, F., Runhaar, H. A., & Vermeulen, W. J. (2012). Towards a conceptual framework for the study of shifts in modes of environmental governance—experiences from the Netherlands. *Environmental policy and governance*.
- Driessen, P. P. (2016). Toward more resilient flood risk governance. . *Ecology and Society*.
- Eakin, H. B.-B. (2012). Livelihoods and landscapes at the threshold of change: disaster and resilience in a Chiapas coffee community. *Regional Environmental Change*, 12(3), 475-488.
- Edelenbos, J. &. (2006). Managing stakeholder involvement in decision making: A comparative analysis of six interactive processes in the Netherlands. . *Journal of public administration research and theory*, 16(3), 417-446.
- Edelenbos, J. V. (2017). Edelenbos, J., Van Buuren, A., Roth, D., & W Stakeholder initiatives in flood risk management: exploring the role and impact of bottom-up initiatives in three ‘Room for the River projects in the Netherlands. *Journal of Environmental Planning and Management* 60, no. 1, 47-66.
- Emanuelsson, M. A. E., McIntyre, N., Hunt, C. F., Mawle, R., Kitson, J., & Voulvoulis, N. (2014). Flood risk assessment for infrastructure networks. *Journal of Flood Risk Management*, 31-41.
- Erdlenbruch, K. T. (2009). Risk-sharing policies in the context of the French Flood Prevention Action Programmes. *Journal of environmental management*, 363-369.
- Evans, E. H.-R. (2006). Future flood risk management in the UK. In *Proceedings of the Institution of Civil Engineers-Water Management* (pp. pp. 53-61). Thomas Telford Ltd.

- Evans, E. P.-R. (2002). Catchment flood management plans and the modeling and decision support framework. In *Proceedings of the Institution of Civil Engineers-Civil Engineering*. Thomas Telford Ltd.
- Evans, E. P.-R. (2004). Foresight Flood and coastal defense project: scientific summary: volume I, future risks and their drivers. *Foresight Flood and coastal defense Office of Science and Technology*.
- Evers, M. J. (2012). Collaborative modeling for active involvement of stakeholders in urban flood risk management. *Natural Hazards and Earth System Sciences*, 12.
- Faehnle, M., & Tyrväinen, L. (2013). A framework for evaluating and designing collaborative planning. *Land Use Policy*, 332-341.
- Farrelly, M. B. (2009). Farrelly, M., Brown, R. R., & D Can demonstration projects act as a mechanism for promoting a transition? In *6th International Water Sensitive Urban Design Conference and 3rd Hydropolis*.
- Fewtrell, L. &. (2008). An attempt to quantify the health impacts of flooding in the UK using an urban case study. *Public health*, 122(5), 446-451.
- Fielding, J. &. (2005). Environmental inequality and flood hazard. *Local Environment*, 10(4), 379-395.
- Filatova, T. (2014). Filatova, T., 2014. Market-based instruments for flood risk management: a review of theory, practice and perspectives for climate adaptation policy. . *Environmental science & policy*, 37, pp.227-242.
- Filatova, T. V. (2013). Spatial agent-based models for socio-ecological systems: challenges and prospects. *Filatova, T., Verburg, P. H., Parker, D. C., & Stannard, C. A. (2013). Spatial agent-based models Environmental modeling & software*, 45, 1-7.
- Fleischhauer, M. G. (2012). Improving the active involvement of stakeholders and the public in flood risk management--tools of an involvement strategy and case study result.
- Folke, C. B. (2016). Folke, C., Biggs, R., Norström, A. V., Reyers, B., & RocSocial-ecological resilience and biosphere-based sustainability science. *Ecology and Society*, 21(3).

- Folke, C. C. (2002). Resilience and sustainable development: building adaptive capacity in a world of transformations. *AMBIO A journal of the human environment*, 437-440.
- Folke, C. C. (2010). Resilience thinking: integrating resilience, adaptability, and transformability. *Ecology and society*.
- Folke, C. J. (2011). Reconnecting to the biosphere. *Ambio*, 40(7).
- Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: integrating resilience, adaptability, and transformability. *Ecology and Society*, 15(4).
- Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., & Walker, B. (2002). Resilience and sustainable development: building adaptive capacity in a world of transformations. *AMBIO: A journal of the human environment*, 31(5), 437-440.
- Foudi, S. O.-E. (2015). Integrated spatial flood risk assessment: The case of Zaragoza. *Land Use Policy*, 42, 278-292.
- Fournier, M. L. (2016). Flood risk mitigation in Europe: how far away are we from the aspired forms of adaptive governance? *Ecology and Society*, 21(4).
- Friedmann, J. (2004). Strategic spatial planning and the longer range. *Planning Theory & Practice*. *Planning Theory & Practice*, 5(1), 49-67.
- Fuchs, S. &. (2017). Tipping points in natural hazard risk management: How societal transformation can provoke policy strategies in mitigation. . *Journal of Extreme Events*, 4(01), 1750006.
- Fuchs, S. K. (2015). A spatiotemporal multi-hazard exposure assessment based on property data. *Natural Hazards and Earth System Sciences*, 15(9), 2127-2142.
- Fuchs, S. K. (2017). Editorial to the special issue on resilience and vulnerability assessments in natural hazard and risk analysis. *Natural Hazards and Earth System Sciences*, 17(7), 1203-1206.
- Gallopin, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global environmental change*, 16(3), 293-303.
- Gerdri, N. &. (2007). Applying the Analytic Hierarchy Process (AHP) to build a strategic framework for technology road mapping. . *Mathematical and Computer Modelling*, 46(7-8), 1071-1080.

- Gerrits, L. &. (2008). Complex bounded rationality in dyke construction: path-dependency, lock-in in the emergence of the geometry of the Zeeland Delta. . *Land Use Policy*, 25(3) , 330-333.
- Gersonius, B. A. (2010). Managing the flooding system's resiliency to climate change. *In Proceedings of the Institution of Civil Engineers-Engineering Sustainability (Vol. 163, No. 1, pp. 15-23*. Thomas Telford Ltd.
- Gersonius, B. v. (2016). Resilient flood-risk strategies: institutional preconditions for implementation. *Ecology and Society*, 21(4).
- Gersonius, B., van Buuren, A., Zethof, M., & Kelder, E. (2016). Resilient flood-risk strategies: institutional preconditions for implementation. *Ecology and Society*, 21(4).
- Giezen, M. S. (2015). Adding value to the decision-making process of megaprojects: Fostering strategic ambiguity, redundancy, and resilience. . *Transport Policy*, 169-178.
- Gilissen, H. K. (2016). A framework for evaluating the effectiveness of flood emergency management systems in Europe. . *Ecology and Society*, 21(4).
- Gilissen, H. K., Alexander, M., Beyers, J. C., Chmielewski, P., Matczak, P., Schellenberger, T., & Suykens, C. (2016). Bridges over troubled waters: an interdisciplinary framework for evaluating the interconnectedness within fragmented flood risk management. *Journal of Water Law*, 25(1), 12-26.
- Godschalk, D. R. (2003). Urban hazard mitigation: creating resilient cities. *Natural hazards review*, 4(3), 136-143.
- Godschalk, D., Beatley, T., Berke, P., Brower, D., & Kaiser, E. J. (1998). Natural hazard mitigation. In *Recasting disaster policy and planning*. Island Press.
- González-Quintero, C., & Avila-Foucat, V. S. (2019). Operationalization and Measurement of Social-Ecological Resilience. *A Systematic Review. Sustainability*, 11(21), 6073.
- Gooch, G. (2008). Participation in water management: theory and practice.
- Graham, S., & Healey, P. (1999). Relational concepts of space and place: Issues for planning theory and practice. *European planning studies*, 7(5), 623-646., 7(5), 623-646.

- Grisham, T. (2009). The Delphi technique: a method for testing complex and multifaceted topics. . *International Journal of Managing Projects in Business*.
- Groffman, P. M., Baron, J. S., Blett, T., Gold, A. J., Goodman, I., Gunderson, L. H., ... & Poff, N. L. (2006). Ecological thresholds: the key to successful environmental management or an important concept with no practical application? *Ecosystems*, 9(1).
- Haasnoot, M. M. (2011). A method to develop sustainable water management strategies for an uncertain future.). *Sustainable Development*, 19(6, 369-381.
- Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global environmental change*, 23(2), 485-498.
- Hall, J. &. (2008). A framework for uncertainty analysis in flood risk management decisions. . *International Journal of River Basin Management*, 6(2), 85-98.
- Hall, J. W. (2003). Hall, J. W., Meadowcroft, I. C., Sayers, P. B., & Bramle Integrated flood risk management in England and Wales. *Natural Hazards Review*, 4(3), 126-135.
- Hall, J. W. (2006). Impacts of climate change on coastal flood risk in England and Wales: 2030–2100. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 364(1841).
- Hallegatte, S. (2009). Strategies to adapt to an uncertain climate change. . *Global environmental change*, 19(2), 240-247.
- Hambati, H. &. (2015). Revealing the vulnerability of urban communities to flood hazard in Tanzania: a case of the Dar es Salaam city ecosystem. *International Journal of Geospatial and Environmental Research*, 2(1), 3.
- Harries, T. &-R. (2011). Harries, T., & PenVictim pressure, institutional inertia and climate change adaptation: The case of flood risk. *Global Environmental Change*, 21(1), 188-197.
- Harrison-Atlas, D. T. (2016). A systematic review of approaches to quantify hydrologic ecosystem services to inform decision-making. . *International Journal of Biodiversity Science Ecosystem Services & Management*, 12(3).
- Hartmann, T. (2012). *Clumsy floodplains: Responsive land policy for extreme floods*. Ashgate Publishing, Ltd.

- Hartmann, T. (2011). Contesting land policies for space for rivers—rational, viable, and clumsy floodplain management. . *Journal of Flood Risk Management*, 4(3), 165-175.
- Haynes, H. H. (2008). Integrating socio - economic analysis into a decision - support methodology for flood risk management at the development scale (Scotland). . *Water and Environment Journal*, 117-124.
- Healey, P. (1997). *Collaborative planning: Shaping places in fragmented societies*. . Macmillan International Higher Education.
- Healey, P. (2003). Collaborative planning in perspective. Planning theory. *Planning Theory*, 101-123.
- Hegger, D. L. (2013). Strengthening and redesigning European flood risk practices (STAR-FLOOD): towards appropriate and resilient flood risk governance arrangement.
- Hegger, D. L. (2014). Assessing stability and dynamics in flood risk governance. *Hegger, D. L., Driessen, P. P., Dieperink, C., Wiering, M., Raadgever, G. Water Resources Management*, 28(12), Hegger, D. L., Driessen, P. P., Dieperink, C., Wiering, M., Raadgever, G. T., & van Rijswijk, H. F. (2014). A4127-4142.
- Hegger, D. L. (2016). Toward more flood resilience: Is a diversification of flood risk management strategies the way forward? *Hegger, D. L., Driessen, P. P., Wiering, M., Van Rijswijk, H. F., Kundzewicz, Z. W., Matczak, P., ... & Larrue, C. (2016). Toward more flood resilience: Ecology and Society*.
- Herath, H. M. (2020). Transformation of flood risk management with evolutionary resilience. . *In E3S Web of Conferences (Vol. 158, p. 06005). EDP Sciences*.
- Herath, H. M. M., & Wijesekera, N. T. S. (2019). A State-of-the-Art Review of Flood Risk Assessment in Urban Areas. *In IOP Conference Series: Earth and Environmental Science (Vol. 281, No. 1, p. 012029)*.
- Holland, B. (2017). Procedural justice in local climate adaptation: political capabilities and transformational change. *Environmental Politics*, 26(3), 391-412.
- Höllermaun, B. &. (2019). Coping with uncertainty in water management: Qualitative system analysis as a vehicle to visualize the plurality of practitioners'

- uncertainty handling routines. *Journal of environmental management*, 213-223.
- Holling, C. S. (1973). Resilience and stability of ecological systems. . *Annual review of ecology and systematics*, 4(1), 1-23.
- Hommes, S. V.-d. (2009). Knowledge and perceptions in participatory policy processes: lessons from the Delta-region in the Netherlands. . *Water resources management*, 23(8).
- Hooijer, A. K. (2004). Towards sustainable flood risk management in the Rhine and Meuse river basins: synopsis of the findings of IRMA - SPONGE. *River research and applications*, 20(3), 343-357.
- Hooijer, A. K. (2004). Towards sustainable flood risk management in the Rhine and Meuse river basins: synopsis of the findings of IRMA - SPONGE. . *River research and applications*, 20(3), 343-357.
- Höppner, C. W. (2012). Linking social capacities and risk communication in Europe: a gap between theory and practice? *Natural hazards*, 64(2), 1753-1778.
- Höppner, C. W. (2012). Linking social capacities and risk communication in Europe: a gap between theory and practice?. . *Natural hazards*, 64(2), 1753-1778.
- Huang, C. S. (2008). Determination of insurance policy using a hybrid model of AHP, fuzzy logic, and Delphi technique: a case study. . *WSEAS Transactions on Computers*, 7(6), 660-669.
- Hufschmidt, G. (2011). A comparative analysis of several vulnerability concepts. *Natural hazards*, 58(2), 621-643.
- Huitema, D. M.-W. (2009). Adaptive water governance: assessing the institutional prescriptions of adaptive (co-) management from a governance perspective and defining a research agenda. *Ecology and society*.
- Hutter, G. &. (2008). Learning how to deal with the uncertainty of flood risk in long - term planning. *International Journal of River Basin Management*, 6(2), 175-184.

- Hutter, G. (2007). Strategic planning for long-term flood risk management: some suggestions for learning how to make strategy at region. *International Planning Studies*, 12((3)), pp.273-289.
- Ishiwatari, M. (2019). Flood risk governance: Establishing a collaborative mechanism for an integrated approach. *Progress in Disaster Science*, 100014.
- Jahan, S. (2000). Coping with a flood: the experience of the people of Dhaka during the 1998 flood disaster. *Australian Journal of Emergency Management*, 15(3).
- Johnson, C. L. (2008). Johnson, C. L., & Priest Flood risk management in England: a changing landscape of risk responsibility? *International Journal of Water Resources Development*, 513-525.
- Johnson, C. P. - R. (2007). Natural and imposed injustices: the challenges in implementing 'fair flood risk management policy in England. *Geographical Journal*, 173(4), 374-390.
- Jongman, B. H.-S. (2014). Increasing stress on disaster-risk finance due to large floods. *Nature Climate Change*, (2 4(4), P.264.
- Jonkman, S.N. and Vrijling, J.K.,. (2008). Loss of life due to floods. *Journal of Flood Risk Management*, pp.43-56.
- Kandilioti, G. &. (2012). Preliminary flood risk assessment: the case of Athens. 8. *Natural hazards*, 61(2), 441-46.
- Keating, A. C. (2017). Development and testing of a community flood resilience measurement tool. *Natural Hazards and Earth System Sciences Discussions*, 17(1), 77-101.
- Keessen, A. M. (2013). Keessen, A. M., Hamer, J. M., Van Rijswick, H. F., & Wiering, M. (2013). The concept of resilience from a normative perspective: examples from Dutch adaptation strategies. *Ecology and Society*.
- Kelly, P. M. (1999). Assessing vulnerability to climate change and facilitating adaptation. . *Centre for Social and Economic Research on the Global Environment*.
- Kelly, R. P. (2015). Kelly, R. P., Erickson, A. L., Mease, L. A., Battista, W., Kittinger, J. N., & Fuj Embracing thresholds for better environmental management. *Philosophical Transactions of the Royal Society*.

- Kerner, D. A. (2014). Resilience attributes of social-ecological systems: framing metrics for management. *Resources*, 3(4), 672-702.
- Kidd, S. (2007). Towards a framework of integration in spatial planning: an exploration from a health perspective. *Planning Theory & Practice*, 161-181.
- Kiedrzyńska, E. K. (2015). Kiedrzyńska, E., Kiedrzyński, M., & Zal Sustainable floodplain management for flood prevention and water quality improvement.. *Sustainable floodplaNatural Hazards*, 76(2), 955-977., 955-977.
- Kienberger, S. L. (2009). Spatial vulnerability units--expert-based spatial modeling of socio-economic vulnerability in the Salzach catchment, Austria. *Natural Hazards & Earth System Sciences*, 9(3).
- Klijn, F. A. (2010). Compartmentalization: flood consequence reduction by splitting up large polder areas. . *Journal of Flood Risk Management*, 3(1), 3-17.
- Koppenjan, J. F. (2004). *Managing uncertainties in networks: a network approach to problem-solving and decision making*. . Psychology Press.
- Krywkow, J. (2009). A methodological framework for participatory processes in water resources management.
- Kryżanowski, A., Brilly, M., Rusjan, S. and Schnabl, S. (2014). . Structural flood-protection measures referring to several European case studies. *Natural hazards and earth system sciences*, pp.135-142.
- Kuklicke, C. (2016). Adaptive and risk-based approaches to climate change and the management of uncertainty and institutional risk: The case of future flooding in England. *Global Environmental Change*, 37, 56-68.
- Kundzewicz, Z. K.-W. (2014). Flood risk and climate change: global and regional perspectives. *Hydrological Sciences Journal*, 59(1), pp.1-28.
- Kundzewicz, Z. W. (1999). Flood protection and management, *Hydrological Sciences Journal*, 417-432.
- Kundzewicz, Z. W. (2017). Kundzewicz, Z. W., Krysanova, V., Dankers, R., Hirabayashi, Y., Kanae, S., HatterDifferences in flood hazard projections in Europe—their causes and consequences for decision making. *Hydrological Sciences Journal*.

- Lane, S. N. (2011). Imagining flood futures: risk assessment and management in practice. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 1784-1806.
- Larsen, S. &. (2015). Ecological thresholds and riparian wetlands: an overview for environmental managers. *Limnology*, 1-9.
- Lawrence, J. R. (2013). Exploring climate change uncertainties to support adaptive management of changing flood-risk. . *Environmental Science & Policy*, 33, 133-142.
- Lawrence, J. S. (2015). Adapting to changing climate risk by local government in New Zealand: institutional practice barriers and enablers. *Local Environment*, 20(3), 298-320.
- Lechowska, E. (2018). What determines flood risk perception? A review of factors of flood risk perception and relations between its basic elements. . *Natural Hazards*, 1341-1366.
- Lele, S. B.-A. (2018). Framing the environment. Rethinking Environmentalism: Linking Justice Sustainability and Diversity, 1-19.
- Li, G. F. (2013). Impact assessment of urbanization on flood risk in the Yangtze River Delta. . *Stochastic Environmental Research and Risk Assessment*, 27(7), 1683-1693.
- Li, R. V. (2016). Rules for the governance of coastal and marine ecosystem services: An evaluative framework based on the IAD framework. Li, R., Van Den Brink, M., & Woltjer, J. (2016). *Rules for the governance of coastal and marine Land Use Policy*, 298-309.
- Liao, K.-H. (2012). A theory on urban resilience to floods—A basis for alternative planning practices. *Ecology and Society*, 17, 48.
- Linkov, I. B.-L. (2014). Changing the resilience paradigm. *Nature Climate Change*, 407.
- Linkov, I. B.-L. (2014). Linkov, I., Bridges, T., Creutzig, F., Decker, J., FoxChanging the resilience paradigm. . *Nature Climate Change*, 4(6), 407., 407.
- Linkov, I., Bridges, T., Creutzig, F., Decker, J., Fox-Lent, C., Kröger, W., ... & Nyer, R. (2014). Changing the resilience paradigm. *Nature Climate Change*, 4(6).

- Liverman, D. M. (n.d.). Vulnerability to global environmental change. *Understanding global environmental change: 1990*, 27-44.
- Lorenzoni, I. B. (2015). *Regional rescaling in UK climate adaptation governance: from agency to collaborative control. Climate adaptation governance: Theory, concepts, and praxis in cities and regions*. Chichester: Wiley.
- Luu, C. V. (2018). Assessing flood hazard using flood marks and analytic hierarchy process approach: a case study for the 2013 flood event in Quang Nam, Vietnam. . *Natural Hazards*, 90(3), 1031-1050.
- Lyles, L. W. (2014). Do planners matter? Examining factors driving the incorporation of land use approaches into hazard mitigation plans. . *Journal of environmental planning and management*, 57(5), 792-811.
- M. Rogers, M. B. (2002). "ELECTRE and decision support: methods and applications in engineering and infrastructure investment. *Journal-Operational Research Society*, vol. 53, no. 12, pp. 1396-1397, 2002.
- MacArthur, J. D. (2011). Stakeholder Roles and Stakeholder Analysis in Project Planning: A review of approaches in three agencies-World Bank, ODA, and NRI.
- Malczewski, J. (2006). Integrating multicriteria analysis and geographic information systems: the ordered weighted averaging (OWA) approach. . *International Journal of Environmental Technology and Management*, 6(1-2), 7-19.
- Mardani, A. J. (2015). Multiple criteria decision-making techniques and their applications—a review of the literature from 2000 to 2014. . *Economic Research-Ekonomska Istraživanja*, 28(1), 516-571.
- Martín-López, B. P.-L.-A. (2017). Delineating boundaries of social-ecological systems for landscape planning: A comprehensive spatial approach. *Land use policy*.
- Mavhura, E. (2019). Analyzing drivers of vulnerability to flooding: a systems approach. . *South African Geographical Journal*, 101(1), ., 72-90.
- Mazza, L. (2010). Strategic planning and republicanism. . *Spatium*, (22), 1-10.
- McBean, E. F. (1986). A critical analysis of residential flood damage estimation curves. *Canadian Journal of Civil Engineering*, 13(1), 86-94.

- McMeekin, N. W. (2020). How methodological frameworks are being developed: evidence from a scoping review. . *BMC medical research methodology*, 20(1), 1-9.
- McMeekin, N., Wu, O., Gemeni, E., & Briggs, A. (2020). How methodological frameworks are being developed: evidence from a scoping review. *BMC medical research methodology*, 20(1), 1-9.
- Medema, W. W. (2014). Medema, W., Wals, A. Multi-loop social learning for sustainable land and water governance: Towards a research agenda on the potential of virtual learning platforms. *NJAS-Wageningen Journal of Life Sciences*, 23-38.
- Mees, H. L. (2014). Legitimate adaptive flood risk governance beyond the dikes: the cases of Hamburg, Helsinki, and Rotterdam. . *Regional Environmental Change*, 14(2), 671-682.
- Meijerink, S. &. (2008). Shifts in the public-private divide in flood management. *International Journal of Water Resources Development*, 499-512.
- Meng, M. D. (2019). Collaborative spatial planning in the face of flood risk in delta cities: A policy framing perspective. *Environmental Science & Planning*, 73(2), pp.95-104.
- Merz, B. &. (2009). Flood risk curves and uncertainty bounds. *Natural hazards*, 51(3), 437-458.
- Merz, B. A.-N. (2014). Floods and climate: emerging perspectives for flood risk assessment and management. . *Natural Hazards and Earth System Sciences*, 14(7), 1921-.
- Merz, B. H. (2010). Fluvial flood risk management in a changing world. . *Natural Hazards and Earth System Sciences*.
- Merz, B., & Thieken, A. H. (2005). Separating natural and epistemic uncertainty in flood frequency analysis. *Journal of Hydrology*, 309(1-4), 114-132.
- Merz, B., Hall, J., Disse, M., & Schumann, A. (2010). Fluvial flood risk management in a changing world. *Natural Hazards and Earth System Science*.
- Merz, B., Vorogushyn, S., Lall, U., Viglione, A., & Blöschl, G. (2015). Charting unknown waters—On the role of surprise in flood risk assessment and management. *Water Resources Research*, 6399-6416.

- Messner, F. (2006). Flood damage, vulnerability and risk perception—challenges for flood damage research. In *Flood risk management: hazards, vulnerability and mitigation measures*. Springer, Dordrecht.
- Messner, F., & Meyer, V. (2006). Flood damage, vulnerability and risk perception—challenges for flood damage research. In *Flood risk management: hazards, vulnerability and mitigation measures* (pp. pp. 149-167).
- Meyer, V. H. (2009). Flood risk assessment in European river basins—concept, methods, and challenges exemplified at the Mulde River. *Integrated Environmental Assessment and Management*, 5(1), 17-26.
- Miguez, M. G., Veról, A. P., De Sousa, M. M., & Rezende, O. M. (2015). Urban floods in lowlands—levee systems, unplanned urban growth, and river restoration alternative: a case study in Brazil. . *Sustainability*.
- Milly, P. B. (2008). Stationarity is dead: Whither water management? *Science*, 319(5863), pp.573-574, pp.573-574.
- Mingers, J. &. (2004). Problem structuring methods in action. *European journal of operational research*, 530-554.
- Moghadas, M., Asadzadeh, A., Vafeidis, A., Fekete, A., & Kötter, T. (2019). A multi-criteria approach for assessing urban flood resilience in Tehran, Iran. *International journal of disaster risk reduction*, 35, 101069.
- Molenveld, A., & van Buuren, A. (2019). Flood Risk and Resilience in the Netherlands: In Search of an Adaptive Governance Approach. *Water*, 11(12), 2563.
- Molinari, D. D. (2017). Review Article: Validation of flood risk models: current practice and innovations. . *Nat.Hazards Earth Syst. Sci. Discuss.*, <https://doi.org/10.5194/nhess-2017-303>, in review.
- Molinari, D. D.-R. (2019). Validation of flood risk models: Current practice and possible improvements. . *International journal of disaster risk reduction*, 33, 441-448.
- Moore, M. L. (2014). Moore, M. L., Tjornbo, O., Enfors, E., Knapp, C., Hodbod, J., Baggio, J. A., ... & Biggs, D. (2014). Studying the complexity of change: toward an analytical framework for understanding deliberate social-ecological transformations. . *Ecology and Society*.

- Moufar, M. M. (2018). Floods and Countermeasures Impact Assessment for the Metro Colombo Canal System, Sri Lanka. . *Hydrology*, 5(1), 11.
- Muduli, K. &. (2013). Developing a framework for the study of GSCM criteria in Indian mining industries. *APCBEE proceedia*, 5, 22-26.
- Nachtnebel, H. P. (2009). Assessment and management of flood risks in Austria. *Structure and Infrastructure Engineering*, 5(4), 333-339.
- Naess, L. O. (2006). Data and processes linking vulnerability assessment to adaptation decision-making on climate change in Norway. *Global Environmental Change*, 16(2), 221-233.
- Neuvel, J. M. (2009). Flood risk management in Dutch local spatial planning practices. *Journal of Environmental Planning and Management*, 52(7), 865-880.
- Neuvel, J. M. (2010). A spatial planning perspective for measures concerning flood risk management. *International Journal of Water Resources Development*, 26(2), 283-296.
- Newig, J. &. (2009). Environmental governance: participatory, multi - level-and effective? *Environmental policy and governance*, 19(3), 197-214.
- Nillesen, A. L. (2015). An integrated approach to flood risk management and spatial quality for a Netherlands' river polder area. *Mitigation and adaptation strategies for global change*, 20(6), 949-966.
- Nirupama, N. (2012). Risk and vulnerability assessment: a comprehensive approach. *International Journal of Disaster Resilience in the Built Environment*.
- Offermans, A. H. (2011). A method to explore social response for sustainable water management strategies under changing conditions. *Sustainable development*, 19(5), 312-324.
- Ohl, C. A. (2000). Flooding and human health: the dangers posed are not always obvious.
- Okoli, C. &. (2004). The Delphi method as a research tool: an example, design considerations, and applications. . *Information & management*, 42(1), 15-29.
- Okuyama, Y. &. (2014). Disaster impact and input-output analysis. *Economic Systems Research*, 26(1), 1-12.

- Opperman, J. J. (2009). Opperman, J. J., Galloway, G. E., Fargione, J., Mount, J. F., Richter, B. D., & Secchi, Sustainable floodplains through large-scale reconnection to rivers.
- Österblom, H. &. (2013). The emergence of global adaptive governance for stewardship of regional marine resources. . *Ecology and Society*, 18(2).
- Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, 419-422.
- .
- Ouma, Y. O., & Tateishi, R. (2014). Urban flood vulnerability and risk mapping using integrated multi-parametric AHP and GIS: methodological overview and case study assessment. *Water*, 6(6), 1515-1545.
- Pahl-Wostl, C. (2007). Transitions towards adaptive management of water facing climate and global change. *Water resources management*, 21(1), 49-62.
- Pahl-Wostl, C. (2006). The importance of social learning in restoring the multifunctionality of rivers and floodplains. *Ecology and society*.
- Pahl-Wostl, C. D. (2005). Transition to adaptive water management: the NeWater Project.
- Pahl-Wostl, C. J. (2011). Maturing the new water management paradigm: progressing from aspiration to practice. *Water resources management*, 25(3), 837-856.
- Pahl-Wostl, C. S. (2009). Resources management in transition. *Ecology and Society*, 14(1).
- Pahl-Wostl, C;. (2007). Transitions towards adaptive management of water facing climate and global change. *Water resources management*, 49-62.
- Papaioannou, G. V. (2015). Multi-criteria analysis framework for potential flood-prone areas mapping. . *Water resources management*, 29(2), 399-418.
- Pardoe, J. P.-R. (2011). Floodplain conflicts: regulation and negotiation. . *Natural Hazards & Earth System Science*.
- Parker, D. J. (2014). *Floods*. . Routledge.
- Pendall, R. F. (2010). Resilience and regions: building understanding of the metaphor. *Cambridge Journal of Regions, Economy, and Society*, 3(1), 71-84.

- Penning - Rowsell, E. C. (2000). New insights into the appraisal of flood - alleviation benefits:(1) Flood damage and flood loss information. *Water and Environment Journal*, 14(5), 347-353.
- Pettersson, M. V. (2017). Assessing the legitimacy of flood risk governance arrangements in Europe: insights from intra-country evaluations. *Assessing the legitimacy of flood risk govern* 929-944.
- Pistrika, A. &. (2007). Flood risk assessment: A methodological framework. *Water Resources Management: New Approaches and Technologies*. European Water Resources Association, Chania, Crete-Greece.
- Plate, E. (2002). Flood risk and flood management. *Journal of Hydrology*, 267(1-2), pp.2-11.
- Plate, E. J. (1997). Flood risk management: a strategy to cope with floods. *In Proceedings of the European meeting on the Oder Flood*, pp. 115-128.
- Plummer, R. B. (2018). Flood Governance: A multiple country comparison of stakeholder perceptions and aspirations. *Environmental Policy and Governance*, 67-8.
- Quinn, T. B. (2019). How local water and waterbody meanings shape flood risk perception and risk management preferences. *Sustainability Science*, 14(3), 565-578.
- Qureshi, M. E. (2003). Application of the analytic hierarchy process to riparian revegetation policy options. . *Small-scale forest economics, management and policy*, 2(3), 441.
- Raaijmakers, R. K. (2008). Flood risk perceptions and spatial multi-criteria analysis: exploratory research for hazard mitigation. . *Natural hazards*, 46(3), 307-322.
- Ran, J. and Nedovic-Budic, Z. (2016). Integrating spatial planning and flood risk management: A new conceptual framework for the spatially integrated policy infrastructure. *Environment and Urban Systems*, pp.68-79.
- Rauter, M. T. (2019). Rauter, M., Thaler, T., Attems, M. S., Obligation or Innovation: Can the EU Floods Directive Be Seen as a Tipping Point Towards More Resilient Flood Risk Management? A Case Study from Vorarlberg, Austria.

- Reddy, B. P. (2015). Using the analytic hierarchy process to derive health state utilities from ordinal preference data. *Value in Health*, 18(6), 841-845.
- Reed, M. S. (2013). Participatory scenario development for the environment A methodological framework illustrated with experience from the UK uplands. *Journal of environmental management*, 128, 345-362.
- Rein, M. &. (1993). Reframing Policy Discourse. The Argumentative Turn in Policy Analysis and Planning.
- Renn, O. K. (2011). Coping with complexity, uncertainty, and ambiguity in risk governance: a synthesis. *Ambio*, 40(2), 231-246.
- Restemeyer, B. (2018). (2018). Resilience unpacked—framing of ‘uncertainty and ‘adaptability in long-term flood risk management strategies for London and Rotterdam. *European planning studies*, 1559-1579.
- Restemeyer, B. W. (2015). A strategy-based framework for assessing the flood resilience of cities—A Hamburg case study. *Planning Theory & Practice*, 45-62.
- Rodgers, M. T. (2016). P30 Developing a methodological framework for organizational case studies: A rapid review and consensus development process. *Epidemiol Community Health*, 70(Suppl 1), A67.
- Rosenhead J, M. J. (2001). *Rational analysis for a problematic world revisited*. Wiley,
- Saaty, T. L. (2008). Decision-making with the analytic hierarchy process. *International Journal of Services*.
- Saaty, T. L. (1987). The AHP—what it is and how it is used. . *Math Modelling*, 9(3-5), 161-76.
- ŞAHİN, M. &. (2018). A Content Analysis Study on the Use of Analytic Hierarchy Process in Educational Studies. *Eğitimde ve Psikolojide Ölçme ve Değerlendirme Dergisi*, 9(4), 376-392.
- Samuels, P. M. (2010). A framework for integrated flood risk management. In *1st IAHR European Division Congress*.
- Sayers, P. (2017). Evolution of strategic flood risk management in support of social justice, ecosystem health, and resilience. . In *Oxford Research Encyclopedia of Natural Hazard Science*.

- Sayers, P. B. (2003). Risk assessment for flood and coastal defense systems for strategic planning (RASP)—a national scale application and a look forward to more detailed methods.
- Sayers, P. B., Hall, J. W., & Meadowcroft, I. C. (2002). Towards risk-based flood hazard management in the UK. *In Proceedings of the institution of civil engineers-civil engineering*, Proceedings pp. 36-42). Thomas Telford Ltd.
- Sayers, P. G.-R. (2015). Strategic flood management: ten ‘golden rules’ to guide a sound approach. *International Journal of River Basin Management*, 13(2),. *International Journal of River Basin Management*, 137-151.
- Sayers, P., Galloway, G., Penning-Rowsell, E., Yuanyuan, L., Fuxin, S., Yiwei, C., ... & Guan, Y. (2015). Strategic flood management: ten ‘golden rules’ to guide a sound approach. *International Journal of River Basin Management*, 13(2), 137-151.
- Sayers, Y. L.-R. (2013). *Flood Risk Management: A Strategic Approach*. Paris, UNESCO.
- Schanze, J. (2006). Flood risk management—a basic framework. In J. Schanze, *In Flood risk management: hazards, vulnerability and mitigation measures* (pp. pp. 1-20). Dordrecht.: Springer, Dordrecht.
- Schanze, J. (2006). Flood risk management—a basic framework. In *Flood risk management: hazards, vulnerability and mitigation measures*. Dordrecht: Springer.
- Schanze, J. (2016). Resilience in flood risk management—Exploring its added value for science and practice. *In E3S Web of Conferences* (pp. Vol. 7, p. 08003). EDP Sciences.
- Scheuer, S. H. (2011). Exploring multicriteria flood vulnerability by integrating economic, social, and ecological dimensions of flood risk and coping capacity: from a starting point view towards an endpoint view of vulnerability. *Natural Hazards*, 58(2), 731-751.
- Scheuer, S., Haase, D., & Meyer, V. (2010). Integrated assessment of urban flood risk, coping, capacity and vulnerability. *In 21st IAPS Conference, Vulnerability, Risk and Complexity: Impact of Global Change on Human Habits*. Leipzig, Germany.

- Schlosberg, D. C. (2017). Adaptation policy and community discourse: risk, vulnerability, and just transformation. *Environmental Politics*, 26(3), 413-437.
- Schmidt, K. A. (2015). Applying the Analytic Hierarchy Process in healthcare research: A systematic literature review and evaluation of reporting. . *BMC medical informatics and decision making*.
- Schneidergruber, M. C. (2004). Living with floods: achieving ecologically sustainable flood management in Europe. *WWF*.
- Schoon, M. &. (2015). Schoon, M., & Van der The shift toward social-ecological systems perspectives: insights into the human-nature relationship. *Natures Sciences Sociétés*, 166-174.
- Scott, M., White, I., Kuhlicke, C., Steinführer, A., Sultana, P., Thompson, P., ... & Russell, E. (2013). Living with flood risk The more we know, the more we know we don't know. *Planning Theory & Practice*, 14(no. 1), 103-140.
- Shilpakar, R. L. (2020). The resilience of a floodplain vegetation landscape. . *Landscape Ecology*, 1-19.
- Siddayao, G. P., Valdez, S. E., & Fernandez, P. L. (2014). Analytic hierarchy process (AHP) in spatial modeling for floodplain risk assessment. I. *International Journal of Machine Learning and Computing*, 4(5), 450.
- Skulmoski, G. J., Hartman, F. T., & Krahn, J. (2007). The Delphi method for graduate research. *Journal of Information Technology Education: Research*, 6(1), 1-21.
- Smit, B. &. (2006). Adaptation, adaptive capacity, and vulnerability. *Global environmental change*, 16(3), 282-292.
- Smith, D. I. (1994). Flood damage estimation-A review of urban stage-damage curves and loss functions. *Water Sa*, 20(3), 231-238.
- Smith, G. L. (2013). The Role of the State in Building Local Capacity and Commitment for Hazard Mitigation Planning. . *International Journal of Mass Emergencies & Disasters* 31(2).
- Smits, A.J.M.; Nienhuis, P.H.; Saeijs, H.L.F. (2006). Changing estuaries, changing views. *Hydrobiologia*, 339–355.
- Solomon, O. &. (2013). Flood frequency analysis of Osse river using Gumbel's distribution. . *Civil and Environmental Research*, 3, 55-59.

- Stedinger, J. R. (2011). Getting from here to where? Flood frequency analysis and climate. *JAWRA Journal of the American Water Resources Association*, 47(3), 506-513.
- Steen, R., & Ferreira, P. (2020). Resilient flood-risk management at the municipal level through the lens of the Functional Resonance Analysis Model. *Reliability Engineering & System Safety*, 204, 107150.
- Stephens, S. A. (2017). Applying principles of uncertainty within coastal hazard assessments to better support coastal adaptation. . *Journal of Marine Science and Engineering*, 5(3), 40.
- Stremke, S. V. (2012). Integrated visions (part I): Methodological framework for long-term regional design. . *European Planning Studies*, 20(2), 305-319.
- Tappenden P, C. J. (2012). Whole Disease Modeling to Inform Resource Allocation Decisions in Cancer: A Methodological Framework. . *Value Health*.15(8):1127–36.
- Tempels, B. (2016). Flood resilience: a co-evolutionary approach: residents, spatial developments and flood risk management in the Dender Basin (Doctoral dissertation, Ghent University).
- Tempels, B. and Hartmann, T. (2014). A co-evolving frontier between land and water: dilemmas of flexibility versus robustness in flood risk management. *Water international*, 39(6), pp.872-883.
- Ten Veldhuis, J. A. (2011). How the choice of flood damage metrics influences urban flood risk assessment. *Journal of Flood Risk Management*, 4(4), 281-287.
- Thaler, T. (2016). Justice and flood risk management: reflecting on different approaches to distribute and allocate flood risk management in Europe. . *Natural Hazards*, 83(1), 129-147.
- Thampapillai, D. J. (1985). Flood damage mitigation: A review of structural and nonstructural measures and alternative decision frameworks. *Water Resources Research*, 21(4), 411-424.
- Thieken, A. H. (2016). Review of the flood risk management system in Germany after the major flood in 2013. . *Ecology and Society*, 21(2).

- Thieken, A. H., Müller, M., Kreibich, H., & Merz, B. (2005). Flood damage and influencing factors: New insights from the August 2002 flood in Germany. *Water resources research*, 41(12).
- Thungngern, J. W. (2015). A review of the analytical hierarchy process (AHP): an approach to water resource management in Thailand. *Applied Environmental Research*, 37(3), 13-32.
- Tockner, K. &. (2002). Riverine flood plains: present state and future trends. *Environmental conservation*, 29(3), 308-330.
- Tompkins, E. L. (2004). Does adaptive management of natural resources enhance resilience to climate change? *Ecology and Society*, 9(2).
- Turner. (2010). Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science? *Global Environmental Change*, 20(4), 570-576.
- Turner, B. L. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the national academy of sciences*, 100(14), 8074-8079.
- Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science*, 211(4481), 453-458.
- UNDRO. (1991). *Coordinator, Office of the United Nations Disaster Relief Mitigating Natural Disasters: Phenomena, Effects, and Options: a Manual for Policy Makers and Planners (Vol. 6)*. United Nations Publications.
- Van Buuren, A. E. (2016). Path-dependency and policy learning in the Dutch delta: toward more resilient flood risk management in the Netherlands? *Ecology and Society*, 21(4).
- van Buuren, A., Lawrence, J., Potter, K., & Warner, J. F. (2018). Introducing adaptive flood risk management in England, New Zealand, and the Netherlands: The impact of administrative traditions. *Review of Policy Research*, 35(6), 907-929.
- van Buuren, A., Lawrence, J., Potter, K., & Warner, J. F. (2018). Introducing adaptive flood risk management in England, New Zealand, and the Netherlands: The impact of administrative traditions. *Review of Policy Research*, 35(6), 907-929.
- Van Buuren, A., Potter, K., Warner, J., & Fischer, T. (2015). Making space for institutional change? A comparative case study on regime stability and change in river flood management in the Netherlands and England. *International Journal of Water Governance*, 4(3), 81-100.

- Van Herk, S. (2014). *Van Herk, Delivering integrated flood risk management: Governance for collaboration, learning, and adaptation*. IHE Delft Institute for Water Education.
- van Herk, S. R. (2015). Understanding the transition to integrated flood risk management in the Netherlands. *Environmental Innovation and Societal Transitions*, 15, 84-100.
- van Herk, S. Z. (2014). Process design and management for integrated flood risk management: exploring the multi-layer safety approach for Dordrecht, The Netherlands. . *Journal of Water and Climate Change*.
- Van Herk, S., Zevenbergen, C., Rijke, J. A. N. D., & Ashley, R. (2011). Van Herk, S., Zevenbergen, C., Rijke, J. A. N. D., & Ashle Collaborative research to support the transition towards integrating flood risk management in urban development. Collaborative research to support the transition towards integration 306-317.
- van Manen, S. E. (2005). Quantitative flood risk assessment for Polders. . *Reliability engineering & system safety*, 90(2-3), 229-237.
- Van Walsum, P. E. (2005). Framework for integrated design of water and land management systems; towards robust water-space partnerships as a basis for adaptation D 1.4. 1.
- Viessman, J. W. (2003). *Introduction to Hydrology*. Upper Saddle River, New Jersey, USA: Pearson Education, Inc.
- Vink, M. J., Benson, D., Boezeman, D., Cook, H., Dewulf, A. R. P. J., & Termeer, C. J. (2015). Do state traditions matter? Comparing deliberative governance initiatives for climate change adaptation in Dutch corporatism and British pluralism. *Journal of Water and Climate Change*, 71-88.
- Vis, M. K. (2003). Vis, M., Klijn, F., De Bruijn, K. M., & Van Resilience strategies for flood risk management in the Netherlands. *International journal of river basin management*.
- Visser, F. (2014). Rapid mapping of urban development from historic Ordnance Survey maps: An application for pluvial flood risk in Worcester. *Journal of Maps*, 10(2), 276-288.

- Vogel, K. L. (2017). Data collection for a damage assessment after the flash flood in Braunsbach (Germany) in May 2016.
- Voinov, A. J. (2018). Tools and methods in participatory modeling: Selecting the right tool for the job. . *Environmental Modelling & Software*, 109, 232-255.
- Walker, B. &. (2004). Thresholds in ecological and social-ecological systems: a developing database. *Ecology and Society*, 9(2).
- Walker, B. G. (2006). Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S A handful of heuristics and some propositions for understanding resilience in social-ecological systems. . *Ecology and Society*, 11(1).
- Walker, B. H. (2004). Walker, B., Holling, C. S., Carpenter, S. Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society*, 9(2).
- Walker, G. (2011). Flood risk, vulnerability, and environmental justice: evidence and evaluation of inequality in a UK context. . *Critical social policy*, 31(2), 216-240.
- Walker, W. E. (2003). Defining uncertainty: a conceptual basis for uncertainty management in model-based decision support. *Integrated assessment*4(1), , 5-17.
- Ward, P. (2013). On the use of tradable development rights for reducing flood risk. *Land Use Policy*, 31, , 576-583.
- Ward, P. J. (2013). Governance of flood risk management in a time of climate change: the cases of Jakarta and Rotterdam. *Environmental Politics*, 22(3), 518-536.
- Waris, M., Panigrahi, S., Mengal, A., Soomro, M. I., Mirjat, N. H., Ullah, M., ... & Khan, A. (2019). An Application of Analytic Hierarchy Process (AHP) for Sustainable Procurement of Construction Equipment: Multicriteria-Based Decision Framework for Mala. *Mathematical Problems in Engineering*, 2019.
- Wasson, R. J. (2016). Uncertainty, ambiguity and adaptive flood forecasting. . *Policy and Society*, 35(2), 125-136.
- Watts, M. J. (1993). The space of vulnerability: the causal structure of hunger and famine. *Progress in human geography*, 17(1), 43-67.
- Weichselgartner, J. (2001). Disaster mitigation: the concept of vulnerability revisited. Disaster Prevention and Management. *An International Journal*.

- Weichselgartner, J. (2001). Disaster mitigation: the concept of vulnerability revisited. *Disaster Prevention and Management. An International Journal*.
- Welsh, M. (2014). Resilience and responsibility: governing uncertainty in a complex world. . *The geographical journal*, 180(1), 15-26.
- White, G. F. (1945). Human Adjustment to Floods. *White, G. F. (1945)Research Paper No. 29, Department of Geography. University of Chicago, Chicago, IL*.
- White, I. &. (2002). Flooding and the role of planning in England and Wales: a critical review. . *Journal of Environmental Planning and Management*, 45(5), 735-745.
- White, I. &. (2016). White, I., From rhetoric to reality: which resilience, why resilience, and whose resilience in spatial planning? *White, I., & O'Hare, P. (2014). From rhetoric to reality: which resilience, why resilience, and who Environment and Planning C: Government and Policy*, 934-950.
- Wiering, M. &. (2006). When water management meets spatial planning: a policy-arrangements perspective. *Wiering, M., & Immink, I. (2006). When water management meets Environment and Planning C: Government and policy*, 423-438.
- Wiering, M., Liefferink, D (2018) Stability and change in flood risk governance: on path dependencies and change agents. *journal of Flood Risk Management*, 230-238.
- Wijitkosum, S. (2019). Fuzzy AHP Integrated with GIS Analyses for Drought Risk Assessment: A Case Study from Upper Phetchaburi River Basin, Thailand. *Water*, 11(5), 939.
- Willroth, P. D. (2011). Modeling the economic vulnerability of households in the Phang-Nga Province (Thailand) to natural disasters. *Natural hazards*, 58(2), 753-769.
- Wilson, E. (2006). Adapting to climate change at the local level: the spatial planning response. *Local environment*, 11(6), 609-625.
- Wolsink, M. (2006). River basin approach and integrated water management: Governance pitfalls for the Dutch Space-Water-Adjustment Management Principle. *Geoforum*, 37(4), 473-487.
- Wu, Y. Z. (2015). Integrated flood risk assessment and zonation method: a case study in Huaihe River basin, China. . *Natural Hazards*, 78(1), 635-651.

- Wutich, A. C.-W. (2018). Integrating sustainability, justice, and diversity?: opportunities and challenges for inclusively framing water research.
- Zandvoort M, Van der Vlist, M. J., Klijn, F., & Van den Brink, A. (2018). Navigating amid uncertainty in spatial planning. *Planning Theory*.
- Zandvoort M., van der Brugge, R., van der Vlist, M. J., & van den Brink, A. (2019). Dealing with uncertainty in collaborative planning: developing adaptive strategies for the IJsselmeer. *Journal of Environmental Planning and Management*, 248-265.
- Zevenbergen, C. G. (2007). Economic feasibility study of floodproofing domestic dwellings.
- Zevenbergen, C. V. (2008). Zevenbergen, C., Veerbeek, W., Gersonius, B., & Va Challenges in urban flood management: travelling across spatial and temporal scales.(2), 81-88.
- Zhou, J. L. (2018). Water resources and sustainability assessment based on group AHP-PCA method: a case study in the Jinsha River Basin. . *Water*, 10(12), 1880.
- Zischg, A. (2018). Floodplains and Complex Adaptive Systems—Perspectives on Connecting the Dots in Flood Risk Assessment with Coupled Component Models. . *Systems*, 6(2),.

APPENDIX

Appendix A: Questions used for development of the framework

Title - A framework to assess the level of resilience of spatial planning process in the face of urban flood risk

Problem statement - How to assess the capacity of planning process to incorporate the uncertainties of urban flood risk

Aspect	Conceptualization - Nonlinear relations - Scenario based decisions - Tangible & intangible impacts - Fixed & flows of elements	Assessment & consideration of factors - Hazard control - Consequence control - Natural uncertainty & knowledge based uncertainty - Multiple scenarios	Mode of intervention (integration) Participatory & collective	Governance mechanisms (Control measures, Types of measures, monitoring) - Based on system response - Spatial planning and structural measures (diverse) - Decentralized - Holistic stakeholders approach
Criteria	1.1 Main objective/goal of the urban Flood management approach 1.2 Identification of flood management strategies 1.3 Design criteria of flood management strategies 1.4 Identification of the floodplain 1.5 Identification of the land uses of urban floodplain 1.6 Evaluation techniques in flood risk assessment 1.7 Characteristics of the flood risk governance mechanism 1.8 Identification of stakeholders 1.9 Any other	2.1 Objectives of the flood risk assessment 2.2 Identification of Flood Hazard Zones 2.3 Identification of Flood impacts in urban areas 2.4 Define flood vulnerability 2.5 Components of flood vulnerability 2.6 Context conditions on flood vulnerability 2.7 Capacity of planning process and tools (recognize the complexity) 2.8 Components of flood vulnerability assessment 2.9 Governing factors of the Planning process 2.10 Problem framing capacity of the Planning process (frame the complexity) 2.11Strategic solution framing capacity of the Planning process (frame the solution) 2.12 Outputs of the flood risk assessment 2.13 Scale of assessment 2.14 Type of analysis 2.15 Any other	3.1 Identification of Stakeholders 3.2 Information and resources flow pattern 3.3 Initiation of Multi stakeholder networks 3.4 Empowerment of stakeholders 3.5 Local participation / local Stakeholder engagement 3.6Technical capacity of stakeholders 3.7 Detail level up to date information available for stakeholders 3.8 Continuous participation of stakeholders 3.9 Motivate of participation 3.10 Objectives of participation 3.11 Outputs of the participation 3.12 Any other	4.1 Integrated Policies 4.2. Floodplain design regulation 4.2. Floodplain planning regulation 4.4. Floodplain Planning process regulation 4.5 Enforcement regulation available floodplain 4.6 Enforcement regulation available floodway 4.7 Flexible Monitoring framework 4.8Any other

01 Conceptualization / criteria	Sub Criteria (Importance to assess flood Resilience)	Allocate a mark 100-0	
		Importance to assess flood Resilience	Current practice
1.1 The main objective of the urban Flood management approach How do you prioritize the objectives of the urban flood management approach?	a. Strategies to increase the capacity to transform and adaptive Making strategies to society to pursue its socio-ecological development objectives of society while managing its flood risk over time mutually by enhancing the preparedness and searching for the most appropriate ways by taking existing opportunities of the socio-ecological system. This can be interpreted as the capacity of a city shift from the fight with water to the living with water (Increase flood ability and the reorganization). More collaborations among stakeholders and broaden the responsibilities of stakeholders including government, community, and political groups. Thus, it will not reduce the existing risk levels but could also make the socio-ecological system more robust for extreme flood events. Therefore, objectives of flood resilience are to increase the capacity to tolerate flooding and to reorganize should physical damage and socioeconomic disruption occur, to prevent deaths and injuries, and maintain current socioeconomic identity.		

	b. Strategies to increase the capacity to absorb and recover Making strategies to respond to flooding and recover as well as remain functions of the socio-ecological system without shifting to a different system state. Increase the capacity of a system to absorb disturbance and reorganize while changing to still retain essentially the same function, structure, identity, and feedbacks c. Strategies to increase the Capacity to resist Making strategies for flood protection and strong withstand with the extreme flood events (by increasing the thresholds of the structural measures). d. Any other		
1.2 Identification of flood management strategies How do you identify or prioritize the flood management strategies in urban flood management	a. Reduce the consequences of floods by spatial planning strategies (redirect/discourage urban growth from floodplains, etc) b. Reduce the consequences of the floods by designing the flood plain (adjustment of the physical environment) c. Reduce consequences by crisis management strategies (evacuation, etc)		

	d. Reduce the probability of flood hazard by technical strategies (dams, drainages) e. Any other		
1.3 Design criteria of flood management strategies What are the criteria used to design flood management strategies	a. Creation of Multifunctional land uses on the floodplain b. Synergies between land and water interactions on the floodplain (coherence between desired ecological objectives and the urban development objectives. Space needs for water to (1) maintain the ecosystem health in rivers and provide services for (2) humans including developing water supply, hydropower generation, flood control, navigation, and other purposes. People benefit indirectly from water provided to ecosystems— such as recreation and cultural identity and much of what we call ‘quality of life. c. Environmental flow patterns of floodplains (<i>Environmental Flows</i> express the quantity, quality, and timing of water that are necessary to sustain a river system (wetland, coastland zone) and the associated fish and wildlife/ maintain multiple ecosystem services. Environmental Flow Requirement for BaseFlows Environmental Flow Requirement for Sediment Transport Environmental Flow Requirements for Evaporation of Surface Water Environmental Flow Requirements for Different Vegetation Types Environmental Flow Requirements for Groundwater Restoration		

	Integration of Environmental Flow Requirements for Various Ecosystem Functions Temporal Allocation of Environmental Flow Requirements d. Hydrological connectedness e. Climatic variables f. Any other		
1.4 Identification of floodplain What is the order of importance of the criteria used to define the floodplain	a. Environmental flow patterns (Space needs for water to (1) maintain the ecosystem health in rivers and provide services for (2) humans including developing water supply, hydropower generation, flood control, navigation, and other purposes). b. Hydrological connectivity of river system c. Flood fringe areas (areas do not receive the depth and velocity of floodwater that floodway floodways receive). d. Floodway (Floodways are the channels of the streams or rivers and those portions of the adjoining floodplain necessary to discharge the 100-year-flood flow without increasing the 100- year flood elevation by more than one foot). e. Long-term historical data of flooding f. Any other		
1.5 Identification of land uses of urban floodplain	a. Consider water as a strategic element in urban development b. Functions of Natural Landscape of floodplain		

What are the order of criteria used to identify the land uses of urban floodplain	c. Economic efficiency and availability of urban infrastructure d. Accommodate extreme flood events e. Any other		
1.6 Evaluation techniques in flood risk assessment What is the order of importance of aspects which used in flood risk assessment or prioritization of management strategies	a. Multiple criteria /prioritize b. Trade-offs of alternatives (context specific) c. Stakeholders' judgments and acceptable levels of alternatives d. Qualitative pros and cons of alternatives e. Quantitative pros and cons of alternatives (monetary)		
1.7 Characteristics of the flood risk governance mechanism What are the salient characteristics of the flood risk governance	a. Multiple stakeholders (multi scale , multi sectors) participation b. Local initiatives highlighted c. Active Community participation d. Integration of Land and water institutions e. Decision making at River basin scale f. Any other		
1.8 Identification of stakeholders Who are the stakeholders in the flood risk governance	a. Multi stakeholders/ as per the complexity of the flood issue b. Community/ floodplain residents c. Local authorities d. Local and regional scale Land institutions e. Local and regional scale water institutions f. Any other		

Conceptualization /criteria	Allocate marks 0-100	
	Resilience	Practice
1.1 Main objective/goal of the urban Flood management approach		
1.2 Identification of flood management strategies		
1.3 Design criteria of flood management strategies		
1.4 Identification of the floodplain		
1.5 Identification of the land uses of urban floodplain		
1.6 Evaluation techniques in flood risk assessment		
1.7 Characteristics of the flood risk governance mechanism		
1.8 Identification of stakeholders		
1.9 Any other		

02 Assessment/criteria	Sub Criteria (Importance to assess flood Resilience)	Allocate a mark 100-0	
		Importance to assess flood Resilience	Current practice
2.1 Objectives of flood risk assessment in decision making How do you prioritize the importance of the main objectives of flood risk assessment	a Managing a combination of flood hazard and vulnerability (managing of the uncertainties incorporated with both hazard and vulnerability) b Managing flood vulnerability (actual damage of specific flood event depends on the vulnerability of the socio-economic system of the particular location and explore why it is damaged) c Managing flood impacts (managing of flood consequences or what extent of potential damage) d Managing of flood hazard e Any other		

2.2 Identification of Flood Hazard Zoning What is the order of importance of parameters used to identify flood hazard zoning in urban areas?	a. Multiple scenarios of flood plain land-use changes. b. Multiple scenarios of climate changes c. River as a system d. Range of flood events (extreme, frequent) e. Spatial variation of extent of flood depth, retention time, flood velocity, etc f. Any other		
2.3 Identification of Flood impacts in urban areas What is the order of importance of parameters used to identify the flood impacts in urban areas?	a. Spatial variation of flood impacts occur due to different scenarios of land-use changes, human activities, etc b. Spatial variation of flood impacts occur for different scenarios of climate change (extreme, frequent events) c. Intangible impacts (natural ecology, social relations, etc) d. Indirect, tangibles impacts (business interruption) e. Direct, tangibles impacts - Any other		
2.4 Define flood vulnerability What are factors considered in defining flood vulnerability	a. Local contextual condition of the community (level of preparedness, integration) influenced flood damage b. Potential causes for deviation from desired goals of socio-economic development of community		

	c. Likelihood of the community experiencing flood damage. d. Any other		
2.5 Components of flood vulnerability What is the order of importance of the components which needed to consider in the assessment	a. Resilience capacity or coping and adaptive capacity of the socio-ecological system b. Susceptibility capacity of the socio-ecological system c. Exposure capacity of the socio-ecological system e. Any other		
2.6 Local Contextual conditions influenced on flood damage What are the local contextual factors that influence flood vulnerability	a. The capacity of decision making Process /framework (spatial planning process) and the planning tools of the socio-ecological system (who is involved and what kind of capacities the stakeholders need to possess; intellectual capital, social capital, and political capital) b. Political context c. Institutional structure and legislations context d. Socio- economical context e. Climatic conditions& natural environmental context f. Any other		

2.7 Capacity of planning process and tools of the socio-ecological system What are the factors needed to consider to assess the Capacity of decision making of the socio-ecological system / Flood risk (Problem identification capacity of Planning Process and Tools (recognize) complexity)	a. Capacity to identify the uncertainties incorporated with flood vulnerability b. Capacity to identify the multi-scale forces (regional, state, global) incorporated with flood vulnerability c. Capacity to identify the socio-economic processes such as urbanization, migration cause flood vulnerability d. Capacity to identify the external factors (a disproportionate division of assets, environmental management capacity, resolve social and economic conflicts, etc) which govern flood vulnerability. e. Capacity to identify the internal factors(human capital, public infrastructure, resources belonging to the inhabitants of floodplain, etc) which govern flood vulnerability. f. Any other		
2.8 Assessment of the flood vulnerability	a. Identify the strategic ways to combine the potential feedback loops and deficiencies of the socio-ecological system to		

What are the consideration factors in the assessment	cope up with flood damage (how strengths and the potentials system and deficiencies can be combined through the planning process& practice to increase resilience) b. Identify the link between the strengthens and the potential feedback loops / coping capacity of the floodplain, flood damage & land use planning practice (what are the potentials/ strengths reduces flood damage, positive feedbacks) c. Identify the link between social condition (an increase of susceptibility) of floodplain, community & land use planning practices (what are the causes for flood damages due to deficiencies of the social system, poverty, housing, income) d. Identify the link between physical conditions (an increase of flood exposure) of floodplain & land use planning practices(what are the causes of flood damage due to deficiencies of the physical environment/ exposure of land uses)		

	e. Identify the link between a set of processes (what are the process of land-use changes on floodplains)& land use planning practices (how flood damage has been developed) f. Any other		
2.9 Planning process governing factors What is the importance of Factors effect on the assessment of the flood vulnerability of the planning process	a. Stakeholders knowledge of flood vulnerability b. Problem framing capacity of the Planning process c. Solution framing capacity of the Planning process d. Any other		
2.10 Stakeholders knowledge What are the factors which determined the Stakeholders knowledge	- a Knowledge of stakeholders; Integration of diverse perception of stakeholders to create multifunctional land use creation. This can be done through the participatory planning process - b Knowledge of stakeholders; Floodplain land use planning has significant in flood management - c Knowledge of stakeholders; Flood Prevention measures are more important than flood control measures		

	d Knowledge of stakeholders; multiple measures/combinations of structural and nonstructural measures need for flood management. e Knowledge of stakeholders; Massive and central technical solutions have limitations to cope up with extreme events f Any other		

2.11 Problem framing capacity of the Planning process What is the order of importance of consideration factors needed to assess the Problem framing capacity of the Planning process	a. Create Governness mechanisms ‘fit’ the problem at hand/stakeholders collaborations b. Create collective actions and ability of planning process to integrate conflict views of stakeholders c. Ability to gain the importance of Ecosystem services in urban development (Buffering capacity to cope up with extreme events) d. Consider interdependency between urban development and water and ability of planning process and planning tools to recognize co-evolutionary nature of the land & water system e. Consider flooding as a natural phenomenon. f. Any other		

2.12 Strategic solution framing capacity of the Planning process What is the order of importance of consideration factors needed to assess the framing capacity of Strategic solutions in the Planning process	a. Self-organization capacity of a planning system b. Consensus development capacity among stakeholders c. Prioritize local needs d. Empower local stakeholders to actively participate in decision making e. Collective decision making/participation of stakeholders f. Any other		
Outputs of the flood risk assessment 2.13 Outputs of the flood risk assessment in the planning process What are the importance of the order of outputs of the flood risk assessment f the flood risk assessment	a. Floodplain governance mechanisms (multi-stakeholder networks) enhance the planning process b. Strategic planning solutions and tools to improve the local capacity of the floodplain community c. Planning strategies to increase the resilience (deficiency of socio-ecological system of floodplain community) d. Planning strategies to reduce susceptibility deficiency of socio-ecological system floodplain community) e. Planning strategies to reduce physical exposure of floodplain/floodplain land uses		

2.14 Scale of assessment What is the importance of aspects considered in the assessment related to the scale	a. Multiple scales of analysis based on the actor networks (problem at hand) b. Social boundaries (municipal, district, province) c. River basin scale (river system) d. Sub catchment scale		
2.15 Type of predictions and analysis What is the appropriate type of analysis in decision making	a. Scenario-parametric approach (Parametric approaches aim to use readily available data of information to build a picture of the vulnerability of an area. Explore the implications of a set of contrasting possible futures/ alternatives. Letting the stakeholders select alternatives they prefer. b. Deterministic modeling approach (Deterministic modeling approaches which use physically-based modeling approaches (probabilistic approach) to estimate flood hazard/probability of a particular event, coupled with damage assessment models which estimate economic consequence to provide an assessment of flood risk in an area)		

Assessment/criteria	Allocate marks 0-100	
	Resilience	Practice
2.1 Objectives of flood risk assessment		
2.2 Identification of Flood Hazard Zoning		
2.3 Identification of Flood <u>impacts</u> in urban areas		
2.4 Define flood vulnerability		
2.5 Components of flood vulnerability		
2.6 Context conditions influenced flood vulnerability		
2.7 The capacity of planning process and tools		
2.8 Components of flood vulnerability assessment		
2.9 Governing factors of the Planning process		
2.10 Stakeholders knowledge		
2.11 Problem framing capacity of the Planning process (frame the complexity)		
2.12 Strategic solution framing capacity of the Planning process (frame the solution)		
2.13 Outputs of the flood risk assessment		
2.14 Scale of assessment		
2.15 Type of analysis		
2.16 Any other		

03 Participatory/ Criteria	Sub Criteria Importance to assess flood Resilience	Allocate a mark 100-0	
		FRM in the face of Resilience	Current practice
3.1 Identification of Stakeholders Who are the important stakeholders needed for collective decision making	a. Communities (floodplain residents) b. All other government agencies related to floodplain and use (RDA, disaster, Industrial board) c. Local authorities, (provincial government) d. Land related institutions (UDA, NPPD) e. All water-related institutions/basin scale f. Any other		
3.2 Information and resources flow pattern What is the order of importance of the flow of resources and information among the stakeholders for collective decision making	a. Hybrid forms of governance or Multi-level interactions b. Horizontal and more decentralized/bottom-up c. State centered and top-down		
3.3 Initiation of Multi-stakeholder networks What is the order of importance of <u>multi-stakeholder networks</u> initiated for collective decision making	a. Locally induced multi-stakeholders networks b. Formal induced multi-stakeholders networks c. Informally induced multi-stakeholders networks d. Agent induced multi-stakeholders network (ADB, world bank, etc) e. Event induced multi-stakeholders networks		

3.4 Empowerment of stakeholders What is the level of empowerment of stakeholders required for collective decision making	a. Equal Empower communities / Floodplain residents b. Equal Empower local authorities c. Equal Empower all land development agencies (UDA) d. Equal Empower all water-related agencies e. Any other		
3.5 Local participation / local Stakeholder engagement Who are the core group in collective decision making (order of importance)	a. Local authorities b. Floodplain residents c. Community organization d. land development institutions at the local level, (UDA) e. Water institutions at the local level, f. Any other		
3.6 Technical capacity of stakeholders / IWRM knowledge; FRM knowledge and expertise What is the level of the technical capacity needed for collective decision making (order of importance)	a. Local authorities level b. Urban development authorities at the local level c. Urban development authorities at the regional level d. Water management agencies at the local level e. Water management agencies regional level f. Any other		
3.7 Detail level, up to date information available for stakeholders Who has to be known the detailed level information needed for collective decision making (order of importance)	a. Communities b. Local authorities c. All government agencies d. All Land use development agencies e. All water agencies f. Any other		

3.8 Continuous participation of stakeholders When Continuous participation is required for collective decision making (order of importance)	a. Pro-action and Prevention stage /During the planning & design b. Recovery stage /During rehabilitation c. Response stage / During Evacuation, crisis management d. Preparation stage /Flood warning e. Any other		
3.9 Motivation of participation What are the actions that can motivate collective decision making (order of importance)	a. Incentives are available for local stakeholders. b. Community participation is a mandatory practice. c. Local authority participation is a Mandatory practice d. All Land development agencies integration is a mandatory e. All water agencies participation is a mandatory		
3.10 Objectives of participation What are the objectives of meetings (order of importance)	a. Share new learning's, knowledge Ideas, ways to strengthen governance b. operationalize the joint objectives of stakeholders c. Alternative management strategies to increase local capacities to cope up with floods d. Local deficiencies for flood e. Dialogues of the flood damage		
3.11 Outputs of the participation What are the outputs/actions of stakeholders participation (order of importance)	a. Multifunctional uses on floodplains b. Ecosystem services of floodplain c. Floodplain zoning and building regulations d. Early warning system /Flood hazard evacuation e. Improve the structural measures		

03 Participatory	Allocate a mark 100-0	
	FRM in the face of Resilience	Current practice
3.1 Identification of Stakeholders		
3.2 Information and resources flow pattern		
3.3 Initiation of Multi stakeholder networks		
3.4 Empowerment of stakeholders		
3.5 Local participation / local Stakeholder engagement		
3.6 Technical capacity of stakeholders		
3.7 Detail level up to date information available for stakeholders		
3.8 Continuous participation of stakeholders		
3.9 Motivate of participation		
3.10 Objectives of participation		
3.11 Outputs of the participation		
Any other		

4Governance Criteria	Sub Criteria (Importance to assess flood Resilience)	Allocate a mark 100-0	
		Resilience	Current practice
4.1 Integrated Policies	a. “ Land & water integration “as a guiding element in sectorial policies Water integrates into a bigger socio-economic agenda.		
	b. “Land& water integration “as a guiding element spatial policy and planning at regional land the local level/water integrates into a bigger urban agenda.		
	c. Land and water integration as a guiding element in socio-political policies water integrates into a bigger political agenda		
4.2. Floodplain design regulation Regulations related to Exposure reduction (order of importance of parameters)	a. Tax, insurance, and local authority rates guidelines for floodplain development		
	b. Public infrastructure provision guidelines in floodplains		
	c. Physical/utility services provision guidelines for floodplains		
	d. Site development guidelines for floodplains		
	e. Building guidelines in floodplains		
	f. Any other		
4.3 Floodplain planning regulation	a. Coastal areas development		
	b. Upper catchment development		

(order of importance of parameters)	c. Flood plain zoning regulations/development		
	d. Flood hazard Zoning regulation		
	e. Any other		
4.4.Floodplain Planning process Regulations related to Susceptibility reduction or integration of planning process	a. Share the cost and benefits of floods among public and private or stakeholders		
	b. Public participation in the planning process.		
	c. Integration land and water institutes planning process.		
	d. Integration regional and local scale needs and connections in the planning process e. Any other		
4.5 Enforcement regulation available for floodplain (order of importance of parameters)	a. Enforcement regulation available for encroachment of floodplain by housing development		
	b. Enforcement regulation available for encroachment of floodplain by infrastructure/utility development		
	c. Enforcement regulation available for encroachment of floodplain by industrial development		

	d. Enforcement regulation available for encroachment of floodplain by property development		
	e. Enforcement regulation available for <u>reclamation of floodplain</u>		
4.6 Enforcement regulation available for floodway	a. Enforcement regulation available for encroachment of floodway by housing development		
	b. Enforcement regulation available for encroachment of floodway by infrastructure / utility development		
	c. Enforcement regulation available for encroachment of floodway by industrial development		
	d. Enforcement regulation available for encroachment of floodway by property development		
	e. Enforcement regulation available for reclamation of floodway		
4.7 Monitoring framework	a. Presence of monitoring mechanism to review the feedback and room for the autonomous change underlying assumptions of institutional pattern		

What is the importance of monitoring framework of flood management (order of importance of parameters)	b Presence of monitoring mechanism to review the feedback and room for the autonomous change /Double loop learning (adaptability), change the underlying institutional pathway		
	c Presence of monitoring mechanism to review the feedback and room for the autonomous change / single loop learning (change the in practice)		
	d Presence of monitoring mechanism to review the feedback of the flood risk management measures with participation of community.		
	e Presence of monitoring mechanism to review the feedback of the flood risk management measures (with participation of the local and regional, government. Agencies		

4 Governance Criteria (Importance to assess flood Resilience)	Allocate marks 0 -100	
	Resilience	In practice
4.1 Integrated Policies		
4.2. Floodplain design regulation		
4.2. Floodplain design regulation		
4.4. Floodplain Planning process regulation		
4.5 Enforcement regulation available floodplain		
4.6 Enforcement regulation available floodway		
4.7 Flexible Monitoring framework		
Any other		

Appendix B: Questions used for Calibration of the Framework

Assumptions	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1. Water and land use are inextricably linked with each other, and, thus, the external pressures on either water or the land result in chains of impacts on both. Flood risk is characterized by nonlinear and non-stationary interactions. Flood risk is a Multi-dimensional phenomenon that involves physical as well as social dimensions such as political, institutional, economic, etc. Long-term planning and management of flood risk are challenged by uncertainty due to the changes in precipitation patterns, land-uses, and changes of contested stakeholder priorities. Flood risks indicate an inadequacy of existing policies and practices in flood risk management. Moreover, flood risk is due to ill recognition and managing of complexity & uncertainty due to socio-spatial-temporal interactions of flood risk. A comprehensive understanding of flood risk requires a systems-based approach. Assessment and managing of flood risk are required a shared understanding of risk with the stakeholders. Thus, FRM is not a problem-solving process rather it is the managing of causative factors of the flood risk. Decision-makers makers of FRM have questioned that the flood occurrence is an unavoidable phenomenon and how to manage the complexity and the uncertainty incorporated with flood risk. Probability-based flood damage assessment is inadequate for decision-making. Therefore, it is required to undertake flood vulnerability assessment to bring flood resilience. Accordingly, flood risk management requires adaptive flood risk management measures. The decision-making process which is based on flood management is required to transform towards flood risk management to cope up with future uncertainties.					
2. Operationalization of flood risk management requires an adaptive and integrated planning process.					
3. The planning process of Flood risk management involves many stakeholders each with their perspectives, objectives, and priorities; hence the process of flood risk management depends upon the governance structures in					

place. Operationalization of the flood risk management depends on how stakeholders appreciate the adaptive and integrated planning process. The planning process is influenced by a dense network of relations, with stakeholders holding various powers, resources, and competencies. Operationalization of FRM is dependent mainly on the planning process as well as the governance network of relations, with stakeholders holding various powers, resources, and competencies. Therefore, the operationalization of flood risk management is determined by the adaptive capacity of 1.1. Planning process & 1.2. Governance of the context					
4. Evaluation of alternative goals & strategies in the Planning process for flood risk management is a critical task due to the inherent uncertainty of flood risk. Therefore, operationalization of Flood risk management requires a common decision-making framework that recognizes the interdependency of stakeholders and hence optimizes the objectives of all stakeholders.					
5. Multi-criteria decision support models in the Planning process for flood risk management are required to evaluate and trade-off multiple, objectives of stakeholders in the planning process. Therefore, multi-criteria decision-making tools such as the Analytical hierarchical process (AHP) imported to handle quantitative and formulate stakeholders' values and preferences, quantifying these priorities and applying them to planning processes.					

The questionnaire used for confirmation of the proposed framework

Goal - Development of a Framework to Operationalize Flood Risk Management

Identification of criteria & sub-criteria

Goal - Operationalization of flood risk management						
Adaptive capacity	Integrated adaptive FRM system Main Criteria	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1.1. Planning process	The adaptive capacity of the flood risk management system is determined by the four criteria as follows. 1.1.1. Conceptualization of planning process					
	1.1.2. Assessment of the planning process					
1.2. Governance of the context	1.2.1. Discourse of the stakeholders in the governance context					
	1.2.2. Interaction mechanism of stakeholders for participatory decision making.					
	Other (your recommendation)					

Identification of main criteria

Main dimensions of the framework	Criteria of the framework to structure the planning process of FRM		Strongly agree	Agree	neutral	Disagree	Strongly disagree
Planning process	Conceptualization	1.1.1 Flood risk management system includes the definition of integrated objectives, strategies, guidelines, and outcomes. This definition is carried out because the stakeholders of the system characterize and assess the flood risk following the non-linear interactions of flood risk. Accordingly, the assessment of flood risk and the evaluation of alternative management measures are based on the multiple objectives of these stakeholders at multiple scales as well as multiple scenarios, focusing mainly on long-term social wellbeing. Therefore, Conceptualization of the planning process means that the stakeholders consider Flood Risk Management to be a continuous, integrated, socially analyzed, and evaluated process to manage the uncertainty.					
	Assessment	1.1.2 Assessment of the planning process means the understanding of the uncontrollable nature of flood occurrence. Therefore, the role of the planning process is the identification of flood risk management measures to increase the adaptive capacities of the social system to manage the uncertainty. Increasing the adaptive capacity of these social systems can thereby involve effectively in the face of diverse scenarios of flood risk. This is done by creating a synergy between multiple objectives of multiple stakeholders at different scales, while considering the integration of the knowledge and the interactions of stakeholders.					

Planning context	Discourse	1.2.1. The discourse of the stakeholders describes the policy principles of the knowledge system of the stakeholders. Stakeholders have recognized the significance of integrated and adaptive goals & strategies for FRM as well as the consideration of the social & spatial independence of flood risk for the long-term wellbeing of the society. Therefore, the Knowledge system of the stakeholders has been recognized to be of utmost importance in the participatory decision-making & implementation process in the operationalization of flood risk management.					
	Participatory governance	1.2.2 Governance mechanism means the availability of an integrated interaction mechanism among stakeholders to share Power & resources for collaborative decision making, and implementation of flood risk management goals, strategies, and guidelines. Governance of the system has recognized and facilitated the legitimacy of the participation of stakeholders in the decision-making & the practice of flood risk management.					

1.2 Selection of sub-criteria

Main criteria of the framework	Sub criteria of the integrated adaptive FRM framework	Strongly agree	Agree	neutral	Disagree	Strongly disagree
1.1.1 Conceptualization of the complexity/Nonlinearity, Nonstationarity of flood risk by the mandatory stakeholders in the planning process.	a) Flood risk is a complex phenomenon and there are interdependencies between social, hydrological, ecological, etc subsystems. Therefore, FRM includes multiple stakeholders from multiple sectors.					
	b) Flood risk management is influenced by multiple factors at diverse spatial scales. Scale					

	sensitivity of flood risk and therefore, the importance of assessing/managing flood risk at a different scale. Therefore, analysis and management of flood risk are required based on the scales.					
	c) There are inherent uncertainties in the flood risk management decision-making process due to diverse stakeholders with multiple knowledge and interpretations of flood risk management being involved in the process of decision making. Therefore, the planning process is to be continuous and based on the social learning process.					
	d) Decision-making process of Flood risk management has required the integration of the multiple objectives of all stakeholders.					
	a) Other (Please Specify)					

Criteria	Sub criteria	Strongly agree	Agree	neutral	Disagree	Strongly disagree
1.1.2 Assessment of the planning process/assessment of the impact of uncertainty & identify the potential ways to manage uncertainty. (selecting of flood risk management goals and the strategies to cope up with the social-spatial & temporal dynamic coevolved interactions of the flood risk) different climatic scenarios	a) Identification of the potential strategies to increase the adaptive capacities to maintain the ecological functions of the floodplains with different climatic scenarios rather than design strategies of flood control measures based on probability thresholds of flood events.					
	b) Identification of diverse flood management measures (including measures to increase resistance capacity, recovering capacity, the transformative capacity to manage the uncertainty of flood risk of different scenarios) to manage flood vulnerability with different climatic scenarios.					
	c) Identification of the potential flood management strategies for Maintenance of Hydrological integration over the watershed/ spatial integration to management uncertainties of different climatic scenarios.					
	d) Identification of the potential flood management strategies to increase social integration / multifunctional land uses over floodplains by identifying commonly acceptable thresholds integrating the diverse spatial claims of stakeholders/ social integration (trade-offs of multiple social interactions of flood risk) to cope up with different climatic scenarios.					
	e) Other (Please Specify)					

Criteria	Sub criteria	Strongly agree	Agree	neutral	Disagree	Strongly disagree
1.2.1. Knowledge system of the governance context/discourses of stakeholders is recommended the importance of participatory decision-making process for operationalization of flood risk management.	a) Institutionalizing of adaptive planning (social learning of stakeholders)					
	b) Institutionalizing of Multilevel governance mechanism					
	c) Institutionalizing of Flexibility in governance arrangements & decision making & implementation					
	d) Institutionalizing of /Legitimization of Local initiatives & community participation for decision making & implementation.					
	e) Other (Please Specify)					

Criteria	Sub criteria	Strongly agree	Agree	neutral	Disagree	Strongly disagree
1.2.2 Participatory mechanism or governance tools to power & resource distribution patterns among stakeholders of the governance systems	a) Mechanisms available for Integration among the land & water institutions at all scales and levels					
	b) Mechanisms available for Integrated goal setting & catchment-wide approach for decision making					
	c) Mechanism available for Multiple regime Governance Traditions (top-down + bottom-up)					
	d) Mechanism available / Legitimized tool availability for Empowering local stakeholders in decision making & implementation of FRM system (spatial planning)					

The questionnaire used for Prioritization of criteria & sub-criteria

Please prioritize the importance of following sub-criteria to operationalize flood risk management. Sub parameters are to be ranked on a scale of 100 in total. Please any comment on any other additional sub-criteria that requires to be included in the list. The score for Each subparameter without considering the main parameter.

Main criteria of the framework	Sub criteria of the integrated adaptive FRM framework	Score out of 100
1.1.1 Conceptualization	a) Flood risk is a complex phenomenon. There is an interdependency between social, hydrological, ecological subsystems which are incorporated with Flood risk. Therefore, FRM includes stakeholders from multiple sectors.	
	b) Flood risk management is influenced by multiple factors at diverse spatial scales. Scale sensitivity of flood risk and therefore, the importance of assessing/managing flood risk at a different scale. Therefore, analysis and management of flood risk are required based on the scales.	
	c) There are inherent uncertainties in the flood risk management decision-making process due to diverse stakeholders with multiple knowledge and interpretations of flood risk management being involved in the process of decision making. Therefore, the planning process is to be continuous and based on the social learning process.	
	d) Decision making process of Flood risk management is required the integration of the multiple objectives of all stakeholders.	
	e) Other (Please Specify)	

Main criteria of the framework	Sub criteria of the integrated adaptive FRM framework	Score out of 100
1.1.2 Assessment of the planning process	a) Identification of the potential strategies to increase the adaptive capacities to maintain the ecological functions of the floodplains with different climatic scenarios rather than design strategies based on probability thresholds.	
	b) Identification of diverse flood management measures (including measures to increase resistance capacity, recovering capacity, the transformative capacity to manage the uncertainty of flood risk of different scenarios) to manage flood vulnerability with different climatic scenarios	
	c) Identification of the potential flood management strategies for Maintenance of Hydrological integration over the watershed/ spatial integration to management uncertainties of different climatic scenarios.	
	d) Identification of the potential flood management strategies to increase social integration / multifunctional land uses over floodplains by identifying commonly acceptable thresholds integrating the diverse spatial claims of stakeholders/ social integration (trade-offs of multiple social interactions of flood risk) to cope up with different climatic scenarios.	

	Other (Please Specify)	
Main criteria of the framework	Sub criteria of the integrated adaptive FRM framework	Score out of 100
1.2.1. Knowledge system of the governance context	a) Institutionalizing of adaptive planning	
	b) Institutionalizing of Multilevel governance system	
	c) Flexibility in governance arrangements & adaptive decision making & implementation	
	d) Legitimization of Local initiatives & community participation	
	e) Other (Please Specify)	

Main criteria of the framework	Sub criteria of the integrated adaptive FRM framework	Score out of 100
1.2.2 Mechanisms available for Participatory governance	e) Mechanisms available for Integration among the land & water institutions at all scales and levels	
	f) Mechanisms available for Integrated goal setting & catchment-wide approach for decision making	
	g) Multiple regime Governance Traditions (top-down + bottom-up)	
	h) Legitimized tool availability for Empowering local stakeholders in decision making & implementation of FRM system (spatial planning)	
	i) Other (Please Specify)	

Prioritization of Main criteria

Please prioritize the relative importance of the following main criteria for the operationalization of flood risk management. The main parameter weights are expected to be presented as a percentage.

Main criteria to define the adaptive capacity	Weight / 100
1.1.1 Conceptualization of the complexity/Nonlinearity, Nonstationarity of flood risk by the mandatory stakeholders in the planning process	
1.1.2 Assessment of the planning process/assessment of the impact of uncertainty & identify the potential ways to manage uncertainty.	
1.2.1. Knowledge system of the governance context/discourses of stakeholders / Conceptualization of FRM system by other stakeholders in the context/ discourses of related stakeholders	
1.2.2 Participatory governance / Power & resource distribution patterns among stakeholders of the governance systems	
Total	

Appendix C: Questions used for validation of the framework

Validation of the framework for operationalization of flood risk management

1. Flood risk management strategies in Panaduara
2. Objectives of the project
3. Project design
 - Consideration factors
 - Scope of the project
 - Scenarios
 - The extent of the project
 - Stakeholders
 - Role of local communities
4. Project implementation process
 - Stakeholders in the implementation process
 - Implementation mechanism
- 5 Monitoring process
 - Indicators
 - Monitoring process
 - Revision process
5. Conformity with existing socio-economic development projects
6. Barriers

Criteria	1	2	3	4	
1. What are the flood risk management strategies?	Hazard controlling strategies	Floodplain conservation strategies	Local community integration strategies	Regional communities' integration strategies	Other
2. What are the Local Factors Considered for designing the project?	Spatial distribution of water flow pattern of the Karepen Ela. Precipitation pattern of the area.; Rainfall intensity/	Floodplain of the area / coastal connection/ natural landscape of the Panadura area	Human settlement pattern / Land use pattern	Stakeholders perceptions	

	Rainfall duration /Frequency				
3. What are the Regional & other factors considered for designing project	Land-use changes the catchment	Regional urban growth	Infrastructure development, industrial development Urban migration Tourism development	Climatic condition Sea level rise Urbanization	
4. What are the scenarios considered for designing the project?	Extreme flood events	Land-use changes/reclamation of catchment	Population growth, urban development trends	Policy changes in the industry, tourism, urban development	
5. Who are the stakeholders involved in designing the project?	Hydrologists, flood controlling agencies	Environmental authorities, agrarian department, water management authorities to maintain the ecological stability of the area, rich biodiversity, etc.	Urban development authorities, real estate developers, local authorities, communities to sustainable urban growth.	Regional urban development agencies, etc, disaster management, policymakers at the regional level	
6. What are the objectives of the flood risk management strategies?	To manage the extreme events and flood damage	To maintain the ecological stability of the area, rich biodiversity, etc.	To improve the spatial quality, recreational values, improvement of the land values	To decrease the flood damage cost, relief cost, management cost, etc	

7. Have you considered the dynamics of the flood that occurred during the design project?	Annual floods	25year recurrence	50- 100-year recurrence	Extreme / rare flood occurrence	
8. Have you considered the dynamics of the land-use changes of the catchment	Residential land use growth	Industrial land use growth	Tourism growth	Infrastructure growth	
9. How do you consider the hydrological function of catchment during designing the flood risk management strategies?	Hydrological connectivity between Upper & lower catchment.	Hydrological connectivity between Groundwater & surface water	Hydrological connectivity between freshwater and coastal zone	Overall water balance of the catchment; Surface runoff, baseflow, precipitation, etc	
10. What are the objectives of the flood risk management strategies?	Provisioning services of the floodplains; to Reduce flood damage to downstream public/private infrastructure (number of structures and/or extent of	Regulate functions of the floodplains (flood storage and groundwater recharge water filtration soil formation soil retention buffer protection micro-climate regulation greenhouse gas	Supporting functions of the floodplains, for example, bird habitat fish habitat frog habitat floodplain vegetation	Cultural Services of the floodplains; aesthetics recreation heritage	

	damage) Reduced livestock losses (number) Reduced crop losses (area) Reduced financial cost (level of emergency response during the flood event) Reduced financial cost (post-flood recovery)	regulation water treatment)			
11. What are the other institutions you have shared knowledge and the information during designing & implementation of the project?	Water-related agencies in the decision-making process.	with land development agencies	With local communities in the decision-making process.	With the politicians, etc in the decision-making process.	
12. What is the available mechanism for that?	Interactive mechanism available for Top-down interactions among	The interactive mechanism is available for bottom-up interactions among the	The interactive mechanism is available for Multisector interactions among the	The interactive mechanism is available for Global-scale interactions among the	

	the stakeholder s in the decision-making process	stakeholders in the decision-making process.	stakeholder s in the decision-making process.	stakeholder s in the decision-making process.	
13. Which are the other institutions you have shared Resources & power in designing the implementation of the project	Water-related agencies in the decision-making process.	with land development agencies	with local communities in the decision-making process.	With the politicians, etc in the decision-making process.	
14. What is the available mechanism for that?	Interactive mechanism available for Top-down interactions among the stakeholders in the decision-making process	The interactive mechanism is available for bottom-up interactions among the stakeholders in the decision-making process.	The interactive mechanism is available for Multisector interactions among the stakeholders in the decision-making process.	The interactive mechanism is available for Global-scale interactions among the stakeholders in the decision-making process.	
15. How do you monitor the effectiveness of the flood risk management project?	Hydrologists	Urban developers	Communities	The local authority, politicians	
16. Have revised the project designing and the implementing process	Guidelines change	Strategies changes	Objectives changes	Monitoring indicators changes	
17. What are the available	Participation of	Participation of Regional-	Participation of	Participation of Global	

mechanism for changing the project goal, strategies and guidelines?	Local-scale stakeholders' provision for catchment-wide decision making.	scale stakeholders provision for catchment-wide decision making	National level scale stakeholders for catchment-wide decision-making.	level scale for catchment-wide decision making.	
18. What is the mandatory requirement for local community participation in designing, implementing, and monitoring the project?	Policy provision for Community participation in decision making in risk assessment	Policy provision for Community participation in goal defining	Policy provision for Community participation in guideline defining	Policy provision for Community participation in local & regional scales at decision-making process and implementation process / multiple scales	
19. What are the available mechanism for that?	Tools available for Community participation in decision making in risk assessment	Tools available for Community participation in goal defining	Tools available for Community participation in guideline defining	Tools available for Community participation in local & regional scales at decision making process and implementation process / multiple scales	

Appendix D: Consensus development with the experts

Prioritization of criteria and sub criteria with the experts (negotiated values)

Prioritization of criteria and sub criteria with the experts

Prioritization of main criteria

Probability of exceedance (%)	Conceptualization	Assessment	Discourse	Participatory
LOW (>75%)	70	100	80	40
Moderate (50-75%)	60	90	70	30
Moderate - High (25-50%)	55	80	65	25
High (>25%)	50	65	50	20
Consensus reached value	60	100	25	65

Prioritization of sub-criteria – conceptualization

Probability of exceedance (%)	Complexity	Scale	Unpredictable	Integration
LOW (>75%)	55	40	85	100
Moderate (50-75%)	45	30	75	95
Moderate - High (25-50%)	40	25	65	85
High (>25%)	30	20	55	75
Consensus reached value	40	25	70	100

Prioritization of sub-criteria – Place-based assessment

Probability of exceedance (%)	Adaptive capacity	Diverse scenario	Hydrological connectivity	Social tradeoff
LOW (>75%)	95	50	35	25
Moderate (50-75%)	87.5	45	25	15
Moderate - High (25-50%)	85	40	20	15
High (>25%)	80	35	15	10
Consensus reached value	85	45	22	15

Prioritization of sub-criteria – Discourse of the stakeholders

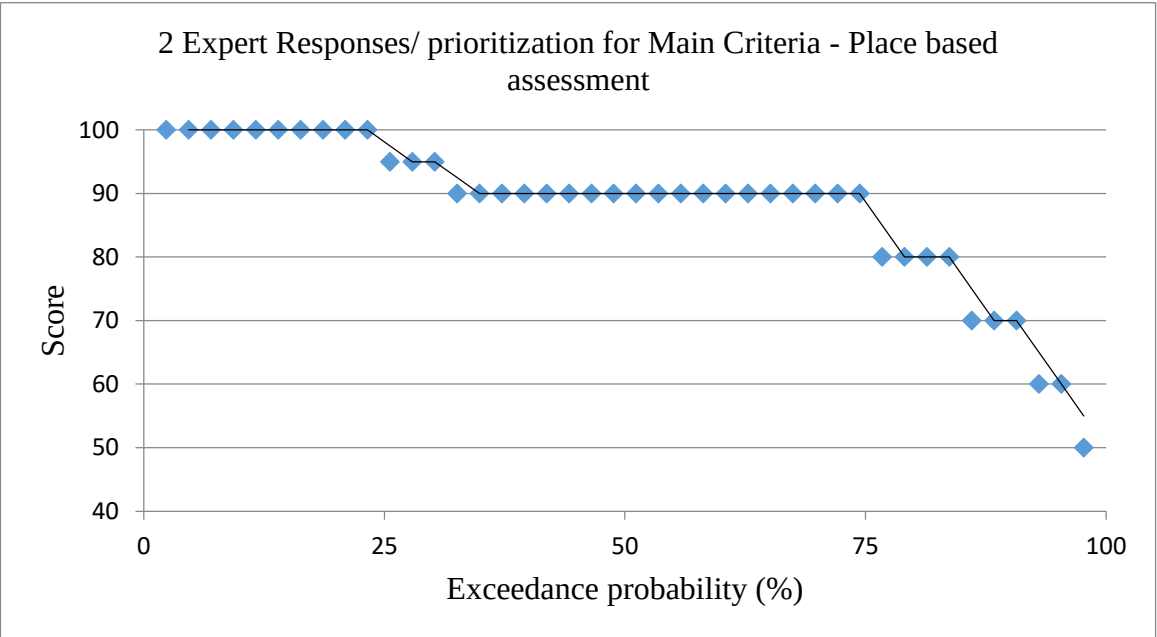
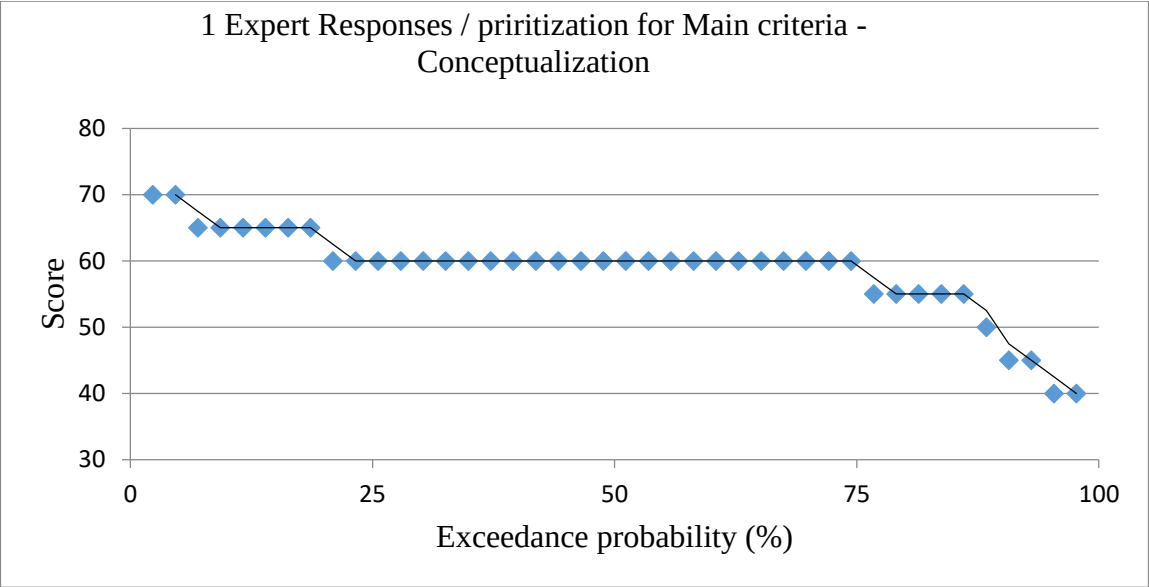
Probability of exceedance (%)	Social Learning	Multilevel	Flexible	Local
LOW (>75%)	95	30	70	40
Moderate (50-75%)	85	20	60	50
Moderate - High (25-50%)	80	15	55	55
High (>25%)	75	10	50	40
Consensus reached value				

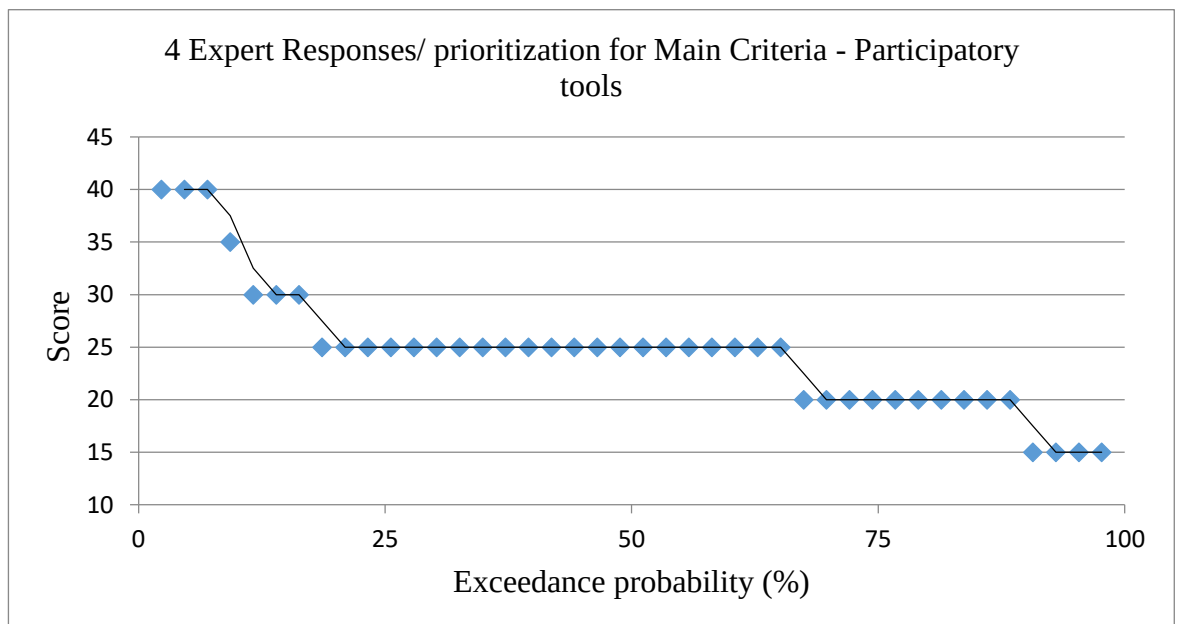
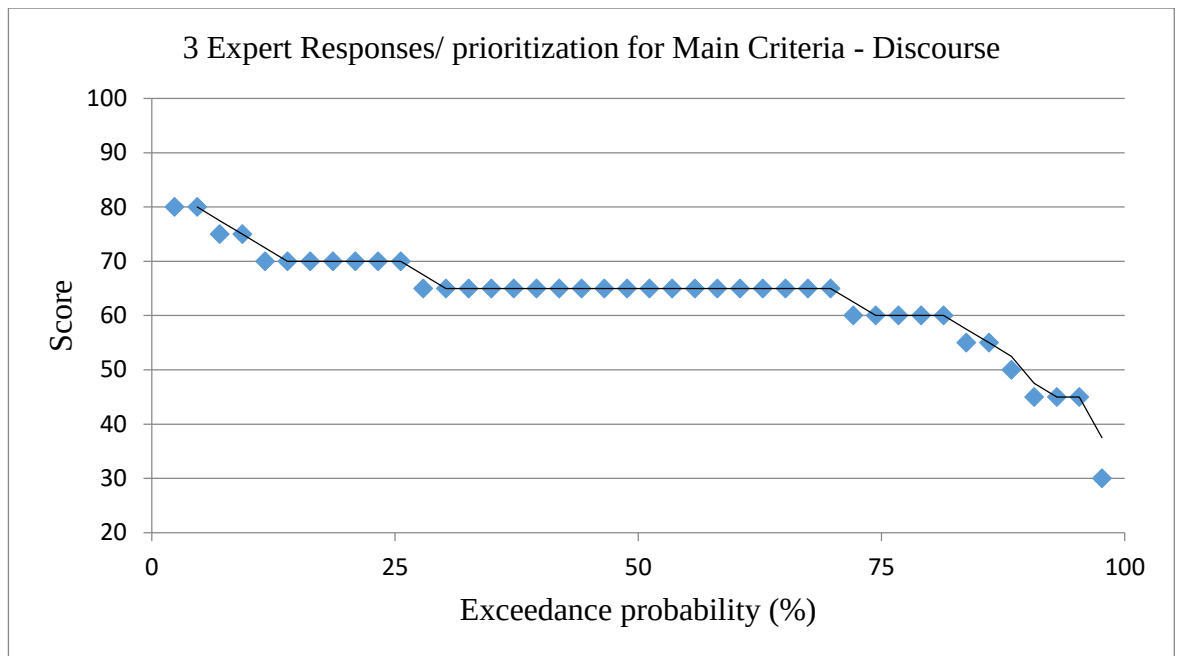
Prioritization of sub-criteria – Participatory governance tools

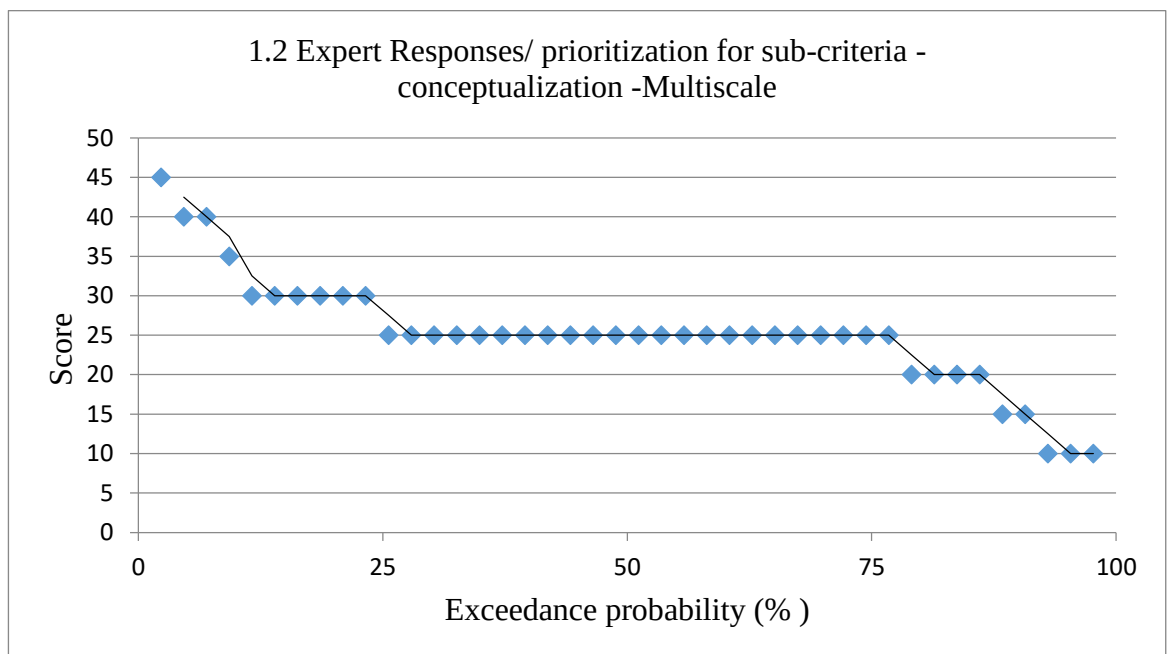
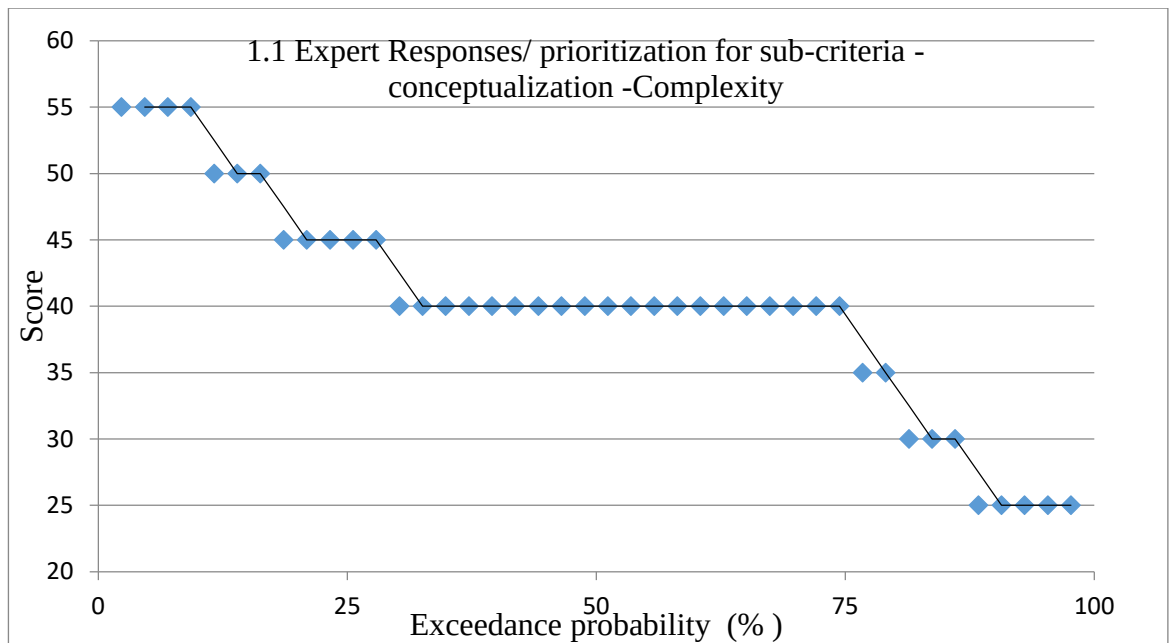
Probability of exceedance (%)	Land and water	Catchment	Flexible	Local community
LOW (>75%)	55	40	35	80
Moderate (50-75%)	65	30	30	70
Moderate - High (25-50%)	70	25	25	65
High (>25%)	85	20	20	55
Consensus reached value	65	30	22	65

Probability charts for each main and sub-criteria of the framework

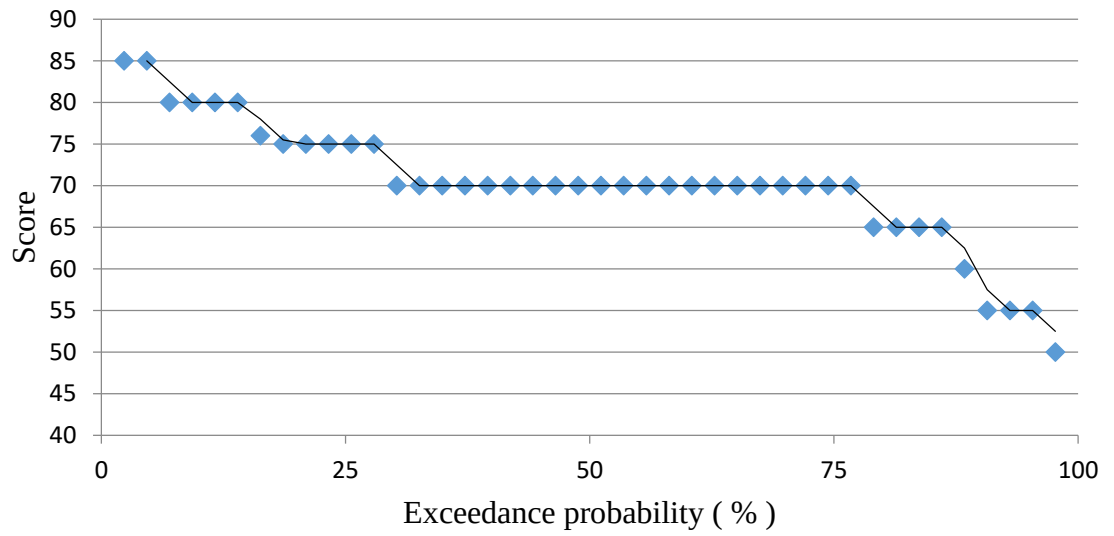
The percentage (%) exceedance of probability curves for the main criteria and sub-criteria of the framework were plotted.



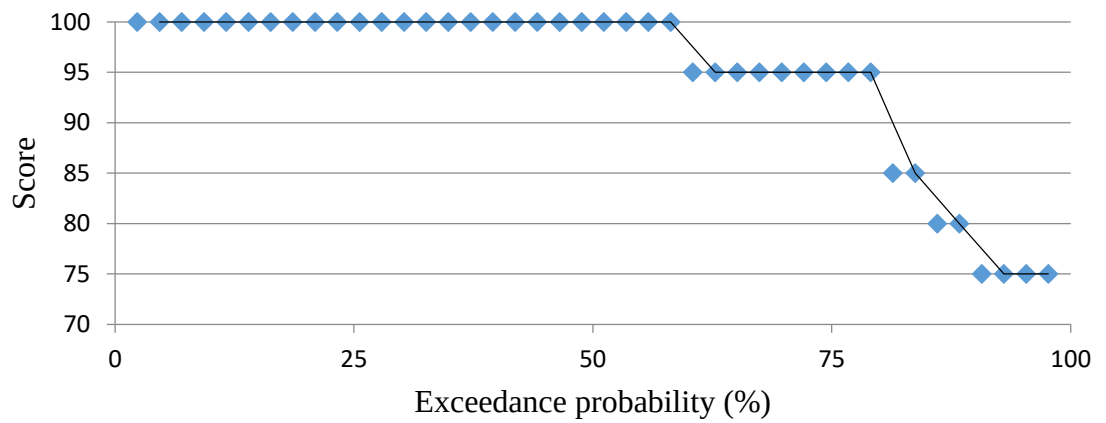


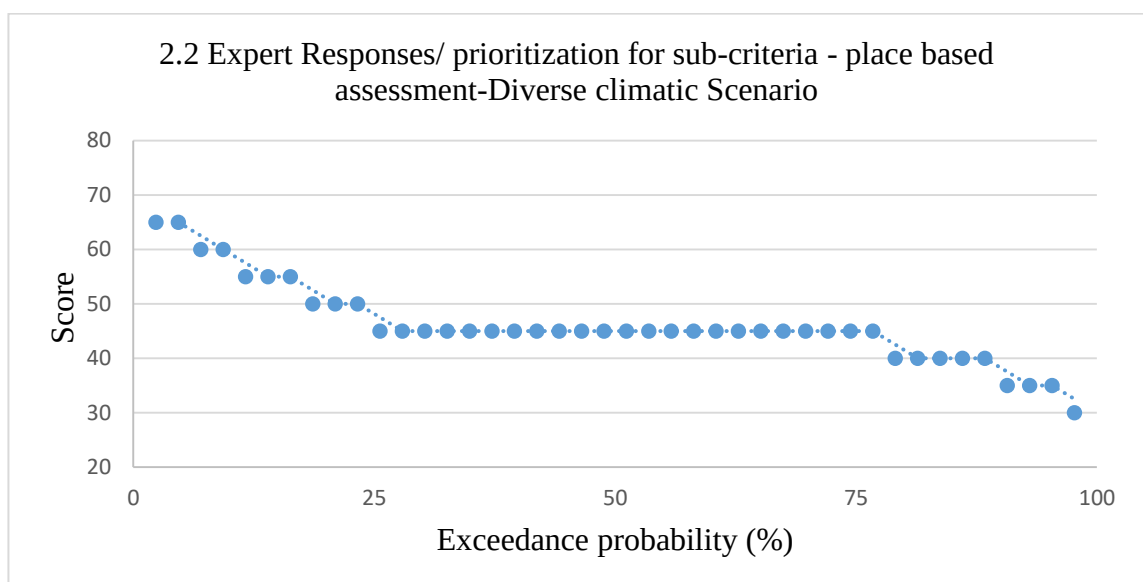
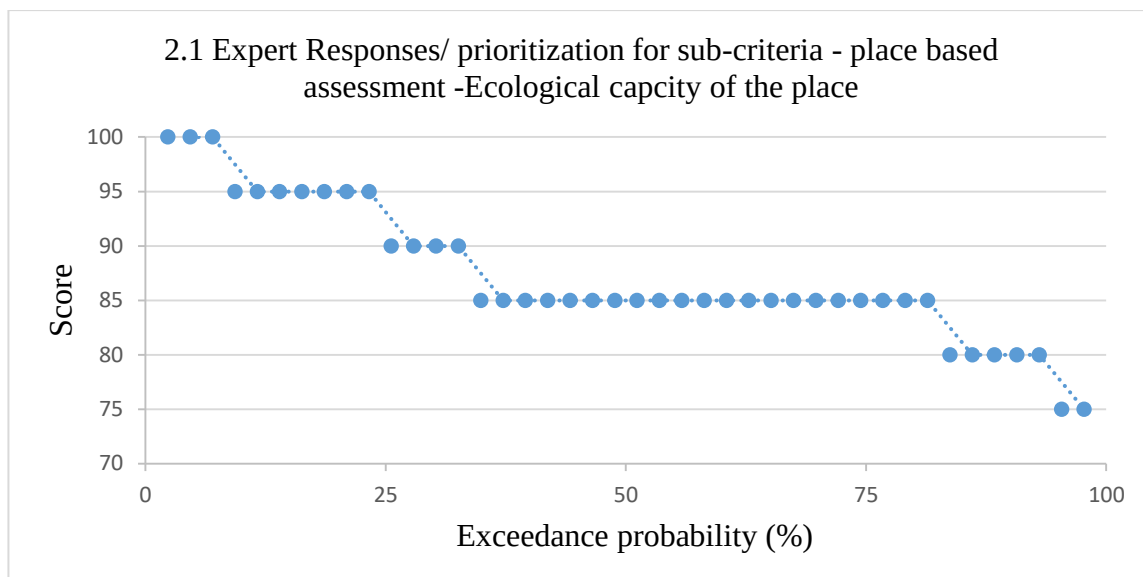


1.3 Expert Responses/ prioritization for sub-criteria -
conceptualization -Unpredictable

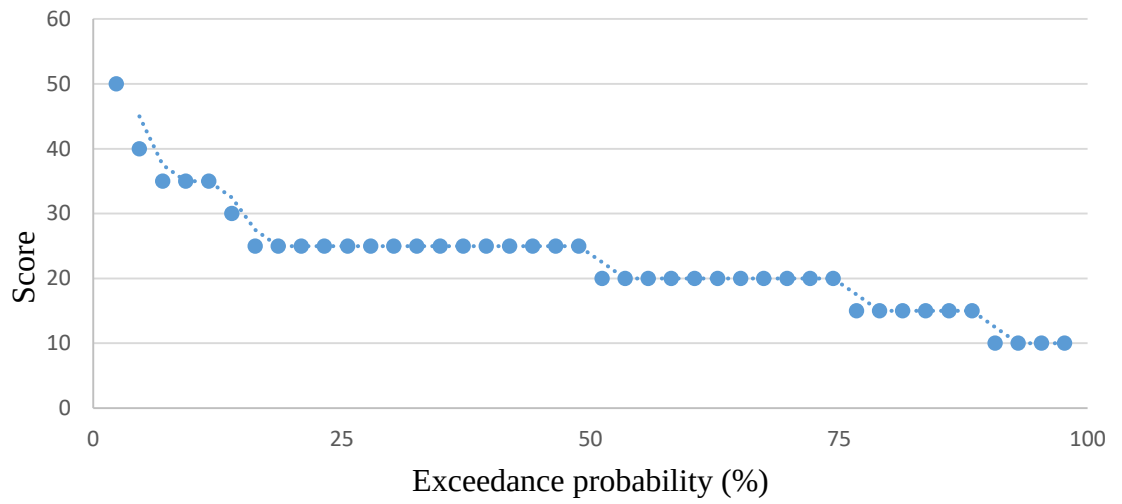


1.4 Expert Responses/ prioritization for sub-criteria -
conceptualization -Social assessment & integration

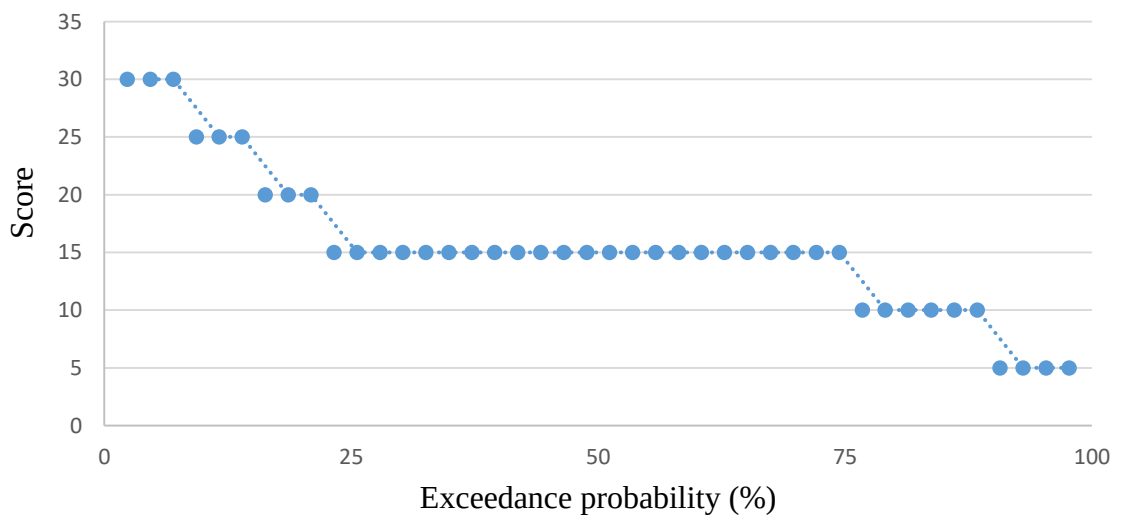




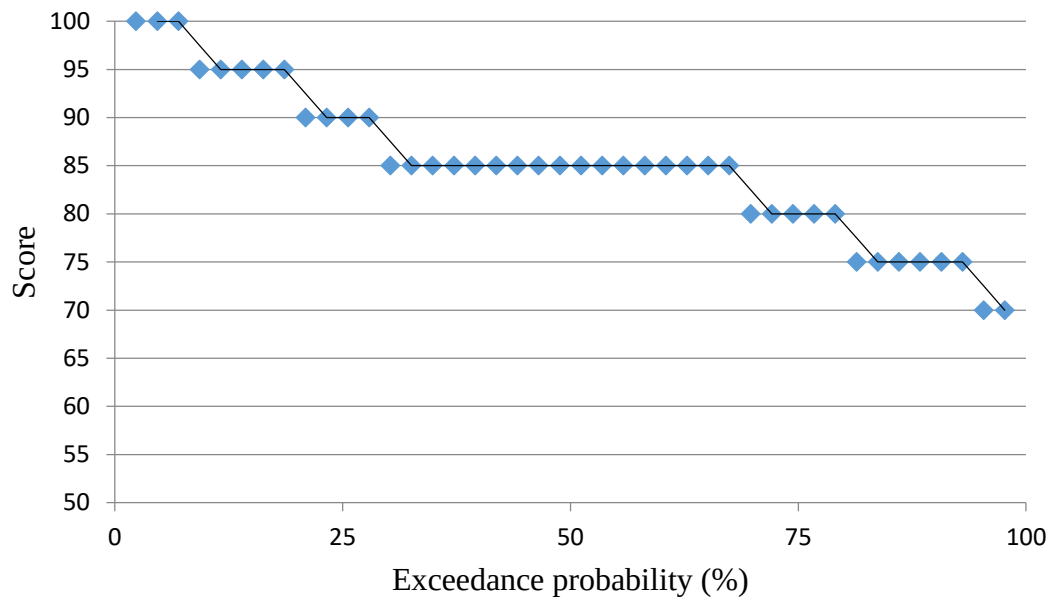
2.3 Expert Responses/ prioritization for sub-criteria - place based assessment-Hydrological Connectivity



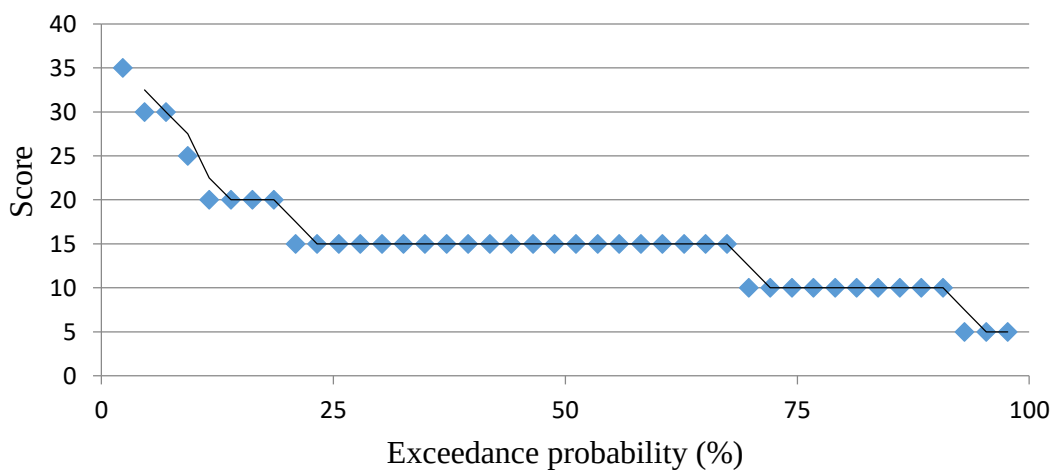
2.4 Expert Responses/ prioritization for sub-criteria - place based assessment- Social Tradeoff



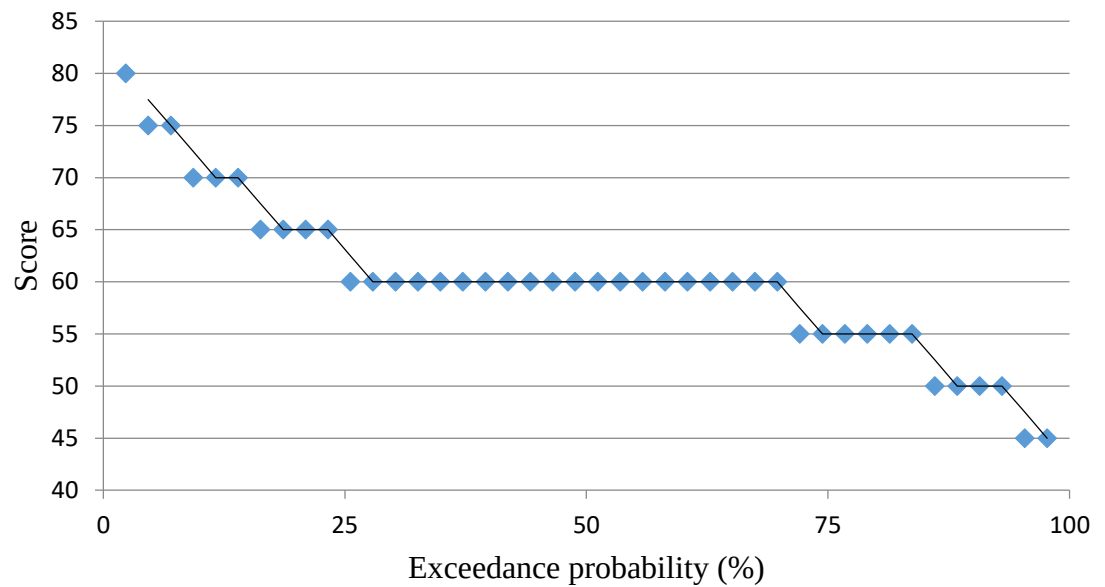
3.1 Expert Responses/ prioritization for sub criteria: Discourse - Adaptive Planning / social learning



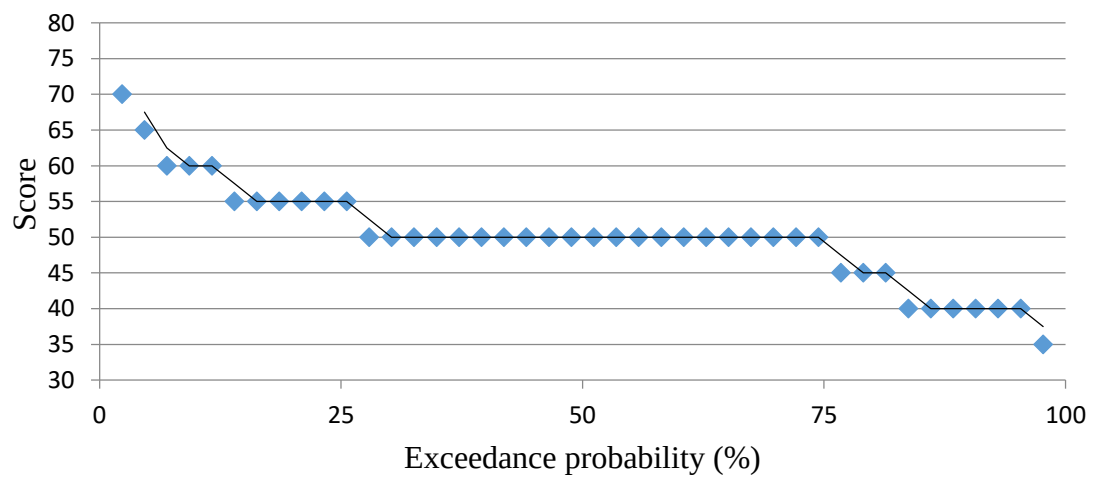
3.2 Expert Responses/ prioritization for sub criteria: Discourse - Multilevel / multi scale integration



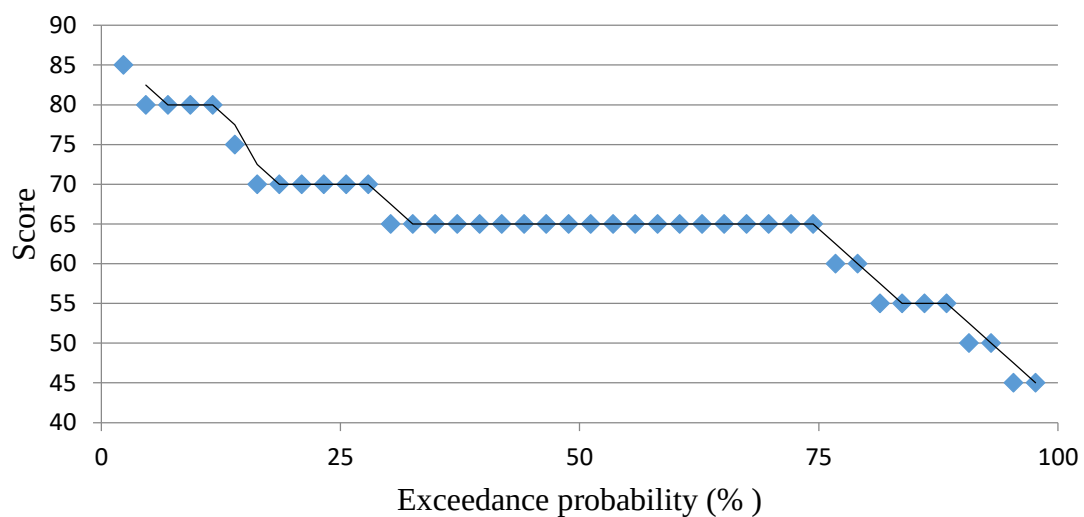
3.3 Expert Responses/ prioritization for sub criteria: Discourse- Flexible decision making process



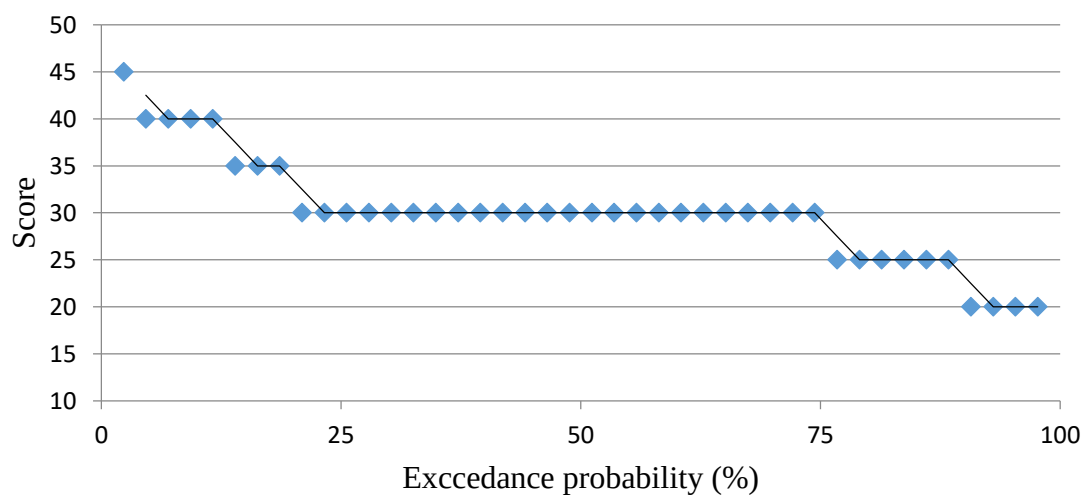
3.4 Expert Responses/ prioritization for sub criteria: Discourse - Local community participation



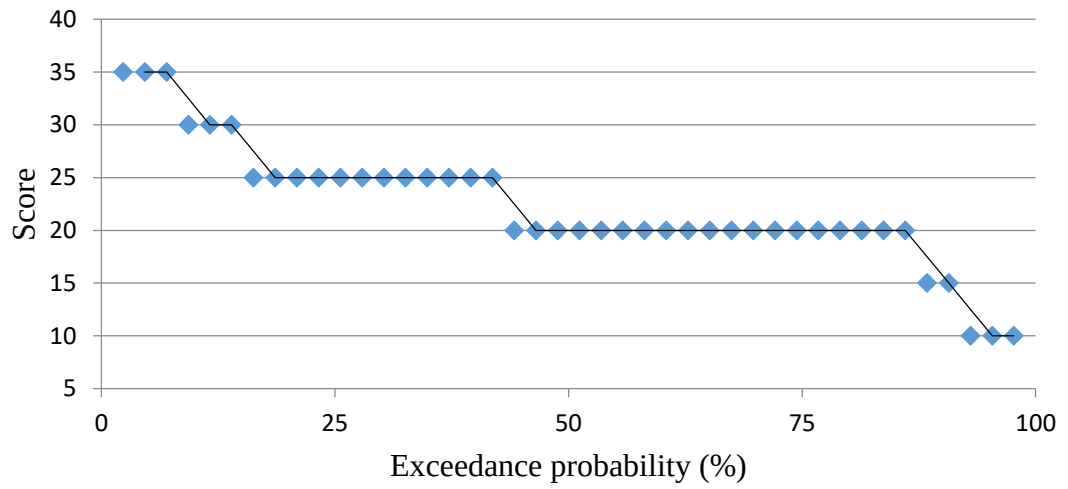
4.1 Expert Responses/ prioritization for sub-criteria: Participatory tools for Land & water integration



4.2 Expert Responses/ prioritization for sub-criteria: Participatory tools for Catchment scale decision making



4.3 Expert Responses/ prioritization for sub-criteria: Participatory tools for Flexible decision making



4.4 Expert Responses/ prioritization for sub-criteria: Participatory tools for Local community participation

