

**SYSTEMS APPROACH TO IMPROVE DISASTER
PREPAREDNESS BASED ON CASE STUDIES**

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Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

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Thesis submitted in partial fulfilment of the requirements for the degree
Master of Science in Civil Engineering

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DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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ABSTRACT

Systems approach to improve disaster preparedness based on case studies

Preparedness planning for a disaster is an essential component in the process of the Disaster Risk Reduction (DRR), which is adhered by many disaster management professionals and authorities globally and locally. There, the question rises 'up to which extent of the disaster should the preparedness planning be done?'. To answer this question, knowledge on the extent of the disaster and its impact should be quantitatively established. When the impacts are considered, there will be impacts which have affected different components of given systems, due to the interrelations that exist within systems and its subcomponents. The spreading of impacts from one system to another due to these interrelations are called as the cascading effect. To identify the cascades and the components of systems, Emergency Operations Procedures (EOPs) and resilience frameworks are used in this study, and to quantify the cascade relationships as a proof of concept, a case study is used.

The chosen case study area is Kaduwela Divisional Secretariat Division (DSD), for the 2016, 2017 and 2018 floods. Kaduwela DSD was severally hit by all three events, as Kelani river is running by the boundary of the DSD. For these floods, data on flood impact such as the number of affected people, establishment of relief camps, supply of food and dry rations and payment of compensation were gathered, as well as the data on flood hazard extent and the exposure such as flood extent maps, elevation maps of the Kaduwela area and the building footprint were gathered. Preliminary interpretations of the data revealed patterns and relationships that define the human behaviour after a flood, and more importantly, the rationales behind initiating the relief requirements were understood, along with the monetary requirements to satisfy those requirements.

Furthermore, mathematical analyses were carried out to identify the regression relationships which predicted the human movement from the flood characteristics in a disaster. The tests were conducted on comparing the Pearson correlations and the multi criteria analysis, between the dependant and independent variables. The analyses revealed that there was more than one model to capture the effects to the humans having various inputs representing the flood characteristics. Therefore, all of the possible models were evaluated, by comparing the results from the models with the original data from the case study. By this, the best model to estimate the number of affected people and families was chosen and it was used as the quantifying relationship from flood characteristics to the human movement.

The aforementioned mathematical relationships are then summarised in to the overall cascading effect diagram, which made the cascade diagram a cascade model. This cascade model is having the flood inundation area as the input parameter which is a flood characteristic. Therefore, now this quantified cascade model could be used to identify the number of people and houses affected, number of relief camps formed, expected costs of number of required facilities, number of security officials and healthcare officials required per relief camp, number of cooked food parcels, dry ration parcels and relief items required and the costs for those which are the output parameters of the cascade model. Furthermore, the model consists with the relationships to estimate the amounts for compensations for building structural and content damage in a disaster.

Keywords: Quantifying flood damages, Cascading effect, Inundation area, Compensations, Damage prediction,

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LIST OF ABBREVIATIONS

AFCOMP	Affected Families from Computation
AFCORR	Affected Families from Correlation
APCOMP	Affected Population from Computation
APCORR	Affected Population from Correlation
CI	Critical Infrastructure
CLD	Causal Loop Diagrams
CRF	Community Resilience Framework
CRIP	Climate Resilience Improvement Project
DEM	Digital Elevation Mapping
DM	Disaster Management
DMC	Disaster Management Centre
DRR	Disaster Risk Reduction
DS	Divisional Secretariat
EOP	Emergency Operation Procedure
FES	Flood resilience supportive Eco-System Service-delivery
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GND	Grama-Niladhari Division
GN	Grama-Niladhari
GO	Government Organisation
LiDAR	Light Detection and Ranging
MCDA	Multi-Criteria Decision Analyses

MDG	Millennium Development Goals
SD	System Dynamics
SDG	Sustainable Development Goals
SMEs	Small and Medium Enterprises
UDA	Urban Development Authority

1. INTRODUCTION TO THE STUDY

The starting chapter of the thesis will give an introduction to the background of the study, how the research questions is formed, its aims and objectives and how the methodology was decided in order to achieve the objective of the study. Furthermore, this chapter will include a detailed structure of this thesis, explaining the content of each chapter. This chapter starts with identifying the research gap which led to this study.

1.1 Problem identification

It is a common phenomenon that many disasters are happening all over the globe which cause a massive loss of life, property damage and breakage of many systems incorporated within a comprehensive unit of systems. This comprehensive unit of a system often refers to a city or a community [1]. If a community is considered, there are many systems and infrastructure that supports the day to day activities of humans, and these systems are interdependent in most cases. Therefore, halting one system due to a natural or man-made cause will weaken the connected systems, which will lead to a loss of performance in the whole system.

The above stated set of scenarios are seen as a series of cascading events, in many studies [1]–[4]. And these occurrences can be discussed with the concept of resilience. The term resilience refers to the ability of a Critical Infrastructure (CI) system to prevent, withstand, recover and adapt from the effects of climate hazards and climate change [5], [6]. In a system, it is normally expected to drop its performance level after the impact of a disaster event, and with time, the system is supposed to recover to its initial state, to gain its previous performance. Some systems can be upgraded; therefore, those systems will have a higher level of activities as well.

Quantification of the impacts from a disaster are very useful in many ways such as in decision making, designing safety drills and making the resources ready for an emergency situation. Knowing the magnitude of the impact before the disaster by an estimation tool will help the decision makers to implement emergency actions to the adequate limit, without costing for excessive amounts of labour and money. By doing this, a country will address its co-alignment with the Sendai Framework for disaster

risk reduction, including improving the resilience of the communities as well as the improvement of preparedness planning for disasters. Currently, the impacts of the disasters are measured only after the disasters, by means of the damage assessments, and a very low level of estimations are done before a disaster to identify its impact.

The studies conducted to identify the disaster impacts considering the cascading effects of a disaster are very limited in both global and local contexts. Therefore, there exists a great research opportunity to identify the magnitude of the disaster, by quantifying and evaluating the impacts of a disaster, taking the cascading effects in to consideration.

1.2 Objectives of the study

The objectives of the study are

1. Identify the cascade interrelations at times of disasters, which exist among and within the systems. A system can be a community or conglomeration of critical infrastructures
2. To develop a mathematical model to evaluate the impact of a disaster considering the cascading effects which takes place in a disaster. This model will be able to estimate the impact in monetary and non-monetary terms for respective damages done in disasters

These objectives were derived based on the current literature and by studying the extent of the studies done in quantification of the disaster impacts. It was brought to attention that not many studies have been conducted to quantify the disaster effects or to identify the cascading nature of the disaster. The concepts of cascading effect were evident in many studies, however very few had attempted to quantify them.

To achieve the aforementioned objectives, the following methodology was used.

1.3 Methodology used in the study

The methodology used in this study is briefed in the flowchart in Figure 1.1.

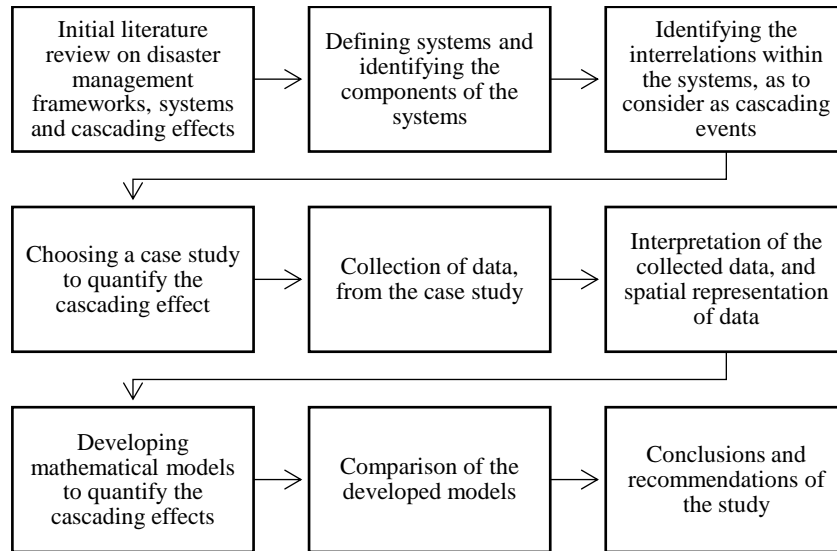


Figure 1.1. Methodology of the research

The initial task of the study was to explore on the literature on the research gaps, as well as the methodologies adopted in past research for the quantification of disaster events. At the same time, the context of the quantification of disaster damages in the global context and the local contexts had to be done, in order to correctly identify the local requirement of disaster damage quantification and estimation. In this perspective, the next step was to define the systems, its boundaries and other definitions and sub components, which is majorly done through the literature, as well as the other operational documents, such as Emergency Operation Procedure (EOP) documents. Then the interrelations between the systems and its sub components were identified which lead to do a case study for a flood affected area, in order to capture the data relating to the disaster event.

Next, these data were displayed and analysed in order to quantify the interrelations identified in the previous step. In other words, for each of the identified interrelation between two parameters, a mathematical equation was produced, based on the empirical data collected from the case study.

1.4 Structure of the thesis

The flow of the thesis is aligned with the process shown in the methodology. Section 1 is for the general introduction to the research study. Chapter 2 will carry the major content from the available literature, which will cover the topics on the disaster management context in Sri Lanka, basic definitions of hazard, exposure, vulnerability and risk, flood damage estimations, critical infrastructure, cascading effects and system. Furthermore, it explores the cascade modelling and the cost modelling of disasters.

Chapter 3 explores on how the case study was done, based on the finding of the previous chapter. The rationale behind selecting the case study area, how and what type of data is collected, how the data represented is discussed in chapter 3.

Chapter 4 furthermore explores the data which was collected and processed according to the study requirements. There, the reasons behind the most of the decisions taken on quantification at the time of the disasters are explored.

Chapter 5 describes the conducted regression analyses, how it was amended according to the results and reasons which were raised with the results of the initial analysis, how the results of the later analyses are represented and interpreted. This majorly includes the attempts to correlate the flood characteristics to the human movement related parameters in the study.

Chapter 6 includes the results and discussion, along with the development and the checking of the mathematical model to quantify the cascading effects, while chapter 7 includes the conclusions and the recommendations of the study.

2. LITERATURE REVIEW: CONTEXT OF DISASTER DAMAGE QUANTIFICATION

Chapter two of the thesis is entirely composed upon the literature review carried out for the study. The literature was referred to from the beginning to the end of the study, and the relevant work was identified, along with the significances and the drawbacks of each study. This chapter will be consist of the current context of disaster management in Sri Lanka, insights on flood damage analyses, concepts on risk, hazard, exposure and vulnerability in flooding situations, systems thinking and the impacts to systems, critical infrastructures, concepts of resilience and the cascading effect of the disasters, dynamic nature of the disaster, and the social and other miscellaneous impacts of the disasters.

2.1 Hazards, impacts and the context of disaster management in Sri Lanka

Sri Lanka is vulnerable to many natural hazards, and from these, floods have been more frequent in the past decades [7]. The intensity of these floods has grown over time, which is a fact evident by the damages and the difficulties done floods [8]–[10]. When the damage done to the human livelihood and the infrastructures are considered, floods stand much higher than almost all of the other disaster types, except for the tsunami in 2004. The global risk index for 2019 ranks floods at the 2nd place in the list of natural hazard risks, while having tsunamis at the first place [11].

These floods are caused by severe rainfalls which are received in main two monsoonal periods and in the inter-monsoonal rainfalls. Usually, a mean annual rainfall of more than 3000 mm are received by the main monsoonal periods while the inter-monsoonal periods give a mean annual rainfall of about 1000 mm [12]. The monsoonal rains take place from May to September (South-West monsoons) and from December to February (North-East monsoons). From these, floods due to the rainfalls from the South-West monsoons have done the largest damage to the country, as evident from the time period of the floods occurred in the past [8], [9], as most of the devastating floods have occurred in the period of May to September. Table 2.1 shows some important statistics on the most recent flood events in Sri Lanka, which demonstrates the impact of the flood disasters.

These flood events have disrupted the country in many aspects. Of those, physical damages, social damages and environmental damages can be identified as the most outstanding damages [8]. Usually, the damages are described as a monetary value, and defining the damages with monetary values has its own complexities. At the same time, it should be noted that the compensation of the damages is done according to the valuation of the damage, from various methodologies. However, to compensate these damages, a huge amount of funds has been utilised for each of the disaster every year, as a part of the disaster management (DM) process of the country [8], [10], [13].

Table 2.1. Impact of recent floods in Sri Lanka

Event	2016 May floods	2017 September floods	2018 May floods
Affected families	124,398	229,235	49,364
Affected people	493,319	879,778	188,328
Deaths	93	219	26
Injured persons	33	154	27
Missing persons	117	74	0
House damages (total)	58,871	3,048	186
House damages (partial)		76,803	10,708
Number of relief camps	373	504	395
Number of families in relief camps	30,027	28,100	22,228
Number of people in relief camps	115,567	109,890	85,093

Source: [8], [10], [13]

A typical disaster management process will contain the usual four stages of a disaster which are preparation, response, recovery and mitigation [14], [15]. Even though the current trend of the global governments is to invest more in Disaster Risk Reduction (DRR) activities, always there will be a component to invest in recovery and mitigation activities as well. Especially in the case of Sri Lanka, even though preventive actions are exercised, the past flood related disasters were evident that there is a huge work to be done in the recovery and mitigation phases as well, such as providing early recovery

assistance with the provision of food, shelter and security. Long term activities could be listed as the provision of shelters and the compensation of the houses depending upon the damage valuations.

The DM activities and the DRR activities of a nation are highly shaped by the disaster management frameworks been employed by the respective disaster management authority in the country. For the Sri Lankan instance, the respective disaster management authority is the Disaster Management Centre (DMC), and the DMC uses its own DM framework to define their objectives, plan the activities and to measure their performance in case of a disaster. However, to keep the compliance with the global standards, the aforementioned DM frameworks are highly influenced by the global standards such as Hyogo Framework for Action (2005-2015) and the Sendai Framework for DRR (2015-2030) yet highly adopted to the local situation. One good example is the roadmap for DM, which is supposed to achieve the targets set by the Sendai Framework for DRR [14]–[16]. These frameworks are often multidimensional (physical, social, economic, ecological etc.), multidisciplinary (as in professions required to handle and absorb the content) and covers a vast spectrum of DRR aspects.

However, the performance measurement of the DM framework is not established to its full potential and at the same time, the existing methods of assessment of the implementation of DM frameworks tend to be more qualitative rather than quantitative [17]. This has become an issue especially for the DRR activities which should be taken as preventive actions, as the activities are not 'seen' as priority activities, compared to the disaster relief activities. This is due to many reasons including the reluctance to deviate from the traditional practices of DM, lacking the technical capacity to cope with new technology and the lack of financial provisions to facilitate such activities.

However, from many global examples, it has proven that investing on DRR activities has reduced a great context of damage, from many dimensions such as infrastructural and social. Therefore, it is important to implement the DRR activities thoroughly, yet more importantly with a better understanding on the reasons to do so. This understanding of the impact of the DRR activities on disasters will be derived through

the results of the disaster analysis studies, which are done emphasizing more in quantitative measurements rather than qualitative measurements.

These disaster analysis studies look into many aspects of the disaster. Many of the studies have considered the propagating nature of the disasters which is known as the cascading effect of the disasters, which will not only trigger various types of other disasters, but also affecting the functionality of the systems and their subsystems which are interconnected to each other. Here, the term system is defined and used in many methods which have eventually led to the quantification of disaster impacts. Some studies have considered the end result of the disaster to analyse the impact and some has considered the dynamic nature of the disasters as well. And the aforementioned concepts on disaster analysis will be discussed on the following sections with the cases made from the literature, with respect to floods.

2.2 Flood damage analyses

Floods damage analyses are done all over the globe for a while using different approaches. The main motive behind a flood damage analysis is to quantifying the flood damages for different forecast scenarios, in order to quantify the benefits of flood protection measures and to support the decision-making procedures. Even the policy making can be influenced by reliable flood damage studies, as the damages done by the floods can be a major driving force for the political decision making [18]. Furthermore, the results by the analysis of the past events could be used to predict the impacts in the future possible scenarios.

The damage caused by any disaster is usually recorded and analysed in monetary terms, but there are instances where complications arise such as trying to determine the monetary value of a human life, ecological reserve where the ethical reasons are considered. The accepted terminology is to identify the impacts which could be directly identified in monetary terms as the tangibles and the others impacts as intangibles. At the same time, damage can be either direct or indirect, depending on whether the disaster was in immediate physical contact to the physical infrastructures, human lives, property and the ecological systems or not. Some example for the indirect damages will include the impact to the business by loss of sales, traffic congestions

and the interruption of the services, Direct damages are relatively easy to identify in the big picture, while the indirect damages are usually hidden for any preliminary flood damage analysis [18]–[20]. Usually the indirect damages are not estimated frequently due to the methodological complexities. An example showing the difference between the direct and indirect impacts, and the tangible and intangible impacts are shown in the Table 2.2.

Table 2.2. Examples for direct, indirect, tangible and intangible impacts

Impacts	Direct (caused by immediate impacts)	Indirect (attributed to the flooding)
Tangible (Can assign a monetary value)	Damage to a bridge	Loss of sales of the businesses
Intangible (Cannot assign a monetary value)	Value of a human life	Damage to the people via disease spread, as a consequence of flooding

The end result of a disaster analysis is often the risk associated with each element of the system considered. Here the risk is usually calculated by considering the hazard extent, exposure and the vulnerability [3], [4], [14], [18]. Sometimes, literature suggest that the probabilities of the risk should be presented for each element of the study [5], [21]. Therefore, it is elementary to have the concepts of hazard, exposure and vulnerability defined in the beginning.

2.3 Risk, hazard, exposure and vulnerability in the context of a flood

2.3.1 Hazard

By the term hazard, usually the extent of the hazard is represented. For an example, for a flood, the inundation depth, inundation area, inundation duration, flood velocity are considered to be the characteristics representing the hazard [18]. However for these characteristics, the hazard data is required to be spatial, and depending on the accuracy of the results required, the resolution of the data could be dependent [4], [18]. Depending on the resolution, such studies can be named as macro (requires the least amount of spatial distribution of the characteristics), meso (requires the spatial

distribution according to the landuse) and micro (requires the spatial distribution of the characteristic for each element present in the study) [18].

On a more extended thought, the return period of a flood (the probability of occurrence: flood happening once in a particular number of years) and the return period of the contributing rainfall can be considered as the characteristics which represent the hazard situation [4], [19]. However, to utilise these information, powerful flood modelling and the analyses have to be carried out in order to generate the spatial results [19], [20], [22], [23].

2.3.2 Exposure

Exposure is the phenomenon of the systems in interest being exposed to hazards. Exposure is usually expressed by the characteristics of proximity to the flood source, elevation of the area, and the frequency of the hazards [18]. In this context, the data required to the exposure study is essentially needed to be spatial, and preferably digitised. The elements being exposed to a hazard can be found and categorised using many methods, which will be discussed later in detail in section 2.4.5.

For an element of interest to be at risk, only being exposed to a hazard is not going to be enough, as the aforementioned element can be highly resilient to the hazard, which is measured by the vulnerability.

2.3.3 Vulnerability

Vulnerability is the measurement of the resilience of a selected element, against the impact of a hazard [1], [18]. Vulnerability analyses are usually ended up with the indications of a damage against the exposure and the hazard characteristic of the hazard. The most popular examples are the depth damage curves for the flood damages [19], [20], [22], [23]. To determine the vulnerability of a particular element, an expertise knowledge on the damage values against the flood characteristics should be present in the process of determining the flood damages. As the flood damages are tend to be represented as monetary values, it is possible to come up with damage values using field expert discussions on damage values on the actual value of the damage and

on the reconstructing cost of the damage, and by consulting the insurance agencies on their expertise on compensating the past damages [19].

At the same time, susceptibility of the elements should be considered as well, checking on how sensitive an element of risk to a given hazard. For an example, the susceptibility of a dwelling unit should be considered depending upon the construction material; whether it is built as a reinforced concrete or from wattle and baid. Which means the two types of elements should be studied separately. This is usually done as a part of the vulnerability analysis, however, at sometimes, it could be seen that this is not given much regard in some analyses [19], [22], [23].

Susceptibility indicators can be divided into two main categories as social and economic units and systems, and ecological units and systems. The social and economic units will enlighten a narrow sense of susceptibility, including the social capabilities such as preparedness, coping capacity and the recovering capacity. In the long run, ecologic impacts and the effects could be more prominent, which could be identified by the resilience indicators [18].

Therefore, it is evident that the flood damage analyses should be separately studied considering the hazard, exposure and vulnerability. At the same time, it is evident that the aforementioned elements at interest are not individual elements, but a part of a functioning system. Which means that there are many interconnections that can affect the element at risk, even it is not directly affected by a disaster. Hence, it is essential to look in to the systems and the impacts to the systems from a disaster event [1], [2].

2.4 Impacts to a system

2.4.1 Definition of a system and the importance of system thinking

According to Simonovic (2010), a system is function which converts the input X in to the output Y as denoted by the Figure 2.1 below. It should be noted that depending on the input magnitude, output has depended. Controlled inputs have generated desired outputs, uncontrolled inputs have generated the undesired outputs. And the partially controlled inputs have resulted in neutral outputs. At the same time, it should be noted that the feedback generated from any output can be used to improve the performance

of the system, by allowing the system to take more controlled inputs. These feedback relationships exist within a system opens the door to a whole new dimension of the disaster dynamics, as the linear thinking will not be valid anymore for the systems with feedback relationships [1], [2]. This phenomenon will be discussed later in details, in section 2.7.

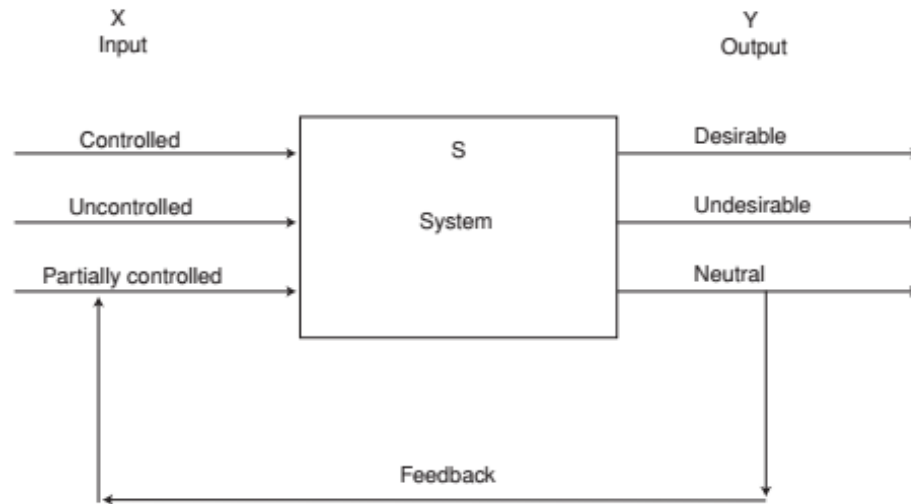


Figure 2.1. Schematic presentation of a system definition [1]

Similar definitions on the systems have been expressed by the other authors in the expertise of disaster management [24]–[26].

It is important to incorporate systems thinking in to the disaster management activities of the country, as the single elements which are at risk are interconnected to each other in so many levels, and those elements are not functioning in isolation. Therefore, if one system gets into a problematic state, it is natural for the associated elements to get affected as well [1]. At the same time, in a disaster situation, the victims and the decision makers will have to take a series of challenging decisions under stress and pressure, therefore it is vital to be aware about the systems and their interrelations within the subsystems, in a crisis situation [24].

Systems thinking has a lot of dimensions in it, such as the dynamic thinking, closed loop thinking, generic thinking, structural thinking, operational thinking, continuum thinking and scientific thinking which could be utilised depending on the nature of the problematic situation created by the disaster [1], [4]. The activities on the disaster

preparedness phase such as formulating, testing and exercising disaster plans, providing training for disaster responders and realising the vulnerability of the community can be highly shaped by the incorporation of system thinking. In the response and recovery phases, it can contribute to shape the activities in assisting the injured, managing the demised, firefighting, damage assessments, reconstruction of damaged infrastructures and the relocation of the victims of the disaster [1], [2].

Furthermore, systems thinking will allow us to capture the big picture, balance between the short-term and the long-term perspectives, and to appreciate the dynamic, complex and interdependent nature of the systems in a disaster situation. Also, it can account for the measurables and the non-measurables of a disaster situation [24]. More important of all, system thinking will guide to approach the proper order of the event and the effects. It will also guide to choose the best feasible solution from a number of alternative options in the presence of many constrains of law, mortality, economic resources, social life, nature and other physical constraints [1].

For further explorations, it is important to know the composition of a system, as there are always sub systems and individual elements exist within a system. Therefore, to understand the inter-relations between the systems, a prelude on system components is presented in the next section.

2.4.2 Components of a system

There are many definitions and interpretations on the subject 'what makes a system'. Simonovic (2010) demonstrates that the systems can be primarily divided based on a number of characteristics. Some of the divisions based on the characteristics are natural and human made systems, physical and conceptual systems, static and dynamic systems, and closed and open systems [1]. A definition for a system is seen as a collective combination of critical infrastructure and the associated livelihood, which is facilitating the functioning of a society by providing the essential services [5]. It is stated that the Critical Infrastructures (CI) and their inter dependencies form a system of systems [6], [27]. Therefore, it is essential to know about the critical infrastructures, and about their types, classifications and the interdependencies.

2.4.3 Critical infrastructures (CI)

When a system or a community is considered, there are numbers of CI present, and it will be easy to identify these CI using the classification methods provided by many scholars in the field. Rehak et al. (2016) claims that the critical infrastructure can be divided in to three main levels. First level is the system level, where the technical and socio-economical infrastructures are considered. In this level, a considerable amount of links exists between the CIs. The second level is the sector level CIs, where the links exist between the sub components within a CI system. The third and the finest level of the CI is the individual element, which is the basic building block of a CI system [6]. Figure 2.2 represents the essence of this paragraph. Furthermore, Rehak et al. (2016) claims that the easiest way to identify the CI element is to use the bottom-up approach. That is to identify all of the elements in a single sector.

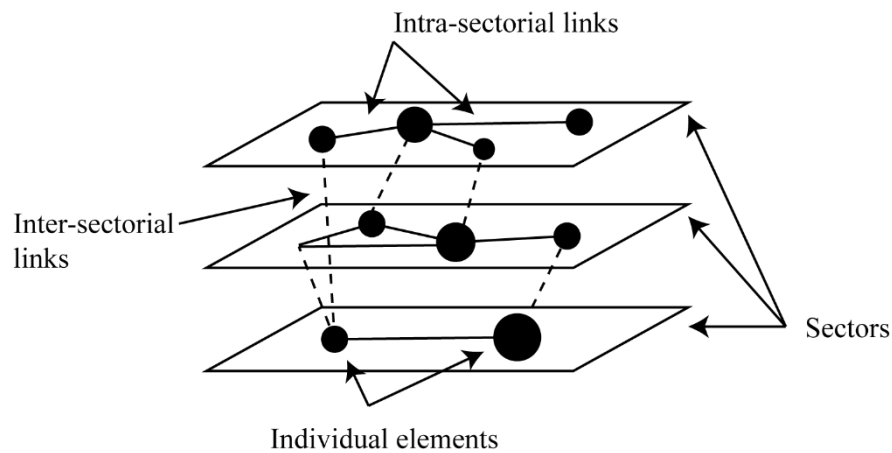


Figure 2.2. Classification of CI

Another approach to identify the CIs are the different frameworks introduced by many of institutions and scholars. These frameworks include the sectors which to be searched for the CIs. At the same time, there is a lot of studies which have been conducted to measure the resilience of the CIs, therefore by referring to the resilience frameworks, a clear idea can be obtained about the CIs in a system. When it comes to the frameworks on the components of systems, disaster management frameworks and the other resilience frameworks are quite outstanding among the other frameworks. On the other hand, it is essential to have an understanding about the resilience frameworks in action, for the purpose of this study too.

2.4.4 Resilience frameworks and other frameworks defining the CI categories

There are number of globally accepted resilience frameworks published by various researchers. Among them, the leading frameworks for resilience are Hyogo framework for action and the Sendai framework for DRR. Mainly from the influence of these globally accepted frameworks, the local frameworks have been designed. The Sri Lankan Community Resilience Framework (CRF) is prepared under the influence of Hyogo framework for action and the Millennium Development Goals (MDG), while the Sri Lankan disaster management plan (2018-2030) is highly aligned with the objectives of the Sendai Framework for DRR and with Sustainable Development Goals (SDG) [14], [15], [28], [29].

The CRF is essentially focussed on the resilience of five sectors, namely social, physical, economic, human and environmental [28]. These five sectors are commonly and equally contributed by the risk knowledge and the risk governance. Each of the five sectors are having sub components where a number of CIs is found. Furthermore, the assessment aspects of the CRF sheds light in the CI incorporated with the resilience building and evaluation activities [28]. Table 2.3 and Figure 2.3 shows the sub components under the five main categories that can be used to identify the CI incorporate with.



Figure 2.3. Community Resilience Framework (CRF) of Sri Lanka [28]

Similar theories are presented in a study which used disaster resilience indicators to benchmark baseline instances. There five resilience categories are defined as social, economic, institutional, infrastructural and community capital. There are number of indicators for each of these categories to identify CIs in the system [30]. Also, validations are provided with case studies in this study.

Table 2.3. Components that can be used to identify CIs from the CRF, Sri Lanka

Social	Physical	Economic	Human	Environmental
Communications	Structures	Income security	Food security	Land use
Support networks	Water supply	Access to markets and employment	Health	Access to natural resources
Organisations	Sanitation	Livelihoods diversity and flexibility	Education	Ecosystem sustainability
Inclusions	Roads	Financial services		
Cohesions		Land tenure		

2.4.5 Resilience of the CI and traits of resilience

When the vulnerability of the CI is considered for disaster damage analysis, it is required to know about the resilience of the CI. The resilience of the CIs is defined as the ability to absorb, adapt and recover from a destruction, for a complex system which are dependent on each other's functionality [5]. Rehak et al. (2018) argues that the resilience of CIs is mainly composed from the technical resilience and the organisational resilience. The technical resilience is mainly constructed on the traits of robustness and the recoverability, while the organisational resilience has the major strength in adaptability. The robustness can be described as the collection of the components of crisis preparedness, redundancy, detection ability, responsiveness and physical resistance. The recoverability is described as the collection of material resources, financial resources, human resources and the recovery process. The adaptability consists of the characteristics of risk management, innovation processes and education and development process [5]. Furthermore, this study has analysed different types of resilience in different sectors having controlled and uncontrolled disruptions (inputs) and the performance is demonstrated. The essence of the aforementioned are summarised in Table 2.4.

Table 2.4. Components of the resilience of CI [5]

Technical resilience		Organisational resilience
Robustness	Recoverability	Adaptability
Crisis preparedness Redundancy Detection ability Responsiveness Physical resistance	Material resources Financial resources Human resources Recovery process	Risk management Innovation process Education and development process

Abenayake et al. (2018) defines the outcomes of the community resilience as the conglomerate of the determinants, attributes and the input process. Each of these components have characteristics which are interrelated to a certain amount which concludes that the community resilience is a function of the re-organising ability, transformative ability and the absorptive capacity, in the case of a flood. It emphasizes that the Flood resilience supportive Eco-System Service-delivery (FES) is compiled of the regulatory services and the provisioning services which deliver to the input processes of the community resilience outcomes. This FES have the attributes of retention and detention, surface runoff, interception, infiltration, precipitation variability, nutrient yield and sedimentation yield. It also has the ecological parameters such as slope, landuse, water infiltration properties and ground water flow properties, rainfall intensities etc. which can be used to identify the incorporated CI and the resilience traits of the incorporated CI [31].

Therefore, by studying the frameworks, a vague set of components of the systems which are more suitable for the Sri Lankan context could be derived and classified as shown in the Table 2.5.

Table 2.5. Components of a system

Physical components	Resilience of buildings
	Value of assets, stocks and household items
	Capacity of roads, functionality of roads
	Functionality of flood protection structures, safety & serviceability of those
	Vulnerability of the vehicles
	Vulnerability of crops
Social components	Population change for a particular time period
	Median income per household
	Unemployment rate, labour force
	Population below poverty level
	Employment change for the particular time period
	Number of schoolers/graduates
	Number of schools and universities
	Health & healthcare status
	Known number of sources of pollution
	Recreational resources
	Water quality data over the particular time period
Ecological components	Natural land cover
	Forest land cover
	Wetlands land cover
	Approximate watershed shape (circular or elongated)
	Watershed size
	Agricultural land cover
	Urban land cover
	Aquatic barriers
	Relative water level change

It is at the most significance to know the behaviour of the CIs under the impact of the disruptive event. Rehak et al. (2016) has defined a set of parameters which creates a unique identity for a CI based on its behaviour when disturbed. Initially, the behaviour is identified by five main categories. These categories are then characterised by the incorporated traits and sub traits of the response of the CI system [6]. The essence of the traits is shown in Table 2.6.

Table 2.6. Characterisation of a CI system after disturbed [6]

Number	Categories	Traits	Sub-traits
1	Area of the action	Society	State security
			Basic human needs
			Economy
		CI	Sectors
			Elements
2	Structure of the action	Direct	
		Indirect	Primary
			Secondary
			Tertiary
3	Intensity of the action	Partial	
		Absolute	
		Weak linkage	
		Strong linkage	
4	Duration	Short term	
		Medium term	
		Long term	
5	Effect of the action	Single	
		Synergistic	

Most characteristics on the Table 2.6 are discussed in the previous sections. However, when the intensity of the action, the authors state that the impact imposed on one system is dependent on the link strength between the affected system and the impact

generated system [5], [6]. At the same time, the effect of the action should be analysed whether it is has a single action or a synergistic action. Here, the term synergistic action means that the two events have generated an effect which is greater than the addition of the effects within the sub systems those were generated. It is the mathematical representation of $1+1>2$. In other words, the effect of the event has impacted the linked sus-systems and other systems, which has provided the evidences for the presence of the dependencies and interdependencies [6].

2.5 Cascading events and the cascading effect of disasters

Cascading events are the events that occur as a direct or an indirect result of an initial event, as defined by the Federal Emergency Management Agency (FEMA), USA [4]. As the definition of cascading effect is considered, it is known as the presence of dynamics in disasters which creates a sequential event series in the human and other subsystems. [3], [4], [27], [32]. The cascading effect may be referred to as the synergistic effects, as mentioned in the previous section as well. These events happen due to the relationships existing within the systems and its subsystems. These relationships are sometimes referred as dependencies and sometimes as interdependencies. Most of the literature has given less regard to the usage of the terms dependencies and interdependencies, but Rinaldi et al. (2001) has stated that the term dependencies refer to unidirectional relationships while the term interdependency refers to bi-directional relationships. A representation of the complex relationships within systems are illustrated in Figure 2.2.

Studying the cascading effects are important in various aspects. First of all, it allows one to see the initially impacted components of a system which is usually seen by many of the stakeholders, as wells as the secondary and tertiary impacted components of the system which are rarely seen by the stakeholders and the practitioners. At the same time, the concept of cascade effects and the results from modelling the cascade effects can be used to educate the political and other institutional leaders of the country to take decisions after 'seeing through' the disaster. It will also help in reducing the workload from the disaster management practitioners. The results given by cascade modelling can be used plan and evaluate training, conduct hazard and risk analysis and

even to design disaster management and response related drills in the long run [3]. Furthermore, it enables one to conduct multi-risk assessments which could be in the forms of single chain events and multiple chain events.

A success story of the utilisation of the cascading effects and the systems thinking is the operation procedures followed by the supermarket chains led by Walmart and the coast guards in the event of Katrina Hurricane. The management had a good understanding about the cascading events that can take place in the period of the hurricane, therefore they have taken the most suitable managerial decisions for the relief operations and decentralised the decision-making process. Some of the supermarkets have hired the consultants in disaster predictions and got their advices on the actions to be taken ahead, by seeing through the disaster. By this, local authorities and the supermarket chains have been highly successful in conducting post disaster relief and recovery operations, performing much better and quicker than the FEMA has acted [33].

Since the cascading effects are the results of interdependencies, studying the interdependencies and finding the methods to quantifying them is the key to understand the extent of one systems impact to the another. For this purpose, it is vital to characterise the infrastructure interdependencies. Table 2.7 represents the 6 dimensions and the components of those, characterising the interdependencies, by a study conducted by Rinaldi et al (2001).

Table 2.7. Characteristics of the interdependencies

	Dimension	Characteristics
1	Type of failure	Common cause, Cascading, Escalating
2	Infrastructure characteristics	Organizational, Operational, Temporal, Spatial
3	State of operation	Normal, Repair / restoration, Stressed / disrupted
4	Types of inter-dependencies	Physical, Cyber, Logical, Geographic
5	Environment	Business, Public policy, Security, Health and safety, Economic, Legal / regulatory, Technical, Social / political
6	Coupling and response behaviour	Adaptive, Inflexible, Loose / tight, Linear / complex

A later study suggests that the types of the interdependencies should be specified as physical, geographical, cyber and logical, as opposed to the findings in the Table 2.7 [34].

The characteristics of the interdependencies lead to the modelling and the evaluation of the interdependencies, which is discussed in the next section.

2.6 Cascade modelling

Many scholars have come up with various approaches to model the cascading effects of a disaster. Some of those share the similar lines of thoughts in the modelling process, while there are some deviations from the conventional modelling techniques.

Cascade representation is usually done through the cascade trees, each branch is representing a cascade chain. The geography of the cascade model is defined by the shape (direction of the cascade flow: left, right, up or down), dimension (number of individual cascade branches), location (number of cascading events) and design (the characteristic which originated a cascade). The closest incident to the disruption is called the proximal end of the cascade tree, while the most distant end of the tree is

known as the distal end. With this, it is possible to assign the levels of affections for each of the incident, as primary, secondary and tertiary levels of affections [3]. An example of the cascade diagram is shown in the Figure 2.4.

As a preliminary framework, Rehak et al. (2018) suggests that the cascade impact assessment should be facilitated with 4 main items, which are: input data, process management, evaluation criteria and the methodology. Under input data, it is required to input the intensity of the triggering event, resilience of the immediate and the secondary and tertiary establishments who will be affected from the initial event, and the interdependency details of the sub-sectors. Under process management, there should be a standard and well-established methodology to assess the cascading effects, and this methodology should be credible enough to take decisions depending on the data. Alongside, there should be evaluation criteria to evaluate the extent of the impacts, especially to the inter connected system components [5].

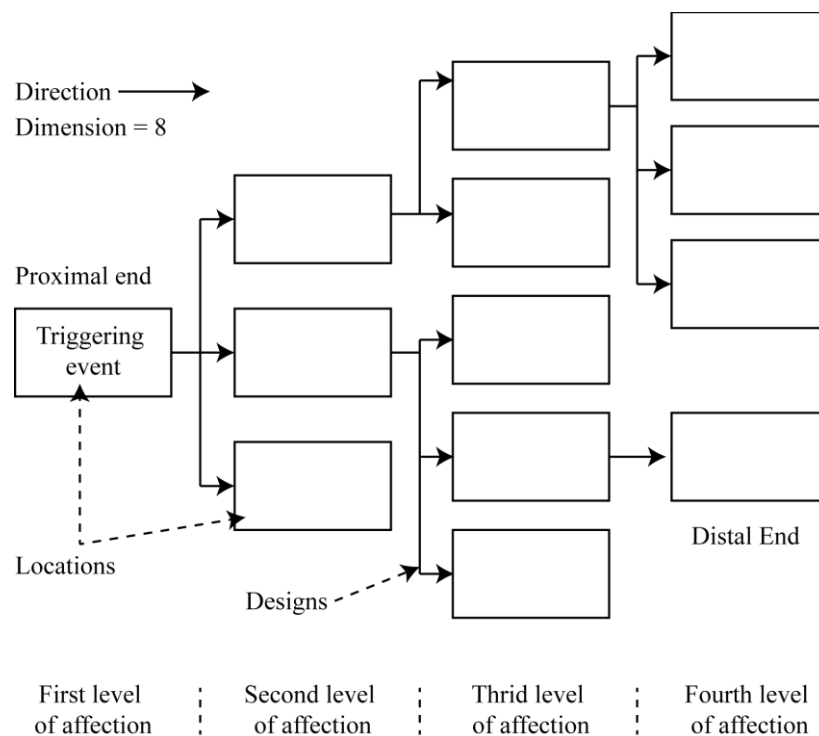


Figure 2.4. Example of a cascade diagram

While assessing the CIs, it is strongly advised to use the systems approach as discussed in the previous sections. It will make sure that all of the interested parties are involved, processing continuity is ensued to have the re-evaluation of the results and the risk

management and integration are done accordingly. For the quantification of the cascading effects, it is required to follow a 3 steps procedure of which the components are identification, analysis and the evaluation.

- Under identification step, initially it is required to select the area of interest that the study to be conducted, then it is required to identify the CI in the selected area.
- Under the second step analysis, it is required to conduct correlation analyses and Multi-Criteria Decision Analyses (MCDA) to find the define the correlation with one component's impact to the other component. Then the final step can be carried out in order to determine the probability of cascading impacts for different CI elements, and eventually denote the risk incorporated for all of the CI elements, individually [5]. This framework and the methodologies are an improvement of the Rehak et al (2016)'s previous work in 2016 [6]. Other authors also have presented similar theories in capturing the cascading effects [3]. However, in this study, even though the concept is illustrated with an example, it has defined the correlations with 1s and 0s only depending on whether there is or is not a correlation between two entities. Therefore, in the example taken, the link strength between the two entities are not well demonstrated, which could be considered as a drawback of the study.
- Under the evaluation step, the results taken by the analysis should be verified and compared with the studies of similar nature.

Dudenhoeffer et al. (2006) followed a slightly different method in capturing the cascade effects of disasters. A method called CIMS method is used in the study, and what if analyses are used to identify the cascading effects. The author claims that will reveal the information about the critical assets, relative importance of each asset and the cost to destroy or repair the individual assets [34].

In another study done to investigate the capacity of the Hyogo framework in addressing CI relationships and the cascading effects. The conclusions of the study stated that cascading relationships are required to be present in disruptions of local and global manufacturing, failure on business, public confidence in government in crisis.

The study uses the Japanese triple disasters as a case study, and highlights the required areas of the Hyogo framework to be improved. Some of the recommendations of the study concludes that the addition of indicators to the national policy, protocols and legal frameworks which support the acceptance of an international aid, identify the interdependencies across the CI and recovery operations have to be serious and quick. It also demands to address the national and the regional risk assessments that account for interrelated disasters [35].

The aforementioned cascading effects are not limited to be static effects, but also can be dynamic effects. The term dynamic gives the meaning of changing over time [1]. The cascading effects always take place within a given time frame, some events occur immediately after the disruptive event has occurred, while some events take much longer than that. Therefore, it would be an essential part to study the time variability embedded in the case of cascading effects.

2.7 Dynamics in a disaster

Dynamic nature of the disaster is assessed manually, or by computer algorithms based on the concept of System Dynamics (SD). The simulation of SD is appreciated over the conventional methods due to many reasons, such as the exceptional power and the simplicity of the algorithms, the ability to apply equally to problems in social, natural and physical nature, and due to the ability to recreate many hypothetical scenarios by altering the input conditions, and the ability to see the results in a very short time.

When the concept of feedback is embedded to the cascading effects, it will no longer be linearly varying with the disaster characteristics. Any effect will be dependent upon the feedback it is receiving from the other events. Therefore, to represent this non-linear way of thinking, Causal Loop Diagrams (CLDs) are used [36]. It will further help to identify the correct order of affecting the CIs, with the magnitudes. There are number of cases where the concepts of SDs and CLDs are used successfully in the literature.

Ramezankhani & Najafiyazdi, (2007) have used SD techniques to model the post disaster activities after the Bam Earthquake. There, they have tried to answer the questions of "*what is the contribution of the broadcast coverage to attract*

humanitarian aid, food, equipment, rescue teams, medical and cleaning teams to the disaster sites", "what is the minimum number of teams required for the burial of the deceased bodies to prevent disease outbreaks", "what are the optimum deliveries that should be carried out by the governance", "which type of disaster relief is required at which site" and "how much of search, rescue and clean is required to minimise the total damage of the disasters". To answer these questions, they have idealised 8 main sectors with the interrelations and each of the sectors are detailed with sub sectors and their inter-relations. Then, the inter-relations are quantified with the mathematical relationships which has ended up in successfully preparing the time-variant graphs of several aforementioned parameters in the questions, enabling to identify the significant values for each of the parameters [26].

A similar approach was taken by Cooke (2003) in analysing the effects of the Westray mine disaster where the emphasis is on the mine capacity, production, human resource and the safety variation with time [37]. Another study reveals how the concepts of CLDs can be used to analyse flood policies and design flood policies in United States [38]. For the flood policy analysis, all of the results are validated and represented with respect to a baseline study of policies. Li and Chen (2014) have also attempted to create a mathematical background in creating the causality networks with cycle chains [21]. Ming and Hong (2011) have successfully identified and evaluated the facts contributing to the transport and information delay in disasters, using SD concepts [25].

However, in most of the literature, there are blurry indications on how the links and the mathematical relationships were produced. At the same time May (2007) characterises the drawbacks of the CLDs are that they require feedback, as well as some variables may be neglected in creating CLDs due to the high level of integration of the model.

2.8 Overall disaster damage assessment

As evident from the previous sections, disaster damage assessments can take various approaches depending upon the requirements, perceptions of the policy makers and the technical capacities. Therefore, it will be sensible to look at the overall procedures

available for damage assessments. This section will consist of methodological approaches, costing of disasters, social aspects and the human behaviour in disasters and the drawbacks in the current methods in the disaster damage assessments.

2.8.1 Methodological approach

Despite from the specific methods suggested in the aforementioned literature, the generalised approach is usually derived by the scenario analysis. The basic steps involve:

- Hazard characterisation according to the area proneness or to the preference of the decision makers
- Exposure and vulnerability analysis, according to the elements at risk
- Identifying the probabilities of transition among the different hazards
- Damage is calculated with reference to a) geographical distribution of the damage level (number or other quantity damaged in the minimum reference unit) and b) time distribution [4]

Other approaches include MCDA techniques where the multi criteria analyses and the correlation analyses have been conducted, and the sensitivity analyses and the what if analyses have been conducted, in order to create scenarios [39]. Finally, all of these analyses will result in presenting the vulnerabilities, or the risks incorporated within, as discussed in previous sections. To make sense of the vulnerabilities, most of those are represented in monetary terms.

2.8.2 Costing of disasters

Usually in disaster damage assessments, either the cost is represented by the empirical data, which are the actual costs incurred in disaster management process or by means of the vulnerability functions. Apart from the conventional models discussed previously, Notaro et al. (2014) claims that the vulnerability functions can be derived from the empirical data, using the correlations of linear, exponential, power functions and polynomial functions and in this study, the data is from a case study [40].

While incorporating for cost, there could be several cost categories and cost models for various cross sections of the societal establishment. For an example, if the human component is considered, cost bearers may be listed as employees, workers and community, which have their own valuing criteria [41]. At the same time, this may create imbalances among the other representatives of the communities as well.

Furthermore, these cost models and the valuing criteria will have significant differences from one to another [41]. As an attempt to rectify the similarities, some studies have focussed on normalising the damage values and identifying the similarities and the discrepancies within global, national and regional standards. An example is the study conducted by [42]. The study reveals the major reasons for the discrepancies as the inconsistency of resources and the incompetency of the normalising methods. To normalise the data globally, the study suggests to use the GDP deflator, population density and the wealth per capita, rather than the conventional measures of GDP and the population.

2.8.3 Social aspects of a disaster

Social elements play a great role in disasters as well amongst the other elements of disasters such as economic, and ecological indicators, but it is less discussed in the subject of quantification. The social context can be more explained in terms of awareness and preparedness, capability to cope and the ability to withstand the consequences [4], while another study has used 16 social indicators, which are essentially classified into three sub categories as socio-economic, organisational and informational [39].

The society is required to be prepared for the flood risk, as the people might not be aware about the flood probabilities and their exposure to floods. Urban communities might not know about the community vulnerability as well. At the same time, people's perception on handling the flood risks, knowledge on warning system, knowledge on topography of the area, effects on urbanisation and politics, and their past exposure will influence their behaviour in a crisis situation. Therefore, it is required to educate and develop the social infrastructure to make the communities more resilient. The management practises to develop the social infrastructure can be determined by the

natural and territorial facts, political facts, economic facts and cultural and spiritual facts [43]. Therefore, it is important to have the social aspects of a disaster quantified to take informed decisions in a crisis situation.

2.8.4 Drawbacks in the current methods in the disaster damage assessments

With the literature analysed, a number of drawbacks can be found in the current methods of disaster management. Especially for Sri Lanka, with the limited number of researches done for the subject of quantification the disaster effects, existing gaps can be huge. Some of the drawbacks are listed as follows.

- The damage evaluations are dominantly done for the physical and tangible direct damages of disasters. A very a smaller number of successive attempts are done in quantifying the damages from indirect tangible, direct intangible and indirect intangible effects of the floods.
- Evaluation of the value of the human life is not carried by many studies due to the ambiguities incorporated within, even though some literature suggests that the economic contribution (e.g.: salary of a person) to the society and the economy could be taken as a representative of one's value to the society.
- When it comes to flood, the flood inundation depth is the most used flood characteristic, while the other characteristics such as the inundated area, velocity, inundation duration are believed to be accurately represented by the inundation depth, which may not be the case always. The other parameters are almost neglected in other studies.
- In most of the studies, the socio-economic aspect is often neglected for quantification analyses, which has a great context of contribution.

3. CASCADING MODELLING OF A FLOOD: A CASE STUDY

Cascading effect is the event of influencing a system or a component of a system, as a result of an incident which took place outside the system, or the sub system, due to the links existing between the systems and the sub systems. As aforementioned in the chapter 2, the cascading modelling can take place once the inter-relations of a system are known, at the time of the disaster. However, to find the interrelations, many sources have to be employed, as most of the interrelations could be hidden to the naked eye, or to a scholar from a single discipline, as the cascading effect always has been multidisciplinary. Therefore, to identify the cascading effects take place at the time of a disaster, the interrelations had to be found in the first place.

3.1 Representation of cascades

In order to identify the interrelations between systems, three methods were used. Those are:

- a) Referring to the EOPs issued by the National Disaster Management Center, and referring to the EOPs sent to the regional disaster management centers or to the representatives of the DMC as known as the Divisional Secretariat (DS) offices.
- b) Referring to the records and news items kept by the DS office regarding various events and proceedings.
- c) Evidence from the literature and the other news items in the days of the disaster

The EOPs published by the DMC is a comprehensive document, which has specified the actions to be taken by 39 government offices and authorities in cases of disasters. These EOPs are clearly defined for the 3 stages of a disaster (pre disaster, during the disaster and after the disaster) and for a range of hazards covering from natural hazards to man-made hazards. It has also demonstrated how the information dissemination flow and the reporting flow should happen (jurisdiction), and for each action, the responsibility is assigned to a particular authorised person [44].

Therefore, from the actions specified in the documents, it was possible to identify the cascades: incidents which take place, along with the responsible authority for each action.

In addition, another set of links were identified by looking at the records kept in the DS offices and the local DMC offices. Since all of the documents, request letters and other documents are preserved with paper trail, it was helpful to identify the actions which were taken place at the times of the disasters and the links between each incident. It was also helpful to identify which incidents have actually taken place and the true magnitude of the incident, apart from what is defined by the book. In addition, the literature and other news from the disaster dates confirmed that some of the incidents should have taken place, in case of flood disasters.

Now since the cascade relationships have been identified, the cascades are represented with their activities and the interrelations within them. Figure 3.1 shows the explored cascade relationships from the aforementioned methods. The explored cascades showed that during a flood, some of the physical facilities will be the primarily affected such as roads, buildings and road infrastructure. Depending on the use of the building, the consequences and the type of the immediate effect will be different. At the same time, some of the services will be disturbed, due to many reasons such as overloading of the facilities, accessibility limitations such as fall of trees. Also, the DMC authorities will start to make the decisions and to act for the post disaster relief work implementations, once the floods strike in.

Within the considered context, the distal ends of the cascade diagram hold on to the activities that takes place in the start of the long-term mitigation planning, such as payment of compensations for fully damaged and partially damaged houses, compensating the household items, cleaning and disposal of the waste and repair of the damaged infrastructure etc.

The next step of this research is to quantify the cascading effect. In other words, it is required to evaluate each link on the contribution from its predecessor to the receiving end. For that purpose, a particular branch is chosen to be studied, due to the data, resource and time limitations incurred with this study. The selected cascade branch is

circled in Figure 3.1 and separately in Figure 3.2. The selected cascade will be evaluated as a proof of concept for the quantification of the impacts of a disaster.

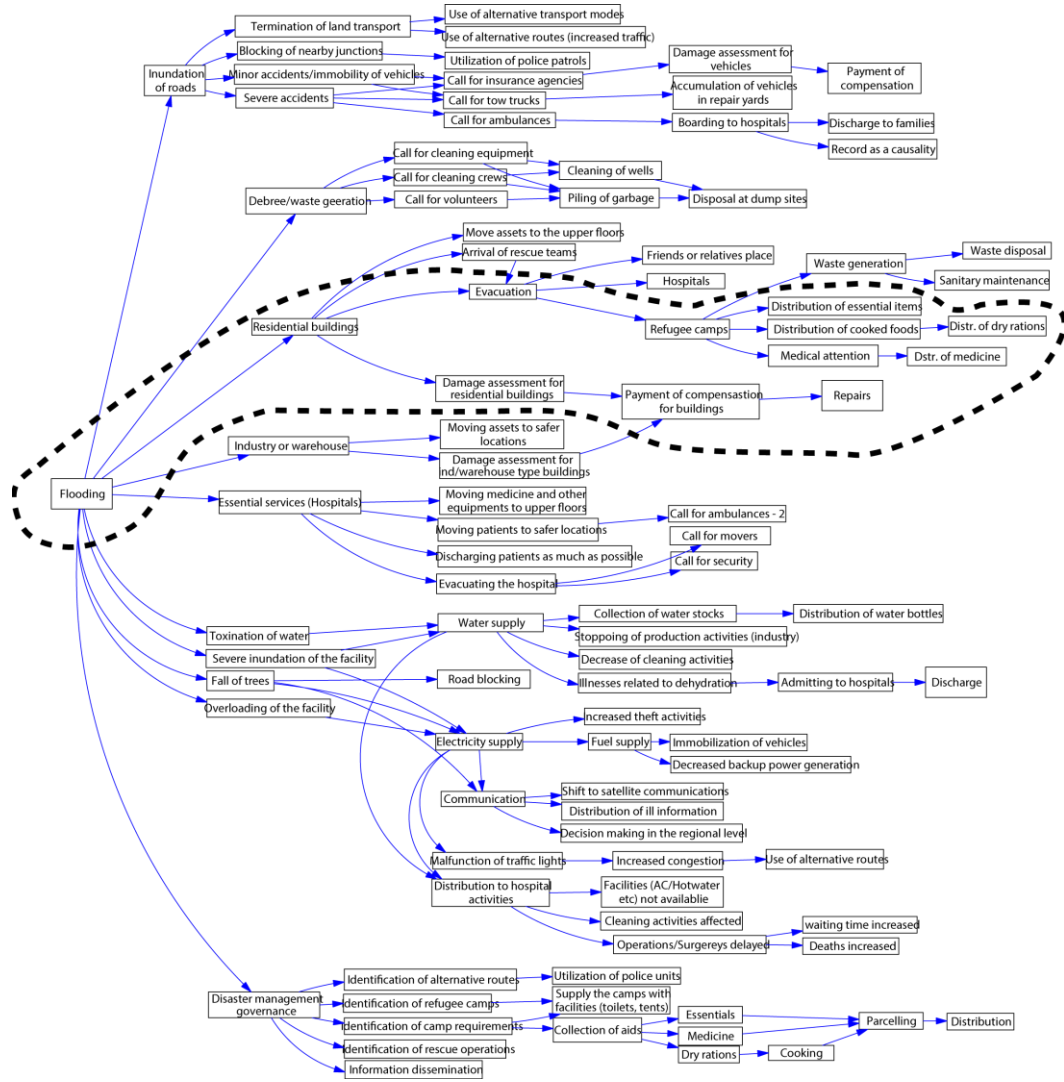


Figure 3.1. Representation of the explored cascade relationships

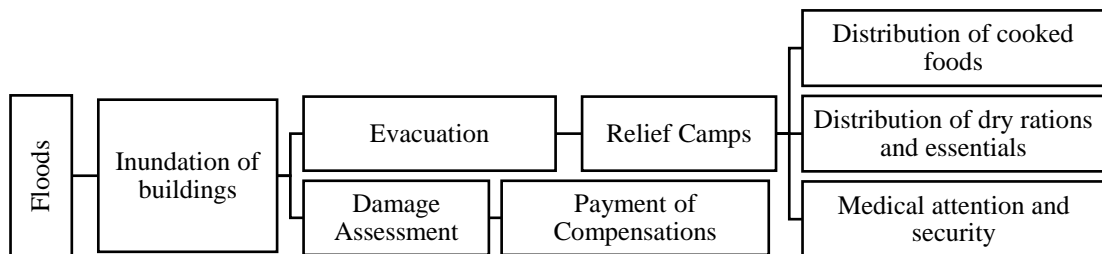


Figure 3.2. Selected cascade branch to evaluate

3.2 Demonstration of the cascading effect: a case study

To evaluate the cascade branch selected in the previous section, it was decided to conduct a case study, to determine the link strengths of the cascade branch. On another perspective, it is to link the flood characteristics shown in the proximal end mathematically to the variables in the distal end, which contain characteristics more related to the human movement and welfare. Therefore, this case study will help in finding the data required to build any correlation that may exist between two given locations of the cascade.

Therefore, for the case study, Kaduwela Divisional Secretariat Division (DS) which is a local government administration unit, of Sri Lanka was selected. Kaduwela DS division has 57 Grama-Niladhari Divisions (GNDs), which are smaller village level administration units under it. A brief introduction to the placement of Kaduwela DS division is provided in Figure 3.3. Figure 3.4 and Table 3.1 shows the GNDs in Kaduwela DS division.

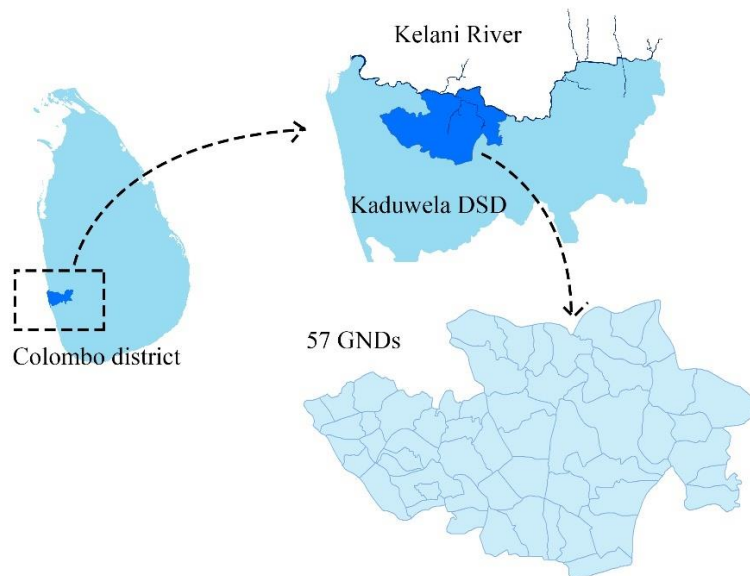


Figure 3.3. Kaduwela DS division

There were many reasons to choose Kaduwela as the case study area. The primary reason was that Kaduwela DS is situated along the boundary of the Kelani River, which is one of the rivers which is having one of the topmost mean annual discharges in the country. Also, Kelani river has the largest basin size of the country, and also has

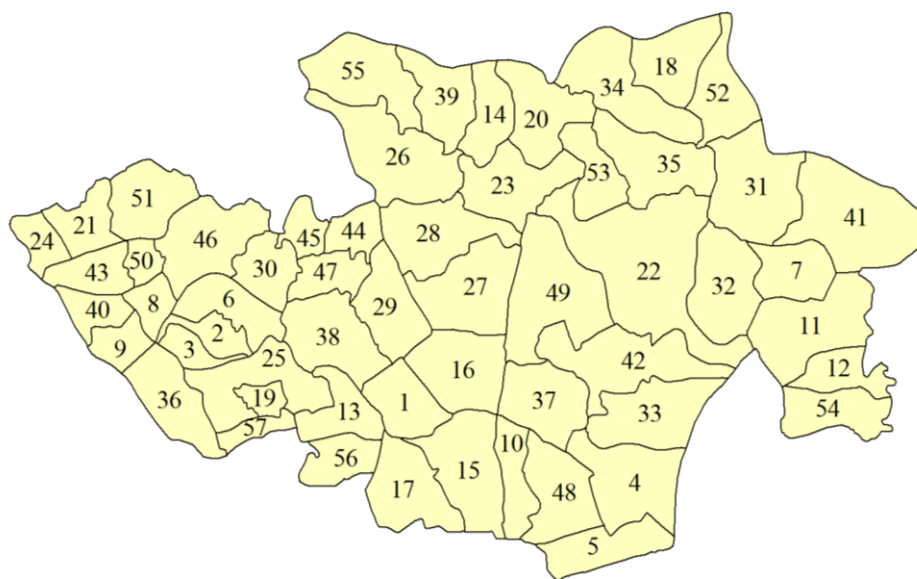


Figure 3.4. GNDs in Kaduwela DS

Table 3.1. Map key for GND map

1	Arangala	21	Kalapaluwawa	41	Ranala
2	Aruppitiya	22	Korathota	42	Shanthalokagama
3	Asiri Uyana	23	Kothalawala	43	Subhoothipura
4	Athurugiriya	24	Kotuwegoda	44	Thalahena North
5	Athurugiriya South	25	Kumaragewatta	45	Thalahena South
6	Batapotha	26	Mahadeniya	46	Thalangama North A
7	Batewela	27	Malabe East	47	Thalangama North B
8	Battaramulla North	28	Malabe North	48	Thaladiyawala
9	Battaramulla South	29	Malabe West	49	Thunadahena
10	Boralugoda	30	Muttettugoda	50	Udumulla
11	Dedigamuwa	31	Nawagamuwa	51	Walpola
12	Embilladeniya	32	Nawagamuwa South	52	Wekewatta
13	Evarihena	33	Oruwala	53	Welihinda
14	Hewagama	34	Pahala Bomiriya	54	Welipillewa
15	Hokandara East	35	Pahala Bomiriya B	55	Welivita
16	Hokandara North	36	Pahalawela	56	Wellangiriya
17	Hokandara South	37	Pore	57	Wickramasinghapura
18	Ihala Bomiriya	38	Pothuarawa		
19	Jayawadanagama	39	Raggahawatta		
20	Kaduwela	40	Rajamalwatta		

the highest runoff/rainfall ratio, at some of the gauge stations [45]. At the same time, a lot of businesses and industrial zones are situated along the river bank, as well as the river is moving through an urban area, there are lots of people who live by the vicinity legally or illegally. The population density of the Kaduwela area is about 2800 people per square kilometre.

Kelani river has recorded its highest discharge in the months of May, June, October and November. And since the river bank area is particularly low-lying, there are floods in these areas in almost every year. Table 3.2 shows some of the number of people and the families affected in the recent years, from Kaduwela DS division, from the floods.

Table 3.2. Affected people and affected families from the recent floods in Kaduwela DS division

Year	2016	2017	2018
Affected people	22,474	11,311	7,018
Affected families	7,105	2,947	1,783

In addition to the damage to the livelihood, Kaduwela has suffered from many infrastructural damages and ecological damages. Due to that, the economic loss and the indirect losses and the intangible losses may have been immense, in each of the aforementioned disasters. And for this case study, administrative boundaries were chosen instead of any other type of physical or geographical boundaries, which is due to the fact that the disaster management processes are handled by the DS divisions and they usually operate within their boundary.

After defining the case study area, the flood data was collected to build the relationships.

3.3 Data collection

Data is collected from various authorities, as the initial intentions were to gather as much as data, to evaluate as much as links in the initial cascade diagram. However, the data and the resources which has a technical background was collected from the government agencies while the data related to the human movement and the spatial

data is collected from the Kaduwela DS division, which is the more localised and ground level authority to capture such data.

3.3.1 Disaster data

Most of the disaster data was captured at the Kaduwela DS office disaster management section. Since Kaduwela does not have a dedicated disaster management center, all of the disaster management functions are implemented through the DS office. Therefore, the resource center ("Sampath Pethikada") of the office has kept all of the records relevant to the disaster situations in the previous years. The term disaster data refers to the data where a lot of general public has interacted with. In other words, the technical emphasis on the data was at a minimum level. All of the datatypes which were able to find from the records are listed below, for the flood events in 2016, 2017 and 2018.

- Number of affected population (GND wise)
- Number of affected families (houses) and Small and Medium Enterprises (SMEs) (GND wise)
- Number and the population at relief camps, with their locations
- Distribution of cooked food, and dry rations with their variation with time and place (Camp wise)
- Variation of the affected people, families and the population at camps with time
- Receipt of funds, and the expenditure of the funds, with time
- Receipt of relief packs and other aids from GOs and other volunteers
- Compensations for damaged houses and SMEs
- Expenses of miscellaneous (fuel, telephone etc.)
- Government circulars and other recommendations
- Requirements initiated and other human requirements

About the data, in some places there are some discontinuities and for some of the data, essential data is missing. For an example, just after the disaster is happened, the

number of people in the camps are not recorded. However, it is understandable that in the very moment that the crisis has started, record keeping may not have been a top priority. On the other hand, data for all three events were recorded in similar standard formats which made it easy for comparison purposes. However, all of the data were in printed and kept in files, therefore, all of the data had to be digitised, before making them suitable for any kind of analysis. Some examples are displayed in Figure 3.5. Furthermore, as mentioned in the list, the maximum resolution of the data is the GND division in the sense of administration boundaries, therefore, any analysis to be conducted would be limited to the resolution of GND divisions. On the contrary, details about the relief camps were available with much details, as the DS division had taken the necessary steps to identify and keep a track record of the capacities of the relief centers by means of number of people can be accommodated, number of toilet

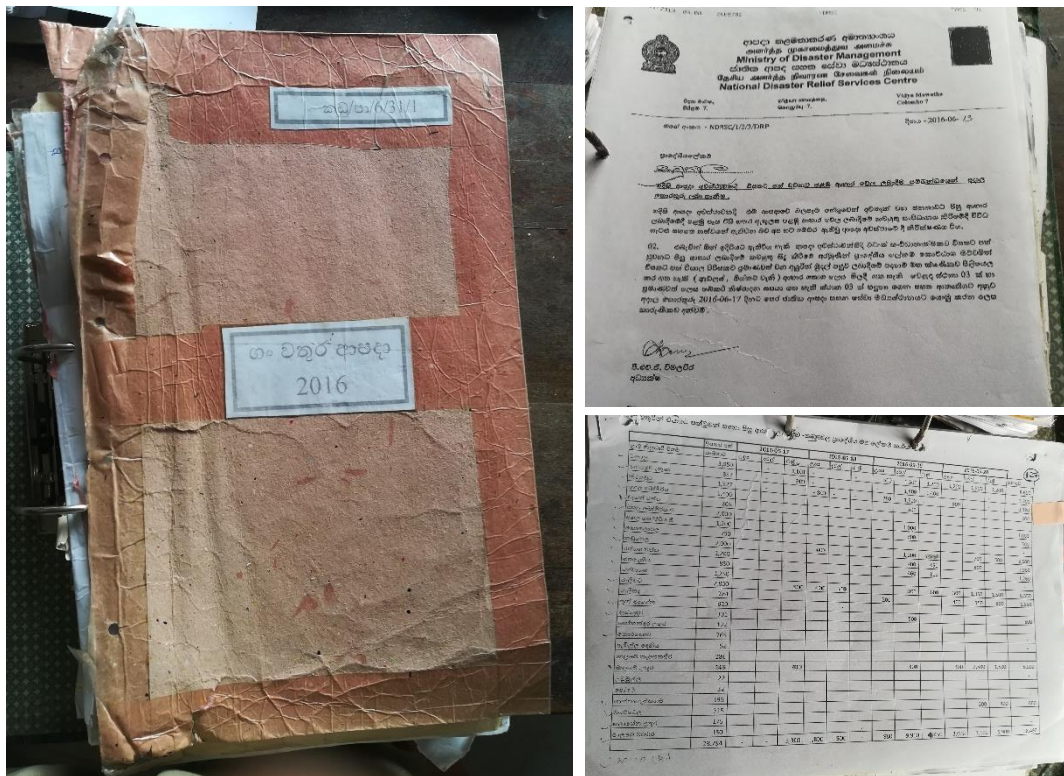


Figure 3.5. Printed and filed document keeping about disaster events

facilities, whether the electricity, telephone and water is readily available as well as the access road details such as the road type as well, after the flood in 2016. The collected data will be presented in the annexes.

In addition to these data, there were records available for all of the requests made for the higher authorities, and records for all of the donations and the other aids accepted. It also carries the records of the voluntary organisations and their contributions at the scene of the disaster. Also, the files contained some of the photographs of the flood



Figure 3.6. Photographs of property damage

scene, which is evident of the flood level as well as the damage done to the properties of the people. Some examples are given in Figure 3.6.

After the disaster data, technical data was collected.

3.3.2 Digital Elevation Mapping (DEM) of the Kaduwela DS division

The DEM of the Kaduwela DS division shown in Figure 3.7 was obtained by the Climate Resilience Improvement Project (CRIP) of the Ministry of Agriculture, Rural

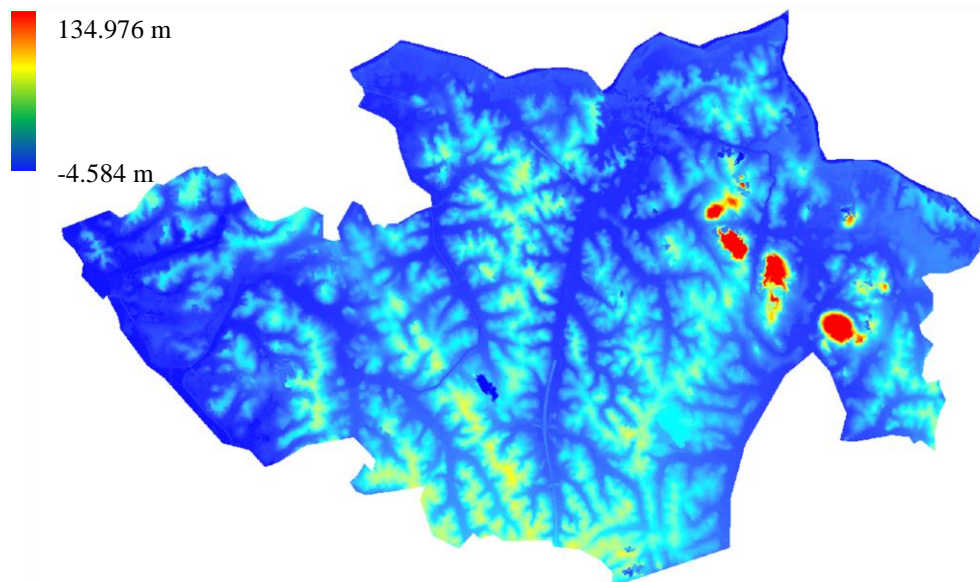


Figure 3.7. Digital Elevation Mapping (DEM) of Kaduwela DS division

Economic Affairs, Livestock Development, Irrigation and Fisheries & Aquatic Resources Development for the research purposes. The resolution of the DEM is 1 m (the lowest distance between two spatial data points), and the DEM was provided as a raster data layer, as the DEM is obtained by a Light Detection and Ranging (LiDAR) survey.

The reason to obtain the DEM was to calculate the inundation depths of the floods for different places at the time of the disaster, as the flood inundation maps are not prepared for the aforementioned disasters. Furthermore, this DEM was used to calculate many other parameters which required the ground elevation to build some parts of the parameters.

3.3.3 Flood extent maps

Next, the flood extent maps were collected from the RiskInfo Website of the DMC (RiskInfo is a website hosted by the DMC, which provides the risk information for various types of hazards for Sri Lanka) [46]. In these maps, the inundated area is shown as the blue patches. Figure 3.8 shows the flood map of the 2016 floods and the Figure 3.9 shows the flood extent map of the 2018 floods for the Kaduwela DS division.

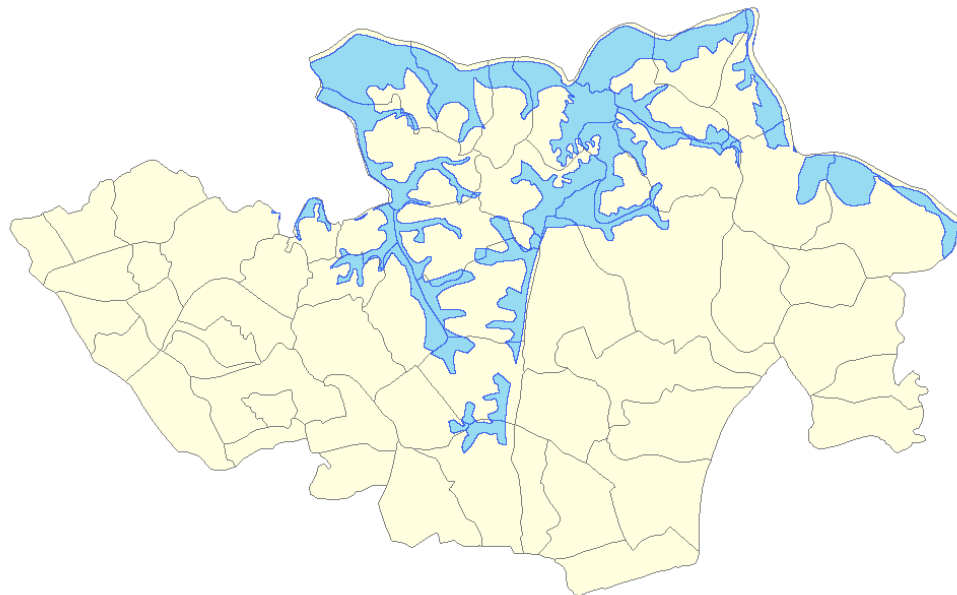


Figure 3.8. Flood extent map of 2016 for Kaduwela DS division [46]

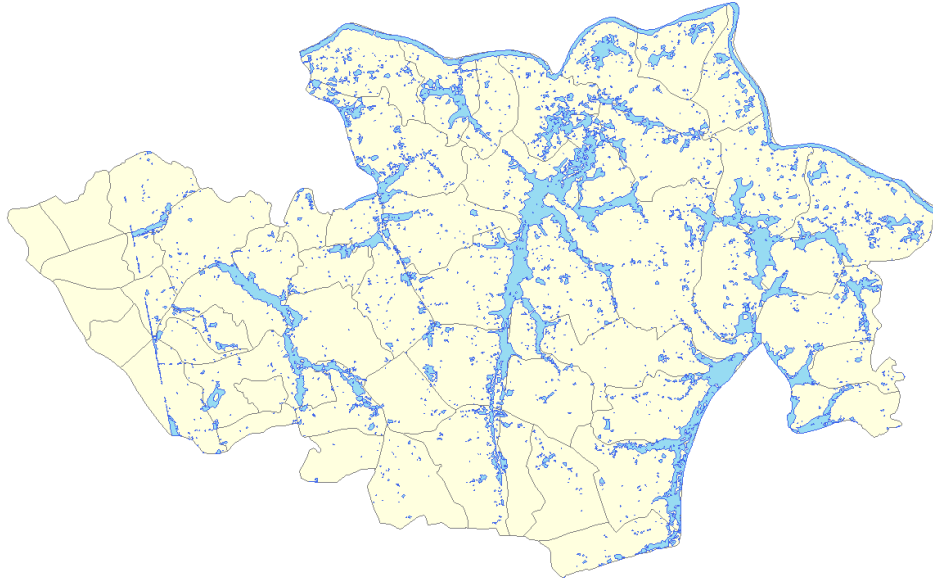


Figure 3.9. Flood extent map of 2018 for Kaduwela DS division [46]

It should be noted the difference between the two flood maps. The map for the 2016 floods is prepared manually, by a field survey conducted by the survey department and the DMC. The maximum flood boundary was marked at the respective locations and later they were connected manually. This exercise is conducted all the length along the Kelani river, for the inundated areas.

The flood map for the 2018 flood is a map produced by a satellite (ALOS). It can be seen that the all of the discrete water patches have been captured by the mapping exercise.

3.3.4 Collection of other data

The other data collected were the building footprints, administrative and other maps from the Survey Department of Sri Lanka and the statistics about the population from the Department of Census and Statistics of Sri Lanka. The building data was initially collected from the OpenStreet maps where the data can be downloaded for free, as well as the data is more updated. However, the data was missing for some of the regions as shown in the Figure 3.10. Therefore, in later stages, a building footprint data layer from the Urban Development Authority (UDA) was used. The data from UDA had information on the building footprint as well as the building height and other minor details.

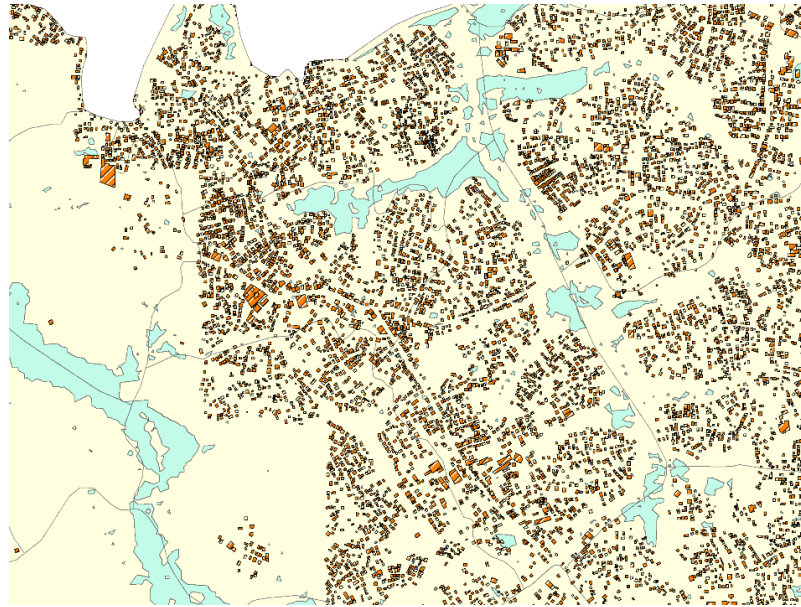


Figure 3.10. Building data from the OpenStreetMaps

3.4 Preparation and the representation of data

3.4.1 Preparation of data

As discussed before, since the one of the goals of the case study is to connect the flood characteristics to the human movement, and as the literature has suggested that the most prominent flood characteristic is the inundation depth which is not provided as a dataset, the inundation depth had to be derived for all of the places. This has to be prepared with the existing flood extent maps and with the existing DEM (ground elevation file).

Since all of the data was processed on Geographic Information System (GIS) platforms (ArcMap Software), the above task was done by initially converting the DEM elevation raster file to a more workable vector layer, which has the point elevation at the resolution of 1 m. Then the inundation depth was calculated for each of the GN division in two methods to result in mean inundation depth for a GN division and to result in the maximum inundation depth for a GN division. The process of obtaining the maximum inundation is as follows.

Initially, the DEM is clipped according to the flood extent map which is discussed in Flood extent maps in section 3.3.3. Now the boundary of the DEM file is having the flood boundary elevation at the boundary. In other words, the ground elevation at the flood boundary is the highest elevation the flood ever managed to climb up to. Since the flood can be assumed to be almost horizontal even at the time of a flow, if the highest flood elevation (which is at the flood boundary) is reduced by the ground elevations, then the inundation values are derived. Then it is straightforward to calculate the mean inundation depths and to determine the maximum inundation for each GNDs. The illustration in Figure 3.11 can be used to get around the method used to calculate the flood inundation depths.

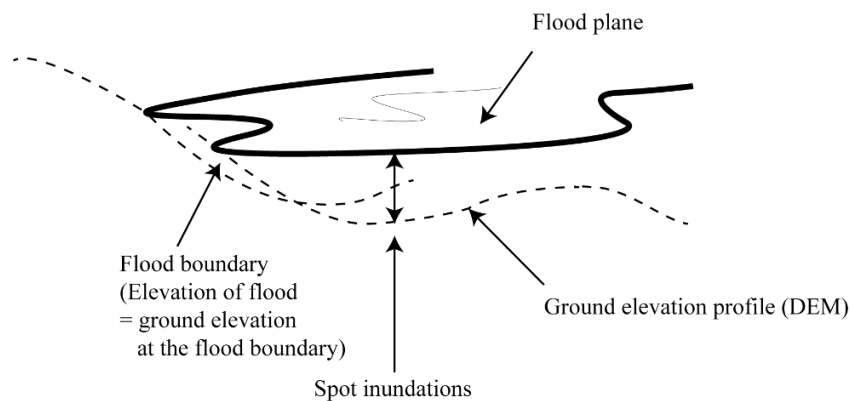


Figure 3.11. Ground elevations and the flood boundary

In order to do so, the boundary elevation at the flood limit has to be highly accurate, as all of the calculations are done with respect to the elevation of the boundary. Therefore, to maintain a high accuracy, while selecting the boundary elevation, the average boundary elevation from three locations have been used. See equations 1 and 2 for the formulas used to calculate the depths.

$$\text{Mean Inundation Depth} = \text{Highest Elevation (at flood boundary)} - \text{Mean Elevation} \quad (1)$$

$$\text{Maximum Inundation Depth} = \text{Highest Elevation} - \text{Minimum Elevation} \quad (2)$$

3.4.2 Representation of data

Before going into the data analysis, it is sensible to take an idea about the magnitudes of the events and the impacts of the events. This will make the comparisons make more sense. Figure 3.12 shows the impact to the people in 2016 floods (GND wise) and Figure 3.13 shows the same for the floods in 2018 (GND wise).

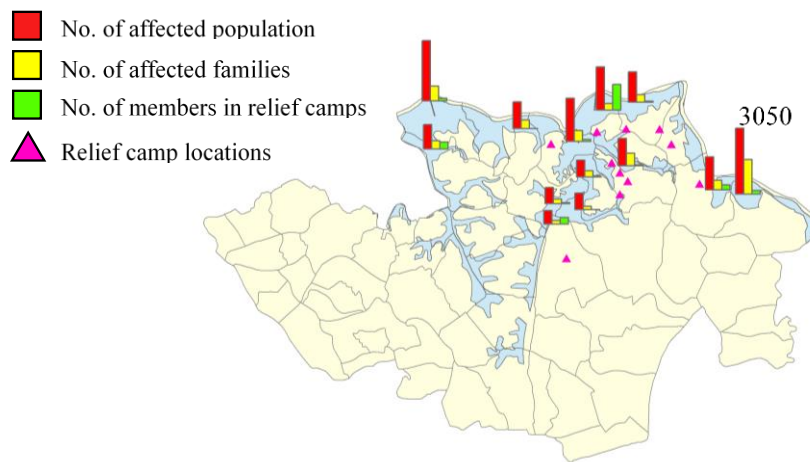


Figure 3.12. Impact to the people in 2016 floods

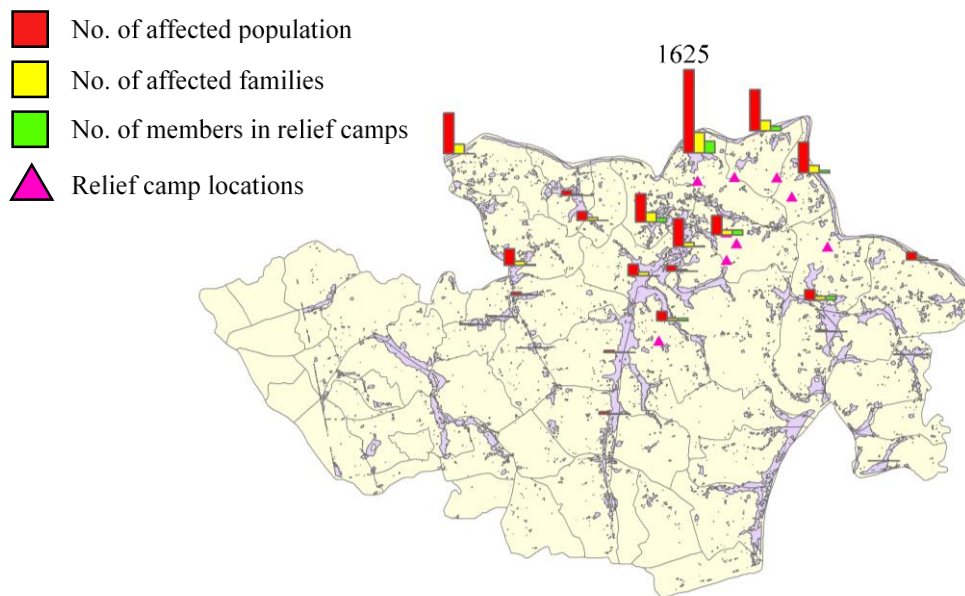


Figure 3.13. Impacts to the people in 2018 floods

4. INTERPRETATION OF DATA

Chapter 4 looks in to answer the question 'how the gathered data could be interpreted in order to identify any relationships or patterns'. In order to do that, initially, the data was visualised in graphs or tabulated formats to see whether there is any pattern or a characteristic which can be identified by overlooking the data. This was initially achieved by plotting many data types against the timeline of the disaster, to see whether there are patterns which vary with time. Then the analysis was continued to check on the mathematical correlations between each data categories. Then depending on the results, further mathematical analyses were carried out.

4.1 Variation of the number of affected people with time

The variation of the number of people affected with time for 2016 floods are shown in Figure 4.1, and the same for 2018 floods are shown in Figure 4.2. Here, term affected refers to the state where the people have to leave their houses and move in to either a relief camp, or to a house of relatives and friends. For 2016 disaster, the disaster has happened on the 18th of May, and the records were kept only after the 21st of May.

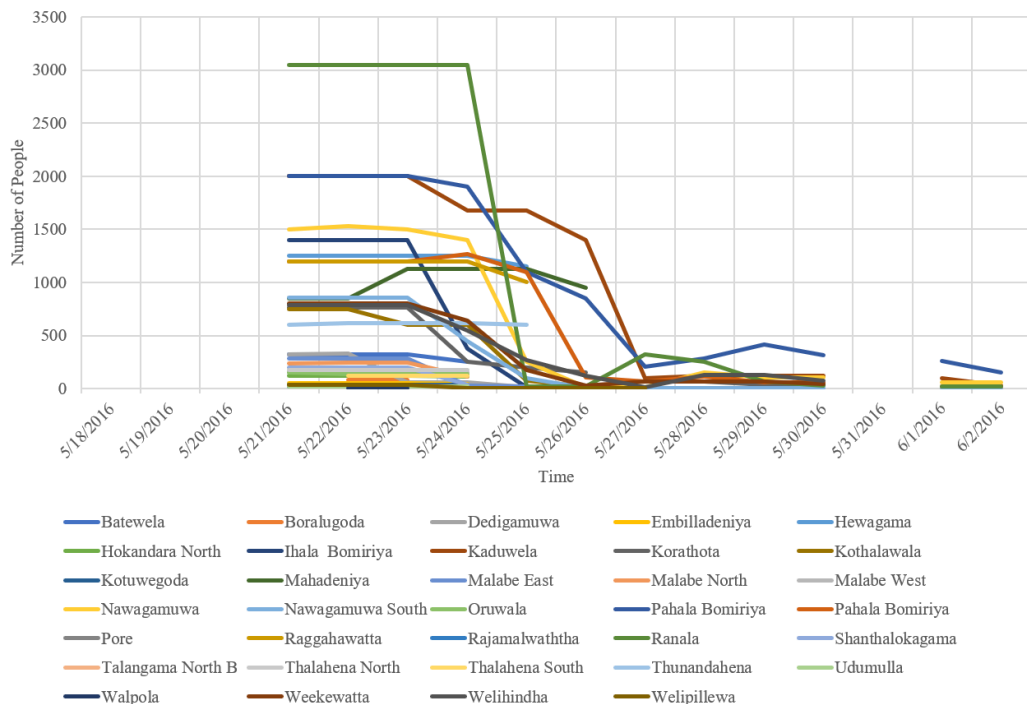


Figure 4.1. Variation of the number of people affected with time for 2016 floods

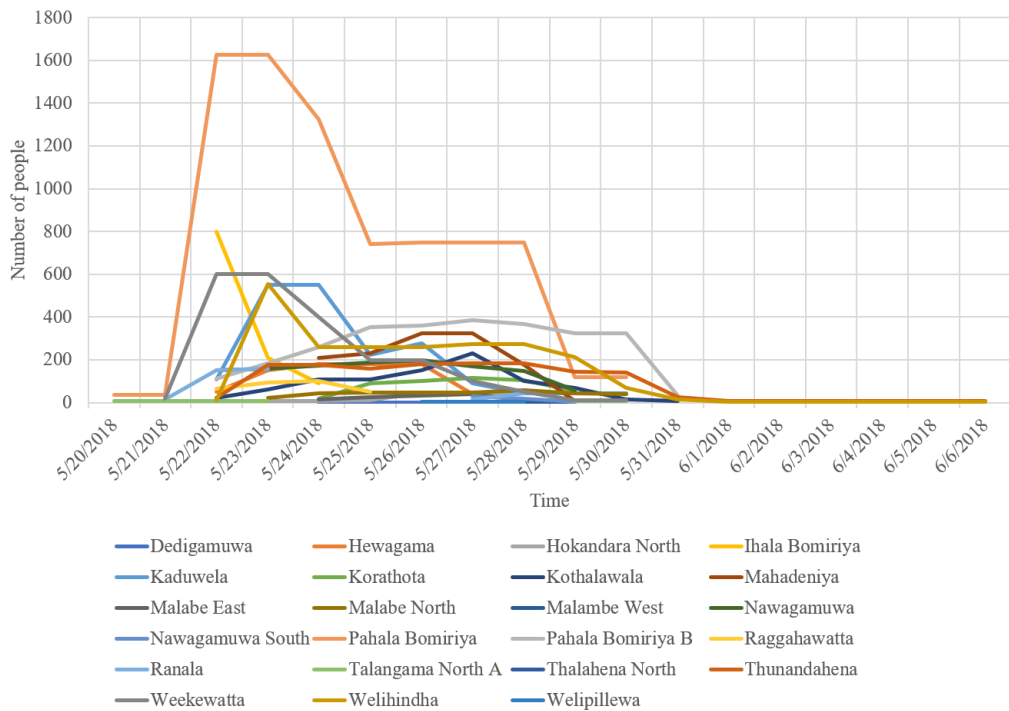


Figure 4.2. Variation of the number of people affected with time for 2018 floods

However, it can be seen that there is a sharp drop of the number of people affected after the 23rd of May, and some after the 24th of May, which means the flood threat has been reduced and the people have started to move back in to their houses.

For the 2018 floods, the data set is more complete, as the number of affected people is recorded from the very beginning of the disaster which was initiated on the 20th May 2018. From this plot, it could be understood that there will be sharp rises of the number of affected people just after the disaster is happened. However, unlike in 2016 floods, the sharp drop of the number of people towards the end of the disaster has happened in two phases. This is because there was a second hazard of flooding, once the initial flooding threat was thought to be drawn away. If carefully looked in to the graphs, it can be seen that this second flood hazard has affected more GNDs than in the first flooding incident, making the authorities to start recording the number of affected people in many new GNDs.

4.2 Variation of the number of people in relief camps

The number of people who came to the relief camps were also recorded, with the location of the camps. Figure 4.3 shows how the number of people in camps were varied in each GND, in 2018 floods. As similarly in Figure 4.1 and Figure 4.2, there are sharp drops present in this graph as well, but those drops may not be significant as a date for the drop is not clear. One reason for this is that some people had to stay in the relief camps for prolonged periods, as their houses were partially or fully damaged.

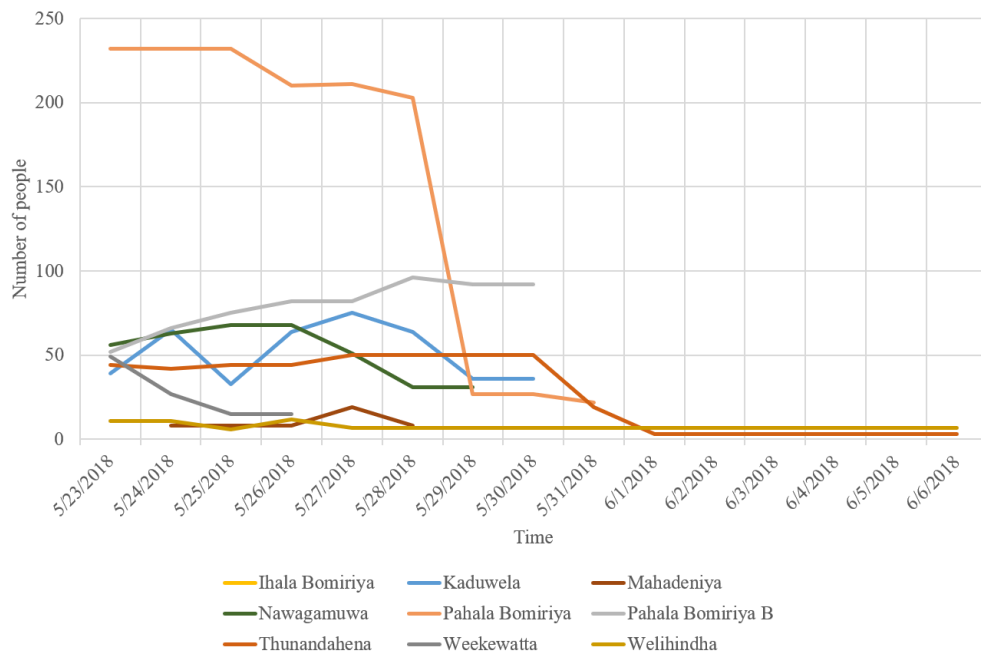


Figure 4.3. Number of people in camps for 2018 floods

Figure 4.4 shows a comparison between the number of the affected people in the Pahala Bomiriya GND, and the number of people who came to the relief camps, in 2018 flood. From the figure, it is clear that a large portion of the affected people have not gone to the camps, which means, they had a place for shelter either at a friend's or a neighbour's home. On the other hand, it could be interpreted as the people who are accounting for the gap had a place for shelter, which is an indication of their preparedness for the disaster. The people who went to the relief camps may be the people who were not much prepared for the disaster nor they had a place to reside, within the reachable area, or at the lowest level of the economy/social hierarchy.

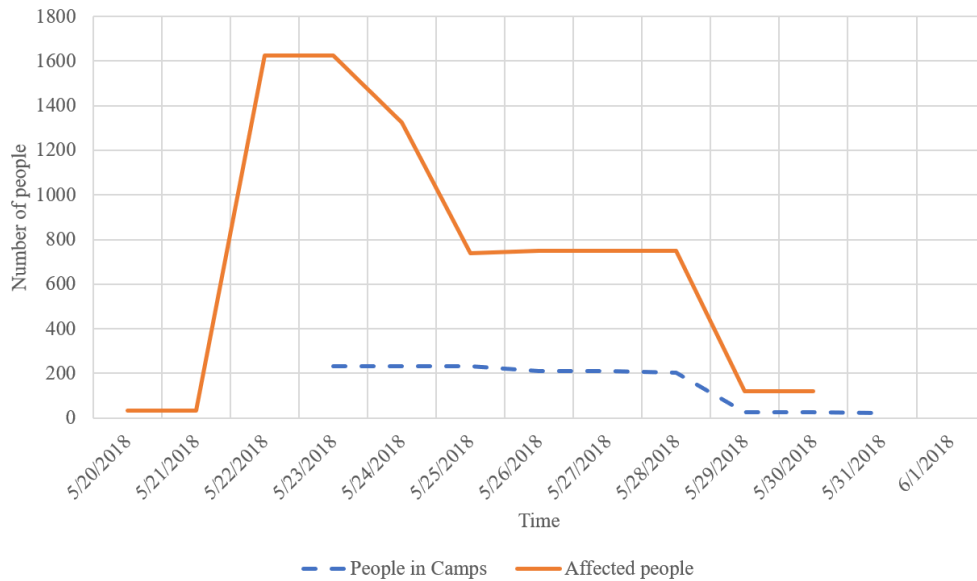


Figure 4.4. Comparison between the number of the affected people in the Pahala Bomiriya GND, and the number of people who came to the relief camps, in 2018 flood

However, it should be noted that the personal perceptions will matter as well, while deciding to go to a relief camp, with special regards to the toilet and other sanitation facilities, security and comfort at the relief camps. Sometimes, the attitude of staying at the relief camp lower their social status.

Another observation is that the drop of the number of people in the camps and the number of the people affected has begun to drop down simultaneously, in the case of Ihala Bomiriya. But this relationship was not necessarily seen at all of the other GNDs.

4.3 Distribution of cooked food

In a disaster situation, once the people are facilitated in camps and other places such as relative's, the next immediate task of the disaster management authorities are to provide cooked food for the affected. This is usually done in two methods. First method is delivering the cooked food packets to the affected people directly, while the second method is to provide the funds to the Grama Niladhari (GN) officer to cook food on their own and facilitate themselves with the cooked food. The second method is implemented only if the GN officer is capable of finding dry food supplies in the disaster situation. The government circular about the cooked food distribution states that the cooked food should be distributed for three days from the start day of the

disaster, via the relief camps. If there is a requirement to extend the cooked food delivery, written requests and permissions should be obtained from the District Secretariat office. Figure 4.5 shows the total number of distributed cooked food packets for each of the meals for the 2016 flood.

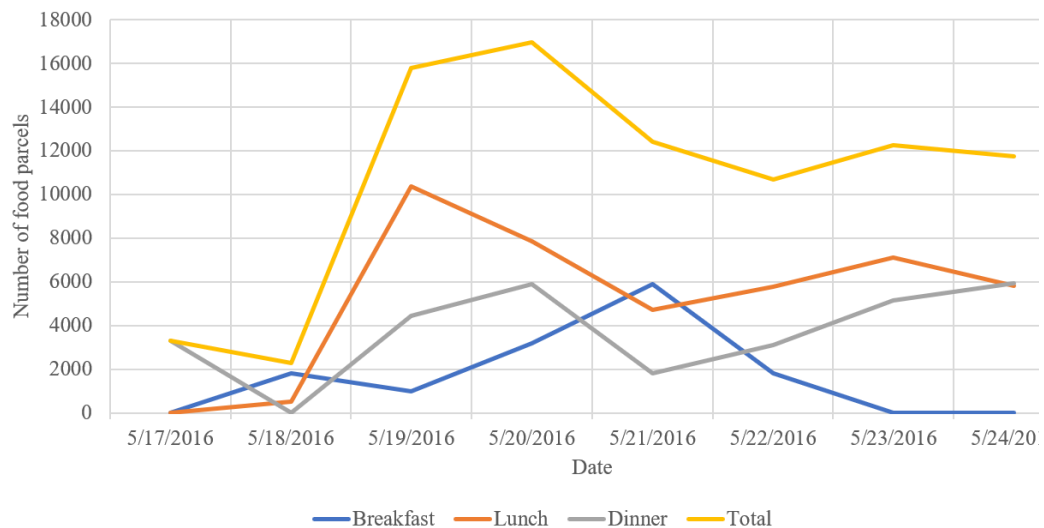


Figure 4.5. Number of cooked food packets distributed

In the case of 2016 floods, the extensions were taken to distribute the cooked food, as the nominal three days were ended in 19th May. For most of the time, breakfast is not provided as it was self-supplied by cooking at the homeplaces and in relief camps. However, lunch and dinner were provided at many occasions. The documents revealed that the cooked food was distributed via the relief camps, however the number of the food packets were decided by the number of the people affected (not by the number of people in camps).

In the first 3 days, the funding for the cooked food distribution was from the government, and after 3 days, volunteers have also stepped in to provide cooked food packets, therefore, for the next 3-4 days, the funding to be utilised have become less. And after the 8 days, the cooked food distribution from the DS office was stopped, as the volunteers overtook the cooked food provision and distribution function, as well as the relief camps developed the capacity to cook food on their own.

4.4 Distribution of dry rations

After the cooked food distribution is over, the next task of the DS office is to provide the dry rations for the affected families. Here, the government circular to distribute dry rations specify that one parcel of dry rations should be given to one family per week. The value of the dry ration packet is dependent of the number of the people in the family as shown in the Table 4.1.

Table 4.1. Recommended value of the dry rations parcel

Number of people in the family	Value of the dry rations parcel (Rs.)
1	700
2	900
3	1100
4	1300
5 or more	1500

**Source: The records from the resource center, Kaduwela DSD*

The circular furthermore establishes the contents of the parcel, and the buying prices of them, as shown in the Table 4.2. These dry rations are sourced either by buying from the local vendors and supermarkets, or by the neighbouring DS divisions who have the capacity, on payment bases. In 2016 floods, it was evident that DS divisions of Padukka, Rathmalana, Matara etc. have sent the dry rations on payment basis.

Table 4.2. Recommended buying prices for relief pack

Item	Buying price	Item	Buying price
Rice	1 kg (Rs. 81)	Kaha	50 g (Rs. 30)
Potatoes	1 kg	Culinary	35 g (Rs. 50)
Big onions	1 kg (Rs. 84)	Chilli powder	100 g (Rs. 40)
Sugar	1 kg	Coconut	1 (Rs. 64)
Lentils	1 kg (Rs. 150)	Soya meat	90 g (Rs 60)
Sprats	1 kg	Tea	100 g
Salt	400 g (Rs. 40)	Salmon	425 g (Rs. 128)
Chilli	100 g	Milk powder	1 kg

**Source: The records from the resource center, Kaduwela DSD*

Alongside with the provision of dry rations, DS divisions have worked to provide other essentials, as shown in the Table 4.3. The data documents and the letters are evident that these items are sourced from the government authorities on the return basis, or on the payment basis and by volunteers.

Table 4.3. Provision of other essentials

Item	Basis of distribution
Water tanks	One per relief camp/GN division
Tents	
Kitchen sets	One per affected family
Mats	
Pillows	
Bed sheets	
Clothes	One per person, depending on age and sex
Schooling stationery	One per child (child count is taken separately)
Pairs of slippers	One per person
Sanitary pads	One per lady

**Source: The records from the resource center, Kaduwela DSD*

4.5 Administration, security and healthcare

Administration function is headed by the DS division, and it is regulated through the GN officers. One relief camp per GN division is nominated as the main camp of the GN division, and all of the data collections and other regulatory work is handled from the main camp. Security officers from the Army are assigned to each camp, depending on the camp size, and at least, 2 army personnel are assigned for a camp.

When it comes to healthcare at the disaster situations it was not common for people to go to the hospitals for the medical assistance, even though hospitals have an EOP to prepare for such emergency requirements. Instead, teams of medical officers visit the relief camps and the teams are assigned to the camps based on the number of people affected, in that particular GND. The medical team composition consists of 1 to 5 medical officers, 1 to 4 nurses, 1 to 3 supportive staff and a driver with an ambulance.

4.6 Cash flows of the DS division

It is important to investigate how the financing goes on in case of a disaster, because financial shortages can be a hindrance for an effective disaster management mechanism. Kaduwela DS records were very thorough in keeping the financial records along with the compensation and other receipt records. Figure 4.6 shows the cash flow of the DSD, immediately after the disaster, which is aligned with the plot for the food distribution.

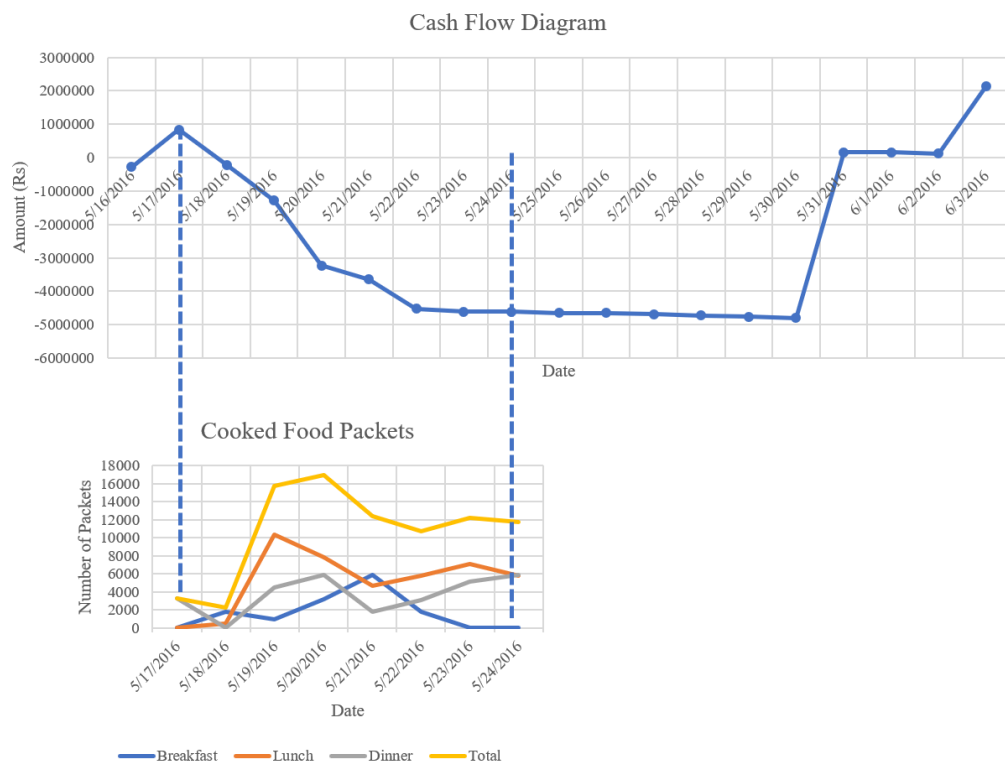


Figure 4.6. Cash flow of the DSD and the cooked food distribution, just after the disaster

It can be seen that the DSD was in a negative cashflow just after the disaster, as expenses had to be made. The cash has been mainly utilised for the distribution of cooked food parcels, as evident from the co-aligned declination of the cash flow graph and the inclination of the total food packets distribution function. In addition, the main functions which were carried in the initial days of the disaster are the cleaning activities and the fuel purchases for the vehicles.

Even though there is a negative cashflow of little less than Rs. 5,000,000, the recession has only existed for a duration of two weeks, and then the cash has flowed in from the municipal councils. Therefore, considering the disaster situation as well, this recession may not have been a serious trouble for the DS division.

4.7 Compensations and other expenses

4.7.1 Compensations

In the long run of the recovery actions after a disaster, for all of the flood victim families and for the small and medium enterprises, a compensation of Rs. 10,000 is given by the government and it is given through the DS division. Additional compensations are given upon the valuation done by the DS division with the help of GN officers. These compensations are paid under three categories: compensations below Rs. 10,000, within Rs. 10,000 and Rs. 25,000 and more than Rs. 25,000. The aforementioned compensations are usually for the structural damages, such as house and wall damages, while the building content damages such as damages to TVs, sofas and refrigerators are evaluated and paid separately.

4.7.2 Other expenses and work carried out

The DS division carries out many other tasks, leading with the cleaning activities. The main cleaning requirements are the drinking water wells and septic tanks. Along with this, the requirement to clear the debris from the public facilities such as roads and public gathering places rises as a requirement as well. For these efforts, resources such as gully bowsers are borrowed from the DS divisions, sometimes from which are located very far from the DS division. For the cleaning, volunteers and the army has taken the front to conduct the cleaning and clearing activities, while facilitating them with supplies and food was undertaken by the DS division. Some of the miscellaneous expenses paid by the Kaduwela division are displayed in Table 4.4 and Table 4.5.

As far as the human resource is concerned, additional officers from distal GN divisions were allocated to the Kaduwela DS to assist with the duties, and some of them were facilitated with telephones and even by paying for their mobile phones.

Table 4.4. Miscellaneous expenses occurred to the Kaduwela DS division

Labour cost	11,500
Fuel	110,597
Food	17,235
Telephone	11,700
Electricity	3,075
Stationery	538,567
Packing	52,970
Kitchenware	154,705
Boats	20,000
Maintenance	10,688

**Source: The records from the resource center, Kaduwela DSD*

Table 4.5. Cleaning expenditure for Happawela, Kaduwela DS

Item	Per hour rate (Rs.)	Number of hours	Per day rate (Rs)	Number of days	Total
Backhoe	1,750	7	12,250	10	122,500
Other equipment					14,740
Debris transport			2,000	15	30,000
Tree saw					37,500
Labour	1,500	8	12,000	10	120,000
Breakfast	75	15	1,125	10	11,250
Lunch	140	20	2,800	10	28,000
Tea	75	20	1,500	10	15,000
Unexpected					20,000
Transport of government officials					15,000

**Source: The records from the resource center, Kaduwela DSD*

However, the aforementioned miscellaneous data are extremely hard to capture into a model, as these expenses are made out of the requirements which occur in the disaster.

5. MATHEMATICAL ANALYSIS OF DATA

This chapter will have the mathematical data analysis done for the available data categories. The intention of the data analysis is to discover the relationships which will connect the flood characteristics to the effect on the people. For this, Pearson Correlation tests for linear regression were performed having the null hypothesis 'there is no significant prediction of "variable representing the effect on humans" and "variable representing flood characteristics"'. Furthermore, multi-criteria analyses were conducted to predict the variables representing the effect on humans, based on the combinations of the flood characteristics and other characteristics. For this, the significance level was taken as 0.05 (confidence 95%) for the independent variables.

5.1 Correlation between the data categories

Recalling the cascade represented by Figure 3.2, now it is possible to build relationships which connects the flood characteristics to the human movement, and to the other activities as shown, with the gathered data categories. Therefore, initially, the correlations with the data categories described in the section 3.3.1 was checked for correlations. The results of the correlations check, the coefficient of correlations (R^2) is displayed in Table 5.2 and Table 5.3, for the floods in 2016 and 2018 respectively. The data points are formulated from GNDs, one point per entry from each GND. Even though a single DS division is taken for the study, different GNDs had had varying flood (entry) characteristics such as the inundation depth, inundation area etc. Therefore, there are plenty of different data points to generate accurate results.

A colour code was used to represent the strength of the Pearson correlations. The green colour of the tables represents the correlations are closer to 1, which is better, and the red colour indicates that the correlations are closer to 0. The intermediate yellow colours and the shades of green and red represent the intermediate correlations.

A key for the entries in Table 5.2 and Table 5.3 are presented below in Table 5.1, to demonstrate how the entries were derived and to show what are the meanings of the entries.

Table 5.1. Key for the entries

Entry	Method/Equation
Affected Families	Number of the affected families, as per the records of the Kaduwela DS division
Affected Max Population	Number of the affected people, as per the records of the Kaduwela DS division
BuilDen	Number of families/Inundated area
GenBuilDen	Number of families/Area of the GND
In_Area	Inundated area
InAreaDen	Inundated area/Area of the GND
InpopDen	Number of affected population/Area of the GND
InpopDenIn	Number of affected population/Inundated area
Max_Elevation	Maximum elevation of the GND
MaxIn	Maximum inundation depth (Flood elevation – Minimum elevation)
MEAN_Elevation	Mean elevation of the GND
MeanIn	Mean inundation depth (Flood elevation – Mean elevation)
MIN_Elevation	Minimum elevation of the GND
OpenStreet	Number of the buildings inundated from the floods, as derived by the buildings from the OpenstreetMaps. (Obtained by clipping the building layer according to the flood extent layer, and by counting the number of buildings in the clipping result, in GIS platforms)
PopDen	Population of the GND/Area of the GND
Population	Population of the GND (Source: Dept. of Census)
ShapeArea	Area of the inundation in GND (flood extent in GND)

Table 5.2. Correlation coefficients (R²) for the parameters for 2016 floods

	AffectedFamilies	Affected Max Po	BuilDen	genBuilDen	In_Area	InAreaDen	InpopDen	InpopDenIn	Max_Elev	MaxIn	MEAN_Elev	MeanIn	MIN_Elev	OpenStreet	popDen	Population	ShapeArea
AffectedFamilies		0.7597	0.0448	0.0873	0.1968	0.0503	0.4393	0.4759	0.0019	0.0032	0.00002	0.0828	0.1886	0.2467	0.2647	0.0035	0.0871
Affected Max Population			0.0348	0.2705	0.4948	0.2438	0.745	0.5131	0.0139	7E-05	0.0337	0.0224	0.5219	0.5064	0.3427	0.0029	0.0928
BuilDen				0.011	0.1456	0.1381	0.1005	0.0588	0.065	0.2211	0.2582	0.0297	0.2575	0.0621	0.2826	0.1223	0.0354
genBuilDen					0.4347	0.6262	0.4526	0.0241	0.005	0.046	0.0819	0.014	0.6606	0.8408	0.0223	0.1137	0.0413
In_Area						0.7211	0.3694	0.03	0.1177	0.2571	0.1225	0.0793	0.5843	0.6663	0.3025	0.0033	0.063
InAreaDen							0.4526	0.0396	0.0492	0.0161	0.2221	0.0048	0.6237	0.6125	0.0807	0.1733	0.0466
InpopDen								0.5255	0.0471	0.087	0.0777	0.0099	0.6583	0.4656	0.1154	0.0972	0.0049
InpopDenIn									0.2762	0.1426	0.0212	0.0541	0.2898	0.0453	0.1299	0.0167	0.0279
Max_Elevation										0.8503	0.1467	0.2157	0.0015	0.0493	0.0018	0.0649	0.001069
MaxIn											0.0103	0.364	0.1018	0.1306	0.0197	0.0169	0.0023
MEAN_Elevation												0.2676	0.2202	0.0021	0.1233	0.1371	0.0064
MeanIn													0.0538	0.0498	0.0013	0.0033	0.0034
MIN_Elevation														0.4184	0.2463	0.0941	0.0131
OpenStreet															0.1464	0.0219	0.0052
popDen																0.0067	0.437
Population																	0.4105
ShapeArea																	

Table 5.3. Correlation coefficients (R²) for the parameters for 2018 floods

	AffectedFa	Affected M	BuilDen	genBuilDen	In_Area	InAreaDen	InpopDen	InpopDenIn	Max_Elev	MaxIn	MEAN_Elev	MeanIn	MIN_Elev	OpenStreet	popDen	Population	ShapeArea
AffectedFamilies		0.9575	0.00001	0.0676	0.0058	0.0157	0.8046	0.7786	0.0948	0.0076	0.1849	0.0057	0.1028	0.1122	0.0283	0.0171	0.0008
Affected Max Population			0.0018	0.0433	0.0049	0.0364	0.8997	0.7982	0.1183	0.011	0.2192	0.0067	0.112	0.0725	0.0394	0.0333	0.0039
BuilDen				0.1713	0.5355	0.2693	0.0038	0.0633	0.0354	0.1189	0.183	0.01295	0.0068	0.0209	0.1691	0.0216	0.1689
genBuilDen					0.0095	0.0161	0.0622	0.1751	0.0222	0.0035	0.0315	0.003558	0.0224	0.6568	0.0076	0.0381	0.0396
In_Area						0.6828	0.0085	0.0347	0.0141	0.0934	0.0941	0.0707	0.0238	0.1002	0.3578	0.051	0.547
InAreaDen							0.0741	0.0695	0.0644	0.0458	0.2145	0.1007	0.0624	0.0663	0.2486	0.0052	0.1248
InpopDen								0.8252	0.1162	0.0148	0.2666	0.004	0.0781	0.0378	0.0184	0.0826	0.052
InpopDenIn									0.0822	0.0073	0.1793	0.0034	0.2302	0.1194	0.000327	0.0369	0.0471
Max_Elevation										0.101	0.5197	0.0978	0.7345	0.0006	0.0109	0.0119	0.0156
MaxIn											0.0053	0.2634	0.0043	0.0314	0.035	0.0227	0.1073
MEAN_Elevation												0.1874	0.4541	0.0317	0.0013	0.0088	0.0002
MeanIn													0.0366	0.0185	0.0075	0.0734	0.0336
MIN_Elevation														0.0123	0.0209	0.0047	0.0088
OpenStreet															0.0607	0.0055	0.067
popDen																0.0247	0.3268
Population																	0.3617
ShapeArea																	

5.1.1 Highlights of the correlations

From Table 5.2 and Table 5.3, it can be seen that there is a limited number of green shaded correlations, and most of the correlations are either yellow or red in colour. To begin with, the correlations between the number of the affected people and the number of affected families can be taken in to consideration. Figure 5.1 shows the Pearson correlations for 2016 floods and Figure 5.2 shows the Pearson correlations for 2018 floods.

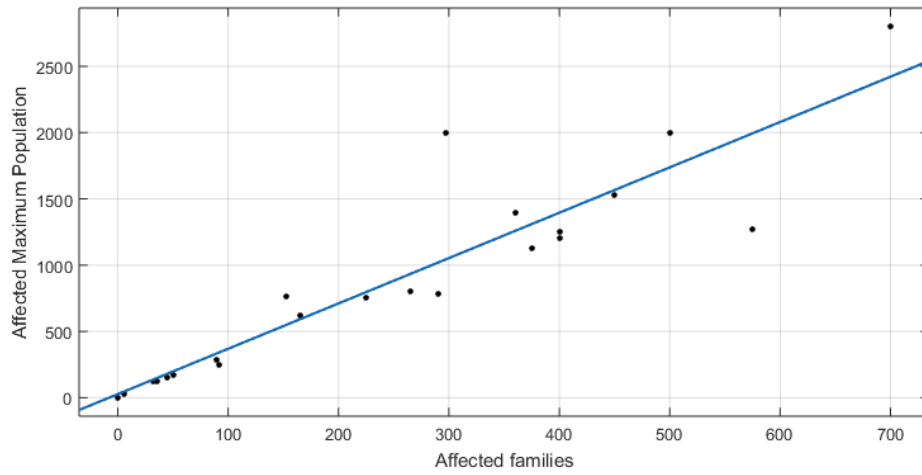


Figure 5.1. Affected maximum population vs Affected families in 2016

$R^2 = 0.7597$, equation: $y = 3.421x + 26.78$

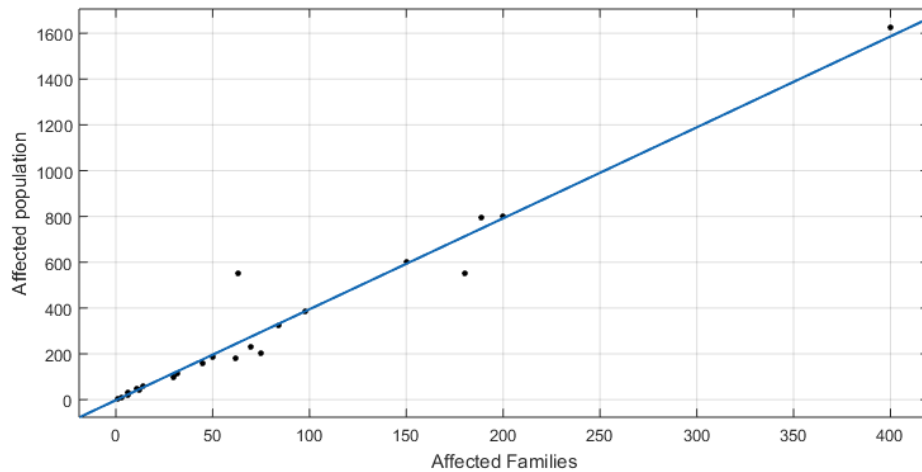


Figure 5.2. Affected maximum population vs Affected families in 2018

$R^2 = 0.9575$, equation: $y = 3.974x - 2.793$

Another interesting observation was the correlation of the inundated area to the affected population. It could be considered as moderately correlated to each other, relative to the correlations obtained so far. Figure 5.3 shows the relevant graph, and the R^2 is equal to 0.4948. At the same time the parameters of inundated area and the number of inundated buildings from the OpenStreetMaps showed an R^2 value of 0.6663.

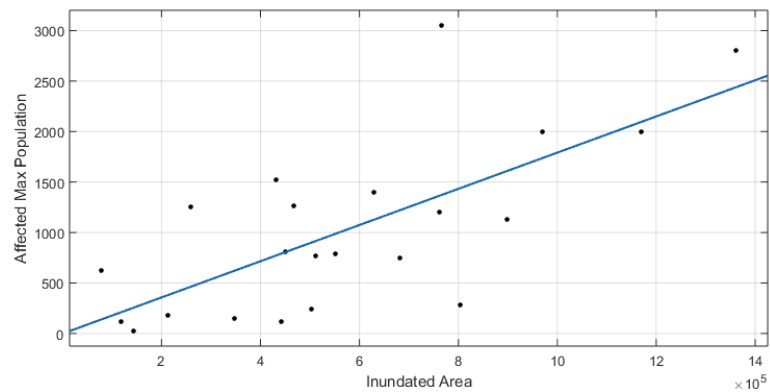


Figure 5.3. Affected maximum population vs Inundated area 2016

One final, yet the most interesting observation is the correlations shown by the parameter minimum elevation. It showed correlations with many parameters such as the number of affected families ($R^2 = 0.5219$) and inundated area ($R^2 = 0.5843$). Figure 5.4 shows the correlation between the inundated area and the minimum elevation of the GND, in the shape of power series.

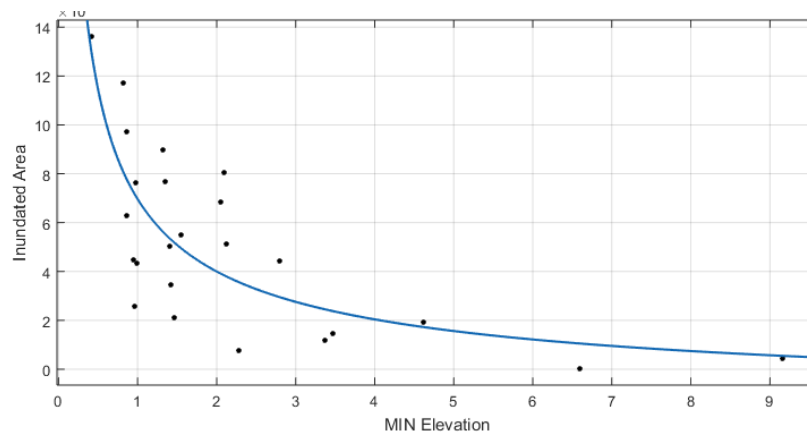


Figure 5.4. Inundated area vs Minimum elevation 2016

However, the best correlation between a flood related and a non-flood related variable were recorded between the minimum elevation and the maximum number of people affected ($R^2 = 0.5219$). And this relationship has a polynomial correlation, which could be defined by $y = 330.2 x^2 - 1996 x + 3132$, as an empirical relationship where y represents the affected maximum population and x represents the minimum elevation of the GND.

5.2 Correlations with the modified entries

With the obtained results in the section 5.1, since there were a smaller number of strong correlations, the attention was drawn into the derivation of new entries. The results of the Person correlations check, the coefficient of correlations (R^2) is displayed in Table 5.5 and Table 5.6, for the floods in 2016 and 2018 respectively. The data points are formulated from GNDs, one point per entry from each GND. The green colour of the tables represents the correlations are closer to 1, which is better, and the red colour indicates that the correlations are closer to 0. The intermediate yellow colours and the shades of green and red represent the intermediate correlations. In addition, more outliers in the data set were removed in this process.

A key for the entries in Table 5.5 and Table 5.6 are presented below in Table 5.4, to demonstrate how the entries were derived and to show what are the meanings of the entries.

Table 5.4. Key for the entries

Entry	Method/Equation
Affected Families	Number of the affected families, as per the records of the Kaduwela DS division
Affected Max Population	Number of the affected people, as per the records of the Kaduwela DS division
Building Density	Number of buildings in the GND/Area of the GND
GnArea	Area of the GND
Highest Elevation of GND	Highest elevation of the entire GND
Lowest Elevation of GND	Lowest elevation of the entire GND
Min Elevation	Lowest elevation of the inundated area of the GND
Population	Population of the GND according to the department of Census and Statistics, Sri Lanka
Population Density	Population of the GND/Area of the GND
Inundated Area	Inundated area of a GND
Theoretical Affected Families	= Building density \times Inundated area
Theoretical Affected Population	= Population density \times Inundated area
UDA inundated Buildings	Number of inundated buildings as derived by the buildings from the Urban Development Authority (UDA). (Obtained by clipping the building layer according to the flood extent layer, and by counting the number of buildings in the clipping result, in GIS platforms)
UDA Total Buildings	Number of the buildings in the GND, as derived from the building data from UDA.

Table 5.5. Correlation coefficients (R²) for the modified parameters for 2016 floods

	Affected F	Affected M	Building D	GnArea	Highest El	Lowest El	Min Elevat	Population	Population	Inundated	Theoretical	Theoretical	UDA inund	UDA Total
Affected Families	0.8191	0.0859	0.0871	0.1102	0.7546	0.6073	0.01	0.2294	0.3638	0.3525	0.2602	0.4433	0.0283	
Affected Max Population		0.0775	0.034	0.0021	0.6397	0.7613	0.0037	0.307	0.5689	0.4788	0.2221	0.5713	0.0686	
Building Density			0.415	0.0023	0.0049	0.0391	0.0034	0.7216	0.1618	0.0103	0.0307	0.0253	0.0008	
GnArea				0.0192	0.0038	0.00005	0.4105	0.437	0.063	0.0034	0.0014	0.0099	0.4333	
Highest Elevation of GND					0.2531	0.1412	0.1174	0.000004	0.0153	0.0208	0.0121	0.0084	0.0486	
Lowest Elevation of GND						0.575	0.0044	0.0337	0.1072	0.1281	0.0515	0.2826	0.0229	
Min Elevation (y)							0.1526	0.1791	0.7032	0.7088	0.6545	0.4366	0.029	
Population								0.0007	0.0033	0.0125	0.0027	0.0054	0.7262	
Population Density										0.3025	0.1291	0.0867	0.0299	
Inundated Area											0.8391	0.8433	0.0148	
Theoretical Affected Families												0.8964	0.0224	
Theoretical Affected Population													0.6701	
UDA inundated Buildings													0.0308	
UDA Total Buildings														

Table 5.6. Correlation coefficients (R²) for the modified parameters for 2018 floods

	Affected F	Affected M	Building D	GnArea	Highest El	Lowest El	Min Elevat	Population	Population	Inundated	Theoretical	Theoretical	UDA inund	UDA Total
Affected Families	0.9575	0.0001	0.0008	0.0031	0.699	0.2237	0	0.0053	0.0003	0.0733	0.00107	0.1527	0.0076	
Affected Max Population		0.0023	0.0246	0.1422	0.2667	0.3581	0.0364	0.0141	0.0008	0.0293	0.0028	0.0679	0.0028	
Building Density			0.189	0.0047	0.2364	0.0103	0.0976	0.7567	0.3989	0.0055	0.0437	0.0613	0.2196	
GnArea				0.0054	0.0314	0.0422	0.2918	0.2925	0.5052	0.1686	0.1814	0.0968	0.27	
Highest Elevation of GND					0.0008	0.1287	0.0484	0.0104	0.0233	0.0563	0.0283	0.0001	0.0199	
Lowest Elevation of GND						0.0942	0.0435	0.116	0.0336	0.0402	0.0098	0.2462	0.1014	
Min Elevation (y)							0.0054	0.0084	0.0284	0.034	0.0247	0.0519	0.0003	
Population								0.1649	0.0022	0.0407	0.0786	0.141	0.7442	
Population Density										0.5042	0.0673	0.0436	0.0952	
Inundated Area											0.5321	0.5496	0.0052	
Theoretical Affected Families												0.836	0.1354	
Theoretical Affected Population													0.1092	
UDA inundated Buildings													0.2333	
UDA Total Buildings														

As opposed to the previous correlation check, this check was able to yield better correlations as shown in the Table 5.7 below.

Table 5.7. Correlations among the modified entries, 2016 floods

	Entry 1 (y)	Entry 2 (x)	R²	Equation
1	Affected Maximum population	Affected families	0.8191	$y = 3.42x + 30.40$
2	Affected families	Lowest elevation of the GND	0.7546	$y = -3.00x^{4.51} + 404.30$
3	Affected Maximum population	Lowest elevation of the GND	0.6397	$y = -42.77x^{3.35} + 1635$
4	Affected families	Minimum Elevation	0.6073	$y = 325.9x^{-1.35}$
5	Affected Maximum population	Minimum Elevation	0.7613	$y = 1917x^{-0.73} - 703.10$
6	Population density	Building density	0.7216	$y = 1.24x$
7	Inundated area	Minimum elevation	0.7032	$y = \left(\frac{41.93}{x+25.98}\right)^{31.39}$
8	Affected families from computation	Minimum elevation	0.7088	$y = \left(\frac{185.91}{x+177.43}\right)^{178.54}$
9	Affected population from computation	Minimum elevation	0.6545	$y = \left(\frac{32.79}{x+23.54}\right)^{27.25}$
10	Inundated area	Affected families from computation	0.8391	$y = 471.21x + 1.11 \times 10^4$
11	Inundated area	Affected population from computation	0.8433	$y = 392.74x - 1.25 \times 10^4$

There are many more other good correlations as shown in the Table 5.5. At the same time, the correlations from the Table 5.6 also confirms the results represented by the Table 5.7, as the similar criteria have shown better correlations.

5.3 Multi-criteria analysis for the flood characteristics

From the previous section, the single variables were taken to get the correlations from the generic entries to the flood related entries. Therefore, the next intention of the study was to identify whether there are any multi-criteria correlations that can be used to connect the generic details to the flood characteristics. For the multi criteria analyses, the R^2 value and the significance values are taken to judge on the model fit, and for each of the run, a confidence interval of 95% was used. Table 5.8 shows the details of the multi criteria analysis, which contains the dependant variable, independent variables and their coefficients, R^2 value and the statistical significance (p value) of the model in predicting the number of affected people. Table 5.9 shows the results of the multi criteria analysis in predicting the number of affected families, in a similar way as shown in Table 5.8. It should be noted that while choosing the independent variables, priority was given to correlate the flood characteristics with non or partially flood related characteristics.

While choosing the dependent variable, initially the number of affected people was considered, and tested for the combinations of the independent variables. Initially the independent variables were chosen according to the regression relationships obtained in the previous analyses, and then the independent variables were filtered according to their significance values for the tests performed later, from the results of the former tests. Then the similar tests were performed for the dependent variable number of affected families, to have a comparison between the dependent variables.

Table 5.8. Results of the multi criteria analysis for the affected population

Dependant variable	Independent variables	Coefficients	R²	Significance
Affected population	Minimum elevation of the GND	-128.283	0.512	0.168
	Area of Inundation	0.02		0.001
	Constant	239.747		
Affected population	Area of Inundation	0.002	0.610	0.000
	Area of the GND	0.001		0.013
	Population	-0.328		0.010
	Constant	674.115		
Affected population	UDA inundated buildings	1.333	0.655	0.000
	Maximum Elevation of GND	-52.953		0.029
	Constant	1184.707		
Affected population	Population of GND	-0.524	0.650	0.009
	Total number of houses	0.421		0.013
	Area of Inundation	0.002		0.000
	Minimum elevation of GND	-53.271		0.605
	Constant	387.250		
Affected population	Area of the GND	0.001	0.783	0.000
	Population of GND	-0.365		0.001
	UDA inundated buildings	1.232		0.002
	Constant	786.505		
Affected population	Area of the GND	0.001	0.790	0.042
	Population of GND	-0.305		0.048
	UDA inundated buildings	1.033		0.010
	Maximum Elevation of GND	-32.381		0.224
	Total number of houses	0.146		0.328
	Constant	836.505		

Table 5.9. Results of the multi criteria analysis for the affected families

Dependant variable	Independent variables	Coefficients	R²	Significance
Affected families	Minimum elevation of the GND	21.930	0.235	0.884
	Area of Inundation	0.000		0.345
	Constant	21.107		
Affected families	Area of Inundation	0.000	0.398	0.067
	Area of the GND	0.000		0.031
	Population	-0.136		0.039
	Constant	313.530		
Affected families	UDA inundated buildings	0.375	0.448	0.003
	Maximum Elevation of GND	-27.361		0.036
	Constant	509.609		
Affected families	Population of GND	-0.151	0.411	0.052
	Total number of houses	0.210		0.042
	Area of Inundation	0.000		0.091
	Minimum elevation of GND	10.420		0.639
	Constant	30.916		
Affected families	Area of the GND	0.000	0.527	0.009
	Population of GND	-0.129		0.029
	UDA inundated buildings	0.326		0.006
	Constant	255.699		
Affected families	Area of the GND	0.000	0.693	0.054
	Population of GND	-0.148		0.025
	UDA inundated buildings	0.296		0.006
	Maximum Elevation of GND	-26.542		0.027
	Total number of houses	0.149		0.065
	Constant	372.112		

With the data categories considered it will be possible to create good relationships based on the R² value and the significance values, to predict the human impact from

the flood characteristics, mathematically. By looking at the values of the R^2 , it could be seen that the correlations obtained for affected people are much representative than the correlations obtained for the affected families.

5.4 Linear correlations for additional compensations

In the compensation process, it was evident that after the number of people is recorded, everybody is subjected to a compensation of Rs. 10,000. However, since the additional compensations are paid based on the damages, the relationship between the total number of houses (families) damaged, and the number of houses which required the additional compensations for structural damage and the content damage was attempted to find.

Figure 5.5 shows the correlation between the number of the houses which required additional compensations for structural damages and the total number of affected houses (families). The R^2 value is 0.9257, and the relationship is given by the equation $y = 0.8968x^{0.9209}$, where y is the dependent variable and the x is the independent variable. Similarly, Figure 5.6 shows the relationship between the number of houses which required additional compensations for the building content damage and the total number of houses. The R^2 value for the relationship is 0.9031, while the relationship is given by $y = 0.0014x^2 + 0.137x + 26.366$, where y is the dependent variable and the x is the independent variable.

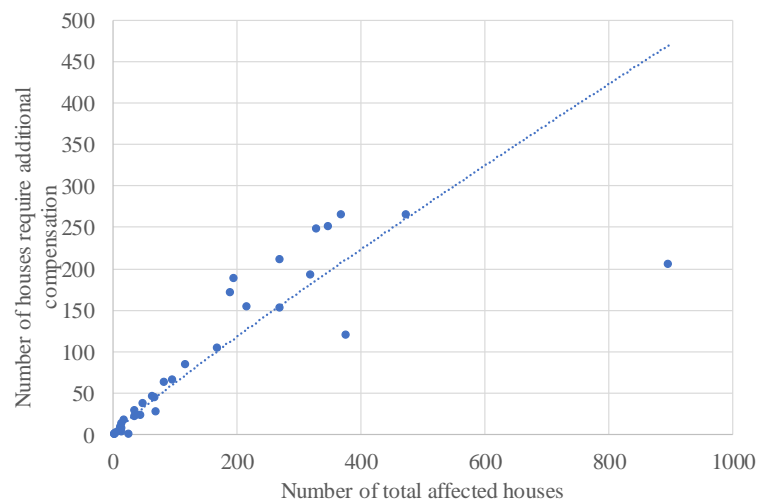


Figure 5.5. Number of houses required the additional compensations for structural damage vs number of total affected houses

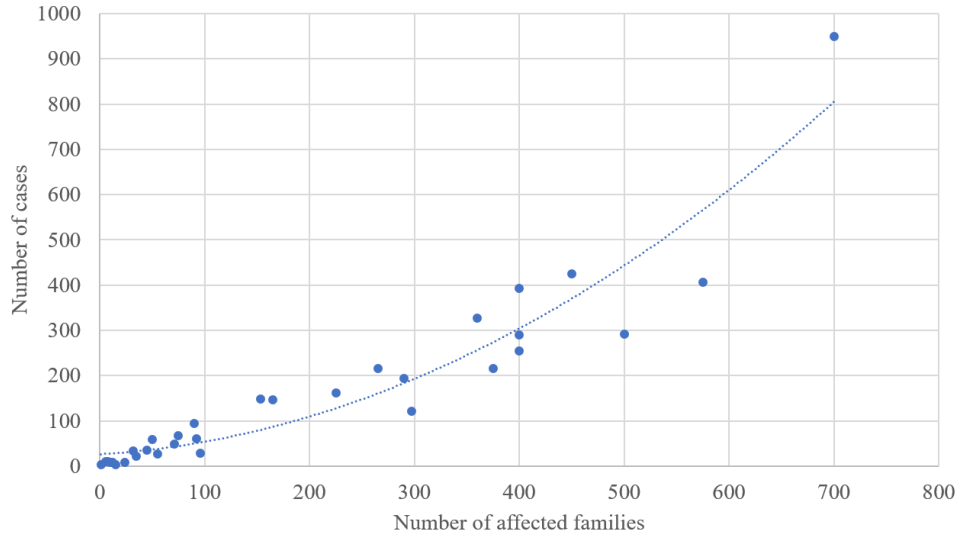


Figure 5.6. Number of houses required additional compensations for content damages vs number of affected families

In addition, the amount compensated for the building content damages against the number of reported content damage cases are given by the relationship $y=19,440x+81,695$ where x is the number of reported content damage cases, and y is the compensated amount. This relationship is derived by the plot shown in Figure 5.7. The R^2 value for the relationship is 0.9875.

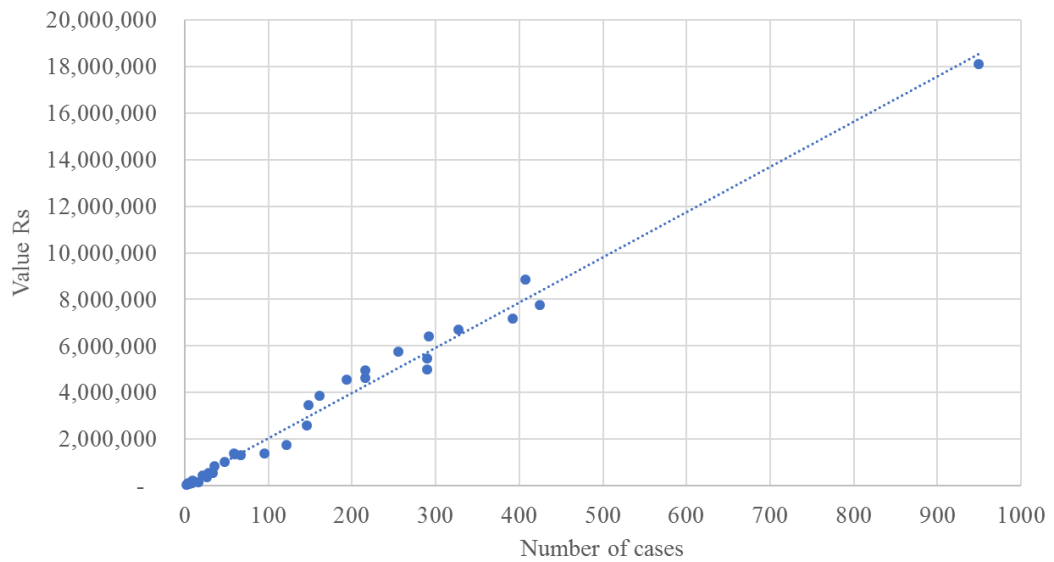


Figure 5.7. Value of building content damage compensations vs number of recorded cases

The relationships obtained in this section could be used to derive the number of houses which require additional compensations for the structural damage, the number of houses that require additional compensation for the content damages and the amount required to pay the compensations once the totally affected number of houses were provided. This information will be particularly important when there are requirements to estimate the amount required for compensations, in cases of calculating opportunity costs for projects which will eliminate the requirement to pay the compensations.

Now, since all of the mathematical relationships have been formed to connect and quantify the links shown in Figure 3.2, the cascade model can be well represented with the quantified relationships.

6. RESULTS AND DISCUSSION

This chapter will summarize the findings and will convert it to a more useable format, ultimately developing into a model that could be used to estimate various types of information, once the flood characteristics are fed in to the model. The preferred flood characteristic is the inundation area, and the model is capable of producing the outputs of number of affected people, families, number of food parcels and dry ration parcels required, number of other facilities required, amount of compensations required etc. to capture the total effect on the community, caused by the disaster.

6.1 Reconstruction of the cascade diagram for the number of affected populations

The cascade diagram shown in the Figure 3.2 is having the activities which take place in the case of the disaster. However, with the data collected and as analysed in the previous chapters, now it is possible to present cascades with a more data category driven approach. Since there is more than one relationship to relate one event to the other event, and also since there are multiple methods to capture the impact and the flood characteristics as shown in the previous sections, alternative mathematical models will be developed which can evaluate the final impact independently, and the model which gives the closest results to the actual values can be taken as the most representative model to represent the cascade effect in the disaster.

Figure 6. represents the methods that the affected population can be estimated, using the correlations derived in so far. The proximal end of the cascade is started with the flood extent, or the area of inundation, as to start with, some kind of a flood characteristic should be input to the model. Another reason is that with many leading government and private projects, there are flood modelling studies being carried out, and the results generated from those studies (flood extent layers and preferably inundation layers) can be used directly in this model to create flood scenarios. In addition, the proximal end can be started with the lowest elevation of the GND and also the results obtained by the multi criteria analysis can be used as well. Significantly, here the parameter of inundation depth was not a significant entry for the data gathered.

In the Figure 6.1, the distal end is the affected number of people, and the number of outputs is presented within brackets. For each distal end, the derivation method is different from one to another, therefore, the results taken will be different from one to another.

To evaluate the results given by the model, each of the distal end will be obtained for a given set of the input parameters from the original data, and then the obtained output will be compared with the actual number of populations which got affected. From this method, the best option to evaluate the number of people affected will be chosen. Note that the usage of the abbreviation of APCORR stands for affected population purely by correlations, and the abbreviation of the APCOMP stands for affected population by computations. The affected population by computation is usually taken as the product of the inundated area and the population density of that particular area. Similarly, the abbreviations AFCORR and AFCOMP stand for the long forms of affected families by correlations and affected families by computations, respectively. The affected population by computation is usually taken as the product of the inundated area and the building density of that particular area. The results referring to the APCORR and AFCORR are purely based on the correlated relationships.

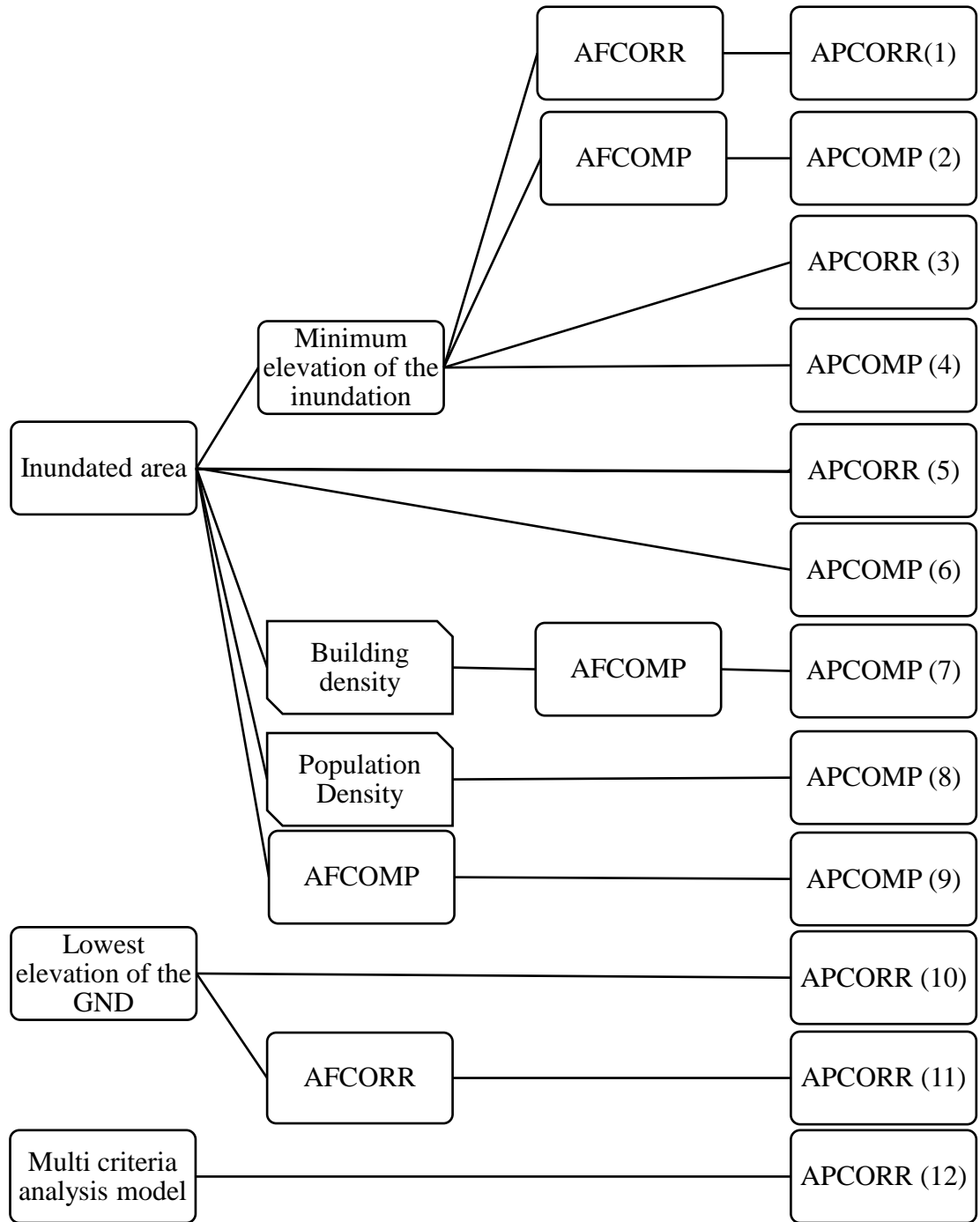


Figure 6.1. Cascade diagram with different approaches to find the affected population

Between two rounded rectangles in the Figure 6.2, there is a correlation relationship, and if a \square shape is in between the rounded rectangle shapes, it means that the simple multiplication of the parameter in the \square shape and the preceding rounded rectangle will result in the parameter in the following rounded rectangle.

The results of the comparison are showed in Table 6.1. Denoted by the '*' are resulting in affected populations by computation.

Table 6.1. Data created by the mathematical models for affected population

Original Data	Figures created by the models											
	1	2	3*	4	5*	6	7*	8*	9*	10*	11	12
1250	411	656	368	724	502	792	1098	1000	823	1590	1399	169
1400	719	1286	774	1683	867	1586	2064	1780	1572	1594	1400	1143
2000	1071	1815	1146	2545	1536	2318	2907	2467	2264	1577	1394	2062
765	615	1093	650	1381	711	1332	839	945	1333	907	945	1711
750	768	1372	831	1820	950	1701	2114	2278	1682	905	943	35
1130	988	1706	1065	2364	1366	2163	2307	1869	2118	1154	1144	1500
286	887	1561	961	2126	1167	1961	1733	2193	1926	334	394	786
246	609	1081	642	1362	703	1317	1437	1903	1318	334	394	-225
150	481	813	471	956	557	981	1413	1166	1001	163	210	318
1527	550	961	566	1179	629	1165	1107	954	1174	1573	1393	964
2000	1333	2109	1386	3042	2086	2746	2261	2204	2669	1600	1402	1892
1268	580	1021	604	1271	664	1241	1277	1174	1246	1370	1291	673
1200	844	1495	915	2019	1086	1870	2115	2201	1841	1556	1387	1441
3050	850	1504	921	2033	1097	1882	1502	1170	1852	-3155	-4460	2762
175	373	571	309	601	481	693	920	961	729	163	210	-349
120	290	385	168	342	451	489	549	572	536	-8169	-13978	-261
26	315	439	212	416	457	546	607	623	590	-96	-82	-327
805	564	990	584	1223	646	1201	1302	1259	1209	1589	1399	612
784	651	1161	693	1487	761	1421	855	1048	1416	905	943	491
2800	1642	2384	1642	3517	2730	3158	2770	3388	3058	1482	1353	2841

To choose the best fitting model, the data created by the model are benchmarked with the data which were originally gathered from the Kaduwela DS. The deviation of the data was checked from the equation 3, and then the sum of the deviations and the average values of the deviations were checked from the values from equation 4 and 5 respectively.

$$\text{Deviation of data} = \frac{|N_i - S_i|}{S_i} \quad (3)$$

$$\text{Sum of deviation of data} = \sum \frac{|N_i - S_i|}{S_i} \quad (4)$$

$$\text{Average of the deviations of the data} = \frac{1}{n} \sum \frac{|N_i - S_i|}{S_i} \quad (5)$$

where: N_i = generated data from the models

S_i = Corresponding standard (original data) from Kaduwela DS

n = Number of datasets

The results from the above check are shown in Table 6.2.

Table 6.2. Results of the similarity test for the affected population

Model	Sum of deviations	Average of deviations
1	24.83	1.24
2	37.27	1.86
3*	19.51	0.98
4	43.27	2.16
5*	32.60	1.63
6	48.37	2.42
7*	54.91	2.75
8*	58.16	2.91
9*	50.45	2.52
10*	79.72	3.99
11	128.62	6.43
12	29.93	1.50

*Affected population by computations

From the results of the Table 6.2, it is clear that the model having the least deviations should be used. From that view, the best suitable model is the model 3. However, it should be noted that the model 3 is resulting in theoretically affected population. The models 1, 5 and 12 are also giving the viable solutions, compared to the original data. Therefore, for the prediction of affected population, the linear regression model of model 1, or the multiple regression model of model 12 can be used. Furthermore, it can be seen that the minimum elevation of the GND should not be used to predict the number of people affected, as the results generated from the minimum elevation of the GND are having the highest variances with original data. However, it should be noted that for some data categories, some of the models have yielded in negative values, which is due to the unavailability of the definitions of the data ranges, fed in to the mathematical model.

The reason to emphasize on the theoretical values of the impact, is because the data is more primitive and portable, even though they can be less accurate. When more primitive data is used for the calculations, faster results can be obtained, as well as the data and the results can be recreated and shared by many of the agencies. Therefore, usage of primitive data is preferred, while trying to improve the accuracy of the data.

6.2 Reconstruction of the cascade diagram for the number of affected families

A similar study was conducted to evaluate the mathematical relationships which resulted in the affected number of families during the disasters as shown in Figure 6.2.

In the Figure 6.2, the distal end is the affected number of families, and the number of outputs is presented within brackets. For each distal end, the derivation method is different from one to another, therefore, the results taken will be different from one to another.

To evaluate the results given by the model, each of the distal end will be obtained for a given set of the input parameters from the original data, and then the obtained output will be compared with the actual number of families which got affected. From this method, the best option to evaluate the number of families affected will be chosen.

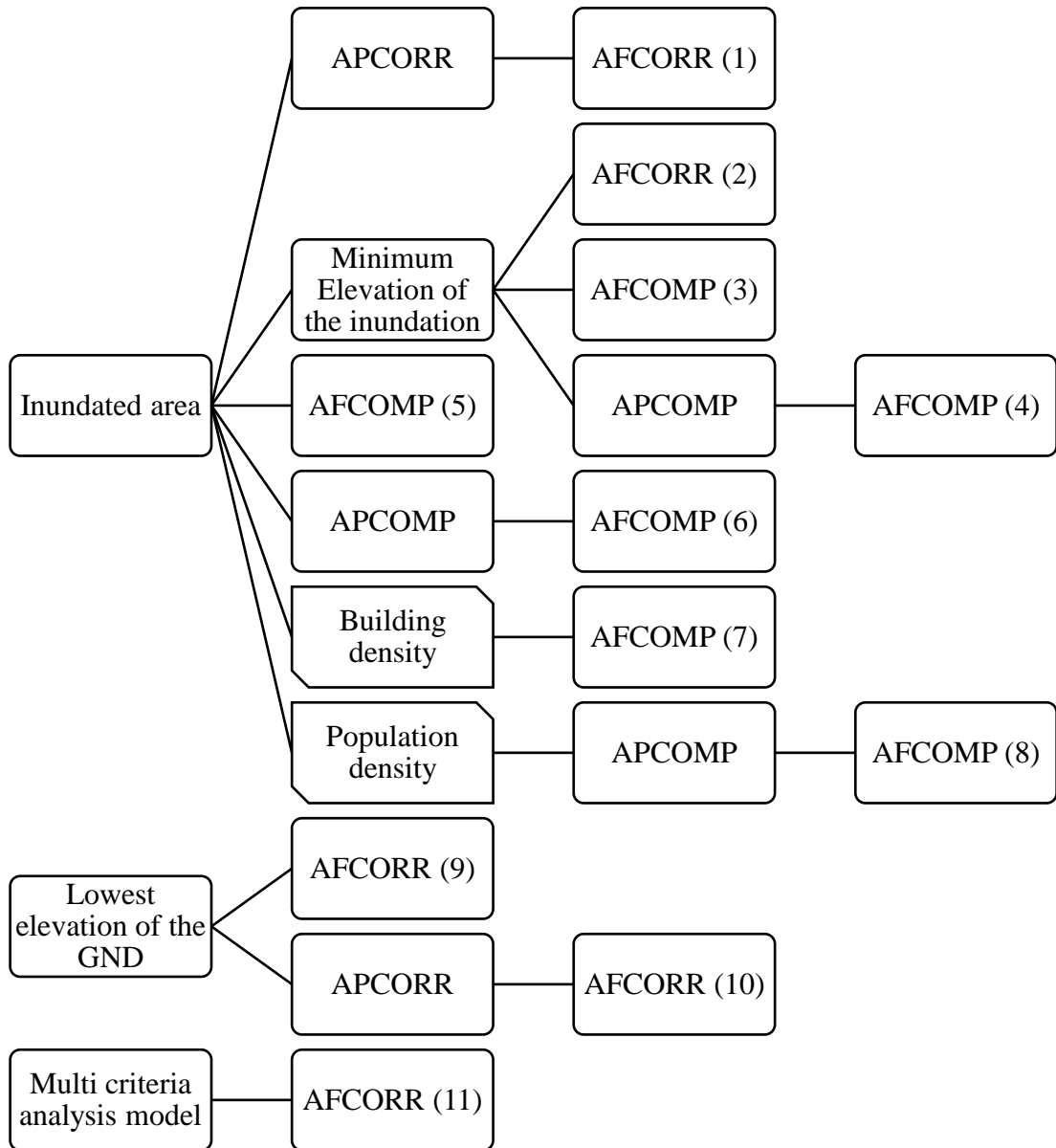


Figure 6.2. Cascade diagram with different approaches to find the affected families

Between two rounded rectangles in the Figure 6.2, there is a correlation relationship, and if a \square shape is in between the rounded rectangle shapes, it means that the simple multiplication of the parameter in the \square shape and the preceding rounded rectangle will result in the parameter in the following rounded rectangle. The results of the comparison are showed in Table 6.3. Denoted by the '*' are resulting in the affected families by computation.

Table 6.3. Data created by the mathematical models for affected families

Original Data	Figures created by the models										
	1	2	3*	4*	5*	6*	7*	8*	9	10	11
400	138	111	466	526	619	586	854	768	401	457	-26
360	245	202	1019	1368	1277	1283	1702	1453	401	458	211
500	441	305	1483	2125	1884	1926	2443	2056	400	453	617
153	200	171	850	1103	1067	1060	626	720	268	257	-500
225	270	216	1094	1489	1373	1384	1747	1891	267	256	-187
375	392	281	1388	1966	1756	1790	1916	1531	326	329	115
90	333	251	1261	1757	1588	1612	1412	1815	107	89	-209
92	197	170	839	1086	1054	1046	1152	1561	107	89	-398
45	154	132	604	729	775	751	1131	914	53	39	-200
450	176	152	734	925	927	913	863	728	399	452	136
297	602	382	1742	2561	2240	2302	1876	1826	402	460	-16
575	186	161	787	1006	990	980	1011	922	369	393	148
400	309	238	1203	1663	1512	1532	1747	1823	397	447	159
1600	313	240	1210	1675	1522	1542	1209	917	-1316	-933	479
50	132	100	391	418	537	499	698	734	53	39	-5
35	123	76	229	191	367	319	372	393	-4106	-2402	-3
265	180	156	760	964	958	945	1033	995	401	457	3
290	214	182	909	1195	1140	1138	641	811	267	256	52
700	791	472	1984	2978	2581	2663	2322	2865	388	425	323
400	138	111	466	526	619	586	854	768	401	457	-26

Similar to the analysis in section 6.1, the similarity of the results by the model were checked against the original data, using the equations 3, 4, and 5. The results of the similarity test is shown in the Table 6.4.

Table 6.4. Results of the similarity test for the affected families

Model	Sum of deviations	Average of deviations
1	16.14	0.85
2	12.75	0.67
3*	74.94	3.94
4*	100.43	5.29
5*	102.51	5.40
6*	100.46	5.29
7*	112.67	5.93
8*	117.62	6.19
9	123.95	6.52
10	75.29	3.96
11	30.93	1.63

*Affected families by computation

By looking at the results, it could be seen that unlike for the models for affected population predictions, model numbers 1 and 2 are having the lowest average deviations from the original values, for affected families. It could also be seen that the models which were set to estimate the computed number of affected families are having huge variances with respect to the original data, and none of them are suitable for estimating the affected number of families. Similar to the results from Table 6.2, results started from the lowest elevation of the GND have not been acceptable, therefore, it should be eliminated in estimating the number of affected families in a disaster. The results from the multi-criteria analysis has yielded in more acceptable results, however, not accurate as the estimates given by the models 1 and 2.

Also, while looking at the results from models 1 and 2, it should be noted that taking the minimum elevation in the inundation has yielded in better results than taking the direct correlations via the affected population. This means that having the minimum

elevation data for the inundated area as an input data will be able to provide with reasonable estimates on the affected number of families.

Comparing the results from Table 6.2 and Table 6.4, it could be seen that these mathematical models are more capable of having accurate results for the number of families affected, than the number of people affected.

6.3 Usage of the mathematical correlations in predictions and other validations

Now, the methods and the mathematical model to connect the flood data to the human movement is cleared by the previous section. Next task is to use the results created by the previous sections to identify the parameters which were discussed in the data collection stage. Since the number of people affected can be found by the previous model, Figure 6.3 will show how to quantify the remaining parts of the cascade, referring to the various data which were collected beforehand. Each of the link is denoted a letter in the alphabet, which will be linked to the relationship as shown in the Table 6.5.

It should be noted that since the inundation areas are fed to the model GND wise, it is safe to assume that all of the GNDs will have at least one relief camp, based on the past experiences.

At the same time, based on the data collected regarding the time stamp of the events, an idea could be taken about the time, that an event is going to take place. Therefore, the cash outflow can be predicted using the essence of the collected data.

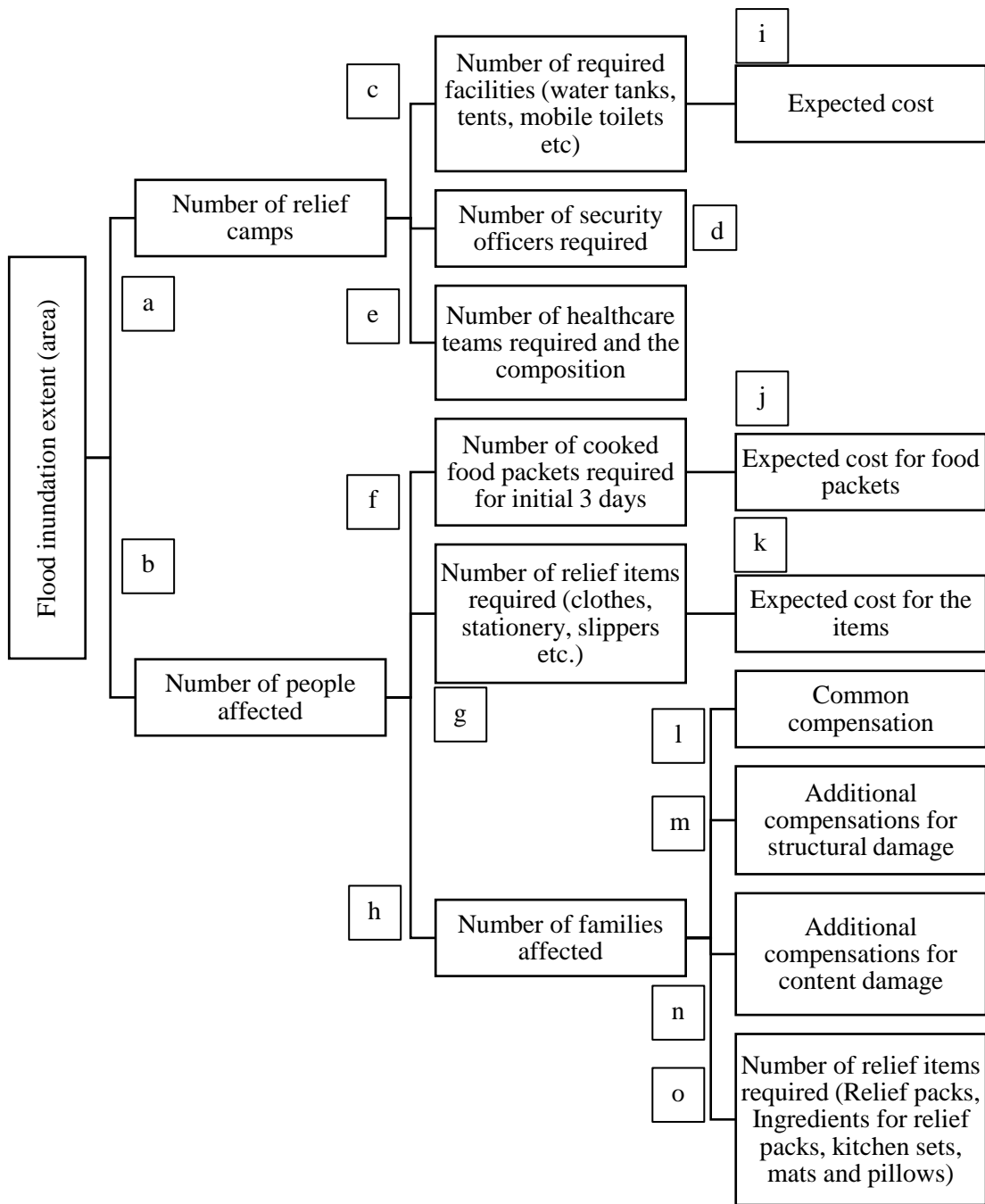


Figure 6.3. Cascade which was quantified in this study

Table 6.5. Key to quantify the relationships

Key	Relationship
a	At least one for each GND
b	Best model from the mathematical models (Table 6.3 and Table 6.4)
c	1 tent, 1 water tank, 1~2 mobile toilets per camp
d	At least 2
e	1 per camp incl. Medical Officers: 1 – 5, Nurse: 1 – 4, Supportive staff: 1 – 3, Driver with the ambulance: 1
f	1 per person, for all 3 meals, or money
g	1 per person, school items: one per child
h	$y = 3.412x + 30.4$
i	Only the transportation cost (Rs 4000~5000)
j	Rs. 60 for Breakfast, Rs 110 for lunch and dinner per food packet
k	Subjected to prices, usually Rs 600-800 for clothes
l	Rs 10,000 per family
m	$y=0.4754x$
n	$y = 19440z + 81695$; where $z = 0.9129x - 20.525$
o	1 per family per week, Rs 1300 per average family of 4 members

6.4 Challenges in the study

While conducting the study, there were some challenges faced due to various reasons. The first challenge was the unavailability of data, and the unavailability of data from a single source. Since the data is collected from the different sources, there could be inconsistencies and inaccuracies between them. And at some times, data was discrete: some data was missing from the collected data sets, and this may have created uncertainties. At the same time, only a limited number of disaster events have happened in the chosen area, of which the data was available. Therefore, counter measures were taken to increase the number of data points to develop the mathematical model, such as taking several available inundation depths which were spread within the flood map, to compare with the local effect it has generated, such as in determining the number of people affected.

About the magnitude of the chosen events, floods in 2016 were having a return period of 30 years (probability of occurrence: once in 30 years), and the magnitude of the 2018 floods have been much lesser than that. The floods in 2017 had a greater magnitude, but the main area it impacted was the down south part of the country, causing lesser damages for Kaduwela area.

The models developed could have inaccuracies in results, due to the fact of using less up to date data, as in for building footprint. The more update data is from the open source data reserves from the OpenStreetMaps, however their data is incomplete, as discussed in previous sections. On the other hand, even though it is less updated, the building data from UDA had a much more complete data set.

In the analysis, challenges were faced as a very a smaller number of mathematical correlations were found connecting the flood characteristics to a characteristic which included human movement, such as the number of families affected and the number of people affected.

Another challenge was the discrepancies with the flood extent maps taken from the RiskInfo website from the DMC. The flood maps did not exactly tally with the contour maps which were generated from the DEM raster file. The contours cross over the flood boundary in many occasions as shown by the Figure 6.4 and Figure 6.5. The

contour values are in meters. Therefore, at times, there were dilemmas on which elevation has to be taken as the elevation of the flood surface, as it is assumed that even for a flowing water body, the surface slope would be negligible, therefore the elevation of the flood water surface has to be similar everywhere in the flood water surface.

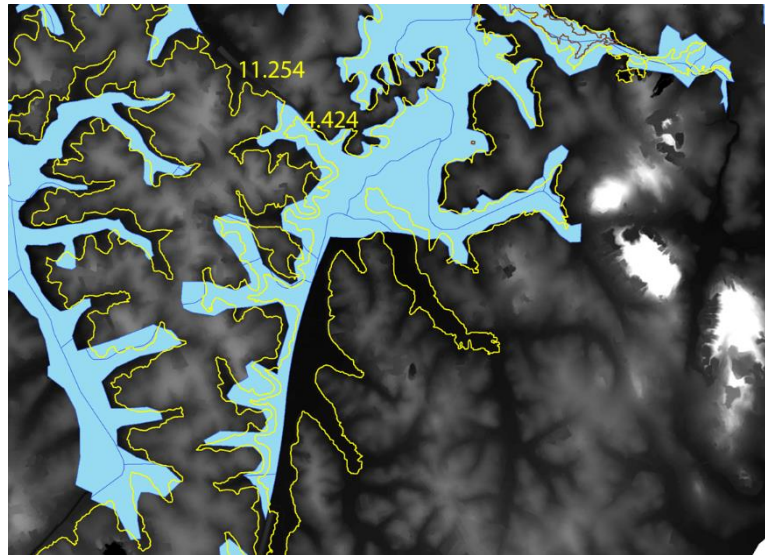


Figure 6.4. Compliance of the flood boundary with the contours for 2016 flood extent map

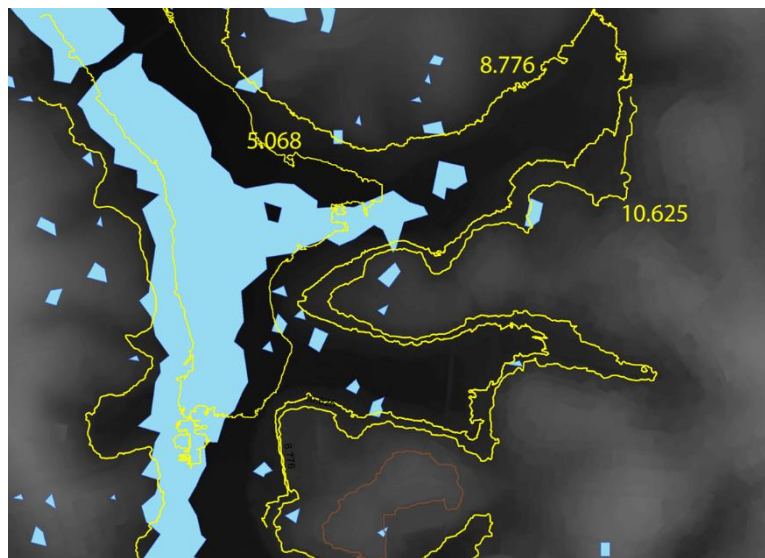


Figure 6.5. Compliance of the flood boundary with the contours for 2018 flood extent map

However, on the other hand it is arguable that the flood maps were prepared by a field survey in 2016, the flood map is having a considerable accuracy with the contour lines for the flood map.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

In the end of the study, there are several conclusions that could be arrived at, regarding the quantification and the evaluation of the impacts to a system, after a disaster situation.

- One aspect of the preparedness planning could be specified as the knowledge of the sequential order of the events that take place after a disaster and the magnitudes of each event, from measurable quantities. Knowing the spatial distribution of the events is important too. Usually there will be a set of events which would take place one after another, which are triggered by the immediate previous event, which is known as the cascading effect of the disasters. The resilience frameworks and the other frameworks relevant to disaster management can be used to identify the components of the systems, along with the EOPs, which could be used to identify the interrelations and the links (cascade relationships) between the components of the system.
- Guided by the actions of the EOPs, empirical data can be used to quantify and evaluate the cascade effect of the events. The analysis could be more enhanced by a spatial approach which is used in this study.
- In the quantification process, flood inundation area was more representative of the flood characteristics, in making the mathematical correlations with the cascading effects which are more related to the human movement, and the other effects which are caused by the human movement can be successfully quantified with the information collected from the governmental authorities. The mathematical model developed in this research could be used to do the future flood impact predictions for the same region.
- The quantified cascade which was presented in this research could be used to identify the number of people and houses affected, number of relief camps formed, expected costs of number of required facilities, number of security officials and healthcare officials required per relief camp, number of cooked

food parcels, dry ration parcels and relief items required and the costs for those. Furthermore, the model consists with the relationships to estimate the amounts for compensations for building structural and content damage in a disaster.

- The input parameter for the model is the inundation area, (for most preferred option in the models) as many flood extent maps are prepared in flood modelling studies in various authorities, which can be directly used in the model developed. The other information such as the cost incurred in the activities can be found straightforwardly from the information collected.
- The results yielded by the developed model(s) and from the information collected can be used for informed decision making, preparedness planning, sourcing of essential items and designing the community resilience improvement activities, with special reference to the spatial variation of the magnitude of the disaster.

7.2 Limitations and recommendations

With the challenges and the other experiences in conducting the research, it was clear that this study can be improved in some aspects, as listed below. In addition, while making use of the study, the following comments should be duly noted.

- The flood characteristics and the human movements can be better represented if the spatial distribution of the people is better represented, with respect to the building number and the user space, based on the occupancy spaces, and building use category and the number of storeys.
- The concept behind the resulting models may be used to generate similar models in the other flood analysis studies, for different geographical areas, as the results produced by this research is highly subjective to the case study area.
- The accuracy of the models may be improved by conducting similar analysis, but with the flood scenarios of different intensities (return periods of the flooding event should be different).
- As an approximation to the flood inundation area, a contour-based inundation may be proposed, as a measure to save the time used to create flood scenarios by flood modelling exercises, as well as to create use cases for the existing model. The similar steps can be followed then, after substituting the flood extent map by the extent map created by the contours.

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APPENDIX A: COLLECTED DATA FOR 2016 FLOODS

Compensations

GN number	GN name	Building Content damage compensations				SMEs (partial damages)	House Damages		Advance Compensation amounts required
		number	amount lkr	Families	People		Full	Partial	
469	Ranala	290	5,461,040	1600	3050	90	0	346	3,460,000
470	Nawagamuwa	425	7,748,870	392	1562	62	2	390	3,920,000
470A	Nawagamuwa South	122	1,768,415	297	857	15	3	113	1,160,000
471	Ihala Bomiriya	327	6,691,547	350	1300	40	7	321	3,280,000
471A	Weekewatta	216	4,622,340	265	805	19	6	210	2,160,000
472A	Pahala Bomiriya	407	8,858,000	575	2000	22	43	429	4,720,000
472B	Pahala Bomiriya	255	5,767,820	450	1900	55	2	267	2,690,000
473	Kothalawala	161	3,852,400	225	750	9	1	267	2,030,000
473A	Kaduwela	292	6,417,040	850	2700	170	8	367	3,750,000
474	Hewagama	290	5,011,120	400	1250	59	0	318	3,180,000
474A	Raggahawatta	392	7,171,690	400	1200	81	0	368	3,680,000
475	Welivita	949	18,083,910	896	3144	85	1	895	8,950,000
475A	Mahadeniya	216	4,973,270	300	850	4	1	193	1,940,000
476	Malabe East	95	1,388,020	96	341	1	0	96	960,000
476A	Malabe West	36	847,490	69	247	15	1	68	690,000
476B	Malabe North	60	1,373,820	90	240	13	0	82	820,000
477	Talangama North A								-
477A	Talangama North B	10	173,060	11	41	1	1	10	110,000
477B	Muththettugoda								-
477C	Pothuarawa			3	12	0	0	3	
478	Thalahena North	59	1,393,520	65	300	1	1	62	630,000
478A	Thalahena South	21	436,790	37	143	1	0	37	370,000
479	Jayawadanagama								-
479A	Pahalawela								-
479B	Asiri Uyana								-
479C	Wickramasinghepura								-
479D	Kumaragewaththa								-
479E	Batapotha	8	103,010	14	50	1	0	14	140,000
479F	Aruppitiya								-
480	Welipillewa	9	173,460	11	42	1	1	10	110,000
480A	Dedigamuwa	29	561,250	91	300	6	1	13	140,000
480B	Embilladeniya	9	212,130	13	41	1	0	13	130,000

480C	Batewela	67	1,330,575	75	298	5	2	65	670,000
487	Oruwala	27	372,520	55	150	8	1	33	340,000
487A	Shanthalokagama	48	1,031,720	71	195	1	0	48	480,000
488	Korathota	148	3,475,120	188	735	36	0	188	1,880,000
488A	Welihindha	194	4,573,900	290	784	3	1	190	1,910,000
488B	Thunandahena	146	2,591,300	168	572	1	3	165	1,680,000
489	Pore	10	178,560	13	41	1	1	12	130,000
489A	Boralugoda	8	126,420	9	38	1	0	9	90,000
490	Athurugiriya	2	50,000	2	8	0	0	2	
490A	Athurugiriya South								-
490B	Taldiyawala								-
491	Kalapaluwawa			43	149	5	0	43	430,000
491A	Walpola	4	100,000	18	55	0	0	18	
491B	Kotuwegoda	3	75,000	24	106	0	1	23	240,000
492	Sri Subbuthipura			18	59				-
492A	Baththaramulla South			1	5	0	0	1	
492B	Baththaramulla North								-
492C	Udumulla			6	22	0	1	2	30,000
492D	Rajamalwaththa			5	23				-
494	Hokandara North	34	569,550	34	122	0	0	34	340,000
494A	Hokandara East	16	142,850	16	52				-
494B	Arangala			1	4	0	0	1	
494C	Hokandara South								-
495	Wellangiriya								-
495A	Ewarihena	5	94,280	5	29				-

Cooked food distribution with time

GN Name	5/17/2016			5/18/2016			5/19/2016			5/20/2016			5/21/2016			5/22/2016			5/23/2016			5/24/2016			Dry rations	
	breakfast	lunch	dinner	breakfast	lunch	dinner	breakfast	lunch	dinner	breakfast	lunch	dinner	breakfast	lunch	dinner	breakfast	lunch	dinner	breakfast	lunch	dinner	breakfast	lunch	dinner		
Ranala			1100				500	1500	1200	1200	1900	1200	1800	1200	1000	800	1200	2000		1000	1000		1000	1000	500	
Nawagamuwa				800			280	1500		800			800		600								1000	1000	362	
Nawagamuwa South			900					1400	1400				300												165	
Ihala Bomiriya								500																	360	
Weekewatta																									265	
Pahala Bomiriya								1000												1100			800	800	575	
Pahala Bomiriya								300																505	450	
Kothalawala															200										230	
Kaduwela				400				1000			700	500	400					500			750	400		1300	1000	500
Hewagama																							1500	1500	400	
Raggahawatta								700	450		800			1050											400	
Welivita			900	600	500			800	600	500	1350	1500	2000	1750			1000	1000	600		1250	750		200	125	50
Mahadeniya								460	800																300	
Malabe East																									90	
Malabe West																									69	
Malabe North			400					300		300	2500	1500	600				1500			1000	1000				92	
Talangama North A																										
Talangama North B																									6	
Muththetugoda																										
Pothuarawa																										
Thalahena North																	150								65	
Thalahena South								200																	35	
Jayawadanagama																										
Pahalawela																										
Asiri Uyana																										
Wickramasinghepura																										
Kumaragewaththa																										
Batapothe																										
Aruppitiya																										
Welipillewa																									11	
Dedigamuwa								500																	96	
Embilladeniya											50							60							12	

Payments for cooked food (food supplies) for suppliers

Date	5/16/2016	5/17/2016	5/18/2016	5/19/2016	5/20/2016	5/21/2016	5/22/2016
New Kumarage			520988.4	835380	1719700	301283.5	751900
New Samansiri hotel				100000			
Kaduwela vi.se.sa.sa.		10326		311036			
Wijaya Products					33190		
Aashik restaurant				80,000			
Daily total		10326	520988.4	1326416	1752890	301283.5	751900

Payments for cooked food (food supplies) for GNDs

	5/16/2016	5/17/2016	5/18/2016	5/19/2016	5/20/2016	5/21/2016	5/22/2016	5/23/2016	5/24/2016	5/25/2016	5/26/2016	5/27/2016	5/28/2016	5/29/2016	5/30/2016	5/31/2016	6/1/2016	6/2/2016
Ranala	25425	25425	25425															
Nawagamuwa	84275	84275	84275															
Ihala Bomiriya		89775																
Weekewatta	25500	25500	25500	25500	25500	25500												
Pahala Bomiriya	37451.396	37451.3958	37451.3958	37451.3958	37451.3958	37451.396				37451.3958		37451.3958	37451.396	37451.3958	37451.396	37451.396		37451.4
Pahala Bomiriya	33468.75	33468.75	33468.75	33468.75														
Kothalawala		46050	46050	46050														
Hewagama		42200	42200	42200														
Raggahawatta		21000	21000	21000														
Welivita	76445.5	76445.5																
Mahadeniya					37600	37600	37600											
Talangama North B			8775	8775														
Thalahena North			51776	51776														
Thalahena South		15075	15075		15075	15075												
Welipillewa			8775	8775	8775													
Dedigamuwa					1440													
Batewela			11855.5		11855.5													
Oruwala		16800		16800	16800													
Shanthalokagama			27195	27195	27195													
Korathota		72000		72000														

Welihindha			8829.33333	8829.33333	8829.33333														
Thunandahena			18717.66																
Athurugiriya South		21937.5	21937.5																
Daily Total	282565.65	607403.146	505106.139	399820.479	190521.229	115626.4	37600	0	0	37451.3958	0	37451.3958	37451.396	37451.3958	37451.396	37451.396	0	37451.4	

Cash flow in DS division

Date	Grand Total Expenditure	Cash Inflow	Cash Flow diagram
5/16/2016	282565.65		-282565.6
5/17/2016	628684.896	1750000	838749.458
5/18/2016	1059380.29		-220630.83
5/19/2016	1811196.81	750000	-1281827.6
5/20/2016	1946037.23		-3227864.9
5/21/2016	416909.9		-3644774.8
5/22/2016	874460.33		-4519235.1
5/23/2016	94710.333		-4613945
5/24/2016	0		-4613945
5/25/2016	37451.3958		-4651396.8
5/26/2016	0		-4651396.8
5/27/2016	37451.3958		-4688848.2
5/28/2016	37451.396		-4726299.6
5/29/2016	37451.3958		-4763751
5/30/2016	37451.396		-4801202
5/31/2016	37451.396	5,000,000	161346.19
6/1/2016	0		161346.2
6/2/2016	37451.4		123894.8
6/3/2016		2,000,000	2123894.794

Number of affected families (From the situation reports)

GN name	5/21/2016	5/22/2016	5/23/2016	5/24/2016	5/25/2016	5/26/2016	5/27/2016	5/28/2016	5/29/2016	5/30/2016	5/31/2016	6/1/2016	6/2/2016
Batewela	75	75	75	50					2				
Boralugoda		24	24										
Dedigamuwa	93	96	12	12	3								
Embilladeniya	12	12	12	10									
Hewagama	400	400	400	400	300								
Hokandara North	32	32	32	30									
Ihala Bomiriya	360	360	360	75	3								
Kaduwela	500	500	500	420	420	380	30	40	40	40		30	10
Korathota	153	153	153	80	37	37		20	10	10			
Kothalawala	225	225	150	150	20	5							
Kotuwegoda	7	15	15	15									
Mahadeniya	300	300	375	375	375	300							
Malabe East	86	90	90	10	5								
Malabe North	90	92	80	22									
Malabe West	45	45	45	45									
Nawagamuwa	360	369	362	450	52	3	3	50	35	35		15	15
Nawagamuwa South	297	297	297	100	20	3	3	3	3	3		3	3
Oruwala	55	35	35	35									
Pahala Bomiriya	575	575	575	550	275	200	70	95	150	75		65	48
Pahala Bomiriya	400	400	400	315	300	30	15	35	25	10		5	5
Pore	7	8	8	5									
Raggahawatta	400	400	400	400	250								
Rajamalwaththa	5	5	5	5									
Ranala	1600	1600	1600	1600	7	7	100	85	20	7		5	5
Shanthalokagama	71	71	71	13									
Talangama North B		6	6										
Thalahena North	50	50	50	50									
Thalahena South		35	35	35									
Thunandahena	150	165	165	165	150								
Udumulla	6	6	6	6		1							
Walpola		1	1										
Weekewatta	265	265	265	160	50	10	20	20	20	15		5	
Welihindha	290	290	290	110	67	30	2	38	40	18		12	
Welipillewa	10	10	10	1	1	1	1						
Welivita	700	700	700	700	700	50							

Number of affected people (From the situation reports)

	5/21/2016	5/22/2016	5/23/2016	5/24/2016	5/25/2016	5/26/2016	5/27/2016	5/28/2016	5/29/2016	5/30/2016	5/31/2016	6/1/2016	6/2/2016
Batewela	325	325	325	250					6				
Boralugoda		84	84										
Dedigamuwa	323	331	61	11									
Embilladeniya	52	52	41										
Hewagama	1250	1250	1250	1250	1150								
Hokandara North	122	122	122	118									
Ihala Bomiriya	1400	1400	1400	375	10								
Kaduwela	2000	2000	2000	1680	1680	1400	100	125	125	125		95	25
Korathota	765	765	765	250	198	155		65	37	37			
Kothalawala	750	750	600	600	75	21							
Kotuwegoda	33	33	33	33									
Mahadeniya	850	850	1130	1130	1130	950							
Malabe East	286	286	286	25	20								
Malabe North	240	246	246	110									
Malabe West	150	150	150	150									
Nawagamuwa	1500	1527	1497	1400	255	12	12	154	105	105		56	56
Nawagamuwa South	857	857	857	450	95	8	8	8	8	8		8	8
Oruwala	150	135	135	135									
Pahala Bomiriya	2000	2000	2000	1900	1100	850	210	285	413	316		261	156
Pahala Bomiriya	1200	1200	1200	1268	1100	105	70	110	60	60		22	22
Pore	30	32	32	26									
Raggahawatta	1200	1200	1200	1200	1000								
Rajamalwaththa	23	23	23	23									
Ranala	3050	3050	3050	3050	21	21	325	255	65	28		21	21
Shanthalokagama	195	195	195	40									
Talangama North B		26	26										
Thalahena North	175	175	175	175									
Thalahena South		120	120	120									
Thunandahena	600	620	620	620	600								
Udumulla	22	22	22	22		3							
Walpola		5	5										
Weekewatta	805	805	805	640	175	25	70	70	70	42		26	
Welihindha	784	784	784	550	268	125	10	126	126	72		38	
Welipillewa	39	39	39	5	5	5	5						
Welivita	2800	2800	2800	2800	2800	205							

Number of camps

GN division	Camp	5/23/2016		5/24/2016		5/25/2016		5/26/2016		5/27/2016		5/28/2016		5/29/2016		5/30/2016	
		Famil ies	Memb ers	Famil ies	Memb ers	Famil ies	Memb ers	Famil ies	Memb ers	Famil ies	Memb ers	Famil ies	Memb ers	Famil ies	Memb ers	Famil ies	Memb ers
Ranala	Ranala Temple																
	Walwvaththa																
Nawagamuwa south	Maitree bodhi vihara			12	35		12	3	8	3	8	3	8				
Nawagamuwa	Roman Catholic Church			39	147		15	3	12	3	12						
	Sri SugathaBimbarama temple											7	28	7	28	7	28
	Phillip Thilakawardana School																
	Thalapitiya araliya Uyana temple											20	60				
Ihala Bomiriya	Ihala Bomiriya Coop pre school			5	25												
	Gunasekaramaya tempple																
	Kanishta vidyalaya			1	3												
Pahala Bomiriya A	Munidasa Kuaratunga Vidyalaya			225	900		150	90	450	70	210	85	230	96	285		
	Sanasa																
	Bowila rd Camp						100										
	Daham pasal mw camp						25										
	Gunasekaramaya tempple						55									53	165
Pahala Bomiriya B	Shailabimbaramaya temple			11	39		44						11	33	11	33	
	Sri Srilankara maha vidyalaya																
	Morawaka waththa praja shalawa						6										
Kothalawala	Siri Samadhi buddhist center																
Kaduwela	Sankhapitta temple			9	52	?	90	9	52	9	52	9	52	4	12	4	12
Hewagama	Hewagama Kanishta V																
Weliwita	St. Maria Vidyalaya			5	15		10										
Welihinda	Praja Shala			6	37		30	6	37	2	10	2	10	2	10		
Thunandahena	Seelasumanarama Temple			63	245		206										
	Community center																
	Abbarwatta			22	66		67										
Mahadeniya	Raja Uyana			10	35		320										
Shanthalokagama	Dharmashrawana Meditation center			6	24												
Kotuwegoda	Wiwekarama center							17	42								
Korathota	Near the Welihinthuwa Power station																
Oruwala	Darmashrama center																
Wekewatta	Asokarama temple																

Summary of the camp details

Summary Until 5/22 Date	no of GS divisions	No of camps	Families	Members	No of meals	No of food parcels		Expense LKR
						Govt	aids	
5/16/2016	25	25	1,401	5,492	3	5492		499,950.00
5/17/2016	28	19	3,945	13,971	3	41913		3,143,475.00
5/18/2016	32	25	6,557	21,024	3	63072		4,730,400.00
5/19/2016	32	39	7,445	23,439	3	14335	55982	1,075,100.00
5/20/2016	30	33	7,886	24,824	3	1850	72622	138,750.00
5/21/2016	31	28	7,619	23,976	3		71928	-
5/22/2016	35	28	7,707	24,259	3	41432	31345	3,107,397.00
Total								12,695,072.00

Requirements at the time of the disaster

GN name	families	Members	water tanks	tents	kitchen sets	mats	pillows	bedsheets	clothes				schooling stationary	dry rations	slippers	kerosene cookers	sanitary pads
									ladies	gents	child-male	child-female					
Ranala	1600	3050	1	1	1600	1600	1600	1600	1300	1050	350	350	700	1600	3050	1600	1300
Nawagamuwa	369	1527	1	1	369	369	369	369	530	508	244	205	449	369	1,527	369	530
Nawagamuwa South	297	837	1	1	297	297	297	297	245	325	144	148	292	297	837	297	245
Ihala Bomiriya	360	1400	1	1	360	360	360	360	535	545	150	170	320	360	1,400	360	535
Weekewatta	265	805	1	1	265	265	265	265	312	293	95	105	200	265	805	265	312
Pahala Bomiriya	575	2000	1	1	575	575	575	575	810	690	230	270	500	575	2,000	575	810
Pahala Bomiriya	400	1200	1	1	400	400	400	400	550	520	65	65	130	400	1,200	400	550
Kothalawala	225	750	1	1	225	225	225	225	375	200	87	88	175	225	750	225	375
Kaduwela	500	2000	1	1	500	500	500	500	800	750	220	230	450	500	2,000	500	800
Hewagama	400	1250	1	1	400	400	400	400	545	455	120	130	250	400	1,250	400	545
Raggahawatta	400	1200	1	1	400	400	400	400	555	525	61	64	125	400	1,200	400	555
Welivita	700	2800	1	1	700	700	700	700					-	700	2,800	700	-
Mahadeniya	300	850	1	1	300	300	300	300	350	390	50	60	110	300	850	300	350

Malabe East	90	286			90	90	90	90	138	120		15		13	28	90	286	90	138
Malabe West	45	150			45	45	45	45	58	52		28		12	40	45	150	45	58
Malabe North	92	246			92	92	92	92	114	111		11		10	21	92	246	92	114
Talangama North B	6	26			6	6	6	6	13	7		3		3	6	6	26	6	13
Thalahena North	50	175			50	50	50	50	87	63		12		13	25	50	175	50	87
Thalahena South	35	120			35	35	35	35	52	51		11		15	26	35	120	35	52
Welipillewa	10	39			10	10	10	10	18	11		5		5	10	10	39	10	18
Dedigamuwa	96	331	1	1	96	96	96	96	163	135		15		18	33	96	331	96	163
Embilladeniya	12	52			12	12	12	12	21	23		4		4	8	12	52	12	21
Batewela	75	325			75	75	75	75	134	131		30		30	60	75	325	75	134
Oruwala	35	135			35	35	35	35	42	50		21		22	43	35	135	35	42
Shanthalokagama	71	195			71	71	71	71	89	66		20		20	40	71	195	71	89
Korathota	153	765			153	153	153	153	347	335		38		45	83	153	765	153	347
Welihindha	290	784	1	1	290	290	290	290	384	360		20		20	40	290	784	290	384
Thunandahena	165	620	1	1	165	165	165	165	232	213		100		96	196	165	620	165	232
Pore	8	32			8	8	8	8	14	12		3		3	6	8	32	8	14
Boralugoda	24	84			24	24	24	24	33	36		7		8	15	24	84	24	33
Walpola	1	5			1	1	1	1	2	3		0		0	-	1	5	1	2
Kotuwegoda	15	33			15	15	15	15	11	13		4		5	9	15	33	15	11
Udumulla	6	22			6	6	6	6	8	9		3		2	5	6	22	6	8
Rajamalwaththa	5	23			5	5	5	5	10	9		2		2	4	5	23	5	10
Hokandara North	32	122			32	32	32	32	48	42		17		15	32	32	122	32	48

Receipt of relief items to Kaduwela DS

Date received	Item	qty	Owned by
6/1/2016	Kerosene gases	30	DMC coord
	Tarpaulin sheets	4	DMC coord
	Small saucepan sets	4	DMC coord
	CDMA phones	20	DMC
8/18/2016	Clothes	200	Korea
7/24/2016	mattresses	101	Sri Lanka Tourism Promotion Bureau
	pillows	96	Sri Lanka Tourism Promotion Bureau
	saucepan sets	31	Sri Lanka Tourism Promotion Bureau
	Gas cookers	31	Sri Lanka Tourism Promotion Bureau
	Gas cylinders	31	Sri Lanka Tourism Promotion Bureau
	Regulators	30	Sri Lanka Tourism Promotion Bureau
5/20/2016	Noodles	1000	NDRSC
	1L water bottles	405	NDRSC
	1.5 L water bottles	204	NDRSC
	3 L water bottles	3	NDRSC
	500 mL water bottles	6	NDRSC
	ladies clothes boxes	5	NDRSC
	men's clothes boxes	6	NDRSC
	Sanitary pads sets	20	NDRSC
5/20/2016	Rice packs 10 kg	105	Matara DS
	Rice packs 50 kg	38	Matara DS
	1.5 L water bottles	978	Matara DS
	5 L water bottles	65	Matara DS
	10 L water bottles	1	Matara DS
	Coconuts	50	Matara DS
5/28/2016	Mats 50 pieces packs	34	Colombo DS
	5 L water bottles	150	Colombo DS
	Noodles boxes	100	Colombo DS
	Tent 10 piece packs	2	Colombo DS
	Cleaning agent boxes	25	Colombo DS
	water filters	10	Colombo DS
	Folding mattresses	25	Colombo DS
	Umbrellas	245	Colombo DS
5/30/2016	Aid Packs	78	Padukka DS
5/30/2016	5 kg rice packs	35	Padukka DS
	5 L water bottles	1	Padukka DS
	1 L water bottles	252	Padukka DS
	1.5 L water bottles	19	Padukka DS
	500 mL water bottles	288	Padukka DS
	Coconuts	53	Padukka DS
	dhal kg	25	Padukka DS
	soya meet	26	Padukka DS
	biscuit small packets	320	Padukka DS
	sugar kg	40	Padukka DS
	tea small packets	155	Padukka DS
	soap	72	Padukka DS
	Siddhalepa	28	Padukka DS
	coconut milk tins	60	Padukka DS
6/6/2016	Pumps	2	NDRSC
	Hose	4	NDRSC
	Foot valves	2	NDRSC
	Copulins	2	NDRSC
	Hose Clips	4	NDRSC
6/6/2016	Bedsheets	375	Colombo DS
	Towels	360	Colombo DS
	Domex (toilet cleaner)	72	Colombo DS
	Rin soap powder	180	Colombo DS
	toothpaste	448	Colombo DS
	Soaps	432	Colombo DS
	Toothbrushes	360	Colombo DS
5/24/2016	Dry rations packs	218	Colombo DS
	Rice kg	1185	Colombo DS
	dhal kg	25	Colombo DS

	Clothe boxes	18	Colombo DS
	clothe bags	1	Colombo DS
	milk powder boxes	228	Colombo DS
	soap powder packs	24	Colombo DS
	500 mL water bottles	1200	Colombo DS
	Biscuit boxes	19	Colombo DS
	slipper boxes	1	Colombo DS
	mosquito coil boxes	1	Colombo DS
	soap boxes	1	Colombo DS
	broom packs	1	Colombo DS
-	Tents	10	NDRSC
	Pakistan tents	20	NDRSC
	Kitchen sets	1200	NDRSC
-	Book bundles	2209	SLS
-	Gully Bowser	1800 L	PointPedro PS
	Gully Bowser	3000 L	UC, Vauniya
	Gully Bowser	4500 L	UC, Vauniya
	Gully Bowser	4000 L	Vauniya South DS

APPENDIX B: COLLECTED DATA FOR 2018 FLOODS

GND Name	Claims less than 10000 for content damages		Claims more than 10000 and less than 25000, for content damages		10000 Rs advances for house damage		Business damages claimed < 25000		Business damages claimed > 25000	
	number	amounts	number	amounts	number	amounts	number	amounts	number	amounts
Talangama North A					3	30,000				
Pahala Bomiriya					110	944,000	4	47,750		
Weekewatta	1	5000	1	10,400	65	544,000			2	132,800
Nawagamuwa			1	38,715	14	125,000			1	102,635
Ihala Bomiriya	7	66500	5	50,225	61	610,000	5	78,400	4	256,360
Pahala Bomiriya	6	54100	2	23,385	81	683,000	1	7,500	1	75,000
Kothalawala					25	240,000				
Kaduwela					32	320,000	1	18,000	2	629615
Hewagama					3	30,000				
Mahadeniya			2	27,590	26	205,000	5	132,120		
Welivita					91	860,000	6	141,000		
Raggahawatta					31	255,000				
Thunandahena					29	225,500	2	12,600		
Welihindha					55	550,000				
Malabe North					7	60,000				
Hokandara North					2	18,000				
Dedigamuwa					2	18,000				
Korathota			1	10,000	5	44,500				
Malabe East			5	57,480	10	100,000				
Ranala					21	149,000			2	68,940
Welipillewa					1	10,000				
Nawagamuwa South					1	7,000				
Malambe West										
Thalahena North					1	10,000				
Shanthalokagama					1	10,000				
Athurugiriya South					1	10,000				

Distribution of cooked food

GND	5/21/2008			5/22/2008			5/23/2008			5/24/2008			5/25/2008			5/26/2008			5/27/2008			5/28/2008		
	Breakfast	Lunch	Dinner	Breakfast	Lunch	Dinner	Breakfast	Lunch	Dinner	Breakfast	Lunch	Dinner	Breakfast	Lunch	Dinner	Breakfast	Lunch	Dinner	Breakfast	Lunch	Dinner	Breakfast	Lunch	Dinner
	Pahala Bomiriya					500	500	500	500						240							280		
Weekewatta					400	400	110	400													150			
Nawagamuwa					65	120	120	120						85										
Ihala Bomiriya	135	400	350	135	250	250	135	250	250	135	250	250	135	250	250	135	250	250						
Pahala Bomiriya					125	125	125	125						300							250			
Kothalawala						22		40																
Kaduwela					125	30	30	30													110			75
Hewagama					85	84	84	84																
Mahadeniya					275	275		275																
Welivita					260	260	260																	325
Raggahawatta					50	50		50	50															
Thunandahena														150										
Welihindha								230			230		250	500		250	250	250	230	230	250	230	230	250
Korathota															80									
Malabe East							6																	
Ranala				142	292	150	142	284	142															

Relief pack distribution

GND	Dry rations distribution					Total dry rations	Well Cleaning number
	900	1200	1400	1600	1800		
Talangama North A	900	1200	1400	1600	1800		
Pahala Bomiriya	1			1	1	3	
Weekewatta	1	27	38	54	56	176	30
Nawagamuwa	6	15	21	26	22	90	30
Ihala Bomiriya	2	3	9	25	4	43	3
Pahala Bomiriya	13	21	28	43	46	151	20
Kothalawala	1	14	18	32	28	93	35
Kaduwela	4	20	12	12	13	61	12
Hewagama	11	18	33	42	54	158	12
Mahadeniya	10	5	4	6	7	32	2
Welivita	2	10	14	29	29	84	5
Raggahawatta	3	24	55	50	73	205	10
Thunandahena	2	11	13	13	19	58	5
Welihindha	5	2	10	9	13	39	15
Malabe North	1	13	13	24	23	74	30
Hokandara North			1	8	3	12	
Dedigamuwa		1	1	3	6	11	
Korathota	1		1			2	
Malabe East		1	1	2	3	7	20
Ranala	1	1	6	1	1	10	
Welipillewa	2	6	7	6	11	32	7
Nawagamuwa South				1		1	
Malambe West	1	2	1	2	1	7	2
Thalahena North				1		1	
Shanthalokagama			1	1		2	3
Athurugiriya South							
Talangama North A							

Affected number of families

GND	5/20/2018	5/21/2018	5/22/2018	5/23/2018	5/24/2018	5/25/2018	5/26/2018	5/27/2018	5/28/2018	5/29/2018	5/30/2018	5/31/2018	6/1/2018	6/2/2018	6/3/2018	6/4/2018	6/5/2018	6/6/2018	Total
Dedigamuwa					2	2	2	1	1	1									2
Hewagama			16	55	62	62	62	10											62
Hokandara North				2	2	3	11	11											11
Ihala Bomiriya			200	56	20														200
Kaduwela			30	180	180	40	86	25	20	18	18								180
Korathota					5	26	29	32	29	15									32
Kothalawala			5	15	32	32	42	70	50	20	3	1							70
Mahadeniya			25		55	65	84	84	45	2									84
Malabe East					4	6	8	12	3										12
Malabe North				8	11	11	13	13	14	10	8								14
Malambe West								1	1	1									1
Nawagamuwa			33	38	55	65	67	72	42	15									72
Nawagamuwa South								5	4	1									5
Pahala Bomiriya	7	7	400	400	350	185	187	187	187	30	30								400
Pahala Bomiriya B			35	46	73	89	86	94	98	87	87	8							98
Raggahawatta			17	30	30	10													30
Ranala		4	42	45		2		4	8										45
Talangama North A	3	3	3	3						3	3								3
Thalahena North									6										6
Thunandahena			5	45	45	42	48	50	50	40	38	6	2	2	2	2	2	2	50
Weekewatta		5	150	150	100	50	50	25	10	4	4								150
Welihindha			3	62	53	63	63	80	80	60	20	6	1	1	1	1	1	1	80
Welipillewa							1	1	1										1
Welivita			73	86	111	149	189	173	163	22									189

Affected number of people

GND	5/20/2018	5/21/2018	5/22/2018	5/23/2018	5/24/2018	5/25/2018	5/26/2018	5/27/2018	5/28/2018	5/29/2018	5/30/2018	5/31/2018	6/1/2018	6/2/2018	6/3/2018	6/4/2018	6/5/2018	6/6/2018	
Dedigamuwa					3	3	3	4	4	4									4
Hewagama			50	150	180	180	180	39											180
Hokandara North				8	8	13	47	47	47										47
Ihala Bomiriya			800	210	90														800
Kaduwela			110	550	550	225	278	91	45	44	44								550
Korathota					20	92	101	115	103	53									115
Kothalawala			22	60	110	110	150	230	100	70	16	7							230
Mahadeniya			97		208	230	323	323	175	8									323
Malabe East					14	24	34	41	12										41
Malabe North				23	42	47	47	47	59	44	39								59
Malambe West								4	4	4									4
Nawagamuwa			150	157	174	189	200	170	147	59									200
Nawagamuwa South								29	19	4									29
Pahala Bomiriya	35	35	1625	1625	1325	740	748	749	749	120	120								1625
Pahala Bomiriya B			113	185	259	353	361	385	369	324	324	34							385
Raggahawatta			64	93	100	50													100
Ranala		14	150	160		8		16	42										160
Talangama North A	9	9	9	9						9	9								9
Thalahena North									18										18
Thunandahena			22	175	175	160	182	184	184	146	140	25	7	7	7	7	7	7	184
Weekewatta		20	600	600	400	200	200	100	50	10	10								600
Welihindha			11	554	260	260	260	274	274	214	67	14	5	5	5	5	5	5	554
Welipillewa							4	4	4										4
Welivita			256	334	435	606	796	667	627	87									796

Number of people in camps

	5/20/2018	5/21/2018	5/22/2018	5/23/2018	5/24/2018	5/25/2018	5/26/2018	5/27/2018	5/28/2018	5/29/2018	5/30/2018	5/31/2018	6/1/2018	6/2/2018	6/3/2018	6/4/2018	6/5/2018	6/6/2018
Ihala Bomiriya					90													
Kaduwela				39	65	33	64	75	64	36	36							
Mahadeniya					8	8	8	19	8									
Nawagamuwa				56	63	68	68	51	31	31								
Pahala Bomiriya				232	232	232	210	211	203	27	27	22						
Pahala Bomiriya B				52	66	75	82	82	96	92	92							
Thunandahena				44	42	44	44	50	50	50	50	19	3	3	3	3	3	3
Weekewatta				49	27	15	15											
Welihindha				11	11	6	12	7	7	7	7	7	7	7	7	7	7	7

Number of families in camps

	5/20/2018	5/21/2018	5/22/2018	5/23/2018	5/24/2018	5/25/2018	5/26/2018	5/27/2018	5/28/2018	5/29/2018	5/30/2018	5/31/2018	6/1/2018	6/2/2018	6/3/2018	6/4/2018	6/5/2018	6/6/2018
Ihala Bomiriya				35	20													
Kaduwela				15	33	14	18	21	19	11	11							
Mahadeniya					2	2	2	5	2									
Nawagamuwa				16	17	17	18	11	5	5								
Pahala Bomiriya				56	56	56	58	59	58	7	7	5						
Pahala Bomiriya B				14	2(17)	29	21	21 (3)	24	23	23							
Thunandahena				12	12	13	13	14	14	14	14	4	1	1	1	1	1	1
Weekewatta				11	7	4	4											
Welihindha				2	2	1	3	1	1	1	1	1	1	1	1	1	1	1