USER REQUIREMENTS TO SUPPORT FUNCTIONAL CHARACTERISTICS OF A DIGITAL EARLY WARNING SYSTEM FOR DAM FAILURES IN SRI LANKA

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DEDICATION

To my beloved Parents and Sisters.....

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ABSTRACT

User Requirements to Support Functional Characteristics of a Digital Early Warning System for Dam Failures in Sri Lanka

Dam failure is one of the most prominent disasters which created very bad impacts on humans as well as the properties. In terms of reducing the impacts of dam failures, early warning systems (EWS) play a major role by creating linkages between the dam safety procedures and the dam stakeholders. Currently, Sri Lanka is using a manual EWS for dam failures, and as a developing country, need to change for a digitalised EWS that consists of a digital platform for dam failures with the aim of reducing the impacts and increasing efficiency and the accuracy. Therefore, this study intends to enhance the functional characteristics of a digital EWS to reduce the impacts of dam failures in Sri Lanka.

The study takes an interpretivism stance in the research philosophy, where qualitative survey was the main research strategy. Semi structured interviews and focus group discussions formed the primary data collection techniques. Manual content analysis and user story analysis were used to identify the causes and impacts of dam failures, functional characteristics of the EWS with supporting system views, user requirements for an effective EWS for dam failures, and the characteristics of the digital platform to support the functional characteristics of the EWS used for dam failures in Sri Lanka. Empirical findings revealed that design, technical, and management causes act as the internal causes for dam failures while natural disasters, and human and animal acts act as the external causes for the dam failures. The loss of human life, social, environmental, economic, institution and political impacts were identified as the impacts of dam failures in Sri Lanka. The main functional characteristics considered for the design of the EWS were identified as forecasting and evaluating the risks, monitoring and detection, and warning and evacuation. Accordingly, data, community, communication, institution or stakeholder, and technology are the system views that support the functional characteristics of the EWS. However, thirty-two (32) user requirements were identified through the focus group discussion, and accordingly, the features were analysed for the digital platform for the EWS of dam failures in Sri Lanka. Finally, a framework has been developed by incorporating all the findings of the study. Hence, that will be beneficial to reduce the impacts of the dam failures in Sri Lanka by making speed and accurate warnings.

Keywords: Causes, Characteristics, Dam failure, Digital Platform, Early Warning System (EWS), Impacts, User Requirements

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EWS - Early Warning System

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CHAPTER ONE

INTRODUCTION

CHAPTER ONE

1. INTRODUCTION

1.1 Research Background

Dams are transverse engineering constructions that vary in size and height and are composed of a variety of materials such as loose pebbles, wood, concrete blocks, or rocks in gabion baskets (Lucas-Borja et al., 2021). They are built by spanning ephemeral or permanent torrents, gullies, and streams (Patel, 2012). These structural components have a long tradition of use in particular hydrologic restoration, erosion minimisation, and land management, and they can be found all over the world (Mekonnen et al., 2014). Dams have always been associated with humanity's development process (Chen et al., 2016). Hence, dams are categorised as large or small, and this categorisation is specifically related to the primary function and application of the structure (Nascimento & Ribeiro Neto, 2017). Dams have served a variety of purposes over the years, and their widespread use is because of the systematic knowledge applied in the design and protection of structures (Hsiao et al., 2021). Hsiao et al. (2021) further asserted that studies and scientific discoveries precede, accompany, and enhance these structures. According to Lucas-Borja, et al. (2021) dams are used to improve the land, manage soil erosion, and moderate water and sediment flow. Hence, dams, irrespective of their size, represent a diverse range of purposes; dams primarily deliver power generation, but they are also employed for flow control, navigation, agrarian supplies (primarily for small properties), and water accumulation (Nava et al., 2021).

A dam failure occurs when a limited or unlimited capacity of fluid, pieces or their mixture collapses onto a horizontal or inclined channel (Chanson, 2006). According to Chanson (2006), it symbolises a broad range of practical problems with significant engineering implications. Among the most well-known examples are the collapses of water reserving dams and earth filling tailing dams (Di Cristo et al., 2010). The failure of these dams could have disastrous consequences for both human life and property (Li & Zhao, 2018). Dam failure can be caused by a variety of factors (Gregoretti et al., 2010). According to Gregoretti et al. (2010), the main causes of tail dam failure are unusual weather and poor dam management, whereas dam material, seepage, geometric dam configuration, and reservoir level all influence the stability of a landslide dam. The most corporate reason for dam failure, especially for moraine dams and earthen embankments, is overtopping (Balmforth et al., 2008).

As per Viseu and Betâmio de Almeida (2009), dam accidents, including structure failure, pose serious risks to people and property. Despite increased dam safety as a consequence of enhanced engineering skills and higher construction quality, a completely risk-free warranty is not feasible, and an unfortunate incident can occur as a result of reducing the strength with the age, human actions, or natural hazards (Ge et al., 2020). Further, Ge et al. (2020) highlighted that those all justify an increased focus on dam security and valley management. Prospective dam failures, as well as public pressure for a secured surrounding, advocate dam risk assessment and reduction in downstream valleys in modern society (Green & Baird, 2020). Some modern technical guidelines and safety legislation encourage and assist dam failure flood risk management (Hsiao et al., 2021), which makes a significant involvement to public safety through downstream valleys as well as economic and environmental resource protection (Viseu & Almeida, 2009).

The latest dam failure happenings in the United Kingdom and the United States emphasise the significance of downstream populations being mindful and well educated about risks so that they can agree and react to warnings in a reasonable and timely manner (Mehta et al., 2020). Following the required evacuation order for 188,000 people downstream of Oroville Dam, for example, some members of the community did not disperse as instructed because they were unsure whether the dam would actually fail, desired to safeguard property, and managed to avoid traffic congestion (Hollins et al., 2018). Hariri-Ardebili (2018) asserted that dam failure can be initiated by operational flaws in the initial design, dam age, or exterior events such as natural disasters that generate conditions which can exceed the dam capacities, having a devasting impact on downstream populations, property, infrastructure, and livestock in the same way that severe flash flooding does. Outside of the dam safety community, international bodies and emergency management organisations have recognised a lack of awareness about the dam failure effects (Mehta et al., 2020).

Mehta et al. (2020) have revealed two critical stages in dam failure risk management: forecasting damages or harms and their possibility via risk assessment and determining risk mitigation strategies while residual outstanding risks are unacceptable. Dam failure risk assessment determines the degree of the flood hazard that could occur as a result of a dam failure, guesses its main outcomes, and assesses its significance (Celik & Gul, 2021). Dam risk management is the result of fundamental factors: a dam is at all times a potential hazard, and there is a necessity to ensure rational and sensible safety to those concerned in the event of an accident (Hollins et al., 2018). The primary goal of dam failure risk management and hazard mitigation is to lower the propable human losses and downstream injuries associated with dam accidents by implementing both structural and nonstructural measures (Mehta et al., 2020). The results of the risk analysis and risk evaluation processes are integrated into risk assessment, and recommendations regarding the need to reduce or simply control the residual risks are made (Bedford, 2013). Oanh (2020), further revealed that risk analysis offers the degree and nature of the uncertainty surrounding the situations under which the dam must perform, as well as the uncertainty surrounding the reactions of the dam to those situations.

Early warning systems (EWS) which are either structural or non-structural instruments, can be used to minimise the influence of dam failures on the community and other constructions while performing as a moderation that is used to lower the risks linked with dam failures (Yang , et al., 2022). These systems place a strong attention on social relationship factors (for example, instead of just communication hardware, integrate technical aspects with collaboration and communication), involvement, education (and thus enhanced risk sensitivity), exercise, and assessment (Weber, 2020; Rajamäki & Katos, 2020). Weber (2020) further revealed as these are the most important factors of enhancing the efficacy of warning systems, and they are frequently overlooked or underemphasised. Messages from EWSs should be directed toward people in danger and should be capable of delivering people regardless of what they are doing, be simple to admittance and use, not generate additional risk, be dependable, offer adequate lead time so that individuals can safeguard themselves and send authenticated messages (Mukhtar, 2018). To be effective, warning messages must be perfect, reasonable, accurate, frequent, believable, precise to the recipients, and provide specific instruction on whatever the outcome will be about and what to do to lower the risk from the approaching possible disaster (Rajamäki & Katos, 2020).

Digital methods with interactive tools have recently become available to help with disaster risk management decision-making (Henriksen et al., 2018). The main objective of the usage of digital technology for EWSs is to make significant improvements in community security, as well as the protective measures of the environment and the economy from the effects of floods and other dangerous occurrences (Goniewicz & Burkle, 2019). As per Rucinska (2014), IT systems will allow support for crisis management in a situation of disaster or any other hazard. A system based on the Internet of Things (IOT) developed by Xu, et al. (2018), utilises a mobile cloud computing platform to use as an evacuation planning system for the large densities of people in disasters. Hence, a digital platform is "*a set of subsystems and interfaces that form a common structure for/from which derivative applications can be developed and distributed*" (Xu et al., 2010, p.1305). Tan et al. (2015) further revealed that digital platforms have grown in importance as a means of organising a wide range of human activities, including economic, social, and political interactions.

Sri Lanka is prone to several natural disasters such as cyclones, droughts, floods, heavy rains, landslides, land subsidence, storms, strong winds, tornados, and tsunami (Keerthiratne & Tol, 2018). Additionally, in Sri Lanka, there are dams of various sizes and types like gravity, embankment, arch, and arch-gravity dams (Navarathinam et al., 2015; Manatunge et al., 2009; Fujikura et al., 2009). Therefore, with the recent climate changes in the world and the aging of the dams, there is a necessity for dam safety. Moreover, the irrigation department of Sri Lanka highlighted that Sri Lanka is at risk of dam failures due to climate changes and the aging of the dams. Hence, it is high time to have an EWS for dam failures. Further, the non-structural nature of EWSs should consider minimising the impacts of dam failures in terms of social, economic, and political paradigms. To facilitate this a digital platform can be a potential solution which can help to interconnect different paradigms of the EWSs.

1.2 Problem Statement

Many dams have been built around the world to provide a variety of benefits such as flood control, power generation, and water supply (Hariri-Ardebili, 2018). Despite providing massive economic comforts, dams can fail and cause devastating floods, posing major dangers to downstream occupants and the economy (Li et al., 2019). As revealed by Pisaniello et al. (2015) unfortunately, not only developing countries but also developed countries are unable to deliver adequate commercial support to confirm that all of their dams are in a sufficiently safe condition. The traditional standards-based approach determines dam safety requirements based on the protected population and economic volume (Ge et al., 2020). However, in a climate of increasing public security, it is becoming increasingly inadequate to handle a single dam or a portfolio of dams in allocating limited resources for their operation, repair, or improvement (Li et al., 2019).

Climate change has increased the frequency of natural disasters such as flash floods, hurricanes, and landslides around the world in recent years (Hsiao, et al., 2021). Natural disasters have a significant impact on human society and can be caused by a variety of hazards (Takabatake et al., 2020). Dow and Cutter (2002) revealed that evacuation planning has been studied for specific risks such as tsunami, earthquakes, and hurricanes. Hydrological hazards are distinct in that they bring a large amount of surface water into urban and rural areas, causing significant damage to civil infrastructure systems and resulting in the loss of lives and property (Chen & Peña-Mora, 2011). Flooding can be caused by a number of factors, including insufficient drainage capacity and heavy rainfall (Balmforth et al., 2008). Dam failure, on the other hand, is one of the most disastrous causes (Samarajiva et al., 2006). When a wavefront occurs, it can quickly reach downstream areas, giving local residents little time to flee danger (Hariri-Ardebili, 2018). Furthermore, reckless evacuation may increase the risk by exposing evacuees to additional hazards (Kitamura et al., 2020). As a result, in response to the emergency and the cascading effects of dam failure flooding, the downstream areas of a dam or reservoir may require pre-planned evacuation instructions (You et al., 2012).

Sri Lankan dam network includes over 350 medium and large dams, as well as over 12,000 small dams in which design, age, and construction structures are varied (Samarajiva et al., 2006). Hence, there should be much attention to dam failures in order to reduce the hazards faced by the communities and the infrastructures. For example, the Kotmale reservoir inundated more than 4000ha of fertile land, including 600ha of paddy fields, from the late 1970s to the early 1980s, displacing approximately 3400 families (Fujikura et al., 2009). Moreover, scholarly articles highlighted that Sri Lanka still has doubts about dam failures (Fujikura et al., 2009; Manatunge et al., 2009).

Most people have practised identifying the risk of dam failures through environmental changes like water stream levels (Mehta et al., 2020). Hence the author further revealed that it is vital to have an EWS for dam failures as there can be the risk of dam failures that cannot be identified through environmental changes such as the aging of the dam. Although the experts in dam authorities communicate about dam failures through mathematical and scientific methods, communities cannot understand those due to their less knowledge of the dam failure causes as they adhered to assess the risk of dam failures through their self-assessments (Khoshkonesh et al., 2019). Therefore, people are willing to have a pre-disaster risk identification method in order to increase the communication between communities and dam operators with the aim of reducing the hazard of dam failures. Celik and Gul (2021) asserted that hazard identification, risk assessment, and control are viewed as a sequential holistic process that is at the heart of risk management and necessitates good planning, management, and feedback systems.

Accordingly, there is a gap between existing EWSs for the dam failures and the response to them through the community (UNDP, 2009). Further, the failures of the traditional EWSs for dam failures in Sri Lanka act as a major barrier to the reduction of risks allocated with dam failures (Samarajiva et al., 2006). There are several scholarly articles based on the dam failures of Sri Lanka (Fujikura et al., 2009;

Manatunge, et al., 2009; Navarathinam, et al., 2015) and only limited articles have discussed the need for an EWS for the dam failures in Sri Lanka (Samarajiva et al., 2006; UNDP, 2009). In addition to that, the government attempts to use digital technologies for current warning systems to fulfill the gaps and it has all been naught because there is no comprehensive strategic plan for implementing the systems. However, the adoption of digital technology for the EWSs of dam failures in Sri Lanka is still at the infancy level (Hettiarachchi & Weeresinghe, 2014). Hence, this study intends to investigate the support of digital platform to reduce the impacts of dam failures in Sri Lanka.

1.3 Aim and objectives

Aim

The aim of this research is to enhance the functional characteristics of a digital EWS to reduce the impacts of dam failures in Sri Lanka.

Objectives

1. To identify the causes and impacts of risks associated with the dam failures in global context and in Sri Lanka.
2. To explore the functional characteristics of EWSs used for dam failures in Sri Lanka
3. To define a set of systems views that can be used to support the functional characteristics of an EWS.
4. To capture user requirements for an effective EWS for dam failures in Sri Lanka
5. To define the features of a digital platform to enhance the functional characteristics of an EWS for dam failures in Sri Lanka.

1.4 Research Methodology

This study adopted an interpretivism philosophy by taking predominantly an abductive approach. Further, the study was conducted as qualitative research as it can be used to create new relationships with the variables to understand the complex processes and to illustrate the influence of society (Shah & Corley, 2006). Further, the researcher creates an environment by interconnecting the communities and the government officers in order to collect subjective and attitudinal information for the user requirements of EWSs. The researcher would perform a specific role in identifying the user requirements and making solutions for them through the digital platform with the observations and measures taken from the key stakeholders. As the research has an exploratory nature a survey strategy was adopted to gather primary data.

When it comes to data collection, semi-structured interviews, and a focus group discussion were conducted in order to have a great understanding of the research area with the people's experiences, beliefs, perspectives, and knowledge. Semi-structured interviews with key stakeholders including communities were conducted to identify the causes of dam failures and the economic, social, and environmental impacts of dam failures (objective 1), to explore the functional characteristics of EWSs in the Sri Lankan context (objective 2), to identify the different system views that support for the functional characteristics of EWSs (objective 3) and to capture the user requirements of the usage of effective EWS for the dam failures in Sri Lanka (objective 4). Finally, objective 5 in which the digital characteristics of EWS for dam failures were evaluated with the necessary input from the experts on the technology. The features of the digital platform that had already been developed as part of another research project (MOBILISE) were evaluated against the user requirements captured to make the digital platform suitably support the EWS for dam failures in Sri Lanka. All the data collected qualitatively through the semi-structured interviews were analysed using qualitative content analysis and user story mapping. The user story mapping consists of 5 steps such as establishing the vision, identifying the users of the system, building the backbone, breaking the activities into user stories, and user story prioritisation. The final step of prioritising the user requirements gathered through the primary data was achieved using a focus group discussion with experts from dam construction and technology.

As such, this study undertook an in-depth inquiry related to dam failures, EWSs, and digital platforms

1.5 Scope and Limitations

Though the literature review explored five functional characteristics of an EWS, this study has limited only to three characteristics as it mainly enhances the digital EWS to minimise the impacts of dam failures in Sri Lanka.

1.6 Chapter Breakdown

The study has been illustrated in the following chapters.

Chapter 01: Introduction

The background for the study with the aim, objectives, and methodology outline is described in chapter 01.

Chapter 02- Literature Review

Comprehensive literature is conducted in chapter 2 with the use of journals, books, conference proceedings, and websites to identify the causes and the impacts associated with the dam failures and the characteristics of the EWSs.

Chapter 03- Research Methodology

This chapter contains the steps that followed to achieve the aim, and objectives of the study with the research philosophy, data collection techniques, and data analysis.

Chapter 04- Data Collection, Analysis, and Discussion

This chapter contains the data collected through semi-structured interviews and user stories. Then the collected data will be analysed according to the manual content analysis and finally, the discussion is outlined the key findings of the study with a revisiting of the literature findings.

Chapter 05- Conclusions and Recommendations

Finally, the conclusion and recommendations of the study are contained in this chapter with the recommendations for future research areas.

1.7 Chapter Summary

The background of the study with the rationale and justification, problem statement, aim, and objectives are discussed in this chapter. In addition, the outline of the methodology adopted to achieve the objectives of the study and the illustration of the chapter breakdown are shown.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Chapter one (Introduction) of this study mainly focused on the background of the study with the research problem, aim, and objectives. According to chapter one dams provides a variety of purposes for human and society such as flood control, electricity generation and/or irrigation, and promoting agriculture. However, the dam will cause severe damage to both humans and society when it fails. This chapter discusses dam construction with its different types and purposes, the causes and impacts of dam failures, and the functional characteristics of the EWSs.

2.2 Dam constructions

A dam can be identified as an obstruction created by steel, concrete, or earth to disturb or manage the flow of water by constructing across streams or rivers and can be defined as a structure used to create reservoirs (Manikowski & Strapasson, 2016). As revealed by Youdeowei, et al. (2019) dams are introduced as engineering structures that are used for the storage, regulation, and diverting of water from rivers, and they are artificial man-made barriers built across the water. However, dams have become unique constructions all over the world (Akindele & Indabawa, 2015). Hence, dam construction encompasses a wide range of disciplines including structural engineering, geotechnical engineering, environmental engineering, hydrology, geology, and hydraulics among others (Manikowski & Strapasson, 2016).

Dam construction has significantly altered the flow regimes of the majority of the world's rivers (Nislow et al., 2002). Dams can alter the natural flow regime by affecting the magnitude, frequency, duration, timing, and rate of change in the flow, as well as the sediment, nutrients, and energy (Magilligan & Nislow, 2005). Changes in flow regimes caused by dam construction cause extensive environmental degradation and a loss of biological diversity (Lytle & Poff, 2004; Castello & Macedo, 2015). River damming is necessary in order to predict a barrier's long-term environmental impact as well as a dominant anthropological effect on river systems (Cecilia et al., 2016). Furthermore, cascade dam construction is becoming more popular as a means of increasing economic efficiency (Yi et al., 2018). Human dam construction has resulted in significant changes in the functioning of riparian ecosystem areas that directly adjoin and influence inland water bodies (Li et al., 2012). Kellogg and Zhou (2014) revealed that dams obstruct material and energy exchange, as well as the longitudinal speed of plant seeds. However, dam construction received very important consideration among all other constructions as it provides essential purposes as well it can emerge into potential risks (Movahednejad, 2021). Therefore, it is necessary to propose specific methods for the construction industry to prevent the risks and hazards associated with dam construction as well as dam failures (Celik & Gul, 2021).

2.2.1 Effects of dam construction

Even though dam construction provides vital service to the country, it may cause bad effects during the construction as well as when they are broken (Green & Barid, 2020). The Flood-pulse cycle is an essential natural flow needed for many types of fish to spawn and such natural hydrological flows which are critical for the other river ecosystem functions can be disrupted by the construction of dams (Arias et al., 2014). Furthermore, dam construction can be disrupted by the transportation of sediments which are required for the downstream agricultural and ecological processes (Barid et al., 2015). Barid et al. (2015) further revealed that there can be cultural sites, natural habitats, and homes that are affected by floods near the reservoirs created by the large dams. As revealed by Scudder (2012), there can be economic, social, and health issues with the people who are displaced due to the construction of large dams. The major reason for such issues is the inability to provide adequate natural or economic resources to rebuild their lives in the resettlement areas (Scudder, 2012). However, dam developers and their government backers profited from their power to minimise the scope of the affected areas, lowering the amount of money required to reduce environmental consequences and compensate rural fishermen for lost livelihoods (Green & Baird, 2016). As revealed by Wu et al. (2019), dams may have an impact on the biodiversity of microorganisms, benthos, plankton, fish (including aquatic mammals), botany, and birds. Dam construction reduced the biomass and richness of water fungal communities in reservoirs and downstream reaches but increased soil microorganisms in downstream lake wetland (Cheng et al., 2015). Even though there are such effects with the construction of dams, there are various types of small, medium, and large dams incorporated with the intended purposes.

2.2.2 Dam types

According to the intended purpose and the usage, design strategies, and construction materials, various types of dams can be found in a wide range of locations around the world (Youdeowei et al., 2019). Among them, earth dams, embankment dams, concrete dams, hydroelectric dams, tail dams, check dams, cascade dams, and arch-type dams are very popular (Lyu et al., 2019; Kang et al., 2013; Li et al., 2012; Youdeowei et al., 2019). Compared to other dams, earth dams are the most sensitive engineering structures which need well-improved design and construction techniques and required continuous analysis to ensure the stability of the dam and when accounting 75% of the dams in the world are earth dams (Alateya & Ahangar Asr, 2019). Hydroelectric dams, tail dams, and check dams are the most popular type of dams in the global context that are varying according to the function of the dam and they are further described as follows.

2.2.2.1 Hydroelectric dams

The demand for energy increased as a result of demographic growth, industrialisation, and economic development in 1970 while acting as a strategy for the expansion of electric energy production (Moretto et al., 2012). Amazon (Belo Monte dam on Xingu River) was prioritised as the region with the highest potential for hydroelectricity by giving importance to the construction of hydroelectric dams as a strategy in Brazil as in early Europe and the USA (Moran, 2016). Chen et al. (2015) further asserted that Amazon is regarded as the hydropower development horizon where 352 dams are scheduled with 96 hydroelectrical dams and 256 smaller dams that have the ability to generate energy. The attention to the construction of national and international hydroelectric dams was opposed by social groups due to the associated negative impacts, especially the flooding of territories of native groups (Fearnside, 2016). Apart from those considerations, the financing difficulties also have stopped the development of hydroelectric dams (Morettoet et al., 2012). The hydroelectric dams were revived in the first decade of the 21st century as a reaction to concerns about electricity generating deficits caused by lower precipitation and lower electricity production in existing dams, as well as poor planning and financing in the electricity sector (Jiang et al., 2018). Kotmale, Victoria, Samanalawewa, and Rantabe are some examples of hydroelectric dams within Sri Lanka (Khaniya et al., 2020). The Samanalawewa hydraulic dam which used water from the Walawe River to generate electricity was commenced in 1988 and completed in 1992 (Udayakumara & Gunawardena, 2018).

2.2.2.2 Tailing dams

Reasonably, tails are considered to prevent the enrollment of the water cycle through rivers in the mining process (Lyu et al., 2019). The chemical reactions of the mining process have effectively disturbed the storage of tailings under the water (Wei et al., 2016). Accordingly, tailings are usually stored in a slurry form which is considered the waste items in the process of providing benefits (Ozcan et al., 2012). However, the aim of constructing tailing dams is to ensure the safety of the natural environment from damage and hazards by safely storing the tailings (Inam et al., 2010). Even though tailings dams are one of the largest structures constructed by geotechnical engineers (Naeini & Akhtarpour, 2018), often there have been tailing dam failures on a global scale which caused huge negative impacts on human life, surrounding properties, and the economy (Smuda et al., 2014).

2.2.2.3 Check dams

Check dams are engineering structures that can be found in a variety of environments around the world that has a long history and they are constructed with general uses like soil conservation, watershed restoration, and erosion mitigation (Mekonnen et al., 2015). However, globally they are widely used as hydrological structures for watershed management for the purpose of groundwater recharge, water capture, sediment retention, and carbon retention (Lu et al., 2012). Kang et al., (2013) have asserted that with the aim of reducing channel erosion, check dams have been constructed across the channels to pool water. Although up to some extent check dams interact with multiple processes and with time the dominant process will be changed with the initial purpose conceived by the designer and it will be associated with a single process (Boix-Fayos et al., 2020). Even though check dams are constructed with a variety of materials, rock check dams are built using large stones which are kept at intervals in the channel as a common and standard practice in the construction sites (Patel A., 2012).

2.2.3 Purpose of dams

The main purpose of dam construction can be identified as the water supply for human activities, water supply for agricultural and industrial use, flood control, and electrical energy supply (Haghshenas et al., 2016). As revealed by Samaras et al. (2014), the main problem for human beings is the control of water that need to sustain their life. As a remedy, dams have been constructed and used as a method to control the water by protecting it from floods, storing water, changing the direction of rivers, and irrigating the lands in the past centuries (Celik & Gul, 2021). Although, apart from the agricultural and storing water for the human day today activities dams have been used in modern society for complex purposes like preventing flood erosions, depositing sand and clay near the river mouths, preparing barren lands for agricultural activities, and hydroelectric power generation (Ribas & Pérez-Díaz, 2019). Fang (2017) revealed that the pattern of the transportation of nutrients downstream can be changed with the construction of dams, as it can reduce the connection of the whole catchment through the interception of sediments and runoff. However, the greatest number of dams in the world have altered the hydrological processes on the earth's surface and especially have affected the transportation of nutrients downstream (Li et al., 2018).

The large area of water level fluctuation zone in which the environment is very difficult to recover, sensitive, and vulnerable was characterized by a narrow riverbed and huge vertical changes with the construction of a hydropower dam at the Lancang River in the Southwestern region (Li et al., 2019). Adhering to the past centuries, these water level fluctuations have caused bad effects on vegetation degradation by creating soil degradation (Zhao et al., 2014), soil erosions (Zhang et al., 2013), land-use changes (Willison et al., 2013), landslides (Liu et al., 2014), and heavy metal pollutions (Song et al., 2019). Therefore, it is vital to recover and protect the water fluctuation zone in order to maintain the health of reservoirs and it has been ensured with the construction of a hydropower dam at the Lancang River (Li et al., 2019).

The relationship between the dam construction and the sedimentation, soil erosion, and soil transportation in riverbeds have descriptively explained by Hallouz et al. (2018) with reference to the Sidi Mohamed Ben Aouda dam on the Wadi Mina in Algeria. Additionally, Kotti et al. (2018) and Hadour et al. (2021), also proved the purpose of large dam construction with the perspective of controlling the flow of sediments to the sea downstream of the dams by relating the Medjerda River in Tunisia and the Wadi Chellif in Algeria respectively. Therefore, many dams in the world have proved that they have declined the sediments that are caused the river flow regulations and river fragmentation (Grygar et al., 2018).

The original hydrological pattern of the water and sediment frequencies will be changed with the storage of water through the construction of dams with the aim of producing hydropower and also it can change the level of water (Liang et al., 2021). The hydroelectric dam construction may trigger some ecological, social, and water resources issues (land use, alters the hydrological cycle through root evaporation, a manifestation of human activities, vegetation retention, etc.) while changing the sand and water exchange in the river-lake systems and controlling the flood associated with the reservoir (Hu et al., 2018). Even though the artificial reconstruction of large-scale hydroelectric dams inevitably created hydrological and hydraulic changes between the river and the lake, there have been large and small dams constructed with the four tributaries in the Hunan province with the purpose of generating power and flood controlling (Li et al., 2018). Hence, these hydroelectric dams have been considered as a key part of the economic solutions through the supply of hydroelectric power (Youdeowei et al., 2019).

Even though the primary purpose of the dams is storage and the retention of water, the construction of dams has created much more purposes such as acting as a center of tourist's attraction, reducing unemployment by introducing new jobs, acting as a rich source of fish and there is a little fallback at the period of droughts (Youdeowei et al., 2019). As a result, numerous types of dams have been constructed all around the world with the aim of helping communities and economies by taking benefits from water resources (Bayazit et al., 2020). Therefore, the authors further revealed that it is difficult to analyse the benefits of dam construction on the social systems, livelihood and health of the people, and culture. Another indirect purpose of dam construction is to increase the production of food and due to that, there is an alleviation of poverty due to the fisheries and irrigated agriculture (Youdeowei et al., 2019). For example, Oyekanmi and Mbossoh (2018) revealed that 35,000ha of farmland capacity have been designed for irrigating by the Bakolori dam in Nigeria and a further 20,000ha by the Tiga dam, 125,000ha from the Kafin-zaki, and 20,000ha from the Challawa dam have designed for the irrigation.

The purposes of the dam construction discussed are summarised in Table 2.1.

Table 2.1: Purposes of dam construction

Direct Purposes	Water supply for human activities
	Water supply for agricultural activities
	Water supply for industrial use
	Flood control
	water storage
	Electrical energy production
	Changing the direction of rivers
	Control flow of sediments
Indirect Purposes	Preventing flood erosion
	Prepare barren lands for agriculture
	Depositing sand and clay near river mouth
	Changing the flow of nutrients
	Increase food production
	Act as a center for tourists
	Introduce new jobs
	Act as a source of fish

Source: (Haghshenas et al., 2016; Celic & Gul, 2021; Ribas & Pérez-Díaz, 2019; Hallouz et al., 2018; Youdeowei et al., 2019)

2.3 Dam failures

The overturning of the still water column in a reservoir as a result of the removal of the sluice gate will represent an ideal sudden dam failure which can introduce a mechanism that involves creating and formulating rapid unsteady flow (Khoshkonesh et al., 2019). The predicting of flood routings, risk management, and hazards analysation are priorotised at the preliminary design stage and the operational stages in order to in detail identify the features of dam failures (Aleixo et al., 2011). As a result, while modifying the hydraulic characteristics of the reservoir, its geometry and the initial conditions may take a key role (Yang et al., 2018). As per the reports published in 2000 by the World Commission on Dams, 40-80 million people worldwide have led to displacements due to dam failures and it has been caused by 60% of world rivers (Khoshkonesh et al., 2019). Even though still there are not any strong reports on the characteristics of dam failures, inflow and outflow hydrographs of control sections downstream, and certain energy and their resulting forces in the reservoir have commonly been identified as the characteristics of dam failures (Khoshkonesh et al., 2019).

Terrible damages may cause for both human life and the properties due to the failures associated with the dams (Li & Zhao, 2018). According to Hsu and Peeta (2014), there should be horizontal and vertical management and cooperation within the organisations in order to identify the dam failures and to maintain a collective relationship between them with the aim of reducing the damages caused by the dam failures. However, it has been identified that the general public has well aware of the dam failures before the organisations identified the dam failures (Sheu, 2014). In addition, Hariri-Ardebili (2018) revealed that much attention has to pay to public dam safety by international bodies and emergency management agencies. Hence, it is a critical task for organisations to arrange emergency medical services (Chen & Yu, 2016), manage heavy equipment (Chen et al., 2011), and the vital task is to activate evacuation plans, and relocate populations for safety during dam failures (Hsu & Peeta, 2014). Though, emergency management agencies connected with the dam regulators and have attempted to monitor EWSs and emergency action plans by introducing new concepts for the public to respond with the aim of reducing the negative outcomes of dam failures (Mehta et al., 2020).

Generally, a dam failure is a time-dependent, non-homogeneous (various materials, different levels of soil compaction, and so on), and multiphase (water-soil collaboration) event which causes destructive losses for both properties and human life by creating major disasters as the end result (Kim & Sanders, 2016). Transferring methods of sediments, hydrology, fluid mechanics, and geotechnical and structural characteristics contributed to the creation of dam failures (Paquier & Goutal, 2016). Apart from those King et al (2019) revealed, that dam failures can be occurred as an outcome of broad selection and the sequence of operating requirements, comprising natural disruptions, component malfunctions, high inflow actions, and operational errors. The weak positions caused due to the pipping or the overtopping on the downstream face or the crest of the earth dams have affected the dam failures (Tannant & Skermer, 2013). Hence, Tannant and Skermer (2013) have further revealed that 0.5% (1 in 200) of earth dam failures have been caused due to piping and interior erosions and among them, 1.5% (1 in 60) have suffered from piping cases. In addition, embankment dams also have suffered from dam failures due to the erosions in the embankment materials by overtopping which is the most regular cause of dam failures and leakages caused by pipping (Sharma & Kumar, 2013). Though, Sharma and Kumar (2013) further revealed by the analysis of past records, the insufficiency of hydrological procedures used earlier to calculate the severity of floods and the lack of details on the planning of spillway designs have affected the dam failures.

However, when compared with the past dam constructions more attention has been given to modern dam safety as modern dams are very large than the earlier and due to the industrialisation of the past and the high density of population around the dams (Wang et al., 2018). Even though there are varieties of dams (arch dams, gravity dams, earth dams, etc.), embankment dams which are called earth fill or rockfill dams have drawn much attention as it has a higher risk of dam failures and as it is the most common type of dam which is in use. Fu et al. (2018) have also identified rockfill dams as the dam type which caused the greatest rate of dam failures and the massive number of disasters that vary from fairly minor to devastating events affected by the downstream areas and nearby environment as hazardous outcomes.

You et al. (2012) have revealed mathematical modeling and dam failure experiments as the two main studies based on dam failures. A number of dam failure models like statistical models, physically-based models, and parametric models have been developed with the interpretation of the dam failure procedure in order to forecast the discharge of the hydrograph and to simulate the breaking improvements (Tschiedel et al., 2020). Nevertheless, breaking erosions can be identified as a multivariable and associative issue and there is large uncertainty with the prevailing technologies used to create the models based on dam failures which are developing to forecast the failing parameters (Tedla et al., 2021). Apart from those, a small-scale laboratory was conducted to predict the dam failure and there is an uncertainty with the outputs due to the scale of the tests (Aureli et al., 2021). Therefore, it is vital to identify the causes and the bad impacts of the dam failure to create a strategy to mitigate the risks associated with dam failures.

2.3.1 Causes for the dam failures

Dam failure is a hazardous consequence and it is essential to identify the causes of dam failures in order to minimise the negative impacts. Ribas et al. (2021) have identified the major causes involved in the dam failures as technical shortages like piping and sliding, obstructions in the spillway due to bank slide into the basin, overtopping, dam excavations for discharge, disasters such as upstream breakings and landslides, meager management, meager layout plannings, and meager designs. In addition to those Escolano-Sánchez and Fernández-Serrano (2015) asserted that it is difficult to conduct frequent inspections to observe the conditions of the dams to prevent dam failures due to the uncontrolled growth of vegetation on the dams and it can harm the embankments.

Moreover, dam failures can occur due to natural disasters like floods, earthquakes, landslides, strong winds, tsunamis, volcanic activity, wildfires, and snow and ice or can be formed due to human actions like terrorist attacks or wars (Ardeshirtanha & Sharafati, 2020). In addition to that Ardeshirtanha and Sharafati (2020) highlighted that global warming which increased the atmospheric temperature can be a threat to dams as it will create floods due to the dissolution of glaciers and also it will increase the rainfall. Besides DeNeale et al. (2019) highlighted that mechanical or electrical consequences and internal erosions also can be taken into natural disasters which caused dam failures if there is no physical initiator. In addition to those, dam failures will create due to the aging of the dam materials, design errors, insufficient maintenance, and the extremely long service of lives (Ribas et al., 2021). In another form, Donnelly and Acharya (2020) revealed that the following matters or combinations of those can create dam failures.

- Inaccurate standard-based design as a result of a failure to anticipate critical environmental activities or inadequate site evaluations
- System failures
- Errors or poor engineering methods and totally inadequate investments during construction and basin filling
- Inadequate inspections, supervision, and the maintenance

Even though the some researches identified the causes for dam failures as natural causes and human actions, some have identified as external causes and internal causes (You et al., 2012). Therefore, according to You et al. (2012) hurricanes, earthquakes, heavy rains, etc were classified as external causes, and foundation failures, dam body failures, aging of the dam, and so on were identified as internal causes. Despite those, the availability of the major constructions near the dams also caused dam failures, for example, thirty thousand dams including eighty-five thousand reservoirs are in danger due to the major constructions (Alamatian et al., 2021). However, Abdedou et al. (2020) also revealed that the uncertainties caused during the design of dam-like meager knowledge, random nature of the input parameters which directly affect the evacuation plans and the inundation mapping, and the measurement errors also can be significantly affected by the dam failures.

On the global scale, frequently there were dam failures associated with the tailing dams which are considered some of the largest structures constructed by geotechnical engineers (Lyu et al., 2019). Failure of a tailings dam causes major environmental contamination and mortality (Kossoff et al., 2014). The failure rate in the reported 18,000 mines throughout the world during the last 100 years is estimated to be 1.2%

(Berghe et al., 2011). The typical water storage dam has a failure rate of 0.01% (Naeini & Akhtarpour, 2018). Further Naeini and Akhtarpour (2018) revealed, that every year, three of the world's 3500 tailing dams will fail. Rico et al. (2008) have asserted that as the embankments of the tailing dams are constructed with the soil, coarse waste, and residual materials from the mining operations and do not have specific regulations on the design standards tailings dams are tends to fail than the other water storage structures. Hence, other than the common natural disasters like earthquakes, floods, and rainfalls Lyu et al. (2019) highlighted that the leakage field directly makes the uncertainty of the tailings dam (seepage and internal erosion), the unsteadiness of the tailings dam foundation (poor foundation conditions), flooding that creates the tailings dam slope to becoming unbalanced (overtopping), an earthquake consequence (static and seismic instability), other reasons like mine collapsing, structural, external erosion, and slope unsteadiness will act as the major causes for the tailing dam failures.

Another aspect that contributed to the tailings dam failure was a lack of proper management of the tailing facilities, which is critical for guaranteeing the safety and stability of tailings dams (Schoenberger, 2016). Schoenberger (2016) further revealed that the proper management of tailing dams includes the minimisation of environmental impacts and subjecting them to legal documents.

However, according to a past analysis conducted before 1974 with 43 countries and 534 dam failures, earth rock dams have contributed to all those causes of dam failures, and it included 28% of failures due to seepages in the dam body while 29% due to the seepage in the foundation and 49% due to the overtopping (You et al., 2012). Further, You et al. (2012) have revealed that it accounts for 85% of dam failures caused by earth dams due to overtopping and seepage according to an analysis conducted with 3498 dam failures between 1954 and 2006 in China where 90% of dams are earth dams. Therefore, despite those cases, overtopping and the failures associated with the piping have been identified as the most instantaneous causes of dam failures and leakages or the seepages have been categorized as the main cause of earth dam failures (Al-Shukur & Mahmoud, 2019). As a result, Ratiat et al. (2020) highlighted, that even though there are much more causes that affect dam failures, frequently earth dams faced leakages which diminish the dam structure and cause dam failures due to technical issues. However, Ribas et al. (2021) have categorised the failure modes of earth dams related to their elements as illustrated in Table 2.2.

Table 2.2: Failure modes of earth dams reference to its elements

Function	Failure Mode	Cause	Effect
Earth dam			
Impound the reservoir	Overtopping	Sudden filling of the reservoir	External erosion
		Exceptional heavy load	
	Mass movement	Mechanical failure	General instability with flooding out of control
		Foundation settling	
Crest			
Ensure free edge of the dam	Blocking access	Deformations	Blocking access
	Excessive deformation	Settling	External erosion
		Mechanical failure	Obstruction of flow
Drainage system			
Control piping and internal erosion	Piping or internal erosion through the dam	Inadequate filtration	Seepage and infiltration
		Clogging	Deformations and cracks
Foundation			
Supporting the dam	Rapid lowering of the reservoir	Geological movements	Deformations and cracks
	Piping due to internal erosion	Inadequate foundation	
Abutments			
Dam steadying and erosion protection	Sliding of earth and rocks	Undersized structure	Dam instability
	Internal erosion into abutment foundation	Faults not detected	Seepage and infiltration
Riprap			
Protect the slope	Stone displacement	Waves due to the wind	External erosion
Spillway			
Adjust the reservoir level	Interrupted floodgates	Drive system failure	Inability to keep reservoir level
	Ramp deterioration	Cracks and deformations	Erosion of the structure

Source: (Ribas et al., 2021)

Some of the major causes of dam failures can be described as follow.

2.3.1.1 Seepage/ Leakages

Seepages are highly influenced by the stability of the dams as most dams are water permeable (Bao et al., 2011). Therefore, it is vital to determine the fields of seepage during the dam failure studies (Hu et al., 2014). As a result, theoretical methods, numerical simulation methods, and model test methods are available to evaluate the seepages of dams to reduce dam failures (Zhang et al., 2011). Due to the complex geological conditions and the inaccuracy of the boundaries, it is difficult to find the seepage or difficult to give solutions for the field of seepage through theoretical methods (Dong et al., 2017). Even though there are two other methods to evaluate the seepage, the most common numerical method is used as the cost for the model test method is very high and the results of the tests depend on the test conditions (Yin et al., 2011). As revealed by Özer and Bromwell (2012) with the piping effects and the drainage failures the dam materials will lose their properties and decrease the shear strength of the dam. As a result, the dam basin may be collapsed, and the dam may tend to fail (Özer & Bromwell, 2012). However, after an investigation, it has been concluded that the improper design and the lack of monitoring from the professionals have affected the occurrence of seepage in the dams (Hu et al., 2016).

2.3.1.2 Foundation failures

According to the researches, foundation failure is a common cause that occurred during past dam failures (Kossoff et al., 2014; Lyu et al., 2019). Therefore, it is necessary to analyse the stability of the foundation with the soil conditions and the used materials with the aim of reducing dam failures (Yu et al., 2013). As per Lyu et al. (2019), the penetrability of the foundation is very significant when considering the stability of the dam structure. Poor penetrable materials used for the foundation base affected increase the pore pressure and shear stress on the foundation (Özer & Bromwell, 2012). Additionally, piping effects can be caused on the foundation if the foundation materials have high water penetrability (Wang et al., 2011). Furthermore, to strengthen the foundation, the surrounding soil conditions have to be investigated while giving greater attention to the slopes (areas with the risk of accidents) and the interface between the fine and coarse grain layers (Özer & Bromwell, 2012). Apart from those, while selecting the location for the dam foundation, surrounding hydrology and geology have to be investigated and it is easy to make ground treatments to ensure the stability of the foundation while having detailed geological data (Lyu et al., 2019).

2.3.1.3 Overtopping

Overtopping has been identified as the main cause of the failing of earth dams and tailing dams (Kossoff et al., 2014). Since most of the reservoirs are very close to the mountains, the water level of the reservoir rises within a very short period during heavy rainfalls (Villavicencio et al., 2014). Meanwhile, due to the poor permeability of the dam, it will fail as a result of overtopping circumstances which directly affect the stability of the dam (Sitharam & Hegde, 2019). Following an overtopping event in a tailing dam, some of the water penetrates into the tailings dam, enabling the tailings sand to saturate, increasing the dead weight of the tailings dam, and triggering gravity erosion (Ozcan et al., 2012). Simultaneously, the tailings sand gets wet, diminishing its strength and, as a result, the stability of the tailings dam will get reduced, and it will be broken (Wei et al., 2016).

2.3.1.4 Earthquake

An earthquake is an unexpected event, and it is critical to have earthquake analysis for the dams as their failures can create a huge loss of both life and costs (Tarinejad et al., 2014). Wang et al. (2011) revealed that while conducting analysis on the effect of the earthquake on the dams in order to evaluate the response of dams to the earthquake, dynamic properties of the dams like damping ratios, mode shapes, and the natural frequencies are very essential parameters. When computing these numerical values to make assumptions about the earthquake, the uncertainties and the complexities during the simplification may cause errors and inaccurate assumptions in the earthquake analysis (Naeini & Akhtarpour, 2018). The main uncertainties may occur with the (a) geometries such as mass distribution and topographical features (b) material properties and the reservoir bed structure (c) initial load like temperature, pressure, and stress, and (d) main load estimations (Tarinejad et al., 2014). Therefore, it is critical to have earthquake analysis on the dams to reduce the risks for humans as well as properties (Løkke & Chopra, 2018).

However, dam failures have badly impacted the people and the properties by creating dangerous consequences for their life patterns (Al-Shukur & Mahmoud, 2019). Therefore, it is very essential to identify the main causes of dam failures to reduce their impacts. Table 2.3 illustrates the causes of dam failures according to the analysis of Zhang et al. (2009).

Table 2.3: Main and subsidiary causes for dam failures

Main Cause	Subsidiary Causes
Overtopping	Insufficient spillway capacity
	Extreme flood exceeding design criteria
Technical deficiencies	Piping in dam
	Sliding of dam
	Piping in foundation
	Piping around spillway
	Quality issues in spillway
	Piping around culverts and other embedded structures
	Quality issues with culverts and other embedded structure
Poor management	Loss of reservoir capacity for flood control due to over storage prior to flood season
	Poor maintenance and operation
	Temporary heightening of spillway crest not removed in time
	Organisation issue: unclear responsibility for dam management
Disasters	Earthquake
	Wars and terrorist attacks
	Breaching of upstream dam
	Reservoir landslides
	Rodent den
Others	Spillway blockage due to bank slide in reservoir
	Excavation on dam for discharging
	Poor design options
	Poor planning of project layout
Unknown	

Source: (Zhang et al. 2009)

Even though there are numerous causes for the dam failures as discussed above, that will be a risk for the dam if only it has any exposure to that cause (Ardeshirtanha & Sharafati, 2020). Therefore, all the identified causes may not be a risk for the failure of all the dams. However, there can be a possibility with its exposure. Based on the above discussion, all the associated causes for the dam failures can be summarised in Figure 2.1.

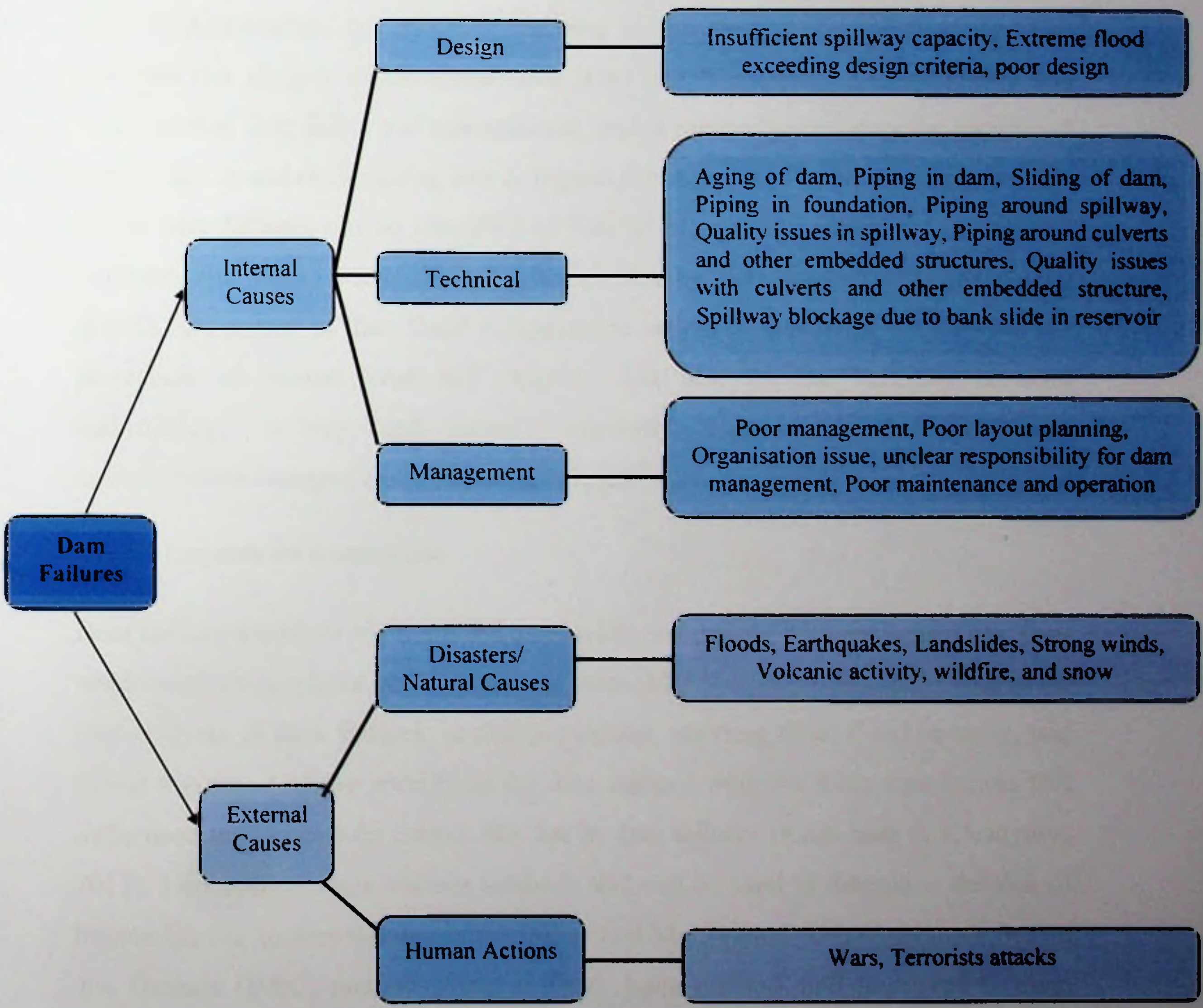

Figure 2.1: Classification of causes for dam failures

Adapted from: (You et al., 2012; Ardeshirtanha & Sharafati, 2020; Ribas et al., 2021)

2.3.2 Impacts of dam failures

Floods caused by dam failure are considered among the most catastrophic types of floods because of their sudden and unpredictable character, which results in significant material losses and the loss of human life, as proven by countless accidents (Lempérière, 2017). The author further revealed that apart from the loss of human life, dam failures generate issues such as social capital loss, large-scale economic costs, and the formation of undesirable environmental consequences. Hsiao et al. (2021) explained the similarities as hydrological risks are distinct in that they transport a large volume of surface water into urban and rural regions, inflicting considerable damage to civil infrastructure systems and resulting in the loss of life and property. The complete risk analysis of risky reservoirs is an effective approach to enhancing and strengthening dam safety and management, and it primarily considers the likelihood of dam failure and the resulting loss or impact (Zhong et al., 2011). The main impacts of the dam failures can be classified as loss of human life, economic, social, and environmental losses (Mo et al., 2019). As revealed by Wang et al. (2019) with societal growth, the notion of dam flood management necessitates a focus not only on the protection of human lives and property, but also on the harmony between anthropology, society, and nature, especially, emphasising the social and environmental damages caused by dam failures.

2.3.2.1 Impacts on human life

Dam failures are adversely impacted human life and mainly it losses human life, their residencies, employment, and the farming lands (Mehta et al., 2020). According to the past analysis of dam failures, at-risk population, warning time, flood severity, and public awareness of the severity of the dam failures were the main four factors that influenced the impacts on human life due to dam failures (Krue-hom & Kwanyuen, 2017). Hence, there were various methods that can be used to determine the risk of human life due to dam failures as the Dekay and McClelland (D&M) method, Brown and Graham (B&G) method, Assaf method, Jiang method, and Improved Graham method (Li method) (Mo et al., 2019). The authors further revealed that the Li method is widely used in the analysis of human life impacts the dam failures.

2.3.2.2 Economic impacts

Similar factors which influenced human life are generally considered in the economic impacts of dam failures (Krue-hom & Kwanyuen, 2017). With respect to the economic losses caused by dam failures it can be divided into direct and indirect economic impacts (Zhang & Tan, 2014). In addition to that, those economic impacts can be further considered with respect to the specified situations like agricultural income losses, physical losses, and industrial and commercial transport service losses (Mo et al., 2019).

The direct economic impacts/losses are the impacts/losses that can be directly financially measured in the flood-affected areas due to the reservoir dam failure (Zhang & Tan, 2014). Basically, direct economic losses have been caused by agriculture (crops, fishery, forestry, animal husbandry), industry, commerce, and infrastructure (roads, railways, telecommunication, and tunnels) (Wang & Zhang, 2018). Therefore, the direct economic loss has been measured as physical losses and income losses (Nigatu & Dinar, 2015). Physical losses are the physical value reductions in buildings, equipment, machinery, and all type of fixed or current assets which were affected by the dam failure floods (Mo et al., 2019). Mo et al. (2019) further explored that the income losses are the profit losses that occurred due to the suspension of production and management activities as a result of the reservoir dam failure and it mainly includes the agricultural income losses and industrial & commercial transport service losses.

As revealed by Mo et al. (2019) indirect economic impacts included the expenses of flood management efforts, losses from decreased agricultural production and factory production, and the rising costs of typical socioeconomic activities.

2.3.2.3 Social impacts

As well as human life and the economy, dam failures badly affect the environment and society (Zhang & Tan, 2014). Not only is there a loss of life due to dam failures, but there is also damage to the physical and mental health of those affected as a result of injury or stress, and a decrease in the quality of daily life (Zhong et al., 2011). Other than that, damage to the cultural properties, art treasures, rare animals and plants, and even harmful political effects (i.e., national and social stability) can be identified as the social impacts due to the dam failures (Mo et al., 2019).

2.3.2.4 Environmental impacts

The environmental and social impacts due to the reservoir dam failures cannot be ignored as much increased attention has been placed on the environment and society (Sun et al., 2014). Accordingly, the effects on the channel morphology, living creatures and their habitats (including rivers, wetlands, topsoil, vegetation, and so on), and the cultural landscape, as well as cause significant damage to the environment through contaminations (eg. River facilities and chemical storage facilities) can be identified as the environmental impacts caused with the reservoir dam failures (Mo et al., 2019).

The findings of the impacts of dam failures can be illustrated in Figure 2.2.

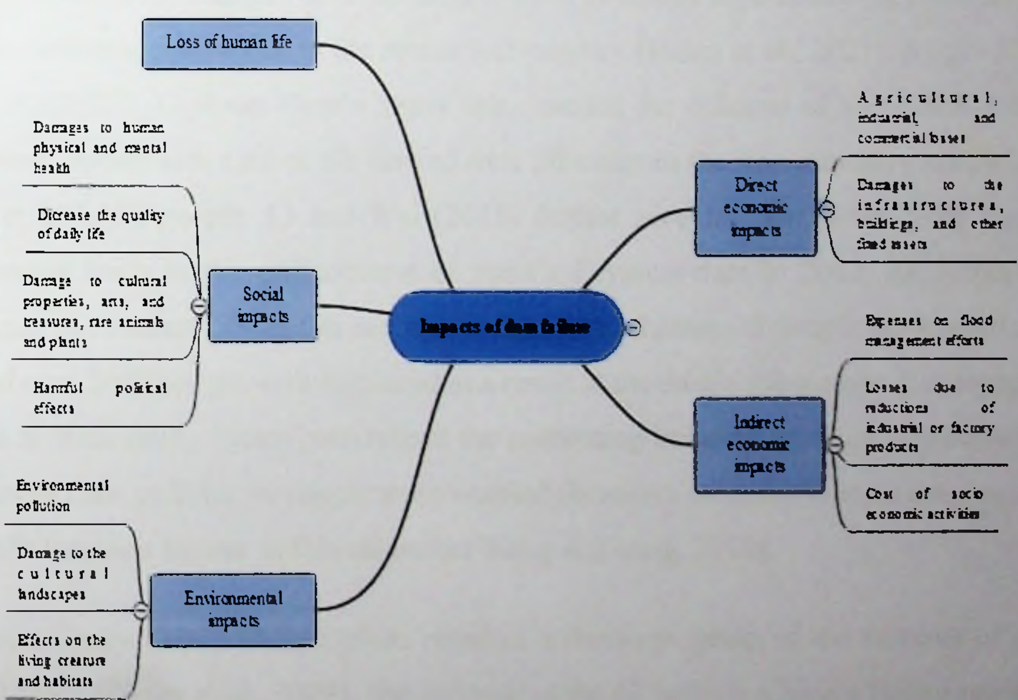

Figure 2.2: Impacts of dam failures

Adapted from: (Mo et al., 2019; Zhong et al., 2011; Zhang & Tan, 2014)

2.4 Real-time examples of the risks of dam failures

This section describes real-time examples of the risks associated with the dam failures in global as well as Sri Lankan contexts.

2.4.1 In global context

In global history, dam failures have been repeatedly reported due to various types of causes and creating very dangerous impacts on both humans and properties. The fall of the Vajont dam in Italy in 1963 resulted in 2066 fatalities, the failure of the Teton Dam in America in 1976 resulted in hundreds of deaths and 1 billion dollars in economic damage, and the failure of the Gouhou dam in China in 1993 resulted in 300 deaths (You et al., 2012).

2.4.1.1 China

The failur of the Banqiao dam in China in 1975 is widely regarded as the most serious dam collapse occurrence in the recent half-century (Hsiao et al., 2021). As per Hsiao et al. (2021), Typhoon Nina's heavy rains caused the collapse of the Banqiao dam; severe floods with tons of silt flowed over 30 cities in the downstream areas, killing over 200,000 people. Li and Wei (2015) further revealed that, after water poured through faults in the embankment of Syria's Zeyzoun dam in 2002, the authorities began to evacuate citizens in nearby districts. Nonetheless, 22 people were murdered, and over 2000 people were displaced as a result of the dam's subsequent disintegration (Li & Wei, 2015). Heavy rain ruined the continuing building of a huge hydroelectric dam in Laos in 2018; 40 people were verified deceased, at least 131 were missing, and 6600 lost their houses in this calamity (Wang & Zhang, 2018).

Accordingly, dam risk mitigation requires a thorough grasp of the features of dam collapses (Zhang et al., 2009). The collapse of the 62 dams in China's Henan province during an intense storm in August 1975 resulted in a regional death toll of over 26,000 people (Ru & Niu, 2001). The Zijin tailings pond dam in Guangdong, China, fell unexpectedly in September 2010 (Miao et al., 2015). As revealed by Miao et al. (2015) this catastrophe led to indirect economic damages of around 460 million yuan, the deaths of 22 individuals, and the destruction of 6,370 dwellings. The authors further explored that the impacted agricultural area was 72.6km^2. The tailings pond dam collapsed as a result of the Fanapi typhoon's torrential rainfall and the mining department's carelessness (Jinghe, 2010). According to Jinghe (2010), the major reason for flooding and tailings reservoir collapse was that the height of tailings reservoir drainage well entry did not meet specified specifications, and the tailings pond management and operation were not in accordance with rules. The dam collapse was caused indirectly by the hydrogeological factors of the tailings pond design, which resulted in poor flood control criteria for the tailings dam (Lyu et al., 2019). The catastrophe was also caused by the incompetence of the design, monitoring, and construction departments (Jinghe, 2010).

2.4.1.2 Brazil

The Fundao tailing dam failed in November 2015 which was one of the largest ever reported failures of the tailings dam due to the increasing rate of serious tailing features (Hatje et al., 2017). More than 35 million m^3 of mining residues are estimated to have slid down a mountainside when the Fundao tailing dam failed, killing 19 people and transforming more than 650km of rivers (Gualaxo do Norte, Carmo, and Doce rivers), which were the major source of water and food for many communities (Miranda & Marques, 2016). Miranda and Marques (2016) further revealed that at least 1,500ha of reservoirs and indigenous Krenak land were harmed.

In 2009, the breach of 11 minor dams in Altamira, Para state, in the Amazon area, caused a domino effect (Tundisi et al., 2014). The burst of a minor dam in 2009 caused substantial socioenvironmental damage in Paragominas, a city with a high concentration of agricultural activity in the state of Para (Nava et al., 2021). In the same city in 2018, the failure of at least six minor dams (cascade effects) resulted in two deaths and flooded 40% of the municipality's urban area, necessitating the declaration of a state of public disaster (Souza et al., 2019). From 1887 through 2017,166 incidents affecting tiny Brazilian dams were documented in a Nava Study (Nava et al., 2021). Nava et al. (2021) further explored that the real numbers are certainly greater because a huge number of incidents are not formally documented by Brazilian regulatory organisations, although there are big dam instances. However, the reported damages in all of these incidents were disastrous in the local context, with different social, environmental, and economic consequences (Tundisi et al., 2014).

2.4.1.3 Russia

The dam levee breach in 2009, caused a slurry flow that destroyed a nearby community and a forest plantation in the Khasyn and Karamken floodplains (Glotov et al., 2018). As per the authors, two nearby residents drowned, and around 25 homes and agricultural structures were seriously destroyed. The vegetation in the lower portions of the Khasyn river valley was nearly totally wiped away. The accident contaminated large amounts of water with residual hazardous components and suspended tailings pulp, endangering nearby fisheries and drinking water supplies. The overall property damage, including mitigating expenses, was nearly 7.5 million USD.

2.4.1.4 Nigeria

Every year, numerous communities in Nigeria lose their homes and farmlands due to the flooding of hydropower dams (Youdeowei et al., 2019). Flooding caused by the breakdown of the Tiga and Challawa dams in Niger and Jigawa states in August 2001 displaced many peoples (Oyekanmi & Mbossoh, 2018). The need to know the extent to which dam structures achieve their expected outcome or intention, the lifespan of each dam before restoration, and the sustainability of dams in Nigeria, drawing the consideration of the government and private owners to the need for dam construction and maintenance, are the main attitudes of the communities (Aladelokun, 2012).

2.4.1.5 United States

The Huangmeishan tailings dam collapsed in 1986 and seepage collapse happened as a result of constant rains for many days, as well as a sub-dam constructed of loose tailings (Davies et al., 2000). As per the authors, this caused the dam to burst, killing 19 people and wounding 95. The Omai tailings dam in Guyana collapsed in 1994 owing to internal erosion, resulting in the flow of sewage into adjacent waterways (Lyu et al., 2019). According to Lyu et al. (2019), this incident caused significant environmental harm by damaging the downstream. The overtopping has caused several dam failures in the United States, for example, the Belci dam collapsed in 1991 killing 25 people with the flood wave and 119 houses were destroyed, Tous dam was breached and lost the lives of 8 people and the costs of the damages were over 400 million dollars, and Teton dam was collapsed by harming for farmlands and towns below the dam and 11 people were died (Sharma & Kumar, 2013).

2.4.2 In the Sri Lankan context

The worst scenario of dam failure in Sri Lanka has considered the Kantale dam failure in 1986 and it was caused due to a crack on the top of the bund close to the left bank sluice (Jayasinghe, 2021). However, as per Jayasinghe (2021), an unusual sound came from the sluice and it takes only half an hour to fail the Kantale dam with a gap of one meter wide and grew to 300m by emptying the tank within 24 hours. Hence, immediately evacuation programs started and Sri Lanka Army, Airforce, Police, and the Navy helped to conduct the evacuation program (Jayasinghe, 2021). Due to that accident, 130 lives were lost, nearly 600 private and government buildings were totally damaged, 630 buildings were partly damaged, agricultural roads and other infrastructures were washed away with a total rehabilitation cost of Rs 525 million during that time, and more than Rs 9000 million from the present worth (Kamaladasa, 2017). Additionally, Kamaladasa (2017) revealed that, during the past decades especially in North Central province, North province, Northwestern province, and the southern province have caused breaching of 35 large dams, 53 medium dams, and 1500 small dams by creating severe damage to the irrigation, agriculture, as well as human life.

However, there are more than 12000 large, medium, and small-sized dams that have been constructed for several purposes (Manatunge et al., 2009). Hence, there are vast areas that have been calculated as inundated areas in each and every province with dams (Fujikura et al., 2009). As a result, every province within the country has the risk of dam failures, and most of the people who live near the dams always behave with the risk of dam failures (Herath, 2021). Samarajiva et al. (2006) further revealed that dam danger detection and monitoring systems are not widely used in Sri Lanka at the moment, with the most prevalent approach being basic visual inspections undertaken mostly by inexperienced, lower-level workers. Therefore, as a remedy, EWSs can be used to reduce the risk of dam failures with the incorporation of the irrigation department.

2.5 Early warning system

Early warning systems (EWS) and risk communications are very important roles in the existence and recovery of the population impacted by disasters (Fan et al., 2018). Hence, EWS is one of the most important tool used to prevent the impact of disasters (Zambrano et al.,2017). According to Zambrano et al. (2017) "early' refers to the prediction of disasters, potential damages, or hazards in the future before it really occurs, "warning" describes the announcement given by describing the danger, and "system" is the component that puts all the information together. Therefore, EWS has been identified as a strategy used to save lives from disasters (Collins & Kapucu, 2008). Generally, EWS is the collection of abilities required to develop and transmit timely and relevant information in order for people, communities, and organisations endangered by hazards to plan and respond effectively and insufficient time to decrease the chance of injury or loss (UNISDR, 2009). Traditionally, Engineers and Scientists have given relevant stakeholders in organisations with disaster risk studies or information and recently, web-based access to data and model simulations, as well as interactive tools, have been accessible to help with the flood risk management decision-making (Poljansek et al., 2017).

While developing an effective EWS, spatial and socio-cultural factors such as hazard and vulnerability mappings (Schlurmann et al., 2011), community education and participation (Collins & Kapucu, 2008), indigenous and local knowledge (McAdoo et al., 2008), and religious and language differences should all be considered (Haigh et al., 2020). Other than that, the developers have to have a solid understanding and knowledge of how to create effective warnings for accurate risk scenarios associated with vulnerable people (Dutta & Basnayake, 2018). The authors further asserted that the effectiveness of the EWS can be achieved with the engagement of experienced experts to manage the system. Basically, EWSs are focused on the people (people-centric) by developing risk knowledge, monitoring and warning service, dissemination of warning information, and public awareness and preparedness (Eckersley et al., 2017). Hence, there are instruments and procedures connected with the EWS which are coordinated by international, regional, and national agencies (Fan, Tian, & Wang, 2018). However, the basic concept behind a common EWS can be illustrated in the following Figure 2.3.

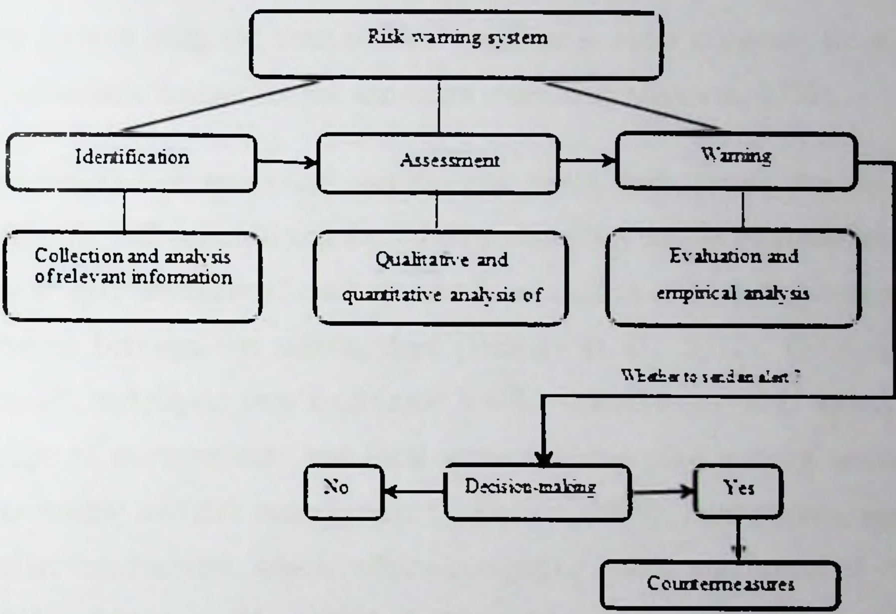

Figure 2.3: A basic framework for an EWS

Source: (Wu et al., 2021)

2.5.1 Key concepts of an early warning system

The installation of a variety of devices and technologies to guarantee early identification and monitoring of risks is typical of warning systems (Osawa et al., 2021). Hence, the main concept associated with the EWS is the prevention of loss of life and damage to people and other structures due to disasters (Dutta & Basnayake, 2018). As per Leonard et al. (2008), EWSs are comprised of scientific and organisational capabilities for assessing acquired data to estimate the level of related risk exposure, potential consequences, and prompt notification mechanisms for people at risk. In addition to that, it is important to consider the coherency, capacity to convey timely predictions, efficient alarms, accurate detection, and warning messages, strong communication, reliable responses, and consistency in order to maintain the effectiveness of the EWSs (Haigh et al., 2020). Wehn and Evers, (2015), also further asserted that good risk communication has the ability to establish public confidence if it is based on honesty, clarity, comprehensiveness, and timeliness (Wehn & Evers, 2015). Even though the major function of an EWS is to deliver the warning to the final destination (community level), the key concept behind that scenario is to filter the gathered information and translated them into recommended action through the technical process using the most suitable language in order to convey the warning in an understandable manner for the end-users (Hamza & Månsson, 2020).

The stakeholder risk awareness and the risk perceptions among the communities affected by the risk scenario and the local communities can be evaluated through the "top-down" and "bottom-up" methods which are used to create better connection and coordination between the stakeholders (Jonoski et al., 2012). By incorporating "bottom-up" techniques into traditional EWSs, stakeholders with access to local knowledge of environments and local networks may play a more active role in decision-making and risk management (Krywkow, 2009). Furthermore, openness in stakeholder involvement, which reflects competing claims and points of view, may boost stakeholder trust (Van Asselt & Renn, 2011). Therefore, it is critical to get systematic input from the community at all phases of risk management (Henriksen et al., 2018). Moreover, when communicating the messages from the EWSs, the communication process has given much attention to technological, managerial, scientific, and social components with the aim of notifying the people at risk by achieving the key purpose of the EWS (Collins & Kapucu, 2008).

When the EWSs are arranged for flooding events, they need to provide a forecast for a variety of time scales, from long-term climate forecasts and hydrological/hydraulic estimates, down to seasonal and monthly outlooks, 10-day predictions, three-day predictions, daily predictions, and all the way to hourly or immediate short-term warnings (Fan et al., 2018). As a result, the EWS has access to the records of the hydrological cycle and it will be useful for stakeholders and the general public to continuously update their data on the state of river flow, groundwater levels, and visualised flooding risks (He et al., 2016). As a result, He et al. (2016) further revealed that the platform of EWSs can be used as a knowledge exchange media for risk management among the involved stakeholders, experts, humans, and decision-makers in which well-organized feedback can be received. However, warnings will initiate a predetermined series of local measures that will result in the safe evacuation of vulnerable downstream populations (Wu et al., 2021). As a result, there are specific characteristics of EWSs used in various disaster management.

2.6 Functional characteristics of an early warning system used in dam failures

The goal of an EWS is to prevent the danger of any type of dam failure (caused due by overtopping, natural disasters, aging, etc.) from becoming a disaster by making destructions for life and property. Hence, in order to achieve the goal of the EWS, it has specific five characteristics or components that must work in unison i) Hazard identification, vulnerability analysis and risk assessment (forecasting and risk evaluation), ii) Detection and monitoring, iii) Emergency management structure, including warning and evacuation, iv) Local dissemination, v) Public education (Samarajiva et al., 2006). Therefore, the EWS is a program used to ensure dam safety by essentially incorporating both risk reduction and risk mitigation procedures (Altinakar et al., 2009).

Apart from the categorised main five characteristics, remedial actions, safe operations, proper maintenance, and emergency management associated with dam failures have been identified as some other characteristics of dam failure EWSs (Steenbergen & Willems, 2013). Though Leonard et al. (2008) further revealed that the aim of dam safety authority with the availability of such characteristics for EWSs is to ensure that dam operators and owners have dam management procedures in place to minimise the possibility of dam-related hazards. As such, the main functional characteristics of the dam safety EWS can be described as follow.

2.6.1 Hazard identification, vulnerability analysis, and risk assessment (forecasting and risk evaluation)

Many hazard warnings are prompted by local officials as well as affected local residents, alerting families, and neighbors (Delenne et al., 2012). As a result, other than the experts' people also act as the valuable source of hazard detection information (Cools et al., 2016). The latest Kantale dam failure is a most related example for the confirmation of the above statement, as the villagers are the first source that noticed the dam failure and alert the dam engineers and the other downstream villages (Jayasinghe, 2021). However, dam inspection staff, as well as villagers close to the dam, should always be trained to identify the dam failures (unusually high-water levels in the canals or muddy discharge from seepage) in a timely manner and to look for early signs of distress conditions (Steenbergen & Willems, 2013). Therefore, when a villager identifies any hazard, they must inform relevant authorities in order to maintain early warnings (Wattanasit & Khwannimit, 2021).

People, industry, and public infrastructure in the dam's flood path are most vulnerable to damage (Akindele & Indabawa, 2015). Therefore, as per Celik and Gul (2021), it is critical to adequately educate these stakeholders on potential hazards and to warn them in the event of a hazard. Hence, the entire downstream network is considered by the EWSs while assessing the risks associated with a potential dam failure (Hsiao et al., 2021). However, through early warning risk analysis, it creates prevention strategies such as careful operation and maintenance to reduce the likelihood of dam failure and mitigation strategies such as public warning systems to help to mitigate the consequences of a dam failure (Samarajiva et al., 2006).

Mow et al. (2017) also revealed that significant improvements have to be done to this characteristic due to the various types of risk events, with the use of many efforts and resources. Accordingly, risk forecasting and evaluation is a major scientific and technical dimension in the system which mainly retains the observations and the predictions with advanced technologies like remote sensing, mathematical modeling, and scientific expertise (Hamza & Månsson, 2020).

2.6.2 Detection and monitoring

An accurate and dependable method of detecting hazards is the foundation of an effective and comprehensive public safety program (Binder, 2017). As revealed by You et al. (2012), in the field of dam safety, hazard detection begins with a thorough examination of the dam's physical integrity. An effective inspection/ monitoring system must include the collection of relevant data to ensure that monitors receive accurate safety status indications, as well as timely data collection/ sensing systems to allow authorities time to analyse data and issue warnings if necessary (Eckersley et al., 2017). A sensor can be identified as a device that is used to convert the environmental measurements into system-understandable and interpreted signals which are going to be monitored, processed, and saved in the EWS (Faulkner et al., 2011). The authors further revealed that, as a result, all the collected data will be associated with the monitoring process. Hence, monitoring is regarded as a critical characteristic while arranging EWS as it processed and stored data for intelligent decisions (Samarajiva et al., 2006). Internet of Things (IoT), Cloud of Things (CoT), sensor web, and sensor networks are some examples of detecting platforms that are aligned with the monitoring systems (Zambrano et al., 2017). Therefore, monitoring is considered a characteristic that aligns with science and technology (Mow et al., 2017; Leonard, et al., 2008; Samarajiva et al., 2006).

Generally, monitoring of EWS conducted through three key elements as observation, measurement, and prediction (Zambrano et al., 2017). As per the authors, the environmental changes which are visible to anyone are the observations while the items expressed in a form of numerical as water levels are the measurements, and predictions are the things that are associated with the analysing procedures and beliefs which are going to be happened based on the observations and measurements. Besides that, high-tech extreme (considering complex factors) and low-tech extreme (observations) are included in the routine inspections and due to institutional failures, dam structures are being monitored solely through visual inspections (for example Kantale dam failure) (Fujikura et al., 2009). Increasing the time lag between hazard detection and hazard events allows enough time to warn and evacuate vulnerable communities, as well as take mitigation actions to minimise property damage (Kim & Sanders, 2016).

2.6.3 Emergency management structure including warning and evacuation

The geographical impacts and the extent of inundation of the dam failure impacts will be dependent on the location and the size of the dam (Duressa, 2018). As revealed by

Duressa (2018) the data from the EWSs are only sent to the local dam officers when only locals are impacted by the dam failure and the data will be transmitted to all other locations to allow a region-wide coordinated response in case of a large dam failure. Established protocols must be placed to allow dam engineers and local governments to make quick and efficient decisions (Wang & Zhang, 2018). If a dam-related hazard is discovered, dam operators should notify pre-designated emergency first responders in local government, community-level organisations, and the media (Samarajiva et al., 2006). Therefore, the warning chain has to be established with three main linkages the originator (scientific author of the warning), intermediaries (media and other government decision-makers), and the respondent (vulnerable communities, emergency services, etc.) (Hamza & Månsson, 2020).

Disaster management plans must be tailored to the specific characteristics of the dam and its watershed area (Hardjosuwarno, 2014). Hardjosuwarno (2014) further revealed that these plans must include instructions for on-site personnel on what steps to take to notify supervisors and warning disseminators. Further, these warning systems should play a dominant role while managing safety programs and supplying information to the public in order to maintain public trust (Samarajiva et al., 2006). However, while developing the warnings have to have to pay much attention to the diverse group of communities with their culture, age, and disabilities (Zambrano et al., 2017). Therefore, as per the authors, the connection between systems and communication technologies will be highly effective with this characteristic of the EWS.

2.6.4 Local dissemination

The "last mile," which carries alerts and warnings to homeowners in vulnerable cities and villages, is one of the most ongoing support in an EWS (Ardeshirtanha & Sharafati, 2020). Just after the detection of a dam-related hazard, warnings and alerts must be issued to local officials (police, municipality, fire services, local military), religious institutions (temples, churches, and mosques), community organizers (such as farmer organisation leaders, Grama Niladhari), and grass-roots organisations (Sarvodaya) (Samarajiva et al., 2006). So that the warning can be disseminated to each individual household at risk, allowing people at risk, allowing people to take the necessary precautions (Zhu et al., 2021). Therefore, as revealed by Zhu et al. (2021) this final component of warning or the instruction for protective measures is required to provide people with the best chance of avoiding serious harm. Hence, here the decision is with the humans whether the warning given is translated into action or not (Hamza & Månsson, 2020). As a result, the authors further evaluated that this characteristic of EWS does not receive more attention similar to all other above characteristics as a system as the warnings chain is developed in the system through the above characteristic.

2.6.5 Public education

The general public must be educated on the nature of hazards and their consequences, who and what is at risk, how people will be warned, what the warnings mean, and what actions must be taken (Eckersley et al., 2017). Warning systems must be tested on regular basis to ensure that they function properly and that the general public understands their purpose and messages (Martin & Rice, 2012). Samarajiva et al. (2006) asserted that the dam safety program's success will be determined in large part by the public's ability to respond suitably to all warning authority's warnings, alerts, and instructions, both in the event of a dam risks and in the general and everyday use of dams and reservoirs. Finally, safety training should include information on potential risk warning signs (e.g., seepage or overtopping) as well as instructions on how a local resident can contact the local dam operator and the central dam hazard unit (Eckersley et al., 2017).

Even though there are five key functional characteristics of the EWS, risk forecasting, monitoring, and warning to those at risk for awareness and preparedness are considered the main characteristics when creating a digital environment for the EWS (Zambrano et al., 2017). Therefore, when arranging EWS with those key characteristics there are different system views that have to be taken into consideration.

2.7 System views that are used to support the functional characteristics of early warning systems

While preparing EWS, different types of system views such as data, communication, institutional/ stakeholder, and community are taken into consideration in order to maintain the effectiveness of the EWS. Hence this section will discuss such different views of EWS.

2.7.1 Data View

The data collection view is very important in the forecasting of the risk associated with dam failures (Leonard et al., 2008). Hence there should be effective planning in all steps of the EWS including decision-making, dissemination, and communication protocols (Galley et al., 2004). Galley et al. (2004) further revealed that data collection plans can be documented with maps, signages, and all other tools incorporating frequency renewals where necessary. Besides that, the risk data can be collected from the communities that felt that they are at risk and it is possible to view it in a detailed knowledgeable manner (Zambrano et al., 2017). Even though the data can be collected through such geo-referenced (inundated) mappings, the risk knowledge is not very reliable (Paton, 2003). Nevertheless, as alternative smart sensors can be used to collect data about the risk situations and using protocols such as XMPP or SIP collected data can be transferred to the responsible organisations to coordinate further actions (Ganti et al., 2011).

2.7.2 Communication View

Generally, EWS is a climatological service, broadcasting corporation, or government organisation that is connected with various communication methodologies and tools in an advanced way compared with traditional institutions (Hamza & Månsson, 2020). Not having improved communication methods from the institutions and the consideration of communication linkages as a secondary with the linked institutions, have affected the inadequacy of EWS (Gross, 2013). However, the author further revealed that communication difficulties are not limited to the institutions and the channels. Further, it is extremely important to consider the requirements and the complexities associated with the communications of warnings for all who are at every basic level of the economy (Villagrán de Leon, 2014). According to the characteristics of the several populations, they will require communication of warning in an advance way compared with the general public (required more time for response for the warning) (Hamza & Månsson, 2020). As per the authors, those populations will cover the public at hospitals, prisons, old-age homes, and other such institutions.

The supply-side approach has been taken in most of the EWSs where experts are at the top or the center (Syafwina, 2014). Then they will pass the messages outward and downwards to the target population (Hamza & Månsson, 2020). As per the authors, this is focused more on the technology and has mitigated the concept of EWS that which has to understand the behavior of humans. However Leonard et al. (2008) have suggested five key categories of communicating warnings messages via natural warning, institutional staff to those in their care, structured organisations and groups to the public, 3rd party hardware and/or staff (aircraft hailers/banners, amateur radio, billboards, call-in phone line, cell broadcast, e-mails, GPS receivers, SMS text messaging, etc), and warning-dedicated hardware (fixed PA loud-speakers, flares, explosives mobile PA loud-speakers, tone-only sirens, tone-activated alert radio).

2.7.3 Institutional/ Stakeholder View

Even though the institutions/ stakeholders have the influence of external factors like attitudinal, financial, logistical, ideological, political, legal, and institutional while forecasting the early warnings (Hamza & Månsson, 2020), they have the responsibility to pass the warning to the last mile of people who are at the local government or regency level (Rahayu et al., 2020). In order to complete such responsibility of institutions, have to maintain a good linkage between multi-institutional stakeholders to disseminate the warning timely even though there is a very limited leading time (Bisri, 2016). However, if the institutions failed to address their responsibilities due to such external influences, they will be badly affected by the communities and the householders' response to the early warning (Twigg J., 2003). According to the reveals of Leonard et al. (2008), institutions have to plan what can be done and what cannot be done while making the early warnings, the special requirements have to be included in a warning message, and the actions that have to be taken place according to the information received through the technical officers within a given time. Apart from those, institutions have to make speed and trust communication methods by testing their availability to educate the people at risk during the early warning (Galley et al., 2004).

2.7.4 Community View

The view of the communities on their own risk differs from the other external stakeholders (Basher, 2006). External parties have identified that it is very difficult to realize how communities understand and respond to the risks and hazards (Leonard et al., 2008). As revealed by Leonard et al. (2008) one reason for that is specialists in early warnings and communities are using two different starting to identify the potential risks and disasters. Specialists start the EWS at a central level internationally or nationally and pass the message outward and downwards where individual villagers are at the boundary of the system (Hamza & Månsson, 2020). However, from the view of communities, individual villagers are at the center of the system (Twigg J., 2003). Twigg (2003) further revealed it is very important to give priority to the community view as there can be individuals or households that are at risk of disasters which are hidden from the system managers who are working with the large dams.

The other difference between experts and the communities is the way that they measure and describe the risk (Leonard et al., 2008). Scientific and engineering methods are used by technical experts to analyse and quantify the risks (Chester et al., 2002). According to the authors, the experts converted those mathematical calculations to general language as high, low, and medium risks. However, people at risk of hazards and disasters used qualitative methods rather than quantitative methods to analyse the risk (Skyttner, 2002). Accordingly, the experts assess and understand the risks in a scientifical way (objectively) whereas communities understand the risks in an irrational manner (subjective) (Leonard et al., 2008).

2.8 Digital platforms

Digital platforms have become critical in providing services to society as a result of the ever-changing technological trends (Anttiroiko, 2016; Janssen & Estevez, 2013). Klievink et al. (2016) have revealed digital platforms as a socio-technical infrastructure that can be used by various actors to succeed in all types of applications and assemble them available to the government as well as the public itself. Hence, digital platforms are the integration of software and applications on the web as a mediator between the service providers and the recipients (Hanafizadeh et al., 2020). Therefore, the authors further revealed that it creates an economic value by giving access to the products and services. According to Dutot and Van Horne (2015), some studies have highlighted the capacity of digital platforms to enhance the connection with customers, from which important insights and innovative ideas can be captured and is useful in responding to the uncertain environment in which business operates. Constantinides et al. (2018) identified digital platforms as a collection of digital resources that enable participants to interact with one another. However, there can be technical and non-technical definitions for digital platforms as illustrated in Table 2.4.

Although, this interaction, as well as the ability to allow users to perform defined tasks while being technologically mediated, is one of the fundamental common characteristics of digital platforms (Cusumano et al., 2019). As well as the concept of this digital platform is not novel (Ciborra, 1996) way its strategic value has increased significantly (Yoo et al., 2012). Indeed, digital platforms are increasingly being used in a variety of industries, including healthcare, telecommunication, banking, transportation, media, and information technology (Kiesling, 2016; Reuver et al., 2015). Accordingly, there can be specific characteristics for digital platforms as described in the following section.

Table 2.4: Definitions of digital platforms

Conceptualization View	Definitions of Digital Platforms	Reference
Technical (e.g., software development & production)	"a building block that provides an essential function to a technological system and serves as a foundation upon which complementary products, technologies, or services can be developed"	(Spagnoletti et al. 2015, p. 364; Yoo et al. 2012, p.1400)
	"set of components used in common across a product family whose functionality can be extended by applications"	(Ceccagnoli et al. 2012, p. 263)
	"The extensible codebase of a software-based system that provides core functionality shared by the modules that interoperate with it and the interfaces through which they interoperate"	(Tiwana et al. 2010, p.676; Ghazawneh and Henfridsson 2013, p.3)
	"a set of subsystems and interfaces that form a common structure for/from which derivative applications can be developed and distributed"	(Xu et al. 2010, p. 1305)
Non-technical (e.g., B2B & B2C transactions)	"a commercial network of suppliers, producers, intermediaries, customers..... and producers of complementary products and services termed "complementors"..... that are held together through formal contracting and/or mutual dependency"	(Tan et al. 2015, p.249)
	"Two-sided networks ......that facilitate interactions between distinct but interdependent groups of users, such as buyers and suppliers"	(Koh and Fichman 2014, p. 977)
	"multisided platform ....exists wherever a company brings together two or more distinct groups of customers (sides) that need each other in some way, and where the company builds an infrastructure (platform) that creates value by reducing distribution, transaction, and search costs incurred when these groups interact with one another"	(Pagani 2013, p. 625)
	"...value is created by facilitating the interaction between two or more mutually interdependent groups of customers"	(Ye et al. 2012, p. 211)

Source: (Asadullah et al., 2018)

2.8.1 Key features of digital platforms

Various features are presented by the digital platforms to represent their attractiveness as an organized model (Asadullah et al., 2018). Basically, digital platforms reduced the transaction costs which include the costs of search, distribution, contracting, and monitoring (Pagani, 2013). Hence, digital platforms incorporate multiple sources into one platform and provide information for intermediate users by reducing the cost of searching (Eisenmann et al., 2006). Through modularity and appropriate governance structures, digital platforms aid in the organisation and coordination of the technological development of complementary products (Boudreau, 2010). According to Asadullah et al. (2018), Apple's iOS and Google's Android platforms are examples that provide a technical and regulatory structure that facilitates and encourages independent software developers' participation in application development. Other than those, generativity, openness, cross-side network effects, and convenience act as the broader features of digital platforms (Evans et al., 2006; Faraj et al., 2016; Hagiu, 2014; Yoo et al., 2012).

According to Zittrain (2009), generativity is the technology's ability to generate new outcomes as a result of large and diverse user populations. In other words, generativity can be described as the ability indicated by digital technologies to create sudden changes in huge, diverse, unrelated, unaccredited, and uncoordinated entities (Dicuonzo et al., 2021). Further, Dicuonzo et al. (2021) discuss openness as the nature and degree of openness enabled by digital technologies in the context of innovations while the term convenience relates to the action potential or possibilities provided by new digital technologies relevant to a particular user.

Other than those, digital platforms need to have the potential to activate innovations within the organisations through their ability of trialability, ease of use, and cost-effectiveness (Sedera et al., 2016). Interactions between directly and indirectly influenced actors, socio-technical dimensions, and the business ecosystem structure of the digital platform (Hanafizadeh et al., 2020). According to Altman and Tushman (2017), to create value, platforms adopt and facilitate interactions with external parties such as individuals, organisations, and communities. Hence, the level of success of a digital platform is determined by the quality of interactions and the value of transactions (Hanafizadeh et al., 2020).

2.9 Conceptual Framework

Based on the discussion above, a conceptual framework has been developed as shown in Figure 2.4. The purpose of the conceptual framework is to present how the functional characteristic of EWS can support to minimise the causes and impacts of dam failures.

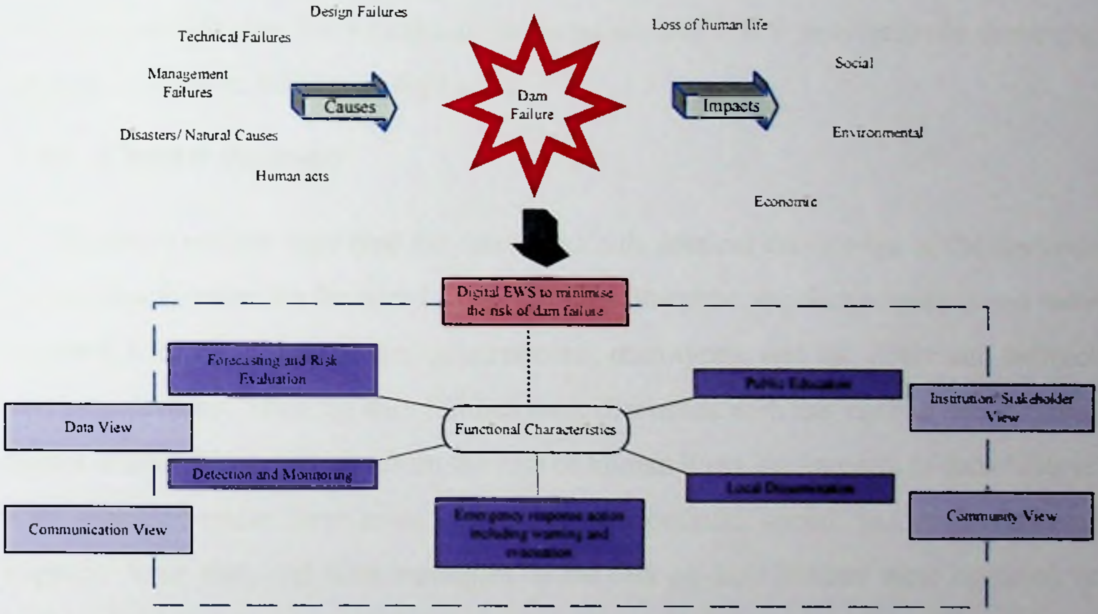

Figure 2.4: Conceptual framework

As shown in Figure 2.4, the dams are a very important infrastructure that gives enormous benefits. However, due to the identified causes, the risks of dam failure will increase and create very disastrous consequences on social, economic, and environmental aspects. As illustrated in the conceptual framework, the EWS is the most suitable strategy to reduce the risk of dam failures during the construction, operation, and maintenance of the dams. The key functional characteristics of EWS are explored, as illustrated in the conceptual framework. How these functional characteristics will be utilised in the context of EWS for dam failures in Sri Lanka is the way forward for this study. As technology has developed and expanded worldwide, it can be used to enhance the characteristics of EWS in one platform (Fan et al., 2018).

Since all the theoretical information gathered on the dam failures can be incorporated with the technology medium by sharing social, economic, and environmental information, technology will be a supportive platform to handle the different levels of information about the dam failures by increasing the efficiency and effectiveness of EWS. As such this research will further analyse the utilisation of technological platforms to effectively evaluate and implement the functional characteristics of EWS for dam failures in Sri Lanka.

Hence this conceptual framework will act as a basic guide to capture primary data in order to contextualise the functional characteristics of EWS to effectively minimise the impacts of dam failures in Sri Lanka.

2.10 Chapter summary

The literature review improved the researcher's theoretical knowledge of the research under consideration. As the initial findings of the literature, the dam constructions were explored with the effect of dam constructions, dam types, and the direct and indirect purposes of dams. Then the dam failures were discussed with the internal and external causes of dam failures. Apart from the loss of human lives, the impacts of dam failures were explored under three main categories as economic, social, and environmental impacts. After that, real-time examples of the risk of dam failures were captured in both global and Sri Lankan contexts. Thereafter EWS was explored with its key concepts, functional characteristics, and the system views used to support the functional characteristics of EWS. At the end of the literature, the digital platform was discussed in order to identify its features. Based on the literature, a conceptual framework was finally developed to use as a guide to the primary data collection.

CHAPTER THREE

RESEARCH METHODOLOGY

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 Introduction

The research aimed to enhance the functional characteristics of a digital EWS to reduce the impacts of dam failures in Sri Lanka. Initially, the research problem of this study was identified as the unavailability of an effective EWS for the dam failures in Sri Lanka. Hence, the systematic approach used to solve the identified research problem is reflected in this chapter. Thus, this chapter represents the methodology followed to accomplish the research objectives with the proper justification of the research philosophy, research approach, research choice, research strategy, and research techniques.

3.2 Research process

Before delving into the specifics of research methodology and techniques, a brief overview of the research process seems appropriate. The research process is a series of actions or steps required to carry out the research effectively, as well as the desired genetic analysis of these steps (Kothari, 2004). Accordingly, the graphical representation of the research process followed by this study is presented in Figure 3.1. The research problem which needs to be answered through this study was identified at the initial stage by conducting a background study. Then after an in-depth literature review was conducted to get the theoretical background. Accordingly, the first, second, third, and fifth objectives were partially achieved through the literature review. Stakeholder interviews were conducted as the primary data collection technique of the study. The collected data was analysed by manual content analysis in order to achieve the first three objectives and the last objective. The fourth objective which is to capture user requirements for an effective EWS for dam failures in Sri Lanka was accomplished through the user story analysis. Finally, the conclusion and recommendations have been developed from the findings of the study.

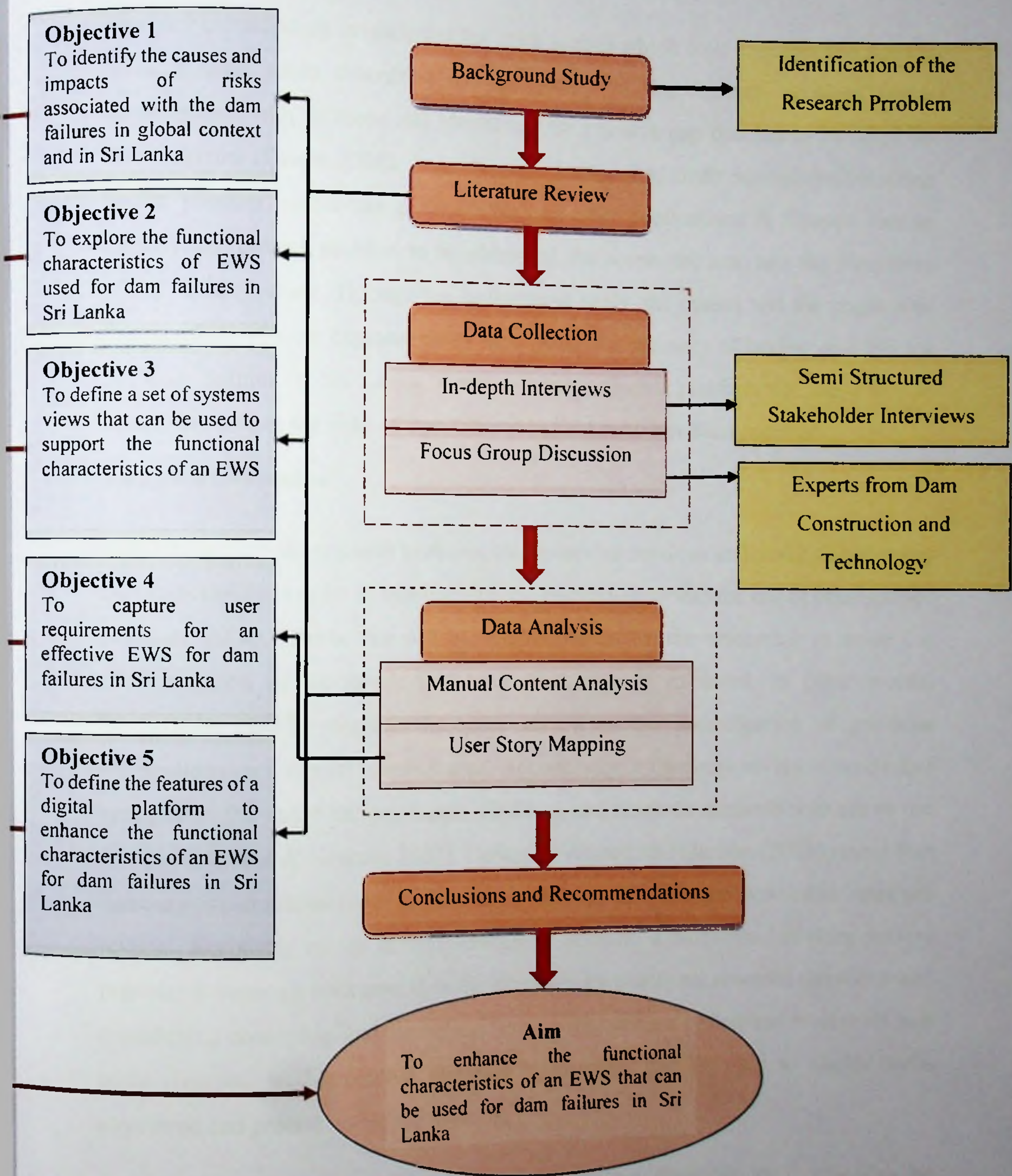

Figure 3.1: Research Process

3.3 Background study and problem identification

The background study investigates the prior studies which have explored the current research area while describing the essentiality of the research problem under consideration with its scope and identifying the research gap that has to be filled by the researcher (Lango, 2020). Accordingly, a background study was conducted using books, journals, conference proceedings, and other publications in Chapter one to identify the research problem to be addressed, the scope, the aim, and the objectives of the research study. Through the background study, the causes and the impacts of the dam failures were explored while identifying the necessity of having an EWS for the dam failures in Sri Lanka. Further, using a digital platform for the EWS to effectively reduce the risks of dam failures in Sri Lanka has been justified.

3.4 Literature review

After identifying the research problem, the researcher needs to undertake an extensive literature survey in order to familiar with the research area with the use of prior studies (Kothari, 2004). Hence, that will be very important for the researcher to avoid the reinvestigation of the issues that have been already explored. In other words, Mudavanhu (2017) describes literature review as the identification of previous publications on a similar research area. Accordingly, a literature review extracts and synthesises the major factors, issues, findings, and research methods relevant to the study (Rudestam & Newton, 2007). However, Arshed and Danson (2015) reveal that there are two dominant types of literature review as narrative and systematic literature review. According to the further reveals of authors, a narrative literature review provides a thorough background in the literature by clarifying research questions and establishing conceptual and theoretical frameworks while a systematic review act as a more rigorous, well-structured literature review that can be used to clarify well-structured and precise research problems.

Accordingly, this study adopted extensive narrative literature as it provides an expanded understanding of the research area. Other than that, narrative literature reviews are intended for topics requiring a thorough review of the literature (Rozas & Klein, 2010). Hence, narrative literature is most suitable for this study in order to achieve the objectives. Therefore, the extensive literature review of this study was conducted to discuss the dam types and their purposes, causes and impacts of dam failures, real-time examples of dam failures in global and Sri Lankan context, EWS and their functional characteristics, and system views that support the functional characteristics of EWS, digital platforms, and their key features.

3.5 Research methodological design

Research methodological design is a broad research strategy that specifies how research should be carried out (Melnikovas, 2018). The authors further reveal that methodology consists of a set of beliefs and conceptual models that structure the overview of the research question and guide the selection of research methods. Hence, this assists in ensuring consistency between selected tools, techniques, and underlying philosophy (Billing, 2004). The research onion model which was proposed by Saunders et al. (2019) is the design widely used by social science researchers to develop methodological design. As such this study has used the research onion as the methodological framework. The research onion offers a lengthy overview of the main sections or stages that must be completed in order to develop an effective methodology (Raithatha, 2017). The research onion model is illustrated in Figure 3.2.

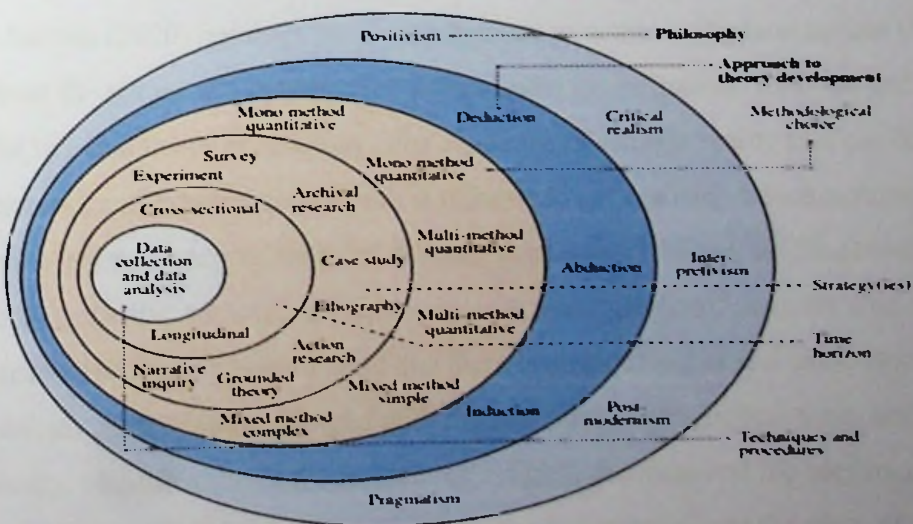

Figure 3.2: Research onion

Source: (Saunders et al., 2019)

As shown in Figure 3.2, the research onion is a tool that assists in organising and developing the research by working through each layer of the onion step by step. Therefore, the researcher needs to follow up all six layers of the research onion (research philosophy, research approach, research choice, research strategy, time horizon, and research techniques) one by one from the outermost layer in order to develop an effective research methodology. The next section presents the design of the research methodology for this study based on the layers of the research onion.

3.5.1 Research philosophy

The first layer of the research onion is the research philosophy, and it is the most significant layer to be considered. According to Saunders et al. (2019) research philosophy contains the beliefs and assumptions about the way that researchers develop a particular research area. Therefore, it will depend on the knowledge that is going to be investigated through the research (Chege & Otieno, 2020). However, there are three main assumptions as ontology (reality), epistemology (knowledge), and axiology (action) which helps to understand the philosophical stance of the research (Aliyu & Adamu, 2015).

Ontology mainly refers to the nature of reality (Saunders et al., 2019). According to Al-Ababneh (2020) ontology assists researchers in determining how certain they could be about the nature and existence of things under investigation. Realism and idealism are the two main ends of ontology. The existence of a single reality that can be studied, understood, and experienced as truth is referred to as "realism" which assumes that the universe exists independently of human experience (Moon & Blackman, 2017). According to the authors, it further reveals that "idealism" assume that reality is constructed within the human mind and there is no anything as real truth. Accordingly, in idealism reality can be changed with the individual's experience, time, and place. In this study, identification of the features of a digital platform and the user requirements for an effective EWS for dam failures exclusively depends upon the users of the EWS. The causes and the impacts of the dam failures and the system views support for the functional characteristics of EWS can be changed with the behavior of the governing bodies. Therefore, the reality of this study depends on the ideas, thoughts, and different perspectives of humans. As a result, this study moved toward the idealistic nature of ontology as this study accepted human interactions.

Epistemology is concerned with all aspects of validity, acceptance, and the method of acquisition of the knowledge in the research area and the way of communicating that knowledge to others (Al-Ababneh, 2020). Epistemology also has three main extremes as objectivism, constructionism, and subjectivism. Objectivism explains that knowledge exists apart from the individual mind and knowledge is evidence-based, improving objectivity while constructionism refers to the meaning that emerges from human interaction with the realities of the world as there is no knowledge waiting to discover it, encouraging the constructivist (Moon & Blackman, 2017). Subjectivism recommends that the knowledge is based on the opinions of the people where subjectivity is encouraged (Saunders et al., 2019). Therefore, subjectivity is highlighted in the epistemological perspective in this study as the user's opinions are perceived to develop the knowledge.

Axiology refers to the value concern of the research. Hence it represents a set of values and ethics used all over the research process, challenging how researchers deal with their own values and ethics as well as the research participants (Saunders et al., 2019). Two main extremes of axiology assumptions are value-laden and value-free. The choice of what and how to study is selected by objective criteria in the value-free study while it is selected based on the human values and experience in the value-laden study (Easterby-smith et al., 2018). As the researcher's own value and perceptions in understanding and interpreting the subject plays a vital role in achieving the objectives, this research assumes a value-laden stance.

Each of the aforementioned philosophical assumptions is associated with a different philosophy namely positivism, interpretivism, and pragmatism.

Positivism

Positivism is concerned with the creation of a comprehensive social system that employs the scientific method in the study of society and human beings for the benefit of both (Al-Ababneh, 2020). According to the authors, positive science is founded on direct experience rather than speculation. This science's knowledge is firmly and exclusively based on something posited, and it is not arrived at speculatively (Easterby-smith et al., 2018). Hence, positivism has the ontological assumption called realism. Positivism is completely objectivist under the epistemological assumption. Objects in the world have meaning prior to and independent of any consciousness of them, according to the positivist viewpoint (Al-Ababneh, 2020). Researchers in the positivism philosophy deal with issues objectively, without influencing the real problem being studied. Therefore, positivists are related to the axiological assumption of value-free. As a result, positivism philosophy necessitates a highly structured methodology, quantifiable observations, and statistical analysis (Saunders et al., 2019).

Interpretivism

Interpretivism philosophy emerged to understand and explain human and social reality in contrast to positivism. The interpretive approach seeks interpretations of the social life-world that are culturally generated and historically situated which is identified as idealism (Dudovskiy, 2018). The Interpretivism philosophy holds that each research is unique and distinct from others. Because of the changing values of business organisations and various interpretations by people, as well as the world's complexity and uniqueness, this methodology is not an effective option for generalisation (Al-Ababneh, 2020). Therefore, this is value-laden in terms of axiology. This interpretivism philosophy approaches knowledge in a novel way by emphasising a subjective and descriptive approach to dealing with complex situations rather than an objective and quantitative approach (Aliyu & Adamu, 2015). Ultimately, interpretivism is concerned with socially defined and subjective reality, in which the researcher's interpretations play an important role by becoming a part of the study (Saunders et al., 2019).

Pragmatism

Pragmatism is a philosophy that is intermediate between positivism and interpretivism research philosophies (Melnikovas, 2018). In terms of ontology, pragmatism asserts that reality happens in the world and supports science's objective nature (Aliyu & Adamu, 2015). Furthermore, this philosophy presumes that individuality influences how people think and act, and thus research is subjective (Al-Ababneh, 2020). Hence as per the authors, this philosophy employs both objective and subjective standards in the view of epistemology. When referring to axiology, pragmatist studies are researcher reflexive in the sense that the study is introduced and maintained by the researcher's doubts and beliefs.

The selected philosophical stance for this research

According to the aim and the objectives of the research, this study explores different views of the respondents to identify the user requirements and the features of the digital platform to enhance the functional characteristics of an EWS for dam failures. In addition, it explores the opinion of the respondents to validate the causes and the impacts of dam failures and the system views that support the EWS for dam failures in Sri Lanka. As a result, since the study recognised that reality is based on social constructions, and knowledge is dependent on subjective measurements by including human beliefs and preferences as part of the study, interpretivism is the most relevant research philosophy of the study.

3.5.2 Approach to theory development

The second layer of the research onion is an approach to theory development. The research approach for theory development can be identified into three approaches namely inductive, deductive, and abductive (Saunders et al., 2019). The inductive (bottom-up) approach begins with data collection in order to investigate a phenomenon and allow a theory to emerge (Soiferman, 2010). In other words, inductive reasoning is the process of moving from particular observations to the development of larger theories. On the other hand, deductive (top-down) approach, the theory is formed from existing theory, and empirical research is carried out to check the feasibility of the specific hypothesis (Park et al., 2020). The Abductive approach primarily includes both inductive and deductive approaches in which the researcher collects data to investigate a phenomenon in order to develop a new theory or modify an existing theory, which is then tested through additional data collection (Saunders et al., 2019).

When it comes to this study, initially considered some pre-established theories or the knowledge related to the causes and the impacts of dam failures, functional characteristics of the EWS, and the features of digital platforms. After that, identified theories and knowledge were further improved with the user requirements in order to identify the features of the digital platform to enhance the functional characteristics of the EWS for dam failures in Sri Lanka.

As a result, the abductive research approach was chosen because the study incorporated elements of both the inductive and deductive approaches.

3.5.3 Methodological choice

The third layer of the research onion is the methodological choice which explains the selection of qualitative, quantitative, and mixed methods for the study. A qualitative method refers to the collecting and analysing of data that is used to deliver descriptions, construct theories, and test theories (Shah & Corley, 2006). Furthermore, the authors reveal that the qualitative method can be used to develop new relationships with variables in order to comprehend complex processes and demonstrate the impact of society. The qualitative method has typically employed "how" and "why" type questions (Thomas & Magilvy, 2011). According to Walliman (2011), the quantitative method focuses on fact-based and numerical data and employs mathematical operations to analyse the study's findings. Kumar (2019) elaborated on this by revealing that the quantitative method follows a strict process to define the scope of a hypothesis based on more effective and high data from a large sample, communicating it in an analytical and aggregate manner. The research questions in the quantitative method typically refer to the term "how much", "how many", "what", "who", and "where" (Thomas & Magilvy, 2011). The mixed method is not a replacement for the qualitative or quantitative methods, but rather a hybrid of the two that avoids the drawbacks of both (Doyle et al., 2009). As a result, mixed research methods provide researchers with a better understanding than relying solely on one method.

In regards to the current study, since it identifies the causes and impacts of dam failures, user requirements, and the features of a digital platform to enhance the functional characteristics of the EWSs which need attitudinal information from society, this study has chosen the qualitative method.

3.5.4 Research strategy

Research strategy is the fourth layer of the research onion which denotes the formal procedure for carrying out the study in terms of achieving the researcher's aim and objectives (Melnikovas, 2018). The main research strategies to be used in studies are the experiment, survey, case study, ethnography, action research, grounded theory, and archival research (Saunders et al., 2019).

Experimentation is a popular research strategy that strictly adheres to a scientific research design where ethnography is used to investigate and explore cultures and societies that are fundamental to the human experience (Fine & Elsbach, 2000). Action research strategy is focused to improve specific practices (Fine & Torre, 2004). Meanwhile, grounded theories are used in qualitative inductive research and the archival method entails the study of ancient records (Saunders et al., 2019).

This leaves both surveys and case studies are suitable strategies for this research. However, due to the exploratory nature of the research, the case study was not considered as it is generally conducted as an in-depth analysis. Hence, the survey strategy has been selected as the most suitable research strategy.

Among the research strategies mentioned above, the survey strategy is adopted for this study. A survey is defined as any procedure for comprehensively gathering data from a sample or population using various methods (Check & Schutt, 2012). This survey method enables researchers to take advantage of various data collection techniques, both quantitative and qualitative, such as questionnaires, interviews, and focus group discussions (Jansen, 2010). In general, the survey method only addresses quantitative aspects that attempt to define arithmetical distributions of variables in a sample or population (Singleton & Straits, 2009). However, as the author indicates, the importance of describing and exploring differences in the population can also be defined within the survey method. Jansen (2010) elaborated that qualitative surveys can be used to investigate the meanings and the experiences of people in a population in relation to a specific subject. Hence, it can be approved that the survey strategy is suitable for this study, as the current study explores the user requirements and the features of a digital platform to enhance the functional characteristics of the EWS for dam failures in Sri Lanka by acquiring the knowledge and the experience from the people who are engaged in such activities.

3.5.5 Time horizon

This is the fifth layer (one before the last layer) of the research onion which explains the time frame of the research. According to Saunders et al. (2019), any research study can be classified as longitudinal or cross-sectional based on the time. A longitudinal study is the examination of an occurrence over time to compare data (Caruana et al., 2015). According to Caruana et al. (2015), cross-sectional study is a "snap-shot" study in which the occurrence is examined at a specific point in time. Surveys and case studies (in general) use a cross-sectional time frame, whereas ethnography, action research, archival research, and case studies (in general) use a longitudinal time frame (Saunders et al., 2019). This research investigates the causes and impacts of dam failures, system views that support the functional characteristics of an EWS, user requirements of an efficient EWS, and the features of a digital platform to enhance the functional characteristics of the EWS of dam failures in Sri Lanka. As such, this research considers a cross-sectional time horizon as it focuses on contemporary issues.

3.5.6 Data collection techniques

Data collection and analysis is the last layer of the research onion. This section discusses only the data collection techniques. Data can be gathered using a variety of techniques, including literature reviews, document reviews, interviews, questionnaires, observations, and focus group discussions. The most common qualitative study techniques are literature reviews, interviews, document reviews, observations, and focus group discussions (Gill et al., 2008). In order to achieve the objectives, this study used a variety of data collection techniques at various stages. Figure 3.3 depicts the data collection techniques used in the study.

Literature Review

Narrative Literature Review

Identifying the dam construction (effects, types and purposes), dam failures (causes and impacts), real time examples for the risks of dam failures (global and Sri Lankan context), EWS (key concept), Functional characteristics of EWS used in dam failures, system views used to support the characteristics of EWS, digital platforms with its key features

In-depth Interviews

Semi-structured interviews:

Identifying the causes and impacts of dam failures, system views that are support the functional characteristics of an EWS for dam failures, user requirements for an effective EWS for the dam failures, features of digital platform to support the functional characteristics of EWS for dam failures in Sri Lanka

Focus Group Discussion

Single focus group:

Proiritising the identified user requirements for an effective EWS for dam failures in Sri Lanka.

Figure 3.3: Data collection techniques used for the study

3.5.6.1 Literature review

As mentioned in Section 3.4, the narrative literature review was conducted to collect secondary data on the causes and impacts of dam failures, functional characteristics of EWSs, system views support for the functional characteristics of EWSs, and the features of digital platforms.

3.5.6.2 In-depth interviews

In qualitative research, in-depth interviews are commonly used as a data collection technique to gain a thorough understanding of the research topic by delving into people's perspectives, experiences, perspectives, and beliefs (Rutledge & Hogg, 2020). In general, there are three types of in-depth interviews based on their nature: structured, semi-structured, and unstructured interviews (Kumar, 2019). Structured interviews are totally organised by the researcher or interviewer, who asks pre-planned questions of the respondents and expects straightforward answers (Stuckey, 2013). The author further explained that semi-structured interviews, in contrast to structured interviews, are based primarily on how respondents respond to questions and have no rigid adherence. As a result, semi-structured interviews are the most commonly used category of in-depth interviews by many qualitative researchers. Unstructured interviews are reflective listening interviews in which the researcher has no pre-planned questions; as a result, these interviews are slanted toward the researcher's interests (Alshenqeeti, 2014). Accordingly, semi-structured interviews are going to be adopted in this study to have the respondent's knowledge and experience on the dam failures and the EWS. Purposive sampling was used during the method to understand the suitable respondents for the study. Purposive sampling selects respondents who can and have been willing to provide information based on the researcher's interest in what needs to be known (Saunders et al., 2019). Therefore, the respondents for the interviews of this study were selected considering their knowledge and experience in the field of dam failures, EWSs, and digital platforms. The interview guideline was prepared with five (05) main sections as illustrated in Table 3.1.

Table 3.1: Structure of the interview guideline

Section	Main focus	Research objective
1	General information	
2	Causes and impacts of dam failures	Objective 1
3	EWS for dam failures	Objective 2, 3
4	Capture user requirements	Objective 4
5	Digital platform for EWSs	Objective 5

3.5.6.3 Focus group discussion

A focus group discussion, which is enabled by a researcher on a particular topic (Tonkiss, 2004), was conducted merely to prioritise the user requirements identified through in-depth interviews with stakeholders. Among the many ways that focus groups can be used in a study, Gill et al. (2008) highlighted the method's ability to clarify, extend, qualify, or challenge data collected through other methods. As a result, in this study, focus group discussion was used to specify and enhance the user requirements gathered through in-depth interviews, allowing group participants to prioritise the identified user requirements. Further, this has detailed in section 3.5.7.2. In terms of group size, three participants were chosen through purposive sampling because Peek and Fothergill (2009) discovered through their experience that a group size of 3-12 is perfect for a focus group instead of larger groups. Accordingly, one participant from the Irrigation Department, one participant from Mahaweli Authority, and one system developer were selected for this study.

3.5.7 Data analysis

Following data collection, the next step is to analyse the collected data using an appropriate data analysis technique, which can be identified as one of the most important parts of any research. Data analysis is primarily used to reduce large amounts of data by categorising and summarising those in order to make sense of the data at the end of the research (Kawulich, 2004).

3.5.7.1 Qualitative content analysis

There are numerous data analysis methods for qualitative analysis, such as content analysis, narrative analysis, thematic analysis, phenomenological analysis, and so on (Kawulich, 2004). Among these, the content analysis method was chosen for this study because it is the most applicable, flexible, and widely used data analysis method for analysing textual data (Billing, 2004). Furthermore, because this method is greatly advantageous in analysing large amounts of data, content analysis is the method of choice for the current study to analyse the large amount of data gathered through in-depth interviews. There are three (03) main approaches to qualitative content analysis: conventional, directed, and summative content analysis (Hsieh & Shannon, 2015).

As the authors discuss further, conventional content analysis is more suitable once existing literature or understanding of a phenomenon is limited. When performing traditional content analysis, the content is scrutinised to classify different concepts or themes, which are then coded (Franzosi, 2004). As a result, this comprises the decrease of information gathered into a coding scheme that aids in the interpretation of the data in a significant manner. The ability to obtain direct information from respondents without enforcing any pre-defined categories is the main benefit of this approach (Hsieh & Shannon, 2015).

Unlike the traditional method, the direct content analysis process reveals core points as initial coding groupings based on existing theories or previous studies (Hsieh &

Shannon, 2005). Because it is based on a pre-existing theory, the directed process comprises a more formal methodology than the conventional method. As a result, this method is intended to justify or broaden existing theory via a predefined coding system (Stock, 2012).

The summative content analysis begins by counting and comparing key phrases or content in the data in order to extract their contextual use (Hsieh & Shannon, 2005). The main goal of this approach is to investigate the application of keywords or content while ignoring their meanings. This method starts by looking for a specific text and counting how many times it appears, then attempting to uncover the basic context for the use of the phrases (Swati et al., 2014).

When conducting this study, the findings are mainly focused on the knowledge, experience, and views of the respondents about the dam failure and the EWSs to identify the features of a digital platform to support the functional characteristics EWS for dam failures in Sri Lanka. Accordingly. The most suitable data analysis method is conventional content analysis and it can be done through manual content analysis and using computer-aided software. This study is going to be adopted for the manual content analysis method.

In addition, user story mapping is adopted for this study to identify the user requirements for effective EWS for the dam failures and to prioritise them. The procedure for the user story is explained in the next section.

3.5.7.2 User story mapping

Different types of users associated with the EWSs for dam failures in Sri Lanka is having different requirements. Therefore, it needed to have a simple format to analyse the different requirements. As a result, the user story method was used for this study.

The user story mapping method is conducted using five (05) key steps in order to analyse the user requirements. These steps are described below with the appropriate justifications.

Step 1 – Establishing the vision

The first step is to establish the requirement of having user story mapping. Hence, this step is used to identify the details of the system that needs to be developed. According to this study, the vision is to "identify the user requirements of having digital EWS for dam failures in Sri Lanka".

Step 2 – Identifying the users of the system

The second step is to identify the users of the system. According to the vision of the current study, the following users were identified and interviewed.

- Officers in the Irrigation Department, Mahaweli Authority, and the Disaster Management Centre
- Officer in Irrigation at the District level
- Officers of the Irrigation Department and Mahaweli Authority at the divisional level
- Grama Niladharis
- Community Members

Step 3 – Building the backbone

The upper row of the user story map is the backbone. According to Muldoon (2020), the backbone specifies the critical capabilities that the system needs. Therefore, user interviews are used to determine the backbone. The user is asked to describe their process from start to finish, including all high-level activities that they will perform while using the system as in Figure 3.4. As a result, the backbone anticipates a gentle user journey through the system in the absence of detailed information. According to this study, each user is asked about their role in the case of dam failures.

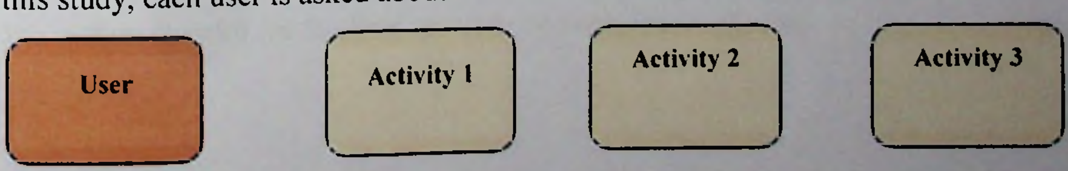

Figure 3.4: Backbone development

Step 4 – Breaking the activities into user stories

At this step, the identified activities are divided into multiple user stories or tasks. Users are asked to explain their needs by highlighting their tasks in the form of user stories as in Figure 2.5. In the current study, users were asked to explain their roles and responsibilities in relation to the dam failures and the EWS. Following that, a comprehensive final user story map was created by combining all of the user story maps, which will guide the decision-making process. Further, user story maps were well structured by avoiding the repetition of the tasks.

A **card** is a brief description of a user story that is used for planning and prioritising user requirements. The card uses a basic predefined format to capture three distinct aspects of a user requirement:

- Who needs the features and functions
- What functionality do end-users or stakeholders want the system to provide
- Why do end-users and stakeholders have to get this functionality (optional).

As <Role>, I want to <Outcome> so that <Value>

Role – User's job role **Outcome** – what need to achieve **Value** – overall benefit of the activity

The **Conversation** refers to the details surrounding the user story that helps to capture the context of the user requirement.

The **Confirmation** contains the constraints and standards that the user is asked from the system in order for the final result to be accepted or rejected.

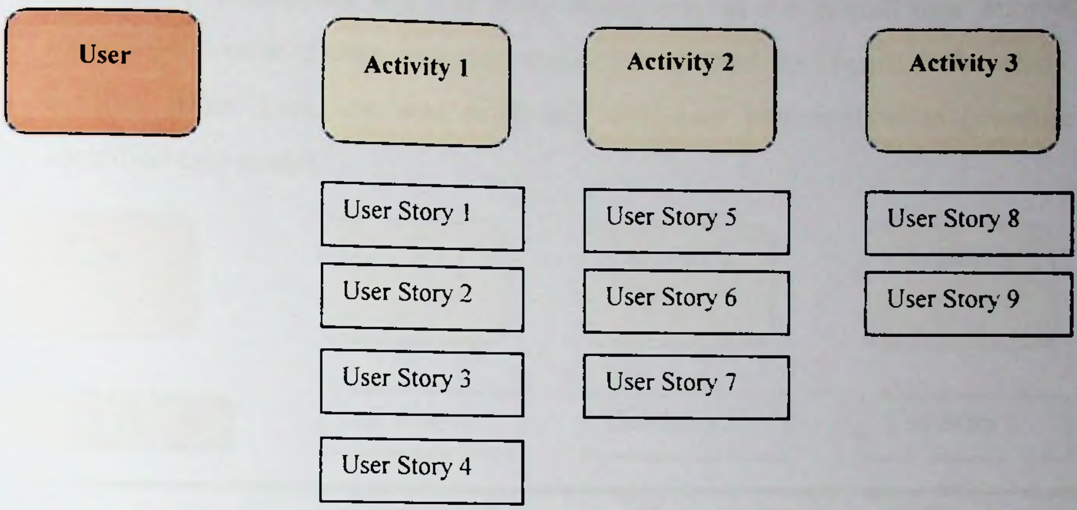

Figure 3.5: User story map

Step 5 – User story prioritisation

There may be a number of user stories for the final system following the completion of interviews with each user. However, it is not feasible to integrate all of the user stories into a single system in the first release. As a result, in this step, user stories are prioritised by estimating their value from the perspective of the users and choosing the most important user stories to be included in the proposed system. Prioritisation methods in use include the MoSCoW method, the complexity matrix, the walking skeleton method, and others (Patton, 2014). Among them, the MoSCoW method is the most frequently used due to its simplicity and user-friendliness, which allows users to easily prioritise user stories. The terms of the MoSCow method are as follows.

- M- Must have - Requirements that must be included in the final system
- S- Should have - Requirements should be included in the system if necessary according to the prioritisation
- C- Could have - Requirements that are desirable but not required.
- W- Won't have - The requirements agreed upon by stakeholders will not be incorporated into a system.

Users are asked to categorise the outlined user stories into each group using this technique as in Figure 3.6. Prioritisation is most commonly accomplished through focus group discussions and user story workshops, as the overall user opinion regarding the value of every user story should be captured. As a result, in this study, a focus group discussion was conducted with user participation to prioritise identified user stories.

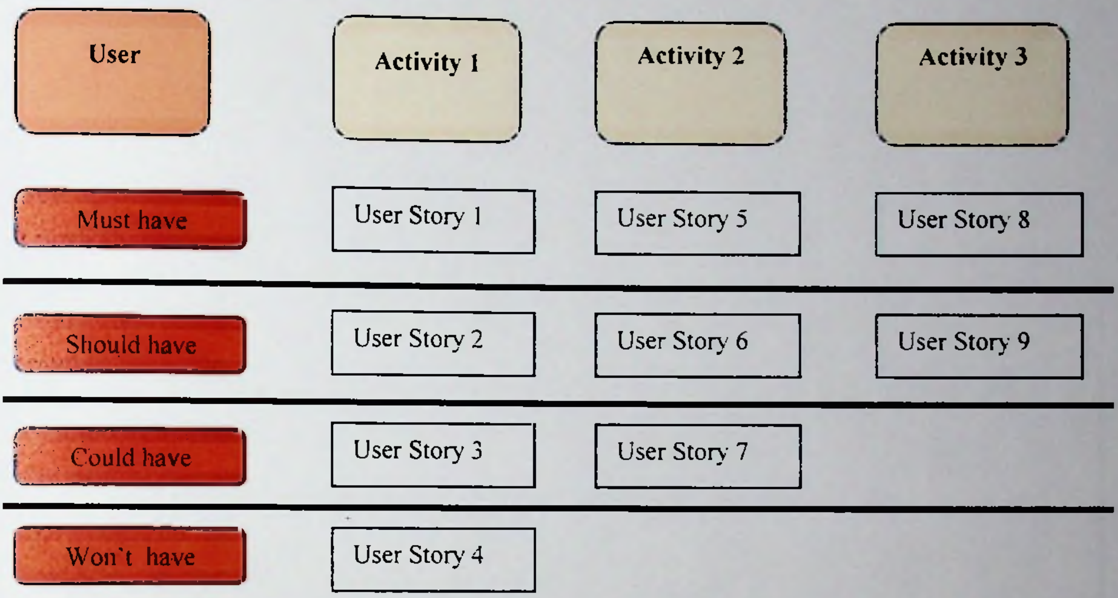

Figure 3.6: User story prioritisation

3.6 Chapter summary

This chapter outlined the procedure followed or the methodology adopted in this study by explaining the justifications. Accordingly, the qualitative research method was adopted by following the qualitative surveys to validate the identified causes and impacts of dam failures, system views used in the EWS for dam failures in Sri Lanka, and to identify the user requirements and the features of a digital platform to support the functional characteristics of EWS for dam failures in Sri Lanka. Hence, in-depth interviews and focus group discussions are going to be conducted to collect the data. Finally, collected data will be analysed in the content analysis method and using user stories.

CHAPTER FOUR

DATA COLLECTION AND ANALYSIS

CHAPTER FOUR

4. DATA COLLECTION AND ANALYSIS

4.1 Introduction

This chapter used to present about the detailed data analysis from the semi-structured stakeholder interviews and focused group discussion along with the process of data collection.

4.2 Data analysis of stakeholder interviews

Since it is intended to investigate the dam failures and the use of an effective EWS for dam failures, the different views and opinions of the stakeholders engaged with the dams and system development are highly acknowledged.

Table 4.1: Profile of the respondents

Respondent	Designation	[illegible]
R1	Director Mitigation Research and Development – Disaster Management Center	22
R2	Director of Irrigation (Hydrology and Disaster Management) – Irrigation Department	24
R3	Chief Engineer (Dam Safety) – Irrigation Department	17
R4	Deputy Director Reservoir – Mahaweli Authority	22
R5	Dam Safety Consultant	42
R6	District Director of Irrigation	25
R7	District Director of Irrigation (Engineering Geology)	22
R8	District Director of Irrigation (Planning and Design)	15
R9	District Director of Irrigation	12
R10	Divisional Director of Irrigation	8
R11	Engineer in charge of Dam – Irrigation Department	6
R12	Engineer in charge of Dam – Mahaweli Authority	5
R13	Assistant Engineer in charge of Dam – Mahaweli Authority	4
R14	Assistant Engineer in charge of Dam – Mahaweli Authority	3
R15	System Developer	7
R16	System Developer	7
R17	Grama Niladhari	2
R18	Grama Niladhari	1
R19	Committee Member	2
R20	Committee Member	1

Therefore, the stakeholders were selected from different levels in order to represent every stakeholder in the warning chain of the dam failures (Directors, Engineers, Grama Niladhari, and Communities). Accordingly, 20 semi-structured interviews were conducted until data got saturated. The profile of the respondents has been tabulated in Table 4.1.

As per the knowledge and the experience of the respondents, causes for the dam failures in Sri Lanka with their impacts, the functional characteristics of the EWS used in Sri Lanka, the system views support for the characteristics of the EWS, user requirements of having an effective EWS, and the features of a digital platform which support for the EWS for dam failures in Sri Lanka are discussed in a detailed way under this section.

4.2.1 Causes for the dam failures in Sri Lanka

The first section of the interview guideline was categorised for the causes and the impacts of the dam failures. According to the literature findings, the causes of the dam failures were categorised as internal causes (design, technical, and management failures) and external causes (disasters/ natural causes and human and animal acts). In addition, respondents mentioned that any of these identified causes can be prioritised as these causes can be changed with the size, type, purpose, and location of the dam. A detailed description obtained from the respondents by identifying the findings for Sri Lanka is included in this section.

4.2.1.1 Design failures

In literature, insufficient spillway capacity, extreme flood exceeding design criteria, and poor design have been identified as the major causes of design failures. During the interviews, respondents highlighted that insufficient spillway capacity can be affected the dam failures in Sri Lanka. When there is a high inflow of water in the reservoir, the spillway will be unable to push the water to the outside due to insufficient capacity. Therefore, due to that, there can be a possibility to fail the dam with the additional pressure created at the spillway. R11 and R14 mentioned that such type of errors can be caused due to the absence of past records about the dam.

Extreme flood exceeding design criteria is the next cause of design failures. R1 mentioned that "*extreme floods exceeding design criteria are theoretically valid and Sri Lanka is not yet practically at a risk of such a cause*". R8 also repeated that by highlighting "*there may no cases have proved incoming flood exceeds the design of the dam*". R11 and R12 who are engineers in charge of dams highlighted that "*most of the dams have been constructed according to the 100-year flood records and if we feel that capacity exceeds the flood, we are designing it to the 1000-year flood*". Therefore, exceeding the flood capacity can be affected by dam failures. However, still it is not recorded from Sri Lanka.

Poor design is the last cause identified under the design failures and R3 who is the chief engineer of dam safety expressed that "*better to include it as the poor design of the dam and the structures*". According to the respondents, this factor covers all the causes that will affect dam failures due to the design of the dam and the dam structures. R1 and R6 highlighted that "*this is mainly affected by the small dams in Sri Lanka*". According to the further explanation of R6, "*as design engineers are not much involved for the designs of small and the medium dams, they are at a risk of dam failures due to the poor design of the dam and the dam structure*". However, respondents mentioned that the design of the dam will be changed according to the dam type (concrete, earth, or rock dam). Hence, before designing the dam and the structure, want to identify the dam type by investigating the climatic changes, location, and the purpose of the dam. Further respondents expressed that, design failures can be caused due to issues in the parameters, insufficient investigations for the collection of data, and inadequacy of information about the past records.

4.2.1.2 Technical failures

The aging of the dam, piping, sliding of the dam, quality issues, and spillway blockages have been highlighted as the main technical causes that affected the dam failures by modifying the literature findings in Figure 2.1.

Sri Lankan dams are governed by two entities as Irrigation Department and the Mahaweli Authority and are operated by the Irrigation Department, Mahaweli

Authority, Ceylon Electricity Board, and the Department of Agrarian Development. According to the respondents, most of the ancient dams are under the control of the Irrigation department and the recently constructed dams are under the control of the Mahaweli Authority. As a result of that, the Irrigation Department has the risk of dam failures due to the aging of dams. Many ancient dams can be discovered in Sri Lanka and there is a high possibility of dam failures in Sri Lanka due to their aging.

Piping is another technical issue that created the dam failures. According to the respondents, piping can be identified as a process similar to internal erosion and it is the seepage of water from the dam with the dam materials. R11 explained that "*if the seepage carries muddy or sediments, there is a piping in the dam body or structure and if the seepage water is clear there is no piping*". Acknowledging that all the respondents mentioned piping can be occurred in the foundation, around the spillway, through the dam body, and around the sluice barrel which is used to get water out from the reservoir for drinking, irrigation activities, and other purposes. Accordingly, if there is a sudden decrease in the water level, the dam officers noticed there should be a seepage at any part of the dam. Literature has identified "piping around culverts and other embedded structures" as a cause for the dam failures. However, respondents acknowledge that explaining "*...there are no culverts around the dam and embedded structures are the sluice barrel and only piping in sluice barrel cause the dam failures*". Supporting all respondent's views, piping can be identified as a major reason for dam failure.

Sliding of the dam is another technical issue that caused dam failures. Similar to a landslide, the side of the dam can slide by taking risks for a dam failure. R2 explained that "*....mainly sliding occurred in between the body of the dam and the foundation*". R3 who is the Chief Engineer of dam safety explained: "*sliding occurred when the horizontal forces exceed the resistance force (friction)*".

Quality issues covered a vast area under the technical failures. Even though there were causes as "quality issues in the spillway and quality issues with culverts and other embedded structure" in Figure 2.1, respondents mentioned quality issues in all head works (dam, spillway, sluice, and all other components) will affect the dam failures other than the quality issues in the spillway. Also, the quality of the culverts does not affect the dam failures. However, respondents explained that the quality should be controlled in terms of materials and construction techniques. R4 who is a Deputy Director of Reservoir explained "*....should compact using sheep foot rollers as there can be seepage in the layers due to the smooth connection between the layers while compact using the smooth rollers*". R7 also explained, "*...not as in building construction, concrete grades, compaction, and the temperature wants to be highly considered in dam construction*". Accordingly, all respondents explained that specifications and construction techniques need to be thoroughly followed in the Sri Lankan dam constructions in order to avoid dam failures. Therefore, the quality of the dam has to be controlled and maintained throughout the life of the dam. If not there can be failures in the dam due to the lateral forces (water pressure) and the horizontal forces (weight). R13 who is the Assistant Dam Engineer explained "*...various types of spillways are available and they are selected based on the geographical features. If the selected type is not matched with the dam location, there can be dam failures*". Therefore, it is needed to maintain and assure the quality of the dam as it covers a large area of failures in the dam in terms of the materials and the construction techniques.

In Figure 2.1 "spillway blockage due to bank slide in the reservoir" has been identified as a cause for dam failures under technical matters. However, respondents explained that spillway blockage can be created dam failures but not only due to the bank side in reservoirs there can be many other reasons. Accordingly, filter blockages can be caused due to the collection of debris, geotextile, and different components of water like iron. Other than that R13 mentioned, "*...the grass and the roots of the weeds can block the filters in the spillway*". Meantime, R2 suggested, "*...the term spillway blockages want to be revised as a spillway and the spillway tail canal blockages*". The spillways are used to pass the water downstream safely. If it is blocked, dam failures can be created due to the excessive pressure created due to the high capacity of water, and the water level also increased. Therefore, spillway blockages can be a cause of dam failures.

4.2.1.3 Management failures

Poor management, poor layout planning, organisational issues, and poor maintenance and operation have been identified as the management of the cause for the dam failures.

Poor management describes the administrative failures under the design, construction, operation, and maintenance. R3 and R6 explain that poor dam management causes less allocation of finance the dam management. In addition to that, R5 detailed, "*...even there is a rich dam management, dam officers are unable to manage the dams with the external conditions such as human protests, political pressures, and sometimes there can be animal threats near the dams*". However, respondents acknowledged that poor dam management directly affects dam failures.

According to the respondents, while preparing the layout plan of the dams it is must to consider all past records related to the location, dam type, size, construction techniques as well as the details of the nearby tanks and the reservoirs. R6 further elaborated using an example: "*...when there are small tanks above the large tanks, the attention given for the small tanks are very less and the allocated finance are not enough to consider such small tanks while preparing the layout plan. Then in a case of a high flood, those small dams can be broken and high water flow entered to the large dam*". Likewise, respondents explained poor layout planning can be a cause of a dam failure.

In Figure 2.1, literature has identified "unclear responsibility for dam management" as a separate cause for the dam failures due to management issues. However, respondents explained that also can be considered an organisational issue. R11 mentioned that "*....when a single officer has the responsibility of large range dams, they will be unable to fulfill their responsibilities even for a single dam*". With respect to that respondents specify there is an inadequacy of the dedicated staff assigned for the dam safety. Other than that R8 and R13 highlighted less training opportunities for the dam operators and less performance on the surveillance will be caused the dam failures under organisational issues. Additionally, R12 mentioned, "*...the loopholes in the communication hierarchy will highly be impacted on the dam failures*".

Poor operation and maintenance are highly impacted by the dam failures. The machines and the equipment used for the dam operation activities need to be properly maintained in order to take the most accurate data for dam management. However, due to the less allocation of government funds, there can be delays with the maintenance of the equipment. Likewise, as per the respondents, insufficient financial capacity is the major reason for the poor maintenance of the dam. R5 mentioned "*....due to the less maintenance there are issues with the operation of dam gates. If the dam officers are unable to open the dam gate, dam failures can be caused due to the high pressure of water. Similarly, if they are unable to close the dam gate, that also will create a disaster with the additional release of water and there will not be sufficient water for the agricultural purposes*". By acknowledging that R12 also mentioned, "*....dam gates need to be properly operated for the proper functioning of the dam*". Accordingly, it is very important to balance both operation and maintenance of the dams to prevent dam failures.

4.2.1.4 Disasters and natural causes

Sri Lanka has a high risk of disasters and natural causes. When those natural causes and disasters exceed the capacities of the dam, there can be a dam failure. Respondents highlighted those dam failures are mainly caused due to floods and landslides. Further respondents asserted that the effect of floods is higher than the landslides. R8 mentioned it as "*.....the effect of the landslides are very less for the dam failures but there can be a possibility to overtop the dam*". R5 who is a dam safety consultant explains that "*...still there are no any dam failure cases due to the earthquakes and according to some of the geotechnical engineers there is a small risk of earthquakes for Sri Lanka*". Further R10, R12, and R13 mentioned there are many trees on the earth dams, and they will be uprooted due to the strong wind. The most important case is damage to the riprap and failure of the upstream slope happens with the strong wind. Accordingly, floods, landslides, earthquakes, and the strong wing can act as causes of the dam failures in Sri Lanka, and volcanic activities, wildfire, and snow are not affected in Sri Lanka.

4.2.1.5 Human acts

In literature wars and terrorist attacks have been identified as the causes of dam failures due to human acts. Respondents have acknowledged those two and validate the Sri Lankan dam failures. During a war or a terrorist attack, there is a possibility to damage the dam structure and the dam gates. As a result dam failures can be occurred by creating bad impacts downstream. R5 explained that "*...due to the different attitudes and the mental health of the people, willfully they will create dam failures by making damages to the dam gates and other parts of the dam structure*". By acknowledging the same opinion R8 also explained "*...different bad behaviours of the humans like removing of soil, speedily boating will contribute to creating unexpected dam failures. Removing soil may be created sliding in the dam structure and due to the speed boating cracks may be occurred in the dam structure with the high pressure*". In addition to those, R11 asserted "*....excessive vibrations on the dam structure due to the transportation of heavy vehicles and other human protests can be created dam failures*". However, R13 and R15 explained, that dam officers are not allowed to transport heavy vehicles through the dam structure and there can be insecure transportation through the dam structure. Apart from the human acts, R4 highlighted animal acts also affect dam failures. Further, he explains that "*...livestock will create cavities near the dam body and that will affect for the dam failures by making sliding and seepages*".

Following Figure 4.1 illustrates the causes that affect the dam failures in Sri Lanka.

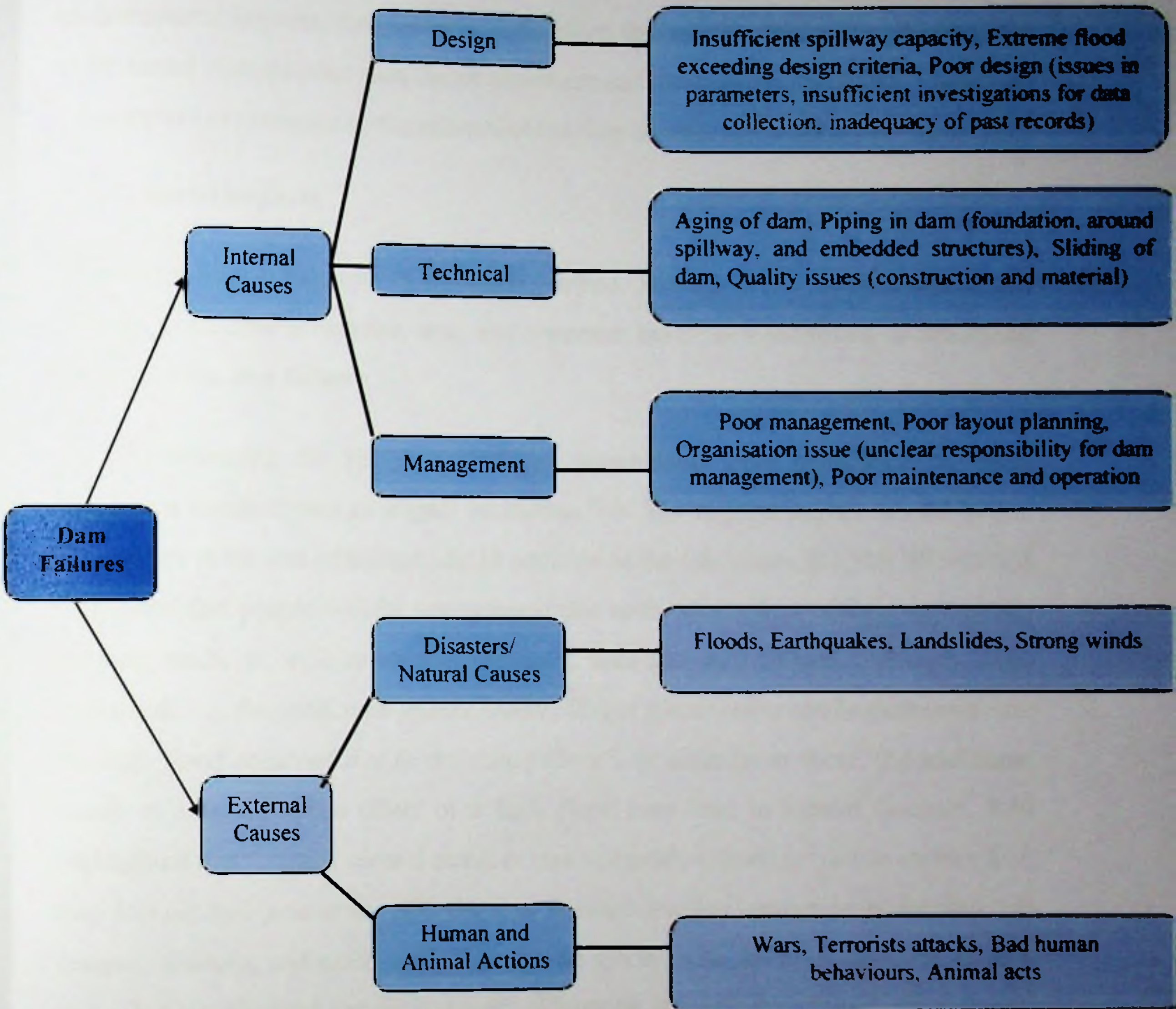

Figure 4.1: Causes of the Sri Lankan dam failures

4.2.2 Impacts of dam failures

Through literature review, impacts of the dam failures were identified as illustrated in Figure 2.2. During the interviews, respondents validated the literature findings for the Sri Lankan context. As in the causes of the dam failures, they mentioned that the impacts of the dam failures will depend on the location and the surrounding conditions of the dam. Even though it is difficult to prioritise the impacts of the dam failure, the most significant impact caused by the dam failure is the human and animal life losses. When there is a failure in a large dam that will highly impact human life causing deaths. Other than that, as identified in the literature there are economic, social, and environmental impacts. Respondents highlighted that much attention should be given to the social impacts other than the environment and the economic impacts. Therefore, a descriptive explanation of the impacts of the dam failures are included in this section.

4.2.2.1 Social impacts

Impacts on human life, loss of livestock (farms), damage to the infrastructures, and damage to cultural properties, arts, and treasures have been identified as the social impacts of the dam failures.

By acknowledging the literature findings, respondents have mentioned the most significant social impact as impact on human life. The highest impact caused by the dam failure is the loss of human life. In addition to the life losses, R3, R6, R7, and R8 mentioned that people will be unemployed due to the disruption of their agriculture, farming lands, as well as animal livestock with the dam failure. Similarly, R11 explained, "*....the residential places (mostly illegal places) also can be destroyed with the high flood occurred due to the dam failure*". In addition to these, the additional shock as a result of the effect of a high flood may lead to mental diseases. R10 highlighted that "*...such mental diseases can be mainly caused for adults as they feel. they lost all their properties with the dam failure*". Further, respondents detailed that dengue, diarrhea, and some epidemics can be spread with the flow of water. Then it will affect the physical and social health of humans. As well the agricultural, farming, and residential losses with the dam failure, will change the daily patterns and the behaviors of humans. Even in the literature that has identified the "decrease the quality of the daily life", R4 explained, "*...that wants to be changed as disrupting the quality of daily life*".

Respondents identified damages to the infrastructure also as a social impact of dam failure. R1, R3, R5, R6, and R12 have explained that when a road, bridge, or any other such infrastructure like railway is damaged by the dam failure, people will unable to complete their day today activities as they have lost or damaged their mode of transport. R8 explained the same scenario "*...sometimes, students will unable or difficult to go to school. Employers will face difficulties while they attend to the office* *places*". Likewise, if there is damage to a road, bridge, or railway that will very badly impact society as people lost their mode of transport.

Damages to the cultural properties, arts, and treasures are also identified as a bad impact on society due to dam failures. R5 explained that "*....churches have destroyed with the Kanthale dam failure which is the most recent highest dam failure in Sri Lanka*". All the other respondents have acknowledged a similar impact while R8, R9, and R13 mentioned it is only an example of such damage and in Sri Lanka, there is a high risk of damage to the cultural properties.

4.2.2.2 Environmental impacts

According to Figure 2.2 and the knowledge and experience of respondents, environmental pollution, damage to the cultural landscapes, and effects on the living creature and habitats have been identified as the environmental impacts of the dam failures in Sri Lanka.

As mentioned by the respondents, pollution is the major impact on the environment with dam failures. R6 highlighted that "*...debris from vast area washed with the water flow and all will be collected near the farmlands and the trees*". R11 further evaluated that "*...poisonous materials from the industries near the dams, also can mix with the water flow and those can be added to the soil. Then it will be difficult to rearrange the lands for agricultural purposes*". Accordingly, many toxins can be added to the environment with the high flood created by the dam failure. Additionally, respondents revealed that it is very difficult to clean the environment as before by removing all the toxins collected after the dam failure.

Another environmental impact is the damage to the cultural landscapes. Cultural landscapes are referred to as the combined work of both nature and humans where the geographic area has both cultural and natural values. Therefore, it can be associated with the historic person, activity, or event which adds cultural values. R3 who is the chief engineer of dam safety explained that "*... reservoirs are connected to one another and if there is a failure in one dam it can be affected for some other reservoirs which are interconnected*". Therefore, there is a possibility of damaging the cultural landscapes including the parks and the plantations. As a result of that endemic plants also can be destroyed.

Effects on the living creature and habitats are another impact of the dam failure. Mostly, there are natural habitats for the animals which are created on their own. However, when high water pressure comes with the dam failures, all the habitats may be destroyed. R5 has detailed that "*...when the high flood occurs with the dam failure, animal livestock including endemic animals may pass with the high water pressure and sometimes they may die. In such a case the animal's habitats are also destroyed which are man-made habitats as well as the natural habitats*". By acknowledging that, the remaining respondents also mentioned that dam failure is a huge threat to endemic plants as well as animals.

4.2.2.3 Economic impacts

Economic impacts were categorised as direct and indirect impacts. Agricultural, industrial, and commercial losses, damages to the infrastructures, buildings, and other fixed assets, loss of livelihood for direct beneficiaries, and disruption to water supply schemes were introduced as the direct economic impacts. The indirect economic impacts were expenses on flood management efforts, cost of welfare and socio-economic activities, cost of compensation and rehabilitation, and impacts on the small businesses including tourism.

Mostly, there are agricultural lands downstream of the dam reservoirs. Therefore, all the respondents mentioned, that farming lands will be destroyed due to the high flood that occurs with the dam failure. As well as R8 highlighted that "*...the water for the agricultural purposes supplied through the dam reservoir and when there is a failure in the dam, the officers unable to supply water for the farming lands. As a result, the farmers are unable to maintain their cultivation due to the inadequacy of water*". Other than that, R10 and R13 expressed, that huge areas of agricultural lands may be polluted by the collection of garbages and other waste materials flowing with the water. Hence, the cultivations will be destroyed and it will be difficult to rearrange the farming lands as previously. Therefore, respondents explained there is a threat to agricultural products with the dam failures and it directly impacted the economy of the country. Similarly, respondents acknowledged that industrial and commercial products may have a threat by the dam failures. R7 explained *"....even though there are no industries near the dam, there can be industries which are dependent on the water supplied by the dam reservoir. Hence, there may be reductions in industrial products due to the insufficiency of water supply with the dam failures*". As the economy of Sri Lanka is based on local products and respondents asserted the reductions in agricultural, industrial, and commercial products will be highly impacted to reduce the country's economy.

The buildings, infrastructures, and other fixed assets also may have a threat by the dam failures. R5 explained that *"...buildings and the infrastructures failed to bear the high pressure of water which outcomes with the dam failures. Therefore, there may be damages for the roads, bridges, and the buildings*". Acknowledging that R8 and R11 mentioned other than the buildings and the infrastructures, the machinery and the equipment at the industries may be damaged by the high flood created due to the dam failure. As a result, it will create additional costs for the reconstruction of those properties to make them usable. Likewise, respondents have validated all the literature findings based on the impacts of dam failures in the Sri Lankan context.

Other than the literature findings loss of livelihood for direct beneficiaries, and disruption to water supply schemes was identified by the R5 and R7 who are Dam Safety Consultant and the Director of Irrigation (Engineering Geology) respectively. R5 highlighted that *"...the most significant impact of dam failure is the loss of human life and many of them may be farmers as most of the humans near the dam engage in agricultural activities. As a result, the country will be lost direct beneficiaries due to the dam failures*". When such a beneficiary lost his life, the other family members may not continue their agricultural activities and that will be directly impacted the country's economy. In addition to those, with the dam failure water supply schemes may also be damaged. Therefore, R6 explained, "*...addition cost need to be expensed for the rearrange of water supply with the disruptions caused by the dam failure*".

Other than the direct economic impacts, there are indirect economic impacts created by the dam failures. However in literature "losses due to reductions of industrial and factory products" was identified as an indirect impact and respondents have explained similar impact was discovered under the direct economic impacts of dam failures. In the meantime of a dam failure, the government entities like the Irrigation Department/ Mahaweli Authority, Disaster Management Centre, Police, Army, and media tackle efforts to manage the risks of the dam failure. Therefore, respondents acknowledged that the costs used to manage the flood will indirectly affect the economy of the country. In addition, the literature review discovered "cost of socio-economic activities" as another indirect impact, and R5 who is a dam safety consultant explained, "*...that has to be modified as cost of welfare and socio-economic activities*". When the public loses their agriculture, homes, equipment, and other assets due to the dam failures, the government arranges welfare and socio-economic activities to distribute them some clothes, food and beverage, and other facilities that they want to be stable by managing the impact of dam failure. R8 mentioned that "*...government makes huge attempts on welfare programs and it will incur a high cost*". Even though that is a responsibility of the government, respondents explained that it indirectly impacts the country's economy. Besides that R3, Chief Engineer of Dam Safety describes "*...government needs to arrange compensation on the loss of human life and their properties due to the dam failures*". Further R6 and R11 acknowledged the similar impact by adding that government needs to make expenses on the arrangement of rehabilitation camps for the children as well as elders. Therefore, respondents mentioned that there will be an indirect impact on the economy with the cost of compensation and rehabilitation due to the dam failure. In addition to those, R2 who is a Director of Irrigation (Hydrology and Disaster Management) explained the impact of dam failures on tourism. R3 also acknowledge the same point and detailed that "*...many tourists come to visit the dams and there are small businesses built up close to dams by aiming the tourists*". Hence, until the completion of the rebuild and the maintenance of the dam after the failure, tourists are not allowed to visit the dam. As a result, that can affect the tourism industry, as well as the small businesses, that target tourists. Therefore, as explained by the R2 and R3 dam failures may cause impacts on tourism and small businesses by making indirect losses to the economy of Sri Lanka.

4.2.2.4 Institutional and political impacts

R5 who is a dam safety consultant further explained that there may be institutional and political impacts other than the economic, social, and environmental impacts of the dam failure. R5 detailed that *"...dams are controlled by the government entities and while there is a huge dam failure, the government institutions may create a blackmark as they were unable to manage it"*. According to her, that impact can go up to the level of the president of the country and there may have international criticisms of the management process of such institutions. Therefore, dam failures may create an impact on the institutions and the politics of the country.

However, all the impacts that may be created by the dam failure in Sri Lanka can be shown in Figure 4.2.

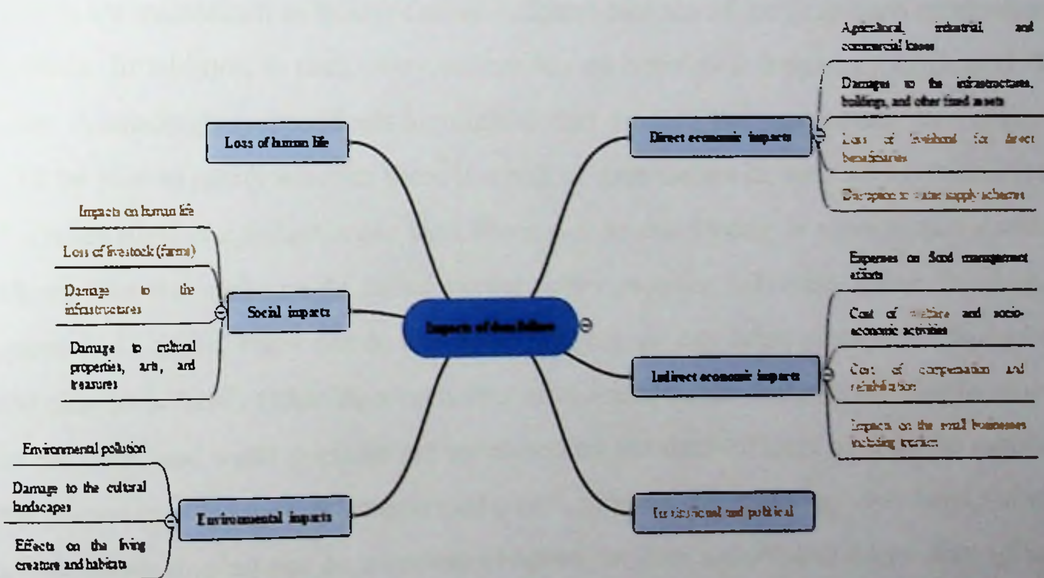

Figure 4.2: Impacts on Sri Lanka due to dam failures

4.2.3 The current mechanism used in Sri Lanka as an early warning system to reduce the impacts of dam failures

Section 3 of the interview guideline was separated for the EWSs. Under the first question of section 3, respondents were asked whether there is a mechanism currently used in Sri Lanka as an EWS to reduce the impacts of the dam failures. All the respondents replied, *"...there is a manual government process used as an EWS, but it* *is not a developed technological process*". Accordingly, they highlighted that, there is no dedicated platform as an EWS to reduce the impacts of dam failures in Sri Lanka. Meanwhile, they elaborated that the current procedure is also a well-improved process in which all the officers at different administrative levels actively participate to reduce the impact of dam failures.

All dams are subjected to inspections and monitoring programs. As well as respondents mentioned that there is an emergency action plan and standing orders. R12 explained, "*...the emergency action plan which illustrates the path how the communication has to be maintained during a case of emergency displayed in every operation room of the office environment*". R11 and R14 also further explained the emergency action plan will display the role specified for every responsible officer when there is a dam failure with their contact details. Apart from that, the standing orders are maintained to follow during different seasons of the year such as monsoon periods. In addition to that, every officer has an appointed frequency to inspect the dam. Accordingly, respondents highlighted that through the inspections dam officers will be able to notify whether there is a risk of dam failure or not. R4 explained it as "*...when there is a failure in our wall, there may be cracks, sag or some features which shows that the wall can be failed during future months. Likewise, when the dam is going to be failed, there can be cracking, sagging, or any other observable feature in the dam structure*". Other than such structural features, the water level, displacement of the dam, and water pressure are measured by the dam officers in order to monitor the behavior of the dam. R7 mentioned it as "*...piping, overtopping, structural failure, vibration or sloping can be a common reason for dam failure and every dam officer inspect the dam in related to those features*".

Accordingly, through the inspections and the monitoring procedure, the dam officers (labours, technical officers, or engineers) will be able to notify the early signals of a dam failure. R4 further explained that "*...there are dam emergency conditions such as full supply water level, high flood level, critical psychrometric curves*". R2, R5, and R8 detailed that, apart from the dam officers, there is a possibility to identify the dam failures by the community. After identifying such a feature they immediately follow the emergency action plan and communicate with the responsible officers (Engineers, Directors, Disaster Management Center, Police, Grama Niladhari, etc.) in order to make precautions for the dam failure and to warn the public.

R4 mentioned that "*....in the Kanthale dam failure also such warning process was followed and warning was passed to the community before 3 or 4 hours. However, due to the communication failures as the technology was not developed present people were unable to evacuate before the failure* ". As explained by R9, "*...the Engineer in charge with the Minneriya dam has identified some changes which can create a dam failure and have removed the downstream people to reduce the impact of the dam failure. However, that failure was not caused as the dam officers make necessary precautions before the failure*". Likewise, there is a government procedure followed as an EWS in Sri Lanka while identify the features of a dam failure. The general early warning process followed by Sri Lanka during a dam failure can be shown in Figure 4.2.

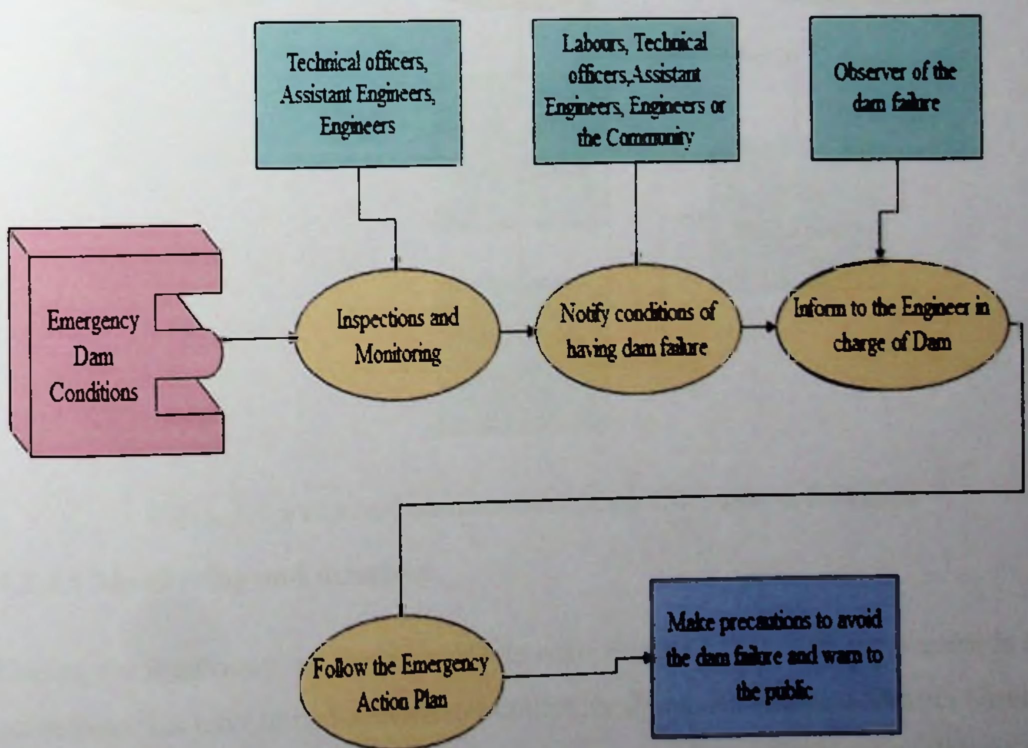

Figure 4.3: Early warning process followed for dam failures Sri Lanka

4.2.4 Functional characteristics of the EWS used in Sri Lanka

Main five functional characteristics of an EWS were identified in the literature review as i) Hazard identification, vulnerability analysis, and risk assessment (forecasting and risk evaluation), ii) Detection and monitoring, iii) Emergency management structure, including warning and evacuation, iv) Local dissemination, v) Public education (Samarajiva et al., 2006). However, as per the scope of the research, only the first three characteristics were continued for the data collection stage. During the interviews, respondents changed the listing of the first three characteristics according to the process they followed to proceed with the early warnings. The following Figure 4.4 display the identified functional characteristics of the early warning process used in Sri Lanka.

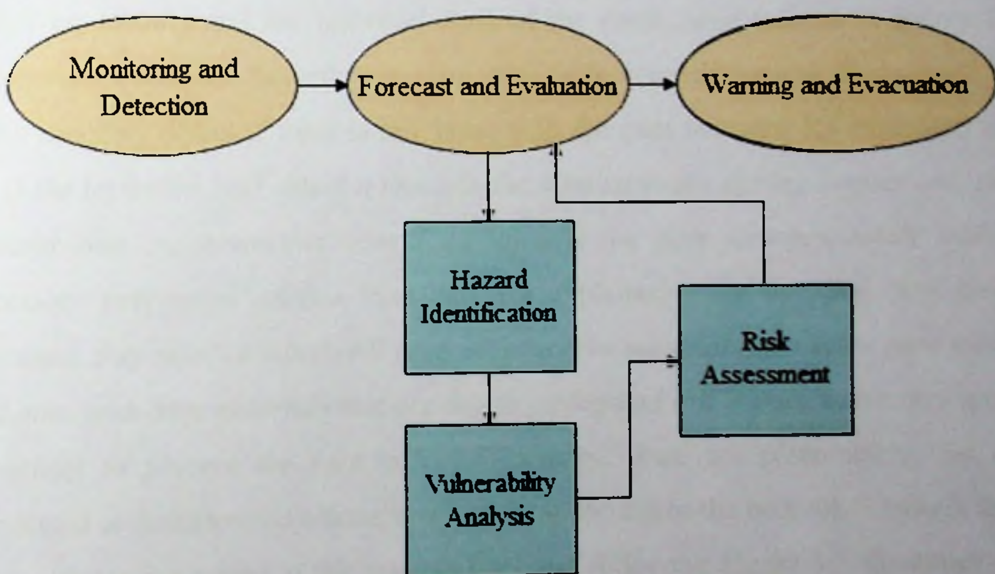

Figure 4.4: Functional characteristics of the EWS used in Sri Lanka

4.2.4.1 Monitoring and detection

During the interviews, all the respondents acknowledged that there are standards and guidelines that have to be followed to monitor the dams. R6 who is a District Director of Irrigation mentioned that "*...there are separate standing orders and guidelines that have to be followed during different seasons of the year like monsoon periods*". Accordingly, respondents agreed that they all have the frequency of inspections to monitor the dam conditions. For example, R8 detailed "*...during rainy or flood seasons all the staff should be attended without any leave and technical staff needs to monitor the dam in 24 hours, Assistant Engineers are inspecting the dam twice a day while the Engineers need to inspect it daily*". Likewise, there is a monitoring procedure specified for each and every dam to detect risk events that occur in the dams. R12, R13, and R14 who were the engineers from the Mahaweli Authority explained that they strictly follow those standards for the monitoring of the dams. R13 detailed that "*...there is inspection schedule that needs to be completed annually and they have divided it for the whole year to complete the tasks weekly in order to monitor and detect the hazards associated with the dam*". Expressing a similar opinion R14 explain "*...there are weekly technical meetings to discuss the dam conditions and the instrumentations*".

However, labours and the technical staff of the dams have trained to follow the inspection schedules. Accordingly, dam staff is monitoring various features of the dams and they detect if there is any issue with the dam features. R3 explained that "*...if the technical staff detect a crack in the dam structure during inspections, they monitor that crack whether it will go towards the dam structure while making necessary precaution*". Other than that, R8 explained "*...if the dam staff detect seepages, they monitor whether it goes with the dam materials or it is the pure water. If it goes with dam materials that are due to piping and if it is pure water they apply groutings to prevent the seepage*". Additionally, there are piezometers that are connected to dams toward a drain that goes from the top to the bedrock. Through that, they monitor the height of the seepage line, and following Figure 4.5 illustrates the readings of the piezometers in the Udawalawa dam.

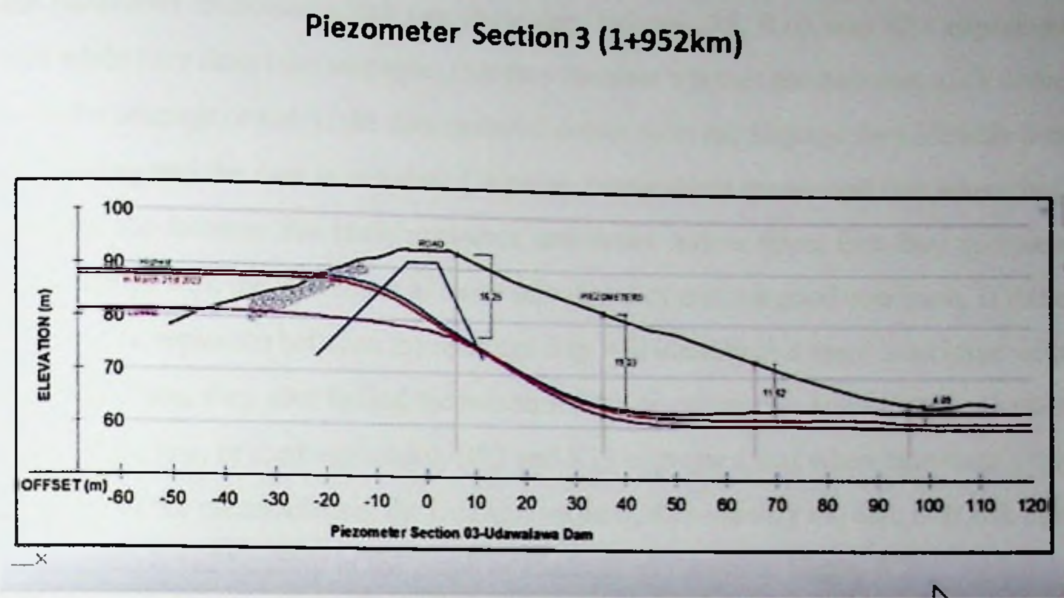

Figure 4.5: Readings of the piezometer in Udawalawa dam

Likewise, dam staff monitor features like rainfall, humidity levels, water levels, water inflow rates, the verticality of the dam, static pressure, settlements in the dam, and the sliding. The findings on monitoring and detection can be summarised in Figure 4.6.

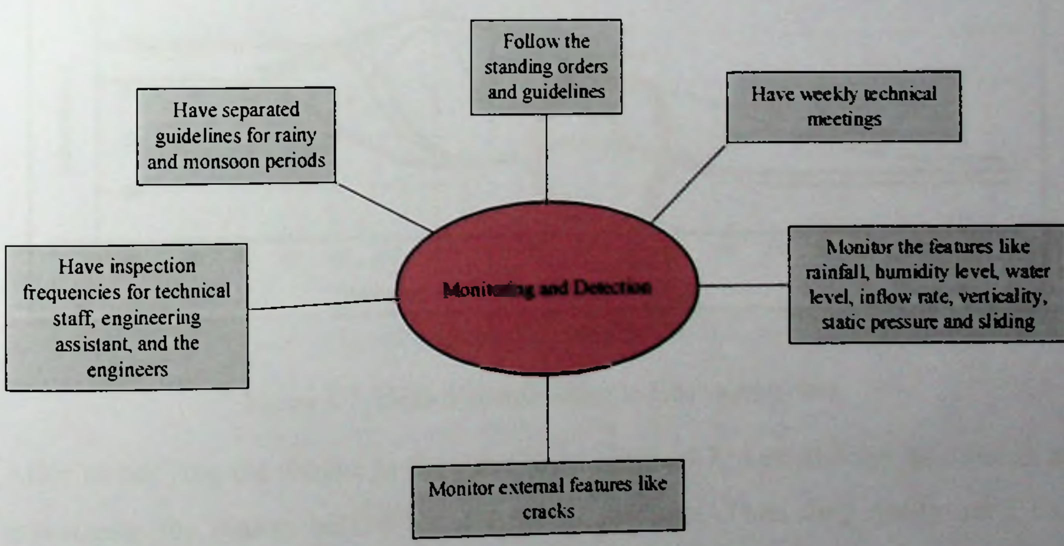

Figure 4.6: Way of monitoring and detecting the dams in Sri Lanka

4.2.4.2 Forecast and evaluation (Hazard identification, vulnerability analysis, and risk assessment)

While monitoring the dams, dam officers will be able to detect various features which are not aligned with the specifications in the guidelines. As a result, they will identify the hazardous situations which can cause dam failures. R8, R10, and R13 explained that while they detect the seepages, first they monitor whether the dam materials come with the seepage or not. If the dam material comes with the seepage they identify that it is piping and the dam is at a risk. Likewise, respondents mentioned that when they monitor the features like static pressures, and water inflow rates, first they compare the readings with the guidelines to make sure that they are in a good condition. If there are any discrepancies between the readings they will identify that there is an issue with the dam. Then, they start to find the reason for the discrepancies and identify whether it is a high, low, or medium hazard. R12 and R13 expressed that when monitoring the readings of the piezometers in the Udawalawa dam, they identify the dam is at risk due to an unexpected bending in the graph of readings as shown in Figure 4.7.

Piezometer Section 4 (2+200km)

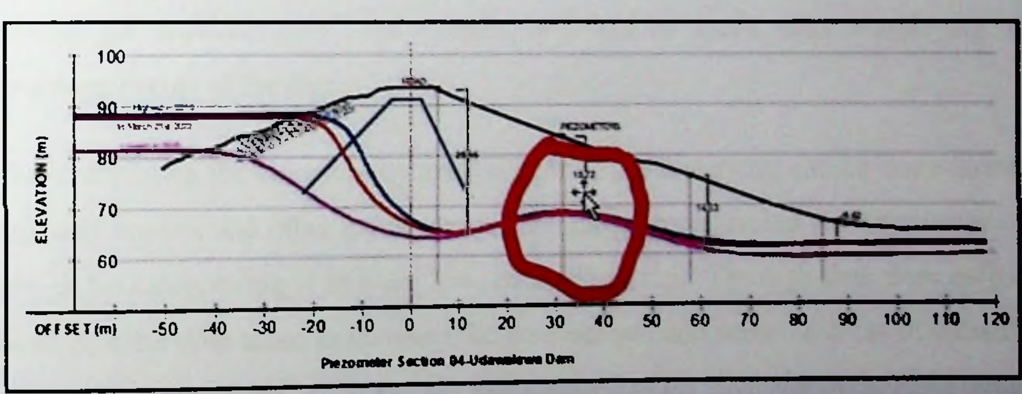

Figure 4.7: Hazard identification in Udawalawa dam

After identifying the change in the curve as in Figure 4.7, dam officers take action to investigate the reason behind the change in readings. Then they notify sand has collected at the bottom of the reservoir and need to create a path to drain the additional water out. R4 and R5 also mentioned after identifying the high water capacity in the spillways, the dam officers take action to cut the reservoir from breaking sections to drain the additional water out. However, if they are doing such cases, they warn the downstream community that they are releasing additional water. R4 detailed that "*...Kanthale and KalaWewa dam failures which caused very recently in Sri Lanka by* *creating very bad impacts were also caused due to the inability to identify the hazard associated with the dam*". Therefore, respondents highlighted that it is very essential to identify the hazards of the dam and to full fill that, should strictly follow the dam monitoring procedures. R1 explained that "...it is not enough to identify the hazard and need to identify the elements affected by the hazard with their level of exposures.

A vulnerability analysis needs to be conducted after identifying the level of hazards associated with the dam. Through the vulnerability analysis dam, officers will be able to identify the inundation areas, irrigable areas, infrastructures, industries, schools, number of living people, and all the affected areas with the identified hazard. R2 detailed that "*...there are pre-identified dam failure modes for Minneriya dam and have conducted the vulnerability analysis for each and every mode of failure to identify the affected areas*". In addition to that R4 and R5 highlighted that there are flood maps that can be used to conduct the vulnerability analysis. Besides that R8 mentioned, "*...at the preparation stage dam officers have mapped the inundated areas which are possible for vulnerabilities*". As a result, that will be useful after identifying any hazardous events of the dam.

After completing the vulnerability analysis, the risk assessments can be done through computer models and other mathematical modelings to represent the significance of the risk by categorising it as high, low, or medium risk. Through that, dam officers investigate the time taken to inundate the downstream and separate areas into the risk levels. R5 detailed that "*....as per the significance of the risk, the authorities decide whether they want to make warnings or not. If the risk is very low, meantime dam officers will take necessary actions to avoid the risk while it is a high risk make immediate actions to evacuate the affected people*".

Accordingly, the way of forecasting and evaluating the risk of dam failures can be shown in Figure 4.8.

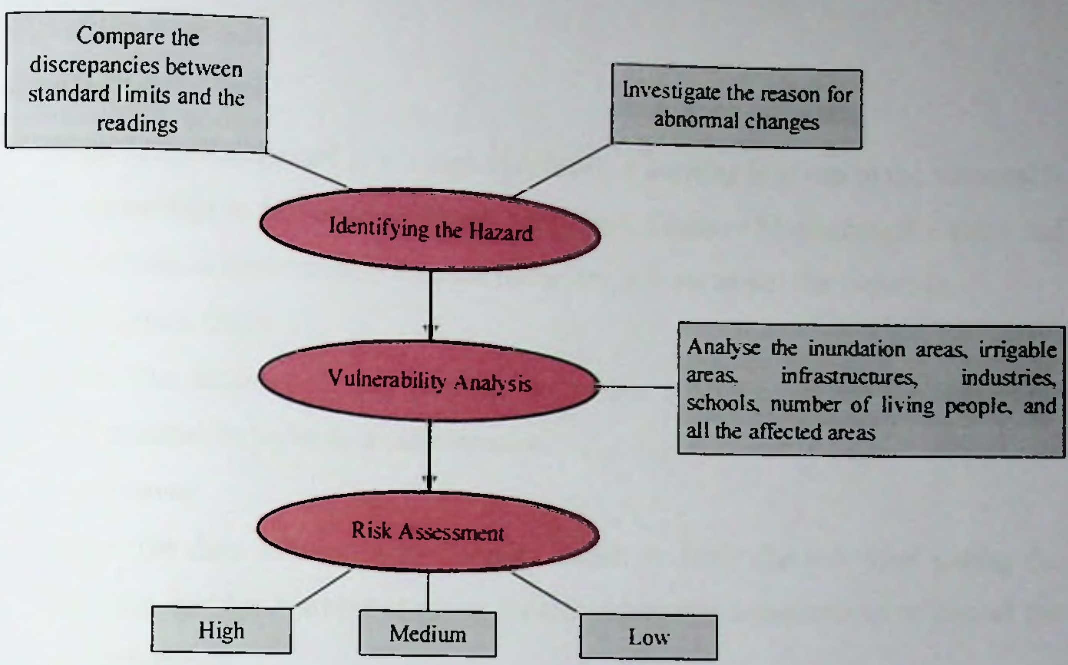

Figure 4.8: Way of forecasting and evaluating the risk in Sri Lanka

4.2.4.3 Warning and evacuation

There are two types of main warnings, warning the identified risk to the top-level dam officers and warning the public that they are at risk of dam failure. However, respondents acknowledged in both Mahaweli Authority and the Irrigation Department they are following an emergency action plan where both types of warnings are included. Further respondents detailed warnings are issued in different stages like alert level warnings, warning, evacuation orders, withdrawal, and the stand down as in the National Emergency Operation Plan.

- Alert

  After identifying that the public is at a risk due to the dam conditions, an initial warning is given to vulnerable communities indicating that there is a risk. Further, the relevant authorities were also informed as per the emergency action plan. R6 detailed that "*...when opening the spillway and while removing extra water from breaking points, an alert is given for downstream community by informing that the water level of the river is high and don't go for bathing these days*".

- Warning

  If the identified hazard is at a high-risk level, a warning is given to the vulnerable communities to reduce the impacts. Meantime, Disaster Management Center and authorities are informed to take the necessary actions as per the situation.

- Evacuation Order

  When the situation is very serious, evacuation orders are given for vulnerable communities to move to a safer location.

- Withdrawal

  When the dam officers take necessary action to settle the risk after giving the warning, another warning is given for the vulnerable communities to cancel the given warning.

- Stand Down

  When the situation becomes normal after the completion of the threat, a warning is given for the communities to return to their locations.

Accordingly, there are different stages of the warning and all the warnings are given by following the emergency action plan. R12 explained, "*...the emergency action plan is updated annually by including the contact details of all relevant officers at every hierarchical level and it is displayed very clearly at operational rooms*". However, respondents highlighted that with the level of the risk the action plan may differ. A general emergency action plan followed in Sri Lanka is illustrated in Figure 4.9.

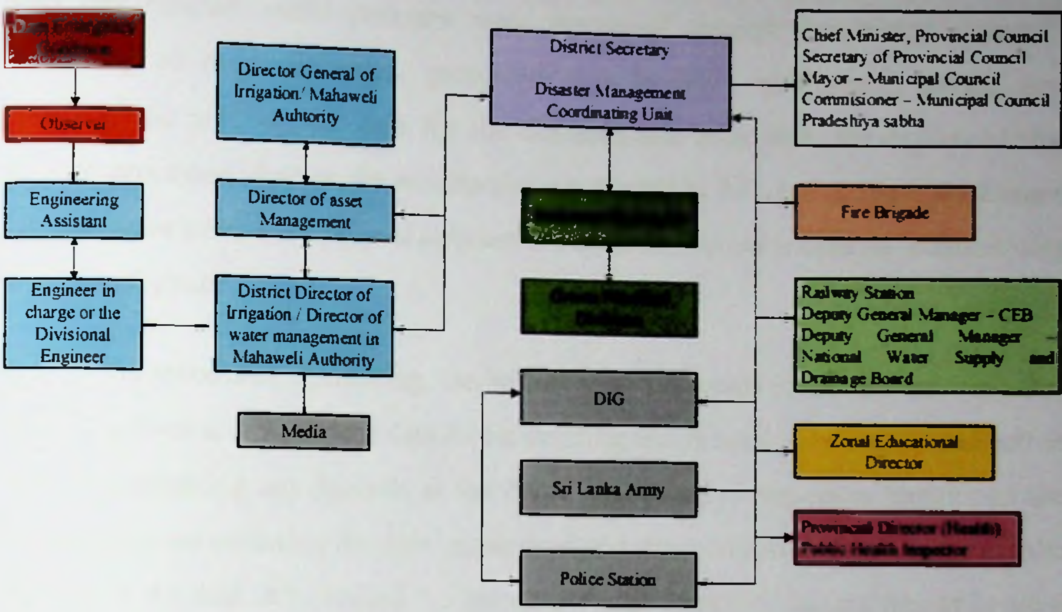

Figure 4.9: Emergency action plan

Therefore, as in Figure 4.9, dam officers follow the emergency action plan when they identify any hazard with the dam. The contact details of the relevant officer with their name are included in this emergency plan. Accordingly, only if necessary dam officers will warn the community through Grama Niladhari and media, and if not dam officers take necessary actions to mitigate the risk of dam failure.

4.2.5 System views to support the functional characteristics of early warning system

After identifying the functional characteristics of the EWS, respondents were asked about the system views support for them. Accordingly, the data view, communication view, institutional/ stakeholder view, community view, and technology view were identified as the system views that support the EWS for dam failures in Sri Lanka.

4.2.5.1 Data view

The data view is very important and supportive for the function of all the characteristics of the EWS. However, R3 and R5 highlighted that data can be taken through manual as well as automated methods. R3 further detailed that "*…the data from the past records and the specifications can be taken manually while the real-time* *data like rainfall, static pressure were measured through automated systems*". According to their responses, processed data to have information during one characteristic will support data for the characteristic after that. R6 explained that "....*the processed data at the monitoring stage need to be used as data for hazard identification while the collected information at identification is used for vulnerability and risk analysis*".

During the process of monitoring, the initial technical details (dam volume, capacity, height, spillways, etc), and the data on the standing orders need to be considered before and after detecting any hazards at the dam. Accordingly, responses mentioned the observations taken during the dam inspections and the monitoring used to identify the failures of the dam. R9 detailed "... *the data on the identified hazard has to be used for the vulnerability and risk analysis by collecting data on the elements exposed for that hazard with their level of exposures and with its vulnerable characteristics*". In addition to those respondents mentioned data from the emergency action plan is used for warnings and evacuations. Therefore, all the respondents acknowledged that data is a very essential and supportive system view for the functioning of the EWS.

4.2.5.2 Communication view

Communication is a very powerful tool in the functioning of the EWS. According to the responses received in communication, the view is supportive of the characteristics of forecast and evaluation and the warning and evacuation. R3 mentioned that "...*there are two ways of communication in the EWS as data collection and the information dissemination*". Meantime other respondents also acknowledged the same decision and highlighted that communication during the data collection is circulated mostly within the organisation while the information is communicated within different organisations.

Accordingly, respondents mentioned that after identifying the risk it wants to be communicated along the hierarchy of the institution. R7 explained that "...*if it is a very serious case, it has to be informed to the relevant authority directors (Irrigation Department or Mahaweli Authority) through a phone call and if it is not a very serious* *case can send a letter or email to the relevant authorities to communicate the hazard of the dam*". Therefore, respondents explained the appropriate mode of communication will be selected based on the level of risk associated with the identified hazard. In addition to R10, R12 and R13 explained that the findings of the vulnerability analysis and the risk assessment can be communicated to the other dam officers for making warnings through maps, graphs, charts, or reports.

However, the communication view is well considered during warnings and evacuations. R3 detailed that "*...while communicating the final decisions, it needs to be filtered and managed based on the receiver of the message. For example, the public wants to know only whether their areas will be inundated with the flood and the leading time of the inundation. Therefore, only that information has to communicate to the public*". In addition to that, respondents explained the most accurate and fastest communication modes need to be considered during the warnings and giving evacuation messages. As well as further they highlighted that all the information communicated to the public and the authorities needs to be well accurate and should communicate to them as soon as possible after taking the decisions. Accordingly, based on the situation, media, telephone calls, Whatsapp messages, SMS alerts, emails, and letters can be used to warn the people and the authorities about the risk of dam failure.

4.2.5.3 Institutional/ Stakeholder view

There are various institutions like Irrigation Department, Mahaweli Authority, Ceylon Electricity Board, National Water Board, Disaster Management Center, and the Police Department that are associated with the decision makings during the dam failures. Accordingly, their support is highly recommended for the warning and evacuation of the EWS during the dam failure. Besides that, respondents highlighted this view is essential for monitoring the EWS.

R4 explained, "*...the stakeholder view is very supportive at the risk identification stage in order to forecast the risk of a dam failure*". Other than that they all highlighted the institutions are very supportive while communicating the risk to the general public according to the level of risk. R8 highlighted that "....*dams are interconnected to each other and it is very important to have the support from the institutions/ stakeholders while identifying the hazard and doing vulnerability analysis in order to reduce the impact of a dam failure*". Further, all the respondents acknowledged that institutional support for the financial allowances and instrument allocation is essential during the monitoring of the dams. Accordingly, EWS is highly seeking support from institutions for the monitoring process and the warning and evacuation.

4.2.5.4 Community view

The community view is supportive of the detection and vulnerability analysis of failures in the dams. Respondents highlighted that downstream people will be able to detect the failures of the dams. R9 explained that "...*downstream communities mostly notify the cracks in the dams, pipings, and the seepages*". As a result, respondents explained communities help dam officers to identify the risks of dam failures. Further, R5, R8, R9, and R11 mentioned, that the community view is very essential for the analysis of vulnerabilities in the dam failures. R9 detailed that "...*community support is needed to identify the industries, agricultural areas, livestock and the disabled persons in the vulnerable areas*". Accordingly, they asserted that the community is the main source who is well aware of the vulnerable areas. Therefore, a community view is needed while conducting the vulnerable analysis.

4.2.5.5 Technology view

Technology is the most essential and most supportive view for the performance of all the characteristics of EWS. R2 explains "...*without technology none of the characteristics cannot be performed effectively*". Accordingly, respondents detailed that GIS technologies, drawn technologies, analysis software, and instrument handling technologies are needed for detection and monitoring, hazard identification, vulnerability analysis, and risk assessment. In addition, respondents highlighted developed technologies for communication like calls, emails, media support, and SMS alerts are used for the warnings and evacuation messages. Therefore, respondents acknowledged it is necessary to have developed technologies to have the optimal benefits of the characteristics of EWS that is used at the dam failures in Sri Lanka.

The system views that support the functional characteristics of the EWS can be represented as the matrix in Table 4.2.

Table 4.2: System views support the functional characteristics of the EWS

System View / **Functional Characteristic**		**Data View**	**Communication View**	**Institution/ Stakeholder View**	[illegible]	[illegible]
Detection and Monitoring	Monitoring	√	x	√	x	√
	Detection	√	x	x	√	√
Forecast and Evaluation	Hazard Identification	√	√	x	x	√
	Vulnerability Analysis	√	√	x	√	√
	Risk Assessment	√	√	x	x	√
Warning and Evacuation	Warning	√	√	√	x	√
	Evacuation	√	√	√	x	√

4.2.6 User requirement analysis for an effective early warning system for dam failures in Sri Lanka through user stories

Under section four of the interview guideline, the user requirements of having an effective EWS for dam failures in Sri Lanka were discussed. Hence the data collected for the user story mapping is analysed in this section.

4.2.6.1 Development of the user story map

The users of the EWS for the dam failures in Sri Lanka were identified under five levels and user story maps were developed for each user with the findings of the interviews.

Officers in charge of dam failure activities at the national level (User 1)

The officers at the Disaster Management Center, Irrigation Department, and Mahaweli Authority were identified as the national level users under User 1. According to R2 and R3, the major role of national-level officers is the **preparation of guidelines and action plans** that needs to be followed by the ground-level officers to reduce the impact of dam failures. R3 explained that they have prepared

- Emergency action plans by specifying national, district, divisional, and village levels to follow during dam failures
- Specific guidelines to be followed during South West Monsoon and the North East Monsoon

However, R5 detailed that "*...it is difficult to prepare guidelines by considering all the technical details of each and every dam. In such cases, they are preparing common guidelines and ask for them to recreate it according to their operational procedures considering the available resources and technical details*".

In addition, national-level officers have the responsibility to **direct, monitor, coordinate, and management** of the administration levels. Further, R2 explained that basic **records about the dams need to be maintained** by the national level officers including the technical measurements of the dams, their past failures, impacts due to the failures, and the feedback received after the failures. Moreover, developed **communication** methods need to be followed to make the connection between necessary authorities during the dam failures.

Therefore, national-level officers **make the connection between the government organisations** to avoid the impacts of the dam failures by warning the downstream communities. As well as national level officers have a challenging responsibility of allocating funds for the maintenance activities of the dams creating linkages with the international and non-government organisations.R3 explained they are **categorising the dams as high-risk and low-risk dams** and allocate the funding as per their categorisation.

After identifying the major roles of User 1, a backbone was prepared for the user story map as in Figure 4.10. Then Figure 4.11 (user story map for User 1) was developed by inserting the tasks with reference to each activity in the identified backbone.

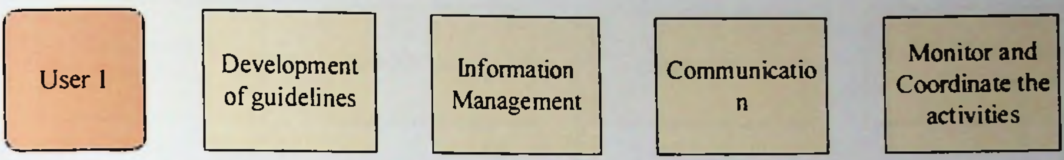

Figure 4.10: Backbone for User 1

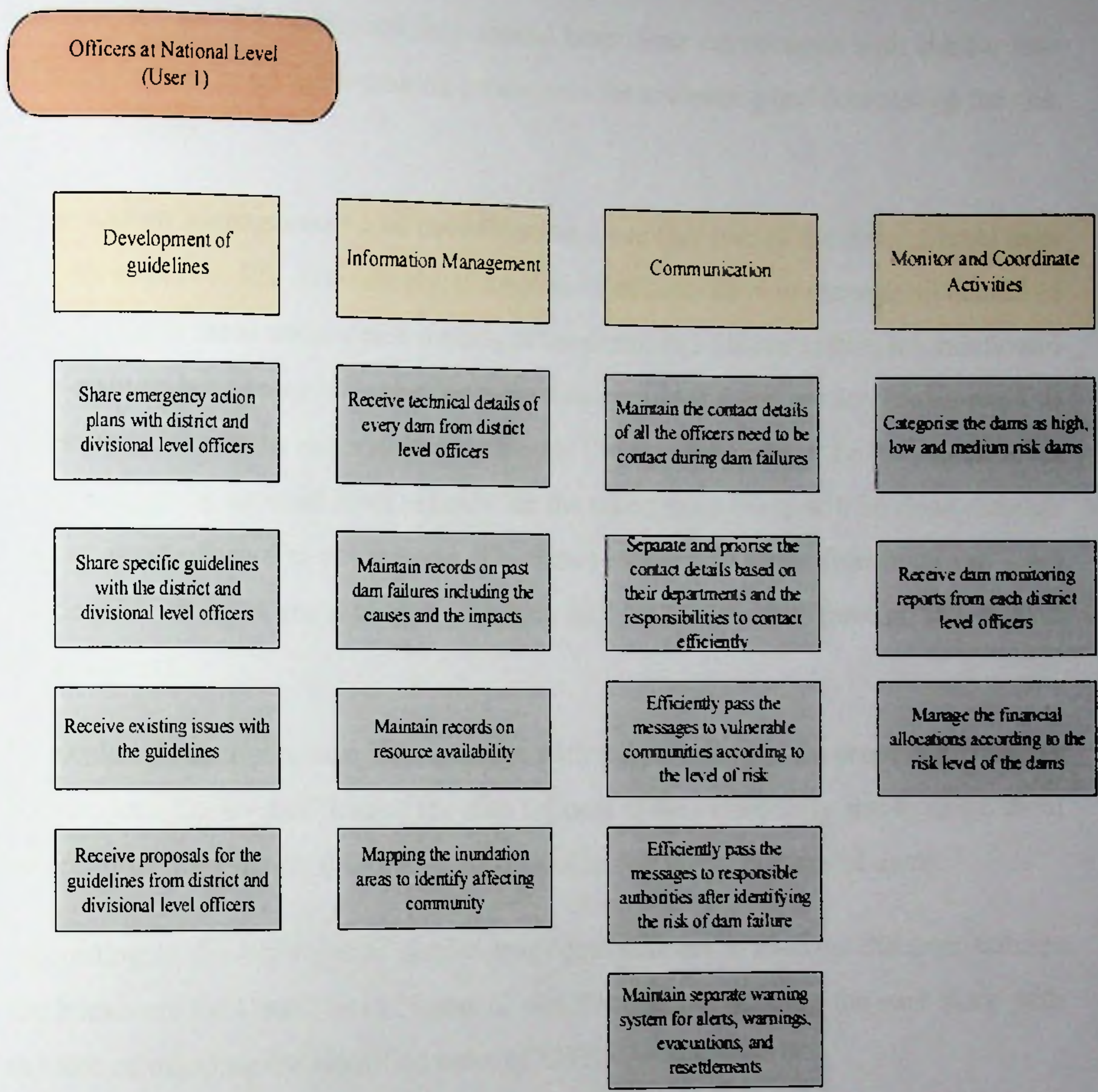

Figure 4.11: User story map (User 1)

Dam Officers at District Level (User 2)

District-level dam officers have a key responsibility to **identify vulnerable areas and to conduct risk assessments** as per R7. However, R7 detailed "*...based on passed record need to keep the recordings on the vulnerable areas for the dam failures and have to maintain risk assessment records*". Accordingly, they need to maintain records on inundation areas, irrigable areas, industries, hospitals, schools, and all other vulnerable areas around the dams.

Other than that, district-level officers need to **make efficient communications** with the national level and the divisional level officers for the effectiveness of the EWS. In addition, R6 and R8 mentioned they should keep close connections with similar line officers during the decision-making procedures for evaluating and forecasting the risk of dam failures.

Information management and coordination is another role of the district-level dam officers as per the R9. Accordingly, district-level officers have to manage all details of the vulnerable areas and the past records of the dams. In addition to that, R6 mentioned they want to keep records on the instrumentations and if there are any issues need to communicate with the national level officers. The coordination of the divisional level officers with the national level officers for the emergency cases will be done through district level officers as per R6 and R7. Hence requesting funds from national level officers for the dam maintenance activities will be coordinated through the district level officers.

R6 explained district level officers engage with the **planning of awareness programs** to introduce the level of risks of the dam failures to the community and to make them aware of the evacuation routes that are available due to the failures of dams.

According to the key roles of district-level dam officers to manage the dam failures the backbone for User 2 as in Figure 12 was designed to develop the user story with the aim of mapping the identified tasks of EWS by User 2.

Figure 4.12: Backbone for User 2

The user story mapping for User 2 is represented in the following Figure 4.13.

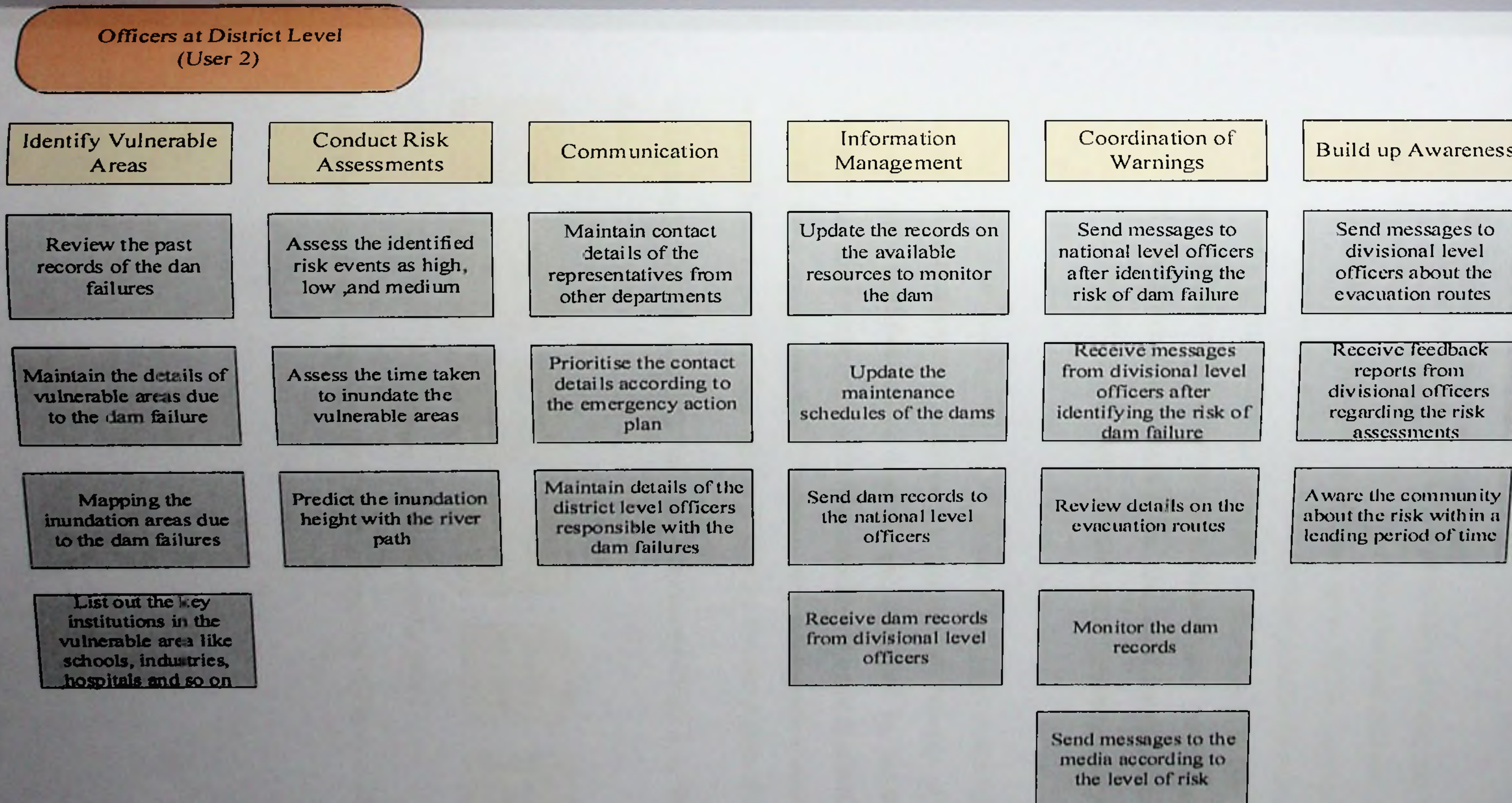

Figure 4.13: User story map (User 2)

Dam Officers at Divisional Level (User 3)

According to the respondents, the high responsibility of managing the dam failures is with the divisional level officers. As a key role, divisional officers, as well as the dam in charge engineers, **follow the guidelines** given by the national level officers to **monitor and inspect the dams.** All the observations on the dam failures are collected by the divisional level officers. R12 detailed "*...they need to follow the guidelines and identify the discrepancies between the standards and the observations*". Further, immediately identifying the hazard of the dam, should communicate to the district-level officers. Therefore, they must maintain good **communication** with the district-level officers.

Similar to the district-level officers, divisional officers also do the **vulnerable analysis and the risk assessments.** Additionally, **keeping all records** of the dams in their division and **identification of dam hazards** are done by the divisional officers. However, all the coordination of the dam activities in order to prevent dam failures are done by them as per the R12. Therefore, respondents acknowledged that the high responsibility to prevent dam failures is with the divisional dam officers.

Accordingly, the backbone for the user story map of User 3 is illustrated in Figure 4.14.

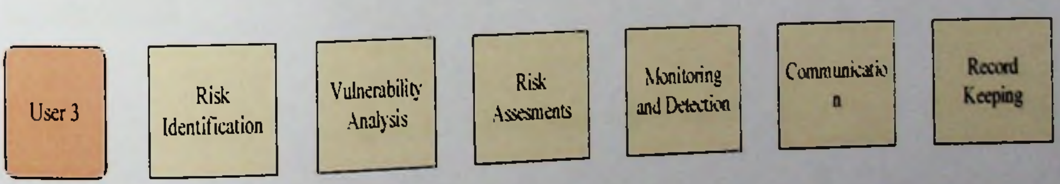

Figure 4.14: Backbone for User 3

The developed user story map for User 3 is presented in Figure 4.15.

Dam Officers at Divisional Level (User 3)

According to the respondents, the high responsibility of managing the dam failures is with the divisional level officers. As a key role, divisional officers, as well as the dam in charge engineers, **follow the guidelines** given by the national level officers to **monitor and inspect the dams.** All the observations on the dam failures are collected by the divisional level officers. R12 detailed *"...they need to follow the guidelines and identify the discrepancies between the standards and the observations"*. Further, immediately identifying the hazard of the dam, should communicate to the district-level officers. Therefore, they must maintain good **communication** with the district-level officers.

Similar to the district-level officers, divisional officers also do the **vulnerable analysis and the risk assessments.** Additionally, **keeping all records** of the dams in their division and **identification of dam hazards** are done by the divisional officers. However, all the coordination of the dam activities in order to prevent dam failures are done by them as per the R12. Therefore, respondents acknowledged that the high responsibility to prevent dam failures is with the divisional dam officers.

Accordingly, the backbone for the user story map of User 3 is illustrated in Figure 4.14.

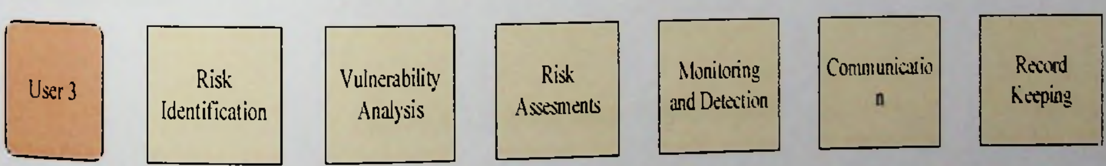

Figure 4.14: Backbone for User 3

The developed user story map for User 3 is presented in Figure 4.15.

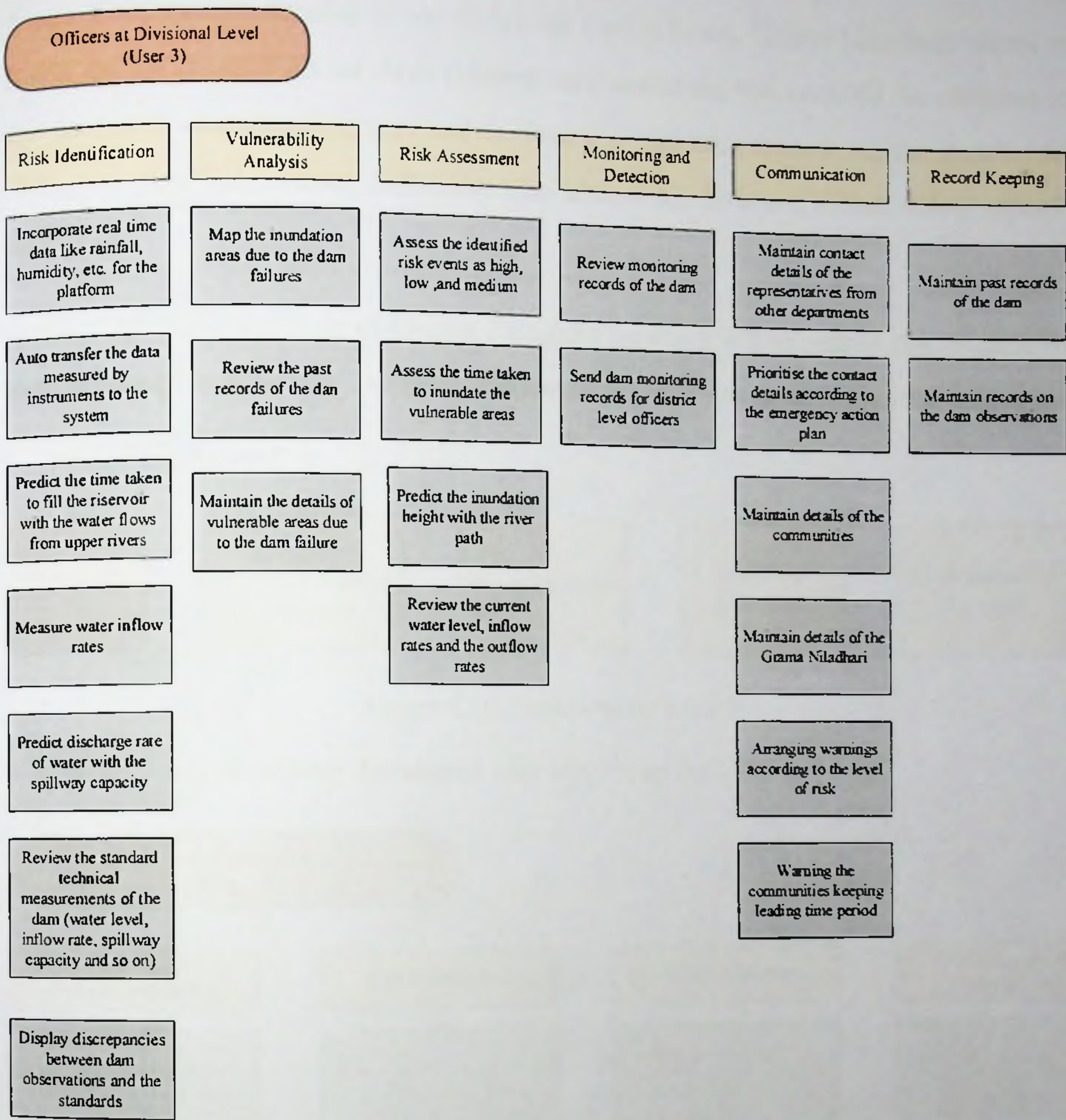

Figure 4.15: User story map (User 3)

Grama Niladhari (User 4)

Since Grama Niladhari is the person who directly communicates with the community, he has a huge responsibility of communicating the risk of dam failures as per R17. Accordingly, Grama Niladhari is **maintaining a communication schedule** that includes the possible contact details of the villagers. Hence, the warnings and the alerts given by the authorities effectively pass to the communities through the Grama Niladhari. Apart from that, R18 explained, "*...need to aware the community about the evacuation routes and should maintain the records on past dam failures to use for* *future forecasting*". Similar to the divisional dam officers, Grama Niladhari wants to **build up awareness about dam failures and maintain the records**. In addition to the past dam records, Grama Niladhari wants to maintain records on the number of villagers, disabled persons, industries available at his division, farms, safety places, and so on.

According to the key role of Grama Niladhari on the EWS to reduce the impacts of dam failures the following backbone (Figure 4.16) was prepared to map the user story for User 4.

Figure 4.16: Backbone for User 4

Figure 4.17 represents the developed user story map for User 4.

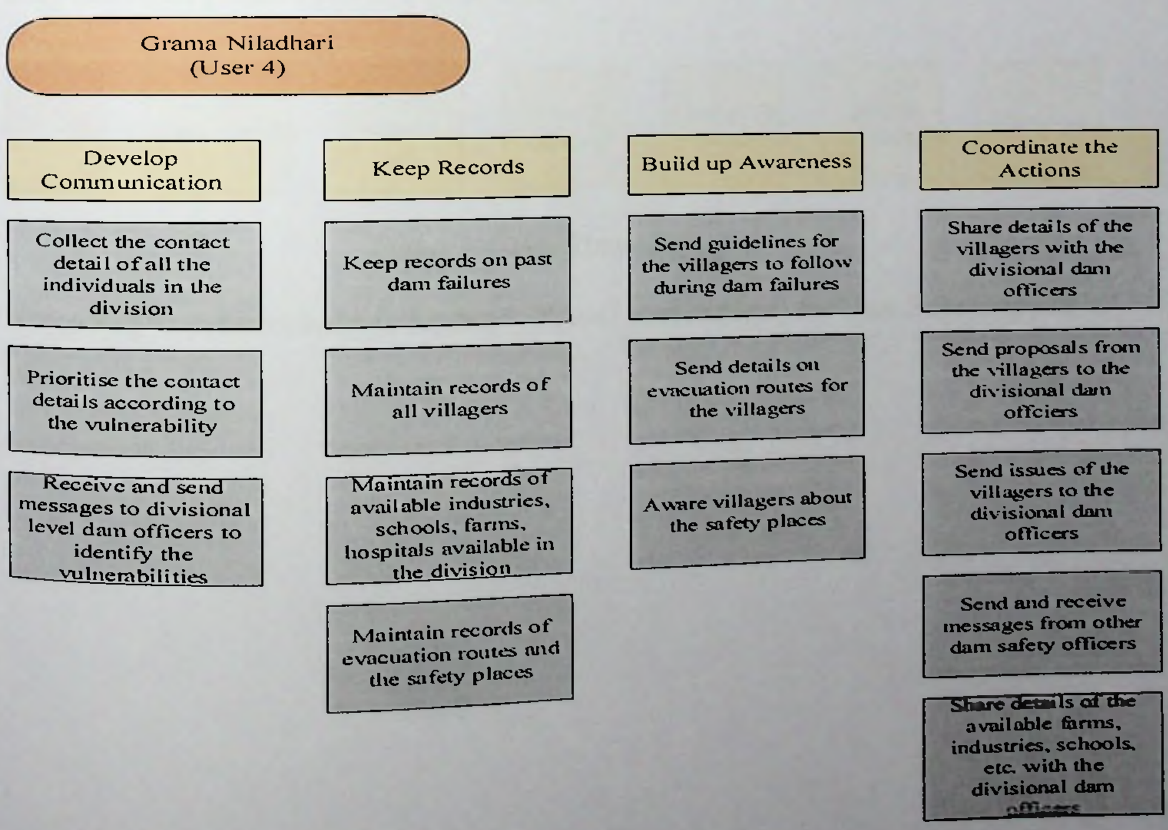

Figure 4.17: User story map (User 4)

Community Members (User 5)

Community is the last mile that seeks the main advantage of the EWS. According to R19, they only need to **know the vulnerable areas** and **whether they are at high risk or low-risk areas with the dam failure**. In addition, the community wants to be aware of the **time taken to inundate the areas and the peak height of the inundation** in order to maintain their safety within the period of dam failure. Other than that R20 mentioned, "*...always they need to update their details with the Grama Niladhari to maintain a good relationship between them to avoid the issues faced by the community*". Accordingly, the community needs to update the communication schedule prepared by the Grama Niladhari. The other important thing for the community is, that they should **aware of the evacuation paths and the community must inform the dam officers whether they have evacuated to safe places.**

Therefore with the basic requirements of the communities, the backbone for the user story map was prepared as in Figure 4.18.

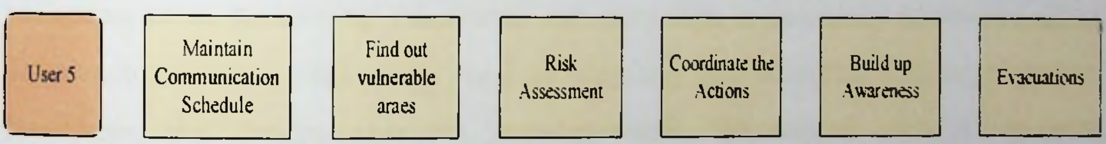

Figure 4.18: Backbone for User 5

According to the backbone in Figure 4.18, user requirements for User 5 are mapped in Figure 4.19.

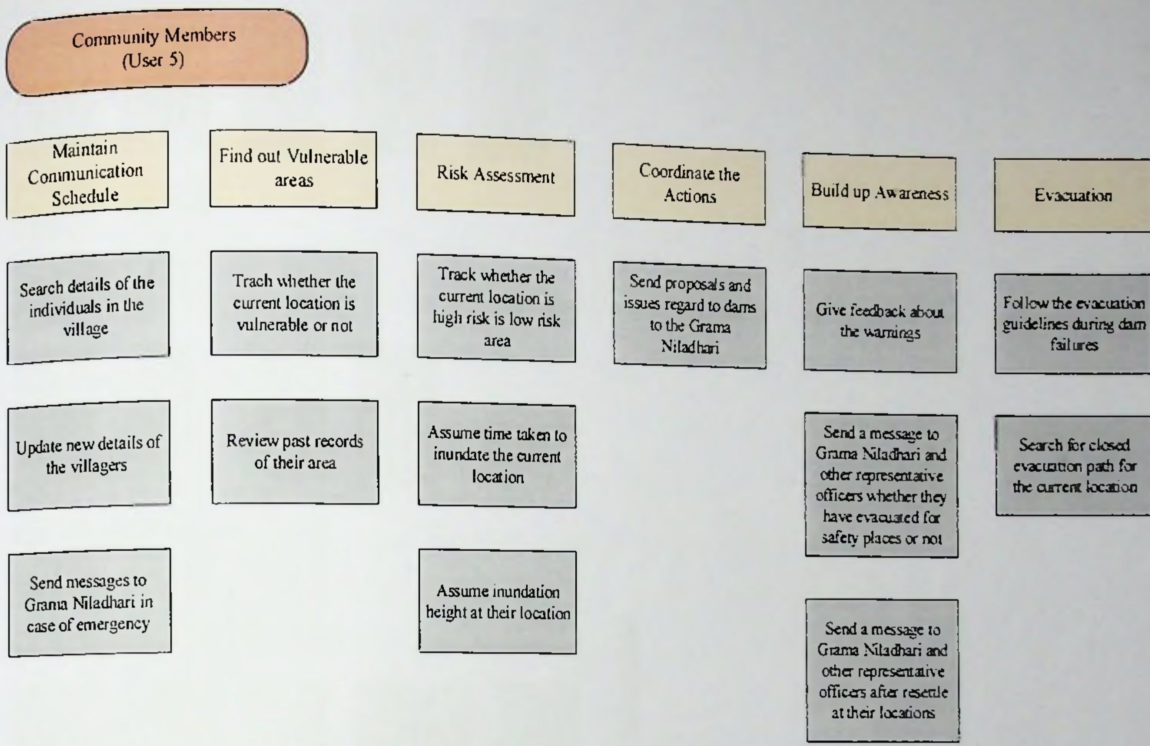

Figure 4.19: User story map (User 5)

Following close monitoring, the overall user story map is created by combining all of the user stories into a single map. The final user story map takes into account all project users, and the requirements are well-organised. The overall map, along with summarised user stories presented in Figure 4.20, has been used for prioritisation.

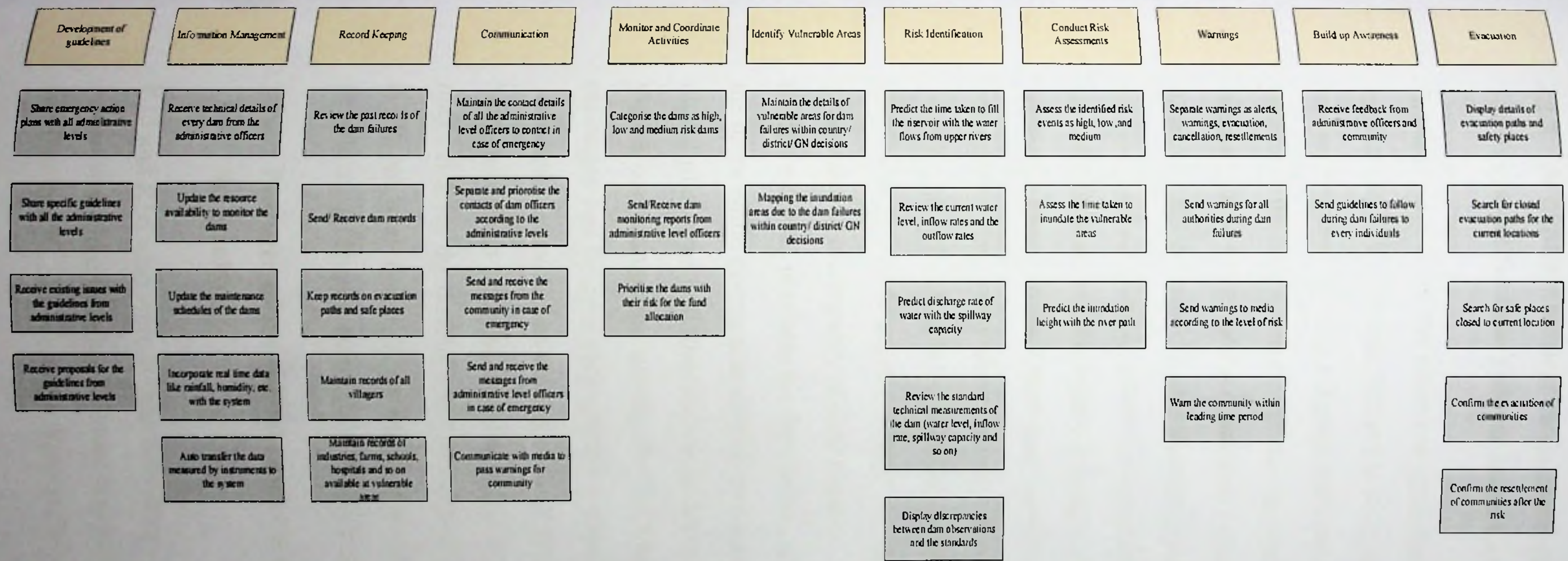

Figure 4.20: Overall user story map to be prioritised

4.2.7 A digital platform to enhance the characteristics of the early warning system for dam failures in Sri Lanka

The fifth section of the interview guideline was separated for the digital platform to support the EWS for dam failures in Sri Lanka. Therefore, respondents were asked for their opinions on having a digital platform for EWS for dam failures in terms of risks and benefits. As a result, all the respondents acknowledged that it is of utmost importance to have such a developed system for dam failures to reduce the impacts. However, R3 detailed "...*due inadequacy of the financial capacities Sri Lanka is not applied such developed system for dam failure EWS*". Further respondents opined the digital platform will be highly effective for accurate warnings to the communities during the dam failures. Other than that R8 asserted "....*for example the rainfall details are taken by so many departments but only a few of them have the knowledge to analyse the rainfall details. In addition, if the officers are unable to log in for some systems, they will be unable to have the major details to analyse the risks of the dam failure due to inadequacy of data sources*". As a result, the respondents acknowledged having a digital platform for dam failure EWS as it gives a collaborative platform for the users while giving access to all major details. Therefore, respondents accepted that digital platforms will disseminate accurate warnings very quickly. Since the usage of digital communication among the Sri Lankan population is very high the warning messages can be sent very quickly without waiting for traditional warning systems. Therefore, respondents described with the optimisation of the resources people can have maximum benefits from the digitalised EWS. According to the respondents, the major risk for the development of a digital platform for dam failure EWS in Sri Lanka is the not availability of strong internet facilities in the interior places, especially in remote areas. Hence, suitable technology needs to be selected in such situations.

4.2.7.1 Features of the digital platform to support the EWS for dam failures in Sri Lanka

R15 and R16 who were system developers opined that a digital platform is just like an online website consisting of more features where more participants collaborate. R15 detailed that "...*zoom can be identified as a most famous platform which can be used* *for educational, business and other purposes where many people can collaborate*". However, before developing the platform, the user requirements need to be identified. Then after, according to the user requirements, the design of the system is created and developed the system.

While developing the digital platform for dam failure EWS, the identified characteristics of the EWS need to be incorporated with the digital platform. Accordingly, detection and monitoring, risk forecasting and evaluation, and warning and evacuation are the main functional characteristics of the EWS. However, respondents explained in each function, the system needs to follow the process in Figure 4.21 to give a better outcome from the digitalised EWS.

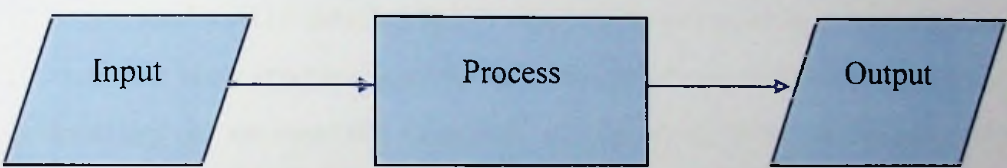

Figure 4.21: Process followed in the digitalised system

R15 detailed that at the initial stage of the development, need to consider and clearly identify the inputs of the system by considering the user requirements according to the main functions of the EWS. R16 described an example "*....system need to consider the standard technical details of the dam and the daily readings of the dam observations as the inputs for the function of detection and monitoring. Then after the inputs are processed by comparing the standard values with the readings and give the output by representing the discrepancies between them to identify whether there is a risk with the dam or not*". Accordingly, for all three major functions of the dam, all the inputs need to be incorporated into the platform. In addition, respondents opined the data need to be classified as fixed data and variable data. They explained that fixed data are the data that are not changed with time such as past records, and standard details while variable data changed from time to time like rainfall details, inflow rates, and so on. Hence R15 mentioned, "*....system will be comparing the variable data with the past records and will forecast future records about the dam failures*". Accordingly, respondents opined after inputting the all details to the system, it will give the output as per the user requirements such as displaying the inundation areas on maps, passing notifications, SMS, or calls for the communities, warning the authorities. However, respondents highlighted platform will be an embedded system where software and hardware are both included. Accordingly, all dam-specific data which includes the databases of the dams need to be installed for the platform. In addition, sensors or other technologies have to be linked to the platform to have daily or weekly observations of the dams. However, developers need to set out any path to install the hardware readings to the digitalised system. In addition, respondents revealed as all the major details are incorporated into the system, it will help to search and find any detail related to the dam failure while reducing the additional time and cost spent to find the details.

However, the platform needs to be speedy. The system has to be loaded within two or three seconds in order to increase its effectiveness of the system. In addition, it should be user-friendly. R16 detailed that "*...the platform has to be established in a way to increase the user experience while reducing the issues*". Further, respondents opined generativity is an essential character of the platform. Accordingly, respondents mentioned, that there should be a natural language system in the platform which can be understandable by all users. R15 detailed further "*....it is not effective to display only the rainfall, need to describe it as low risk or high risk*". R16 also detailed "*...not effective to display the raw data, need to interpret the data to the consumers*".Therefore, respondents highlighted increasing the generativity of the platform is essential to interpret the consumers in an understandable manner.

Security is another feature of the platform. According to the respondents, there should be logins and logouts for the authorities and it needs to be customised according to the duties of the authorities. However, access to the platform is given to all users by customising them. Accordingly, respondents mentioned open access is given by creating security by separating admin, contributors, and the readers. R16 detailed that "*....genarally all can read the system, but according to the role of the users the system will give the access for the updates. However, the users can manage the system in accordance with their role*". Therefore, respondents opined the security of the platform needs to be maintained for the protection of the data while cutomising the system according to the users.

According to the respondents, the platform for the dam failure EWS should be convenient and easy for the users. Therefore, R15 mentioned, "...the contributors should allow inputting the master data in a familiar way like excel format or google sheet". R16 further detailed that "....*for the contributor who has to upload much data can allow using excel format while the minor data can input via google forms*". In addition, they opined the platform needs to be visible clearly to all users and should be adjusted according to the user's display mode.

Moreover, respondents explained for ease of use in low-risk situations only a "notification" can send to the communities while in high-risk situations a "call or SMS" can send to the communities. However, respondents highlighted that the warnings also should be customised for the authorities and the communities. R 15 explained that "...*the information required for authorities and the communities are not similar. The communities want to know only whether they have a risk from the dam failure and the level of the risk caused due to the dam failure while the authorities want to know the root causes for the dam failure*". Therefore, according to the user (the authority or a community), the warnings need to be customised. Other than that, the platform needs to indicate that the messages sent through the platform are received by the others and vice versa.

Accordingly, the features of the digital platform created for the EWS for dam failures in Sri Lanka can be illustrated in Figure 4.22.

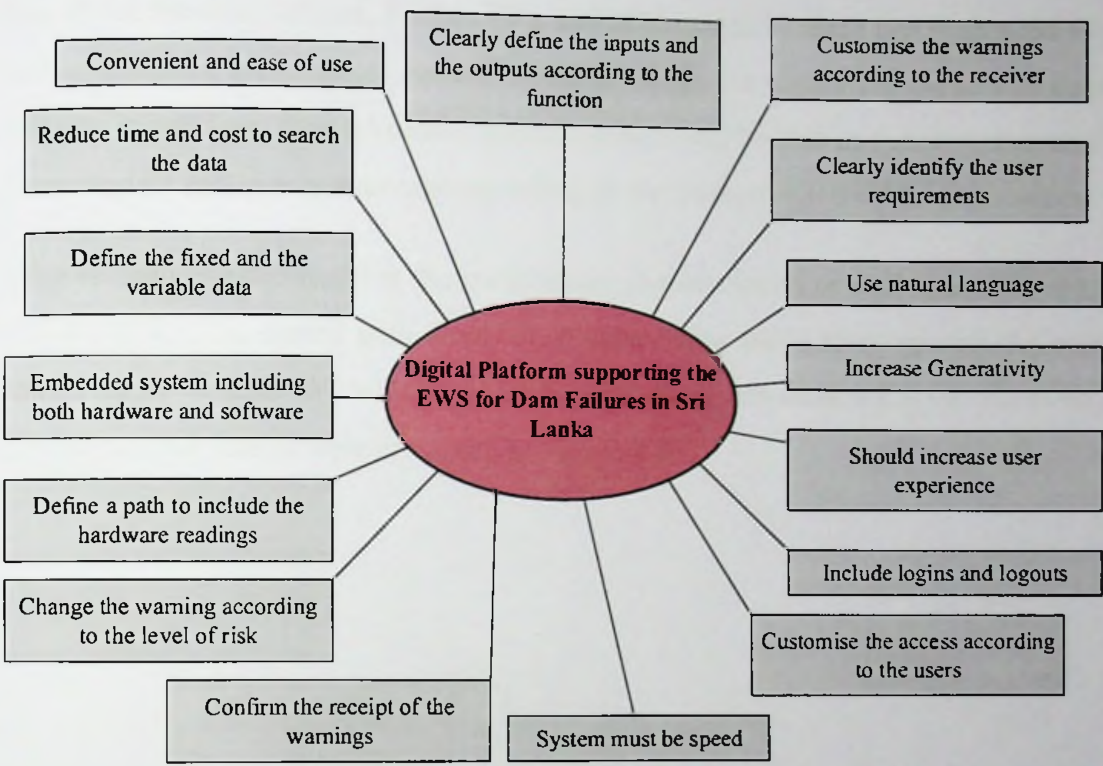

Figure 4.22: Features of the digital platform to support the EWS for dam failures in Sri Lanka

4.3 Data analysis of focus group discussion

A focus group discussion was conducted for the prioritisation of identified user stories. The participants were selected on their exposure to the dam failures and they are presented in Table 4.3.

Table 4.3: Profile of the participants

Participant Code	Participant Description	Expertise
FG1	The government officer who is aware of dam failures	17 years of experience in dam safety
FG2	The government officer who is aware of dam failures	10 years of experience in dam safety
FG3	Business Analyst	3 years of experience in software development

Before starting to prioritise the user stories, a small introduction to the study was given to the participants. As a result, participants valued the current study as all the responsible persons can work towards the platform and it will be easy to handle the data about the dam failures. Further FG1 and FG2 explained there is a high need for having EWS for dam failures and it is a timely solution to reduce the impacts of dam failures. In addition, they acknowledged this system will be able to distribute the most accurate data and timely warnings according to the level of risk for the communities.

After introducing the study to the participants, the developed overall user story map (Figure 4.20) was shared with them. Then after being asked to categorise the user stories under "MoSCoW" which was introduced under sub-section 2.5.7.2. However, prioritised user stories were presented in Figure 4.23.

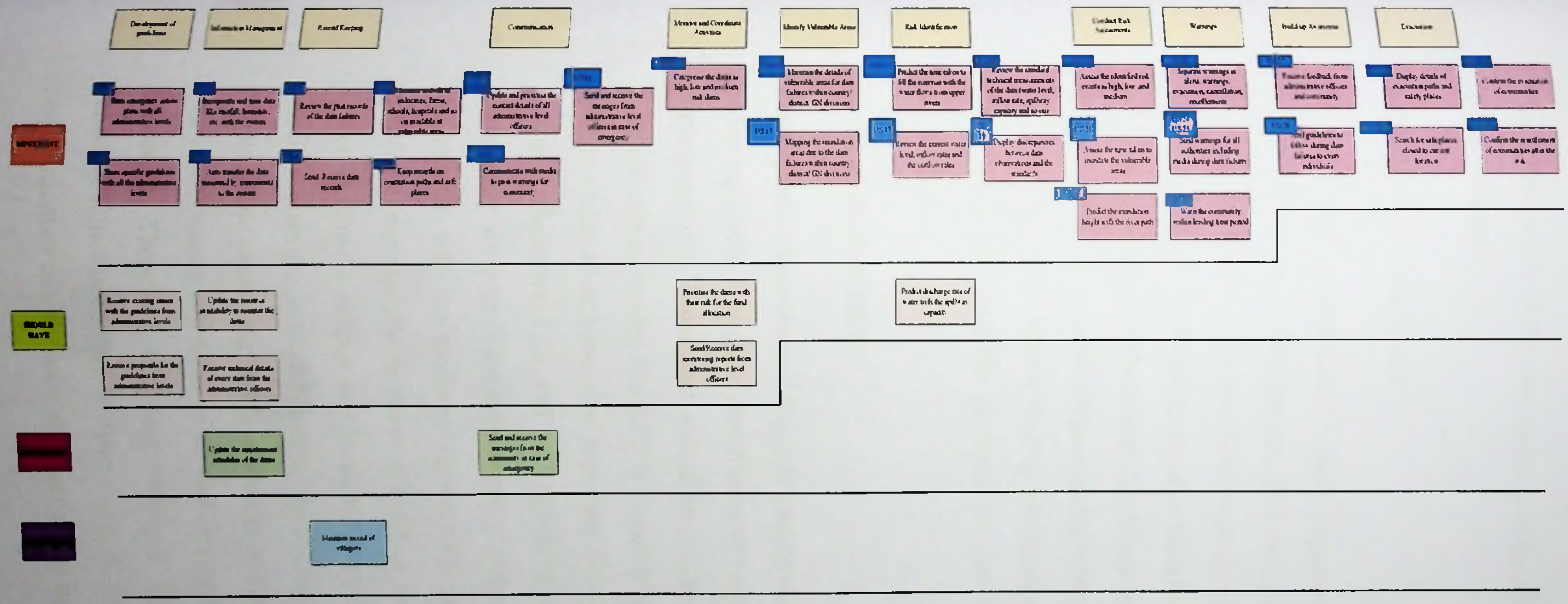

Figure 4.23: Prioritised user story map

The prioritisation of the user stories was done based on the following details given by the participants.

Development of guidelines

Participants explained that it is very important to follow the guidelines in order to reduce the impacts of dam failures. FG1 mentioned, "*...no need of making precautions after the failures and it is beneficiary to follow guidelines to reduce the risks*". Further participants elaborated that the incorporation of emergency action plans and guidelines with the system will be beneficial for future users of the system. Accordingly, all the requirements under the development of guidelines were categorised under "must have" and "should have" where sharing emergency action plans and the guidelines are "must" and receiving the proposal and the issues of guidelines are placed under "should".

Information management

Participants acknowledged that information management is an important requirement of having EWS. However, identified user requirements have been categorised by the participants into "must have, should have, and could have" categories. FG1 explained, "*...main aim of having this EWS is to giving an accurate warning for the community and in order to achieve that real-time data must be incorporated directly to the system*". Therefore, FG1 and FG2 agreed to incorporate real-time data and to auto-transfer the readings of the instruments with the system. Further, FG2 mentioned, "*...if the system has updated the information on resource availability, officers can effectively manage the resource allocation for the dams*". By the way, participants agreed it is not a serious requirement for an EWS. Therefore, participants agreed to consider resource availability as a "should have" requirement. Similarly, they agreed to categorise managing technical details of the dams as a "should have" requirement. The maintenance activities of the dam are conducted by the officers by following the schedules. Therefore, FG1 acknowledged that the incorporation of a maintenance schedule is not necessary to have on the EWS. Hence, they agreed to categorise the requirement of maintenance schedule under the "could have" category.

Record keeping

Participants opined this as a very essential requirement for EWS. FG1 detailed "*...EWS must have past records to forecast the future risks of dams failures*".Further explained that "*...newly appointed officers will not be very familiar with the dam environment, they will be face troubles while making the evacuation warnings*". Since they acknowledged it is a must to maintain the records of evacuation paths on the EWS. Hence, except for the maintenance of villagers' records other two requirements were identified as "must have" requirements. In addition to that, participants discussed villagers' details are already maintained separately at each Grama Niladhari division and it is not very important to consider at the current stage of the EWS.

Communication

All participants accepted to update and prioritise the contact details of all administrative level officers as a "must have" requirement of the system. FG1 explained that "*...the advantages like time-saving opportunities and increasing of effectiveness of the warning will be achieved while the officers can access the contact details of all officers from a single place*". They elaborated that, it will be beneficial if the contact details were entered in an organised manner including their position, name, telephone number, and departments. Further, they are expecting categorisation of the contact details as divisional level, district level, and national level. In addition, participants included dam officers, police, and army, officers in disaster management, and the media as the officers at different administrative levels. Moreover, immediately communicating the messages from ground-level officers to top-level officers is also incorporated as a "must have" requirement. After analyzing the risk as high or low, that should be passed to the public through the media. Hence, participants opined it as a "must have" in an EWS. Managing the EWS by the community is not a very essential requirement as per the participants. Therefore, they make it a "could have" requirement for an EWS.

Monitor and coordinate activities

Participants opined this as another important set of requirements for the EWS. According to the identified user requirements, participants acknowledged allocation of funds and receiving dam monitoring reports as non-functional requirements of separating the dams as high, low, and medium risk dams. Therefore, participants kept dam categorisation as a "must have" requirement while the other two are "should have" requirements.

Identify vulnerable areas

Participants highlighted that identification of vulnerable areas is of utmost importance in an EWS. In order to warn the people, it is necessary to identify the vulnerable area. Hence, the identified requirements under the vulnerable areas were maintained as "must have" requirements of an EWS of dam failures.

Risk identification

These are the essential features of an EWS as per the participants. FG1 detailed "*...the standard measurements on the technical details of the dam must be in the system to compare the dam observations with the standard measurements to identify the risks*". Therefore, those two requirements were classified as "must have" requirements. Other than that, it will be easy to identify the risk of dam failure when the system can predict the water inflow and outflow rates. As a result, participants opined to use it as a "must have" requirement of the EWS. Further FG2 mentioned, "*...community can pass the warnings effectively about the water levels when the system predicts the time taken to fill the reservoir by the upper rivers*". Apart from that, the prediction of the discharge rate of water with the spillway capacity has been identified as a requirement of the EWS. However, participants mentioned that can be used as a non-functional requirement and that was classified as a "should have" requirement.

Conduct risk assessments

Assessing the risk event as high, low, and medium risk, time is taken to inundate the areas and the prediction of peak heights of the inundation with the river path was identified as the user requirements under the risk assessment. FG1 mentioned, "...risk assessment is a major characteristic of an EWS". Accordingly, all the participants agreed to accept all three requirements as "must have" requirements of an EWS for dam failures in Sri Lanka.

Warnings

The warning is the main function of an EWS. FG1 detailed "...*to be an effective warning system, the community must be warned within a leading period emergency after identifying the risks*". In addition, warnings must be classified as per the risk in order to inform the risk level to the community. Further, while identifying the risks, the warnings must be passed to all relevant authorities like Irrigation, Disaster Management Center, Police, and Army to manage the hazards. Participants acknowledged that in the user story map all the key requirements have been identified and participants accepted those as the "must have" requirements of an EWS.

Build up awareness

Participants accepted that EWS needs to have feedback from officers and the community to upgrade its performance. In addition, to be aware of the procedures, the EWS needs to present the guidelines to be followed during the dam failures as the community does have not much knowledge on how they want to behave during a such hazard. Therefore, participants classified those identified requirements of the EWS under the "must-have" category.

Evacuation

Participants detailed the major function of an EWS is to identify the risk and give early warning for communities to evacuate to safe places. Accordingly, the user story has identified a display of safe places and gives details about the evacuation paths as user requirements. In addition, participants also opined it is better if the system can confirm the evacuation of the community before the risk and resettlement of the community after the risk. Therefore, all the identified user requirements were accepted by the participants under the "must have" category.

4.4 Prioritised user stories for the preparation of an early warning system for the dam failures in Sri Lanka

According to the results of user story prioritisation in Section 4.3, 'Must Have' user stories were chosen for the initial phase of the creation of the EWS for dam failures in Sri Lanka. As a result, the interview data was used to develop the Card, Conversation, and Confirmation (3Cs) (discussed in section 3.5.7.2) elements of each user story in the 'Must Have' category.

Table 4.4 is used to tabulate the 3Cs for the first user story. Likewise, 3Cs for identified 32 user stories under the "must have" category (Figure 4.21) were presented in Appendix A.

Table 4.4: User story - 01

User Story Number	US - 01
User Story (Card)	As a Director at the National level, I want to share the **emergency action plan** with all **administrative levels.** So that, officers will be able to behave properly after identifying the risks of dam failures
Conversation	**Emergency action plan** – The communication hierarchy which has to be followed after identifying the risk **Administrative levels** – All dam officers at divisional, district, and the national level including the Irrigation department, Mahaweli Authority, Disaster Management, Grama Niladhari, and so on.
Confirmation	Display in a general folder in which all levels of officers have the access to download.

4.5 Chapter summary

This chapter presented the analysis of data collected through the stakeholder interviews. Accordingly, the causes ad impacts of dam failures in Sri Lanka, the functional characteristics of the EWS for dam failures in Sri Lanka, and the system views that support the functional characteristics of EWS were identified through the semi-structured interviews conducted with the stakeholders of the dams. In addition, the user requirements of having an effective EWS for dam failures were identified during the interviews. Then after, the features of the digital platform to enhance the identified characteristics of the EWS were discussed in this chapter. Finally, the chapter concludes by prioritising the user story maps which are recommended through a focused group discussion for a digital EWS for dam failures in Sri Lanka.

CHAPTER FIVE

RRESEARCH FINDINGS AND DISCUSSION

CHAPTER FIVE

5. RESEARCH FINDINGS AND DISCUSSION

5.1 Introduction

This study contributed to enhancing the functional characteristics of a digital EWS to reduce the impacts of dam failures in Sri Lanka. Accordingly, the causes and the impacts of the dam failures, the functional characteristics of the EWS with the system views that support them, and the user requirements of having an EWS for dam failures in Sri Lanka were identified. In addition, the characteristics of a digital platform to support the EWS for dam failures in Sri Lanka were explored. In order to achieve the aim of the study, the findings from the data collection stage must be justified further by reviewing the findings from the literature review. Thus, the findings of the empirical investigation are used to strengthen the findings of the literature in this chapter.

5.2 Causes and the impacts of the dam failures

The findings of the study revealed that much attention needs to be given to the safety of the dams, as it can create many negative impacts on society, the environment, and the economy. As disclosed by Li and Zhao (2018), dam failures have become a global crisis that creates very bad impacts on both humans and properties. This view was further endorsed by the respondents as well as where they specifically mentioned that Sri Lankan dams are at a critical stage of dam failure due to several causes. Accordingly, respondents categorised the causes for dam failures as internal and external causes in a similar way to the discloser of You et al. (2012). However, Figure 3.1 represents the global causes that affect the dam failures and the respondents have to contextualise those literature findings to the Sri Lankan context. Accordingly, the causes that affect the dam failures in Sri Lanka has represented in Figure 4.1. Since both literature and the data collection have identified internal causes for dam failures as design, technical, and management failures, there were slight changes in the content of those categorisations. The literature review in Figure 2.1 has identified piping around the culverts and the quality issues with the culverts as internal causes affect for dam failure and respondents detailed that there are no culverts with the dams and it is not valid for the Sri Lankan context. In addition, respondents have changed the external cause named "human actions" in Figure 2.1 as "human and animal acts" during the data collection. Ardeshirtanha & Sharafati (2020) have identified wildfire, volcanic activities, and snow as natural disasters that affect dam failures, and during data collection, it was clear those factors are not validated in the Sri Lankan context. Even though there are many causes that affect Sri Lankan dam failures in Figure 4.1, respondents explained those causes cannot be prioritised as their impact on the dam failures can differ with the dam conditions and their locations.

Mo et al. (2019), Zhong et al. (2011), and Zhang and Tan (2014) described the global impacts of dam failures as represented in Figure 3.2. Similar to the causes of the dam failures, respondents validated and contextualised the literature findings to the Sri Lankan context during the data collection. Accordingly, the contextualised and validated findings for Sri Lanka are represented in Figure 4.2. As disclosed by Mehta et al. (2020) the most significant impact of dam failure is the loss of human life. Similarly, respondents also accepted that and prioritised the impacts of the dam failures. Accordingly, other than the loss of human life, the highest impact is on society as all the impacts of dam failures directly or indirectly impacted society. Then the next impact is on the environment, economic and the last is the institution and the political impacts which were revealed during the research findings.

5.3 Functional characteristics of the EWS used for dam failures in Sri Lanka and the system views support for them

The EWS is a program that ensures dam safety by incorporating risk reduction and risk mitigation procedures as per Altinakar et al. (2009). The research findings also validated a similar fact with the further explanation of EWS as it is a timely solution taken to reduce the impacts of dam failures. Hazard identification, risk assessment, and vulnerability analysis (forecasting and risk evaluation), ii) Detection and monitoring, iii) Emergency management structure, including warning and evacuation, iv) Local dissemination, and v) Public education are the basic functional characteristics of an EWS as explored by the Samarajiva et al. (2006). However, according to the aim and the scope of this study only the first three characteristics were taken into the data collection stage. During the interviews, respondents were detailed about the functional characteristics of the EWS used for dam failures in Sri Lanka. Accordingly, Sri Lanka is currently using a manual system to warn the people during dam failures and the procedure followed in Sri Lanka is represented in Figure 4.3. Similarly, the functional characteristics of the EWS are presented in Figure 4.4. Hence, it is clear that the characteristics explored by Samarajiva et al. (2006) can be contextualised in the Sri Lankan context.

There needs to be timely data collection on dam safety and want to follow scheduled inspections to monitor the dams and detect the failures of dams as per Eckersley et al. (2017). Research findings also confirmed that with the knowledge and the experience of the respondents. The procedure followed for the monitoring and detection of the dam has represented in Figure 4.6. Further, Hamza and Månsson (2020), explored that developed technologies and the knowledge of the expertise are used for risk forecastings. Similarly, that was revealed through the data collection, that piezometers are used to forecast the height of the seepage line and there are many other technics used to measure the technical features of the dams in order to forecast the risk. However, the risk forecasting method used in Sri Lanka is in Figure 4.8. When arranging the warnings, there has to be an organised format to follow to pass the warnings as per Wang and Zhang (2018). The data collection also found an emergency action plan as in Figure 4.9 which is used to follow after identifying any failure in the dams to make the warnings. Therefore, accordingly, the functional characteristics named forecasting and risk evaluation, Detection, and monitoring, warning and evacuation have contextualised the Sri Lankan EWS used for dam failures.

In addition to the functional characteristics data view, stakeholder/ institution view, communication view, and community view have been identified as the system views that support the functional characteristics of the EWS (Leonard et al., 2008; Zambrano et al., 2017; Hamza & Månsson, 2020; Rahayu et al., 2020). Despite those system views, the technology view was identified as another very important system view that supports the function of the EWS used for dam failures in Sri Lanka. Hence, the way of supporting those identified system views for the characteristics of the EWS was tabulated in Table 4.2.

5.4 A digital platform to support the EWS for the dam failures in Sri Lanka

During the data collection, it was confirmed that digitalised effective EWS is very essential for the dam failures in Sri Lanka to reduce the very bad impacts of the dam failures. However, findings further revealed the financial incapabilities of the Sri Lankan government are affected by the inapplicability of digital platforms for the EWS for dam failures in Sri Lanka. As explored by Klievink et al. (2016), a digital platform is an organised structure used for collaborative decision-making using technological trends. Research findings also revealed the same idea and identified the user requirements for the design of the digital platform for dam failure EWS. Accordingly, semi-structured interviews were used to identify the user requirements, and conducted focused group discussions to prioritise the identified user requirements. Accordingly, thirty-two (32) user requirements were prioritised. Clearly identify the user requirements, clearly define the inputs and the outputs, define fixed and variable data, speed of the platform, usage of natural language, increase generativity, maintain the security, including logins and logouts, and change the warning according to the level of risk, convenience and the ease of use are some of the features of the digital platform used to support the EWS of dam failures in Sri Lanka. Further, features have been presented in Figure 4.22.

The following framework in Figure 5.1 will be useful for the Sri Lankan government officers who are responsible for dam failures to minimise the impacts of dam failures. Accordingly, the framework illustrates the features and the key functional characteristics of an EWS that can be developed in a digital platform.

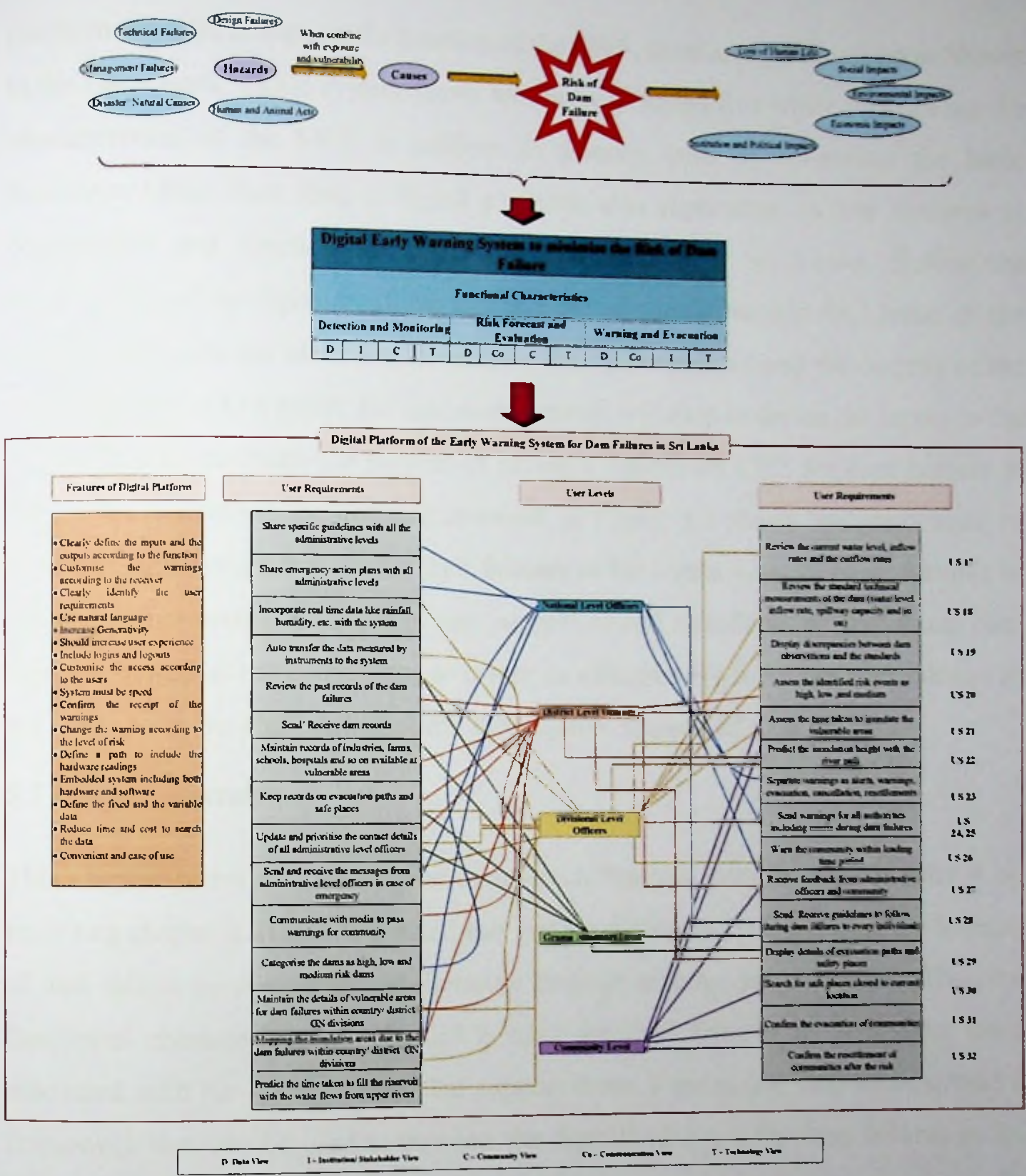

Figure 5.1: Framework to illustrate research findings

As shown in Figure 5.1, a digital platform can be used for an EWS of dam failures in Sri Lanka. Accordingly, if any dam is exposed to an identified cause of a dam failure, there is a high vulnerability for the dam failure and that will affect society, the environment, and the economy in relation to the surrounding of the dam. Therefore, the digital platform is the best solution for the EWS to minimise the negative effects of dam failure. However, in order to have an effective digital platform for the EWS, the identified functional characteristics (risk forecasting and evaluation, monitoring and detection, warning and evacuation) have to be incorporated into the digital platform. In order to support the function of the EWS, there are system views as Shown in the framework. Those system views will be very supportive while functioning the characteristics of the EWS to achieve its primary goal by enhancing the basic functions. Other than that, a digital platform also represents its key features to demonstrate and function the EWS for dam failures in Sri Lanka. Before the development of the digital platform for the EWS of dam failures in Sri Lanka, all the user requirements are identified to enhance the functionalities and the outputs of the digital platform. As a result, the user requirements will help to define the inputs to the system in order to create the success of having a digitalised EWS for dam failures in Sri Lanka. Therefore, the above framework in Figure 5.1 shows the importance of having a digitalised EWS for the dam failures in Sri Lanka with its basic features to enhance functionality. Hence, it is very supportive and beneficial for Sri Lankan dam officers as well as the community to create an effective EWS for the dam failures in Sri Lanka with the aim of minimising the negative impacts of dam failures.

5.5 Chapter summary

This chapter provided a discussion of research findings presented in Chapter 4 by revisiting chapter 3. Hence as the first sub-section discussed the causes and the impacts of dam failure by comparing the literature findings and the data collection. Then the functional characteristics of the EWS used for dam failures in Sri Lanka were discussed with the system views that support them. Finally, the chapter presented a framework that can be used to develop the digitalised EWS for dam failures in Sri Lanka.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter focused on drawing overall study conclusions based on the achievement of five objectives through the literature review, data analysis, and discussion in previous chapters. In addition, the study's contribution to knowledge and practice was highlighted in this chapter. Recommendations were made based on the findings of the entire study in order to contribute to dam safety mechanisms in Sri Lanka. Furthermore, the study's limitations were acknowledged, and future research areas were suggested to broaden the current study in all other associated directions.

6.2 Accomplishment of objectives

The aim of the study was to enhance the functional characteristics of a digital EWS to reduce the impacts of dam failures in Sri Lanka. The aim was accomplished by completing five major research objectives. The conclusions reached under each research objective are presented in detail below.

Objective 1: To identify the causes and impacts of risks associated with the dam failures in the global context and in Sri Lanka.

The objective was fulfilled through the main two subsections of the literature (sub-section 2.3.1 and sub-section 2.3.2) and the data collection (sub-section 4.2.1 and sub-section 4.2.2). Accordingly, global causes for the dam failures were presented in Figure 2.1, and causes that can be affected by Sri Lankan dam failures were presented in Figure 4.1.

However, in both cases, the causes were separated as internal causes and external causes. The internal causes were design, technical, and management failures whereas external causes were disasters/ natural causes and human acts. Even though the literature identified the external cause as human acts, it was modified as human and animal acts while it was discussed in the Sri Lankan context. In both global and the Sri

Lankan contexts the design failures are insufficient spillway capacity, extreme flood exceeding design criteria, and poor design. The technical failures caused for Sri Lankan dam failures are aging of the dam, piping, sliding of the dam, and quality issues (construction and material) in the dam. Other than those causes, the piping and the quality issues with the culverts were identified as technical causes affect for the dam failures globally. Poor management, poor layout planning, organisation issues, and poor operation and maintenance were explored as the management causes that affect the dam failures. The unclear responsibility for dam management which was identified as a separate global management failure was considered under the organisational issues during the interviews. In addition, volcanic activities, wildfire, and the snow which affected global dam failures were not affecting Sri Lanka as locally those natural causes are not highly impacted. Other than that wars and terrorist attacks were considered human actions under the external causes for dam failure. In addition, bad human behaviours and animal acts were considered in local dam failures.

Figure 2.2 and Figure 4.2 have been used to describe the impacts of the dam failures in the global context and Sri Lanka respectively. Accordingly, sub-section 2.3.2 and 4.2.2 were used to describe the dam failure impacts. The most significant impact of the dam failure is the loss of human life. Other than that there are economic, social, and environmental impacts. However, during data collection, the impacts for the Sri Lankan context were prioritised as loss of human life, social impacts, environmental, economic, and institution and political impacts under the sub-section 4.2.2.

<u>Objective 2: To explore the functional characteristics of EWSs used for dam failures in Sri Lanka</u>

Section 2.5 was separated for EWS and section 2.6 identified the functional characteristics of the EWS. Accordingly forecasting and risk evaluation, detection, and monitoring, emergency management structure including warning and evacuation, local dissemination, and public education were identified as the key functional characteristics of the EWS. However, according to the aim and the scope of this study only the first three characteristics were considered for the data collection stage. Therefore, sub-section 4.2.4 was used to identify the functional characteristics of the

EWS used for dam failures in Sri Lanka, and clearly, it is present in Figure 4.4. According to the analysis of the data, monitoring and detection are the first functions of the EWS used for dam failures in Sri Lanka, and by following that risk forecasting and warning are conducted. Currently, the functions are accomplished through a manual procedure followed by the dam officers in Sri Lanka.

Objective 3: To define a set of systems views that can be used to support the functional characteristics of an EWS

A set of system views that support the functions of the EWS was identified in the literature and discussed under section 2.7. Accordingly, data, communication, institution/stakeholder, and community views were identified as the supporting system views. However, during data collection, additional data was added to the literature findings and identified the technological view as additional view support for the functional characteristics. Accordingly. Those were discussed under the sub-section 4.2.5 by contextualising to Sri Lankan context. The way all the system views support the functional characteristics was tabulated in Table 4.2.

Objective 4: To capture user requirements of an effective EWS for dam failures in Sri Lanka

Objective 4 was fully accomplished through the primary data collection. The interviews were conducted according to the five-level in order to identify the user requirements and develop user story maps as described in the sub-section described in 3.5.7.2. Accordingly, all the identified user requirements were discussed under sub-section 4.2.6. the overall user requirements were displayed in Figure 4.20. Then after identifying all requirements were prioritised conducting focus group discussion. Hence, three selected users participated in the focus group discussion, and the findings have been analysed in section 4.3. All the user stories were categorised according to the "MoSCoW" classification which was described in sub-section 3.5.7.2. Finally, thirty-two (32) user stories were prioritised as "must have" requirements for the development of an effective EWS for the dam failures in Sri Lanka.

Objective 5: To define the features of a digital platform to enhance the functional characteristics of an EWS for dam failures in Sri Lanka

Objective five was achieved through the both literature review and the primary data collection. Hence, section 2.8 discussed the digital platforms, and sub-section 4.2.7 was used to discuss the primary data findings on the digital platform to enhance the functional characteristics of the EWS used for dam failures in Sri Lanka. Accordingly, the study found that the platform needs to be an embedded system where both software and hardware are incorporated to the accuracy of the outputs of the system. In addition, before designing the platform, the user requirements need to be clearly identified and the designing and the development of the platform will be based on the requirements. Speed of the platform, increase generativity, maintenance the security, use of natural language, convenience, and ease of use are some general features of the digitalised EWS and more characteristics of that have been presented in Figure 4.22.

6.3 Recommendations

The recommendations to enhance the functional characteristics of the EWS used for dam failures in Sri Lanka through the integration of digital technology are as below.

- **Consideration of identified causes and the impacts of the dam failures while developing the EWS for dam failures in Sri Lanka.**

The study presented a number of causes and the impacts of dam failures that affect Sri Lanka. Those causes and the impacts need to be thoroughly considered while developing the EWS for dam failures in Sri Lanka.

- **Consideration of user requirements of having a digitalised EWS for dam failures in Sri Lanka.**

The study has prioritised thirty-two (32) user stories according to the requirements of every level of the users of the EWS. Therefore, it is of utmost importance to consider the identified user stories while developing the digitalised EWS for dam failures in Sri Lanka.

- **Increase the investments in the digitally developed systems**

As a developing country, the financial allocation for these innovative systems is insufficient, which hinders researchers. As a result, it is advised to invest more in digitally enhanced dam safety systems, which may provide numerous benefits by reducing the risk.

- **Development of implementation plan**

Because of resource scarcity and network barriers, it is recommended that authorities pay close attention to ensuring the effective implementation of digital systems at the local level.

- **Improvement of the awareness**

The importance of digital integration for EWS of dam failures should be communicated to the community through awareness programs, and the community should be encouraged to use these digital systems to mitigate the impact of dam failures.

6.4 Contribution to knowledge

This study contributed to the knowledge primarily on the possibility of reducing the impacts of dam failures with the integration of digital technology for the EWS. In addition, the knowledge encapsulated in this study can be utilised to gather information about the following areas.

- Identifying the possible causes that affect the dam failures in Sri Lanka with their social, environmental, economic, institution, and political impacts.
- Understanding the major functional characteristics that need to be incorporated with the EWS used for the dam failures in Sri Lanka.
- Identify various system views that support the effective functioning of the dam failure EWS.
- Assess the user requirements for the development of digitalised EWS for dam failures in Sri Lanka

- Understand the features of the digital platform which can be used for the effectiveness of the EWS for the dam failures in Sri Lanka.

6.5 Contribution to practice

The end results of this study will be beneficial for the improvement of dam safety by reducing dam failures with the integration of digital technology. The following recommendations were prepared in accordance with the outcomes of this study.

- Measures can be taken to reduce the causes of the dam failures and the impacts of the dam failures.
- Development of digitalised EWS for the dam failures in Sri Lanka with the identified user requirements.
- Measures can be taken to improve the identified characteristics of the digital platform for the EWS of dam failures in Sri Lanka.

6.6 Further research directions

The following future research directions were proposed to extend the research further.

- Extend the research to develop the digital platform for EWS of dam failures in Sri Lanka using the identified features and the user requirements.
- Identify strategies to increase the involvement of digital technology for the EWS of dam failures in Sri Lanka.
- Assess the success of the digital platform for the EWS of dam failures among the dam safety officers in Sri Lanka.

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APPENDIX A: USER STORIES

User Story Number	US - 01
User Story (Card)	As a National level dam officer, I want to share the **emergency action plan** with all **administrative levels.** So that, officers will be able to behave properly after identifying the risks of dam failures
Conversation	**Emergency action plan** – The communication hierarchy which has to be followed after identifying the risk **Administrative levels** – All dam officers at the divisional, district, and the national level
Confirmation	Display in a general folder in which all levels of officers have the access to download.

User Story Number	US - 02
User Story (Card)	As a National level dam officer, I want to share **specific guidelines** with all **administrative level officers.** So that officers can operate and monitor the dams effectively during monsoon and rainy periods.
Conversation	**Specific guidelines** – The documents prepared include specifications and guidelines for the operations and the monitoring during the monsoon periods and other periods during the whole year **Administrative levels** – All dam officers at the divisional, district, and the national level Guidelines are displayed as pdf files and they can be edited by national-level officers by login in to the folder.
Confirmation	Display in a general folder in which all levels of officers have the access to download.

User Story Number	US – 03
User Story (Card)	As a divisional-level dam officer, I want to incorporate **real-time data**. So that officers will be able to easily coordinate the dam activities and identify the dam hazards.
Conversation	**Real-time data** – Rainfall details, wind speed, and the humidity levels
Confirmation	The user needs to select the type of data that he wants and select the area. Then the relevant data will appear.

User Story Number	US – 04
User Story (Card)	As a divisional-level dam officer, I want to auto-transfer the data measured by the instruments to the system. So, it will increase the accuracy of data and will easy to operate and monitor the dam.
Conversation	There are pressure gauges, and piezometers to measure the pressure and monitor the seepage line of the dam. If there is a mechanism to auto-transfer the data that will be more accurate than the eye readings of the technical staff as there can be small errors with the readings of different officers.
Confirmation	Users need to select the instrument and the data type, then the instrument reading will be displayed.

User Story Number	US – 05
User Story (Card)	As a district-level/ divisional-level dam officer/ Grama Niladhari, I need to review the past records of the dam failures. So, that I can predict the risks of future dam failures.
Conversation	The dam failure needs to describe under location, causes for the dam failure, and the impacts. Other than that, the details about the socio economic activities and the compensations have to be included.

Confirmation	Users need to select the name of the dam then it will be displayed all the details about the dam failure highlighting the causes and the impacts of the dam failure.

User Story Number	US – 06
User Story (Card)	As a district/ divisional level dam officer, I need to send and receive the dam records. So that officers can easily monitor the dam and identify the risks of the dam.
Conversation	Folders need to be created separately for each dam. Offiecrs need to select the district, and division. Then enter the name of the dam. Divisional officers will edit the details.
Confirmation	A notification has to send to the divisional level officers if the weekly reports are not submitted.

User Story Number	US – 07
User Story (Card)	As a district-level dam officer/ Grama Nildhari, I need to maintain the records of industries, farms, hospitals, schools, and so on. So that others will review the details and will manage the efficiency and effectiveness of the warnings.
Conversation	The detailed list has to be separated into the district, division, and Grama Niladhari levels. The editing access has to be given to each divisional level dam officer. Industries – Owner's name, contact number, number of workers, area of the land, location Farms – Owner's name and contact number, area of the land, Type of farm (cultivation or animal farm), location Hospital – Contact number, area of the land, location, number of staff members

	Schools – Contact number, area, location, number of staff members and the students
Confirmation	Users need to select the particular administrative level and select the option to edit the details. The user needs to log in for the editing and enter the relevant details. (user can only edit his area and can only review the other's areas)

User Story Number	US – 08
User Story (Card)	As a district/ divisional level dam officer/ Grama Niladhari, I need to keep records on evacuation paths and safe places. So that it can be used in an emergency case.
Conversation	All details should be able to review Accessible for all the registered users Separate according to the district, division, and the Grama Niladhari level
Confirmation	When the user enters the district, division, and Grama Niladhari sector from a drop-down button, the details about the available evacuation paths and the safety places appear.

User Story Number	US – 09
User Story (Card)	As a district/ divisional dam officer/ Grama Niladhari, I need to update and review the contact details of all administrative-level officers. So that it will easily maintain the communication linkages.
Conversation	Contact details – Name, District, Division, Grama Niladhari division, Names of the in-charge dams, contact number (mobile and landline), Position Can be reviewed by all the users

	Only the relevant officers can update the details by login entering the user name and the password. Others can review the details.
Confirmation	Users can select the relevant officer using the administrative level and the designation. Then the details should appear.

User Story Number	US – 10
User Story (Card)	As a district/ divisional dam officer/ Grama Niladhari, I need to prioritise the contact details of all administrative-level officers. So that it will enhance the awareness of dam failures.
Conversation	Prioritising – Grama Niladhari division, divisional, district, and the national level
Confirmation	Users can select the name of the dam under the contact details, then all relevant details will be displayed from the ground level to the top of the hierarchy.

User Story Number	US – 11
User Story (Card)	As a national/ district/ divisional level dam officer, I need to send and receive messages from the administrative officers in case of emergency.
Conversation	All administrative level officers can view the messages and only responsible persons can log in and respond to the messages received.
Confirmation	Having separate colour codings to indicate whether the messages have been send, received, read, and reply.

User Story Number	US – 12
User Story (Card)	As a district-level dam officer, I need to make communication with the media. So, that warning can be effectively passed to the community.

Conversation	Access is only given to the responsible officers and has to aware the media about the level of risks associated with the dams.
Confirmation	Users can define whether the messages have received the risk details of the dams.

User Story Number	US – 13
User Story (Card)	As a national-level dam officer, I need to categorise the dams as high, low, and medium risks dams. So, that it will be easy to allocate finance for the maintenance activities and to prioritise the dams according to the level of awareness.
Conversation	All the users can review the risk level of the dams and only the national level officers can prioritise the dams by comparing all the dams.
Confirmation	While prioritising dams for funds and instrument allocations users can search the risk level of dams. Then the dam list will be appeared by separating as high, medium, and low-risk dams.

User Story Number	US – 14
User Story (Card)	As a district/ divisional level dam officer/ community member, I need to review the details of vulnerable areas under the district, divisional, and Grama Niladhari levels. So that can easily identify the risk.
Conversation	All the users need to review the vulnerable areas and only responsible officers can log in and update the details. Vulnerable areas have to be highlighted using colour codes as high, medium, and low.
Confirmation	Users can select the district and the division by a drop-down button and select the name of the dam. Then the user will be

	able to review the vulnerable areas on a map with different colour codes for the level of vulnerability (high, medium, low)

User Story Number	US – 15
User Story (Card)	As a national/ district/ divisional level dam officer, I need to map the inundation areas to easily identify the areas affected by the dam failure.
Conversation	All users need to review the inundation areas due to the dam failure.
Confirmation	Users can select the district and the division by a drop-down button and select the name of the dam. Then the user will be able to review the inundation areas on a map

User Story Number	US – 16
User Story (Card)	As a divisional level dam officer, I need to predict the time taken to fill the reservoir from the water from the upper flows to forecast the risk of dam failure.
Conversation	All administrative level dam officers can view the details while dam in charge officers log in and update the system.
Confirmation	Users can select the district and the division by a drop-down button and select the name of the dam. Then they will be able to review the rate of water filling into the reservoir and can forecast the risks.

User Story Number	US – 17
User Story (Card)	As a divisional-level dam officer, I need to review the current water level, inflow rates, and outflow rates of water to predict the risks of dam failures.

Conversation	All administrative level dam officers can view the details while dam in charge officers log in and update the system.
Confirmation	Users can select the district and the division by a drop-down button and select the name of the dam. Then they will be able to review the water levels, inflow rates, and outflow rates to forecast the risks.

User Story Number	US – 18
User Story (Card)	As a divisional-level dam officer, I need to review the **standard technical measurements** of the dam to monitor the functions of the dam.
Conversation	Standard technical measurements – water level (full supply level, high flood level), inflow rates, outflow rates, spillway capacity, and so on. All the users can review the details
Confirmation	Users can select the district and the division by a drop-down button and select the name of the dam. Then the system displays all the standard technical details of the dam.

User Story Number	US – 19
User Story (Card)	As a divisional-level dam officer, I need to review the discrepancies between the dam observations and the standard technical measurements. So that officers can easily identify the dam risks.
Conversation	All administrative level dam officers can review the details. The differences have to be shown on graphs to compare the observations and the standard measurements.
Confirmation	Users can select the district and the division by a drop-down button and select the name of the dam. Then the discrepancies

	will be shown as numerical values and as figures to clearly illustrate the comparison.

User Story Number	US – 20
User Story (Card)	As a district/ divisional dam officer, I need to assess the identified risk as high, low, and medium. So that the warning style can be changed accordingly.
Conversation	The cut-off values for the separation of high, low, and medium risks with the technical measurements have to be incorporated into the system. Then the system will categorise the risk accordingly. All the users will be able to review the details.
Confirmation	If any dam is at a high risk a notification should be displayed as soon as possible. Other than that, users can select the district and the division by a drop-down button and select the name of the dam. Then the system will display the risk level with the analysis.

User Story Number	US – 21
User Story (Card)	As a district/ divisional level dam officer/ community member, I need to assess the time taken to inundate the vulnerable areas. So that, an evacuation order can be given to the community explaining the due time.
Conversation	All the users can review the results. Only the responsible officers can update the details by logging in to the system and entering the user name and password. The inundation map has to be updated by including the time taken to inundate.

Confirmation	Users can select the district, division, and the Grama Niladhari division by a drop-down button and select the dam. Then by selecting the inundations can review the inundation areas with the time indications. The details can be represented on the inundation map.

User Story Number	US – 22
User Story (Card)	As a district/ divisional level dam officer/ community member, I need to predict the inundation height with the river path. So that, it can be used while making evacuation orders for the communities.
Conversation	The details can be reviewed by all users. The inundation heights should be separately marked on the inundation map.
Confirmation	Users can select the district, division, and the Grama Niladhari division by a drop-down button and select the dam. Then by selecting the inundations, users will be able to review the inundation heights on the map.

User Story Number	US – 23
User Story (Card)	As a national-level dam officer, I need to separate the warning as alert, warning, evacuation, cancellation and the resettlement. So that, it will enhance the awareness about the dam failure.
Conversation	Separate alarm methods or notifications need to be prepared to classify the warnings and public need to aware what alarm is stand for warning methods.
Confirmation	Different alarm systems have to be defined to separate the warning methods. After analysing the risks of the dam, a

	warning notification will appear. Then the user can make the warning accordingly.

User Story Number	US – 24
User Story (Card)	As a national-level dam officer, I need to send warnings to **all authorities** to get help to reduce the risk of dam failure.
Conversation	All authorities – Irrigation, Mahaweli, Police station, Army, Disaster Management Center, CEB, Water Board, Railway Stations, and so on.
Confirmation	After assessing the risk as high, low, and medium as in US 20, users can select the warning type and then select the authorities. Therefore, according to the level of risk, the user can warn the authorities to take their support to reduce the impacts of damfailures.

User Story Number	US – 25
User Story (Card)	As a district-level dam officer, I need to send warnings to media. So that, the communities can be easily aware about the dam's failure.
Conversation	Warning types need to be informed to the media to increase public awareness. Media can be informed through an auto-generated message including the dam name and the vulnerable areas.
Confirmation	While making the warning types for the communities, the description needs to be sent as a message to the media, including the warning type, dam name, and the vulnerable areas.

User Story Number	US – 26
User Story (Card)	As a divisional level dam officer, I need to warn the community within a leading time. So that community can reduce the impacts of dam failure.
Conversation	After identifying the time taken to inundate the areas as in US 21, the warning has to be passed to the communities and other authorities.
Confirmation	The user has to make the warning soon after predicting the time taken to inundate the areas. Users can select the district and the division by a drop-down option and enter the name of the dam. Then select the vulnerable area and make the warning by selecting the warning type. A special alarm needs to be played if the warned time is lesser than the time taken to inundate that area.

User Story Number	US – 27
User Story (Card)	As national-level, district-level dam officers/ community, I need to have the feedback to revise the following warnings and the guidelines.
Conversation	The feedback of the officers and community members should be received.
Confirmation	Users need to fill out the feedback sheet by mentioning the guidelines and the warning methods.

User Story Number	US – 28
User Story (Card)	As a national-level dam/ Grama Niladhari, I need to send and as a community member, I need to receive the guidelines to follow during the dam failures. So that, it can enhance awareness.
Conversation	The pdf is uploaded and can review by all the users.

Confirmation	Users can select the guideline and download/ upload the pdf document to follow during the dam failure.

User Story Number	US – 29
User Story (Card)	As district/ Grama Niladhari, I need to update the details of evacuation routes and the safest places to use in case of a dam failure.
Conversation	Details need to be separated according to the district, divisional, and Grama Niladhari levels. Can map the evacuation routes.
Confirmation	Users can log in to the system and have the edit option under the dams and enter the detail of the category of evacuation routes.

User Story Number	US – 30
User Story (Card)	As a community member, I need to search the closed evacuation route and for a safer place by entering the location. So that, the community can effectively evacuate.
Conversation	The location can be displayed on a map.
Confirmation	Users have to enter their current location and select the evacuation route and safer place option. Then the path will be shown on the map.

User Story Number	US – 31
User Story (Card)	As a community member, I need to confirm that I have evacuated to a safer place to reduce the impacts of dam failure.
Conversation	The map needs to be updated based on their permanent address.

Confirmation	Users have to enter and search their permanent address on the map which displayed the vulnerable areas and put on tik on the "evacuated" option.

User Story Number	US – 32
User Story (Card)	As a community member, I need to confirm that I have resettled after the dam failure to inform I have left safe with the dam failure.
Conversation	The map needs to be updated based on their permanent address.
Confirmation	Users have to enter and search their permanent address on the map which displayed the vulnerable areas and put on tik on the "resettled" option.

APPENDIX B: STAKEHOLDER INTERVIEW GUIDELINE

Lichini Nikesha,
Postgraduate,
Department of Building Economics,
University of Moratuwa.
Date

Dear Sir,

<u>Conducting an Interview for M.Sc. (Major Component by Research)</u>

I am a postgraduate student undertaking a Master of Science (major component by Research) degree programme at the Department of Building Economics, University of Moratuwa. In order to fulfill the requirements of the degree, I am required to conduct research and produce a thesis under the supervision of the Dr. M. Thayaparan and Prof. T. Fernando.

The topic of my research is "Characteristics of a Digital Platform for Supporting an Early Warning System for Dam Breaks in Sri Lanka". The aim and objective of the research are;

Aim – to enhance the functional characteristics of an early warning system that can be used for dam breaks in Sri Lanka

Objectives,

1. To identify the causes and impacts of risks associated with the dam breaks in the global context and in Sri Lanka.
2. To explore the functional characteristics of early warning systems used for dam breaks in Sri Lanka
3. To define a set of systems views that can be used to support the functional characteristics of an early warning system.
4. To capture user requirements for an effective early warning system for dam breaks in Sri Lanka
5. To define the features of a digital platform to enhance the functional characteristics of an early warning system for dam breaks in Sri Lanka.

To achieve the objectives of my research I intend to conduct semi-structured qualitative interviews with key stakeholders who have sufficient knowledge, expertise and experience related to dam construction and dam breaks. In this regard, you have been identified as one of the potential participants who could contribute by providing valuable information for this research.

Therefore, I would like to invite you to take part in an interview, which will be conducted either physically or virtually (depending on your convenience). The interview will last for no more than an hour. The interview guidelines will be shared in advance. The medium of collecting data will be note-taking and audio recording (with the permission of the interviewee) in order to collect data more accurately. I assure you that the information collected will be purely used for the research purpose, and the confidentiality of the details will be strictly maintained.

Thank for agreeing to take part in the interview. The interview guidelines are attached herewith for your perusal.

Thank you.
Yours faithfully,
Lichini Nikesha
Postgraduate,
Department of Building Economics,
University of Moratuwa
Email: lichininikesha@gmail.com
Tel: +9471 271 5956

Section 1: General Information

Name of the respondent (optional) : ....

Name of the organization (optional) : ....

Designation : ....

Years of experience : ....

Section 2: Causes and Impacts of Dam Break

Answer the following questions based on your knowledge, expertise, and experience. Provide specific examples/experience sharing where possible.

01. The internal and external causes of the dam breaks based on the literature findings are given below. Can you validate the findings, both causes, and categories, considering the context in Sri Lanka?

Main Category	Subcategory	Causes	Remarks
Internal Causes	Design	Insufficient spillway capacity	
		Extreme flood exceeding design criteria,	
		poor design	
	Technical	Aging of dam	
		Piping in dam, Sliding of dam	
		Piping in foundation, Piping around spillway	
		Quality issues in spillway	
		Piping around culverts and other embedded structures	
		Quality issues with culverts and other embedded structure	
		Spillway blockage due to bank slide in reservoir	

	Management	Poor management	
		Poor layout planning	
		Organisation issue	
		Unclear responsibility for dam management	
		Poor maintenance and operation	
External Causes	Disasters/ natural causes	Floods	
		Earthquakes	
		Landslides	
		Strong winds	
		Volcanic activity	
		Wildfire	
		Snow	
	Human Actions	Wars	
		Terrorists attacks	

02. The impacts created by dam breaks (based on literature findings) are given below. Can you validate and elaborate on the impacts in the context of Sri Lanka?

Category	Impact	Remarks
Direct Economic Impacts	Agricultural losses	
	Industrial losses	
	Commercial losses	
	Infrastructure damages	
	Damages to buildings, machinery, equipment, and other fixed assets	
	If any, please specify…	
Indirect Economic Impacts	Expenses on flood management efforts	
	Losses due to reductions of industrial and factory products	
	Cost of socioeconomic activities	
	If any, please specify…	
Social Impacts	Damages to human physical and mental health	
	Decrease the quality of daily life	
	Damages to cultural properties, arts and treasures, rare animals and plants	

	Harmful political effects	
	If any, please specify...	
Environmental Impacts	Effects on living creatures and habitats	
	Cultural landscapes	
	Pollution	
	If any, please specify...	

Section 3: Early Warning System for Dam Break

03. Are you aware of any mechanisms that are currently used as an early warning system to reduce the impacts of dam breaks in Sri Lanka?

a) If yes, elaborate on the nature of the system and its effectiveness.

....

....

b) If No,

b.1) What could be the procedure to be followed during a dam break to minimise the impacts in Sri Lanka?

....

....

b.2) Do you recommend an early warning system to reduce the risk of dam breaks in Sri Lanka? Please elaborate why?

....

....

04. The following list provides the functional characteristics of an early warning system, based on the literature. Can you contextualise these characteristics for dam breaks in Sri Lanka?

(i)Hazard identification, risk assessment, and vulnerability analysis (forecasting and risk evaluation), ii) Detection and monitoring, iii) Emergency management structure, including warning and evacuation ~~iv) Local dissemination, v) Public education~~ (Include within the Scope (i) to (iii))

Functional Characteristic		**Remarks**
Forecast and Evaluation	Hazard identification	
	Risk assessment	
	Vulnerability analysis	
Monitoring	Detection	
	Monitoring	
	Maintenance	
Response	Warning	
	Evacuation	

05. Can you define the views of the system to support the functional characteristics of the dam break identified in question 4.

Views / **Characteristics**	**Data**	**Communication**	**Stakeholder/ Institutional**	**Community**	**Technology**	**If any other, please specify**	
Hazard identification							
Risk assessment							
Vulnerability analysis							
Detection							
Monitoring							
Maintenance							
Warning							
Evacuation							

Section 4: Capture User Requirements

06. What are the tasks and potential benefits that you are expecting for effective early warning systems? You can answer with reference to your job role.

Tasks	Benefit	Non-functional requirement

Section 5: Digital platform for Early Warning Systems

07. Are you aware of the digital platforms and how do you define a digital platform?

....

....

08. What is your opinion (in terms of benefits and risks) on the usage of the digital platform for early warning systems used in Sri Lanka for dam breaks?

....

....

09. Can you explain the features of the digital platform if we want to use it to enhance the functional characteristics of the EWS for dam failures?

....

....

I would like to thank you for the information given and the time you have dedicated to this research. If you are interested to know the outcomes of this research, it would be my pleasure to share it with you.

APPENDIX C: STAKEHOLDER INTERVIEW TRANSCRIPT

Lichini Nikesha,
Postgraduate,
Department of Building Economics,
University of Moratuwa.
Date

Dear Sir,

<u>Conducting an Interview for M.Sc. (Major Component by Research)</u>

I am a postgraduate student undertaking a Master of Science (major component by Research) degree programme at the Department of Building Economics, University of Moratuwa. In order to fulfill the requirements of the degree, I am required to conduct research and produce a thesis under the supervision of the Dr. M. Thayaparan and Prof. T. Fernando.

The topic of my research is "Characteristics of a Digital Platform for Supporting an Early Warning System for Dam Breaks in Sri Lanka". The aim and objective of the research are;

Aim – to enhance the functional characteristics of an early warning system that can be used for dam breaks in Sri Lanka

Objectives,

1. To identify the causes and impacts of risks associated with the dam breaks in the global context and in Sri Lanka.
2. To explore the functional characteristics of early warning systems used for dam breaks in Sri Lanka
3. To define a set of systems views that can be used to support the functional characteristics of an early warning system.
4. To capture user requirements for an effective early warning system for dam breaks in Sri Lanka
5. To define the features of a digital platform to enhance the functional characteristics of an early warning system for dam breaks in Sri Lanka.

To achieve the objectives of my research I intend to conduct semi-structured qualitative interviews with key stakeholders who have sufficient knowledge, expertise and experience related to dam construction and dam breaks. In this regard, you have been identified as one of the potential participants who could contribute by providing valuable information for this research.

Therefore, I would like to invite you to take part in an interview, which will be conducted either physically or virtually (depending on your convenience). The interview will last for no more than an hour. The interview guidelines will be shared in advance. The medium of collecting data will be note-taking and audio recording (with the permission of the interviewee) in order to collect data more accurately. I assure you that the information collected will be purely used for research purpose, and the confidentiality of the details will be strictly maintained.

Thank for agreeing to take part in the interview. The interview guidelines are attached herewith for your perusal.

Thank you.
Yours faithfully,
Lichini Nikesha
Postgraduate,
Department of Building Economics,
University of Moratuwa
Email: lichininikesha@gmail.com
Tel: +9471 271 5956

Name of the respondent (optional) :

Name of the organization (optional) :

Designation :

Years of experience :

Section 2: Causes and Impacts of Dam Break

Answer the following questions based on your knowledge, expertise, and experience. Provide specific examples / experience sharing where possible.

01. The internal and external causes of the dam breaks based on the literature findings are given below. Can you validate the findings, both causes and categories, considering the context in Sri Lanka?

Main Category	Subcategory	Causes	Remarks
Internal Causes	Design	Insufficient spillway capacity	*Yes, this occurred in Sri Lanka*
		Extreme flood exceeding design criteria,	*theoretically, this is ok. But I think there may not be such cases reported in Sri Lanka. There may be no cases that have proved incoming floods exceed the design. For other countries, this can be.*
		poor design	*This is the major reason for breaking small dams. Insufficient spillways are also covered with poor design. The designer has to foresee all the climate changes and all other*

			areas while making the design.
	Technical	Aging of dam	*Yes*
		Piping through the dam, Sliding of the dam	*Seepage is water particles that go through the dam body, with the seepage water dam materials (soil particles) moving away. That is piping (internal erosion). So, it is a major cause of dam failures.*
		Piping in the foundation, Piping around spillway	*yes*
		Quality issues in spillway	*various types of spillways are available and they are selected based on their geographical features. The selected type may not be suitable for the dam location.*
		Piping around culverts and other embedded structures	*Piping around the sluice may cause, there to be no culverts embedded with the dam body. Sluice is the structure constructed to get the water out for irrigation, drinking, and others.*
		Quality issues with culverts and other embedded structure	*There may not be culverts across the dams in Sri Lanka.*
		Spillway blockage due to bank slide in reservoir	*this can be a reason*
	Management	Poor management	*this is affecting*
		Poor layout planning	*This not comes under the management, goes to the technical cause*
		Organisation issue	*yes*

		Unclear responsibility for dam management	*can be accepted*
		Poor maintenance and operation	*This may be the main reason and should come at first under management.*
External Causes	Disasters/ Natural causes	Floods	*unexcepted floods exceeding the design may cause dam failures*
		Earthquakes	*major reason not in Sri Lanka but in Japan, Australia*
		Landslides	*Can be*
		Strong winds	*Can be with the breaking of trees*
		Volcanic activity	*Not affected to Sri Lanka*
		Wildfire	*Not affected to Sri Lanka*
		Snow	*snow melting caused temperature changes and make dam failures mostly in many countries (Canada) but not in Sri Lanka. Unexpected inflows to the dam.*
	Human Actions	Wars	*Affected*
		Terrorists attacks	*affected*

02. The impacts created by dam breaks (based on literature findings) are given below. Can you validate and elaborate the impacts in the context of Sri Lanka?

Category	Impact	Remarks
	Agricultural losses	*Production losses in agriculture. When a dam breaks water availability for*

Direct Economic Impacts		*agriculture is under threat as unable to supply water downstream*
	Industrial losses	*Industries that depend on the water supplied by the dam are at risk*
	Commercial losses	*Yes*
	Infrastructure damages	*Downstream roads and all structures are a treat*
	Damages to buildings, machinery, equipment, and other fixed assets	*Yes*
	If any, please specify…	*Livestock losses. Live losses (This is the main impact). Kanthale dam failure has caused to death of more than 300 people and damage to more farmlands and buildings*
Indirect Economic Impacts	Expenses on flood management efforts	*Yes, impacted*
	Losses due to reductions of industrial and factory products	*This may be covered also through the direct impact*
	Cost of socioeconomic activities	*Yes*
	If any, please specify…	*Students will be unable to go to school*
		There may be transport issues due to the damages caused for roads and railways
Social Impacts	Damages to human physical and mental health	*Yes*
	Decrease the quality of daily life	*Yes*
	Damages to cultural properties, arts and treasures, rare animals and plants	*affect for religious activities (In Kanthale dam failure a church has destroyed)*
	Harmful political effects	*May be*
	If any, please specify…	
Environmental Impacts	Effects on living creatures and habitats	*Yes*
	Cultural landscapes	*Yes*
	Pollution	*Yes*
	If any, please specify…	*Can affect fauna (animals) and flora (plants), endemic plants and animals may be destroyed*

Section 3: Early Warning System for Dam Break

03. Are you aware of any mechanisms that are currently used as an early warning system to reduce the impacts of dam breaks in Sri Lanka?

b) If yes, elaborate the nature of the system and its effectiveness.

There is no dedicated platform, but there is a manual government system. There is an authority to manage the dams. In addition, an Engineer is in charge to monitor the dam with changes associated with the dam. In Kanthale scenario also there was a warning before 3 or 4 hours but that time was not enough to evacuate all the people. And also at that time, it took much time to pass a warning.

In Sri Lanka, there is a manual system to make early warnings but there are no developed platforms. However, all major dams are monitored. But there may not be sophisticated systems for small dams.

The Engineer in charge of the dam can identify whether there are any signs of failure like slagging, or crackings. For example, the Engineer in charge of the Minneriya dam has identified some changes in the dam and has removed the downstream people to reduce the impact of the dam failure. However, that failure was not caused due to some reason making the precautions to rearrange the dam. And also there is a mechanism to pass the messages to the downstream people.

b) If No,

b.1) What could be the procedure to be followed during a dam break to minimise the impacts in Sri Lanka?

....

....

....

b.2) Do you recommend an early warning system to reduce the risk of dam breaks in Sri Lanka? Please elaborate why?

....

....

....

04. The following list provides the functional characteristics of an early warning system, based on the literature. Can you contextualise these characteristics for dam breaks in Sri Lanka?

(i)Hazard identification, risk assessment, and vulnerability analysis (forecasting and risk evaluation), ii) Detection and monitoring, iii) Emergency management structure, including warning and evacuation ~~iv) Local dissemination, v) Public education~~ (Include within the Scope (i) to (iii))

Functional Characteristic		**Remarks**
Forecast and Evaluation	Hazard identification	*There are instruments and monitoring procedures to identify the hazards (there are pressure gauges to measure the pressure, and the technical staff know what the limits of the static pressures are, if there is a change they know that there is some issue), Verticality of the dam is measured. If the dam shifted above the limit there is a issue. Likewise, there are procedures and instruments to check the risk. It is done by technical and Engineering staff with the dam experience. There are trained labours to monitor the features of the dam and it inform to the Engineer.*
	Risk assessment Vulnerability analysis	*There are computer models and methods to assess the risk. There are various modes to cause the dam failures with the identified features. Then identify what areas are affected with the dam failure. Have identified the different modes of breaking the Minneriya dam and have identified from the studies what areas may be effected, how much time taken to inundate the areas.*

		Have methods to identify the agricultures, villages, schools, industries which will affect by the dam failure.
Monitoring	Detection	*Through the instruments as early described the dam operations are monitored. However, if there is an abnormal change in the standard measurements dam officers quickly detect it and take immediate precautions as per the standing orders provided.*
	Monitoring	
Response	Warning	*When the risk is low, give the alerts, and if the risk is high warn the community through loudspeakers and other community members. If the situation is serious make evacuation orders to move to a safer place.*
	Evacuation	

05. Can you define the systems views to support the functional characteristics of dam break EWS identified in question 4.

Views / **Characteristics**	**Data**	**Communication**	**Stakeholder**	**Community**	**Technology**	**Institutional**	**If any other, please**	
Hazard identification	*Technical details of the reservoir (volume, height, full*	*Through phone call, letter, email*	*Should communicate to the decision makers at irrigati*	.	*Analysis software, GIS software. Softwares specifie*	*Technical details of the reservoir (volume, height, full*		

	capacity, dam breach section) What is the failure Downstream canal volumes		*on or Mahaweli*		*d for dam breaks*	*capacity, dam breach section) What is the failure Downstream canal volumes*		
Risk assessment	*Need to know about the hazard, what are the exposure of the elements for that, level of exposure, what are their vulnerability with the characteristics*	*Maps, report, table*	*The owner does the risk assessment. Dam size and nature differ the stakeholder. Dams are interconnected to each other*	*Know who are the downstream people*	*Software to do the risk assessment, drawn technology. GIS*	*Need to know about the hazard, what are the exposure of the elements for that, level of exposure, what are their vulnerability with the characteristics*	*Maps, report, table*	
Vulnerability analysis	*Similar to the risk assessment*							
Detection		*According to the level of risk, commun*	*According to the level, stakeho*		*Equipment to detect the hazards*			
Monitoring								

		ication differ	*lders differ*					
Warnin g **Evacuat ion**	*The details of the adminis trative officers and the level of the risk*	*Very importa nt to pass the warning s and the alerts*	*Need help from various instituti ons to pass the warnin g to mitigate the risk*		*Various technol ogies like phone calls, sms, and announ cments are used to pass the warnin g by informi ng about the risk*			

Section 4: Capture User Requirements

06. What are the tasks and potential benefits that you are expecting for effective early warning systems? You can answer with reference to your job role.

Tasks	Benefit	Non-functional requirement
Communicating the risk to the vulnerable communities	*Minimize the loss and damage*	*Can have feedback to identify how they safe*
Communicating the risk to the relevant stakeholders of infrastructuters	*Minimize the loss and damage*	*Can have feedback to identify how they safe*
Should maintain the contact details of administrative officers	*Can easily make preparations for the dam failure by*	

	making good collaboration	
Better to indicate the guidelines and emergency actions plans	*Easy for the officers during the operations and the maintenance*	

Section 5: Digital platform for Early Warning Systems

07. What is your opinion (in terms of benefits and risks) on the usage of the digital platform for early warning systems used in Sri Lanka for dam breaks?

It is good. Through EWS Can effectively communicate, can increase the lead time and accuracy also will be high. Therefore, it is an essential requirement for a country like Sri Lanka.

08. Can you explain the features of the digital platform if we want to use it to enhance the functional characteristics of the EWS for dam failures?

While developing the platform it is necessary to identify the user requirements of having such digitalised system. Then after that, all the inputs and the outputs are defined. Then after, all the inputs are processed to get the outputs by making the user requirements a success. In this case, there is software as well as hardware to enhance the characteristics. So that this is an embedded system that consists of both hardware and software. Then after should maintain the security of the system by making the user name and the password. And also as there are different levels of users the system needs to be customized accordingly. Furtehr, it has to be used in a natural language as all the users need to understand the functionality of the system. In addition, to improve the characteristics of the EWS the dam observations through instruments need to be incorporated to the sytem. As a result, there needs to be a method to incorporate instrument readings into the system. Data need to be classified as fixed data and variable data. fixed data are the data that are not changed with time such as past records, and standard details while variable data changed from time to time like rainfall details, inflow rates, and so *on. Then the system will be comparing the variable data with the past records and will forecast future records about the dam failure. The platform needs to be speedy. The system has to be loaded within two or three seconds in order to increase the effectiveness of the system. In addition, it should be user-friendly. The platform has to be established in a way to increase the user experience while reducing the issues". It is not effective to display only the rainfall, need to describe it as low risk or high risk. Therefore, not effective to display the raw data, need to interpret the data for the consumers.*

I would like to thank you for the information given and the time you have dedicated to this research. If you are interested to know the outcomes of this research, it would be my pleasure to share it with you.