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EVALUATING DISASTER RESILIENCE OF TRANSPORTATION INFRASTRUCTURE USING GIS

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

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Abstract

Almost countries around the world have experienced any types of catastrophic natural disasters, such as volcanic eruptions, magnificent earthquakes, landslides, floods, droughts, cyclones, tornados, snow /sand storm, coastal erosion and tsunami. Hundreds of thousands of lives, property and physical infrastructures, including with transportation system & its infrastructure i.e. highways, railways, ports & air ports are caused to overwhelm, due to such these types of disasters. Traditional reconstruction practices, as a "post-disaster resilience strategy" is an extra burden to the economies of the countries. Application of modern technological strategies, on disaster resilience practices, as a "pre- disaster resilience strategy", is behaving on conceptual stage among the 3rd world, developing countries, while the developed countries are on its testing and utilizing stage in micro / macro levels. Hence an efficient pre-disaster resilience assessment process should be developed, especially for the transportation system in the developing countries, based on up to date technology. All physical and demographic information that is related to the factors affecting disaster risk on transportation infrastructure such as terrain, soil condition, drainage pattern, weather pattern land use, population which is available in a scattered manner, has not been analyzed in an integrated manner to identify the disaster possibility on transport infrastructure. Identification of disaster resilience of existing and proposed transportation infrastructure will be very useful to minimize impacts due to any natural disaster.

The main objective of this research is to develop a methodology, which helps to build up a systematic tool to identify the possible risk areas, on transportation infrastructure, based on the information available, using ArcGIS software.

The initial step of the methodology of this research is, based on disaster records and relevant data, which were gathered from the responsible institutes, online journals and research papers, library & field surveys, as the data collecting phase. Along with the literature survey relevant data such as disaster records, together with floods and landslides data, land use pattern, soil, geographical & climatic data, demographic information will be collected and to prepare a GIS database. By using world famous frequency estimation methods, i.e. Gumbel's , Weibul's, Gringroatan's, Hanzen's, Blayerd's, the flood return periods were calculated. By using simple statistics, the flood gauge heights, corresponds to the different flood return periods were defined. The flood and landslide risks were identified in order to the given parameters, by the responsible institutes; and ranked them for analyzing purposes. Finally, by integrating the flood and landslide risk ranks, using a program, written in VB, the total disaster risk, of a place, area, could be identified, and produced the results in map media, by using the ArcGis software.

10 km circle area, covers with 314.28 km^2, around the Ratnapura town, in the Ratnapura sub catchment of Kalu River, has been selected as the pilot site to do the cause study. After the application of the defined methodology to the pilot site, the results were obtained as, 58.1%, (182.4381 km^2 out of 314.28km^2 pilot site) is belonging to Very low (or No risk) risk area, while other Low risk, Moderate risk and High risk areas were 20.9% (65.7067 km^2), 19.3% (60.75185 km^2) and 1.7% (5.262446 km^2) respectively. And all the inundation areas correspond to flood return periods, and major risk areas of flooding and landslides were produced by using ArcGIS software.

Key words: *Disaster resilience, Flood returns period, ArcGIS, frequency estimation.*

Dedication

To
My Loving
Father, Mother & Wife

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Abbreviations

DMC SL –	Disaster Management Center – Sri Lanka
ESRI -	Environmental System Research Institute
FDV –	Flood Discharge Volume
FGH –	Flood Gauge Height
GIS –	Geographical Information System
MSL-	Mean Sea Level
NBRO –	National Building Research Organization
OS -	Operating System
RS -	Remote sensing
SL -	Sri Lanka
UTM –	Universal Transverse Mercator
VB -	Visual Basics

CHAPTER 01

Introduction

1.1 General

"Disaster" is a most prominent and widespread word among all around the world in the recent decades. A disaster is either a natural or man-made hazard which has come to fruition, resulting in an event of substantial extent causing significant physical damage or destruction, loss of life, or drastic change to the environment. Billions of people in more than 100 countries are periodically exposed to at least one of the natural disaster (Moe *et al.*, 2007).

Volcanic eruptions, Earthquakes, Landslides, Floods, Droughts, Wildfire, Solar flares, Gamma ray burst, Cyclones, Tornados, Hurricanes, Snow/Sand storms, Avalanches, Blizzards, Coastal erosion, Tsunami, Limnic eruptions, Epidemics, Terrorism, etc.. are the most significant disasters in the current world. The disasters can occur, due to the factors such as geological / geomorphologic, hydrological, meteorological, anthropogenic or any other natural or man-made extra terrestrial factors. As a result of these, hundreds of thousands of lives, billions of natural and manmade property, physical infrastructures are loss, damaged or destroyed. Specially, the transportation system & its infrastructure that include highways, railways, ports & air ports are badly affected. Indian Ocean earthquake and tsunami in 2004, Tōhoku earthquake and tsunami in 2011, Great Flood of 1931 in China, Pakistan floods in 2010, Tsunami occurred near Fukushima, Japan in 2011, Hurricane Katrina- 2005 in the USA are some of the examples for the worst disasters in the world.

Sri Lanka also prone to different kinds of natural disasters including floods, cyclones, landslides, droughts and coastal erosion. Recorded earthquakes over the past 400 years were relatively in small magnitude and have not caused significant damages (Jayawardane, 2006). Nevertheless with a new tectonic boundary formed below Sri Lanka, it is now not possible to exclude any future earthquake damages. Different types of disasters can cause significant impact on transportation infrastructure (Figure- 1.1), in addition affecting the people, property and the environment.

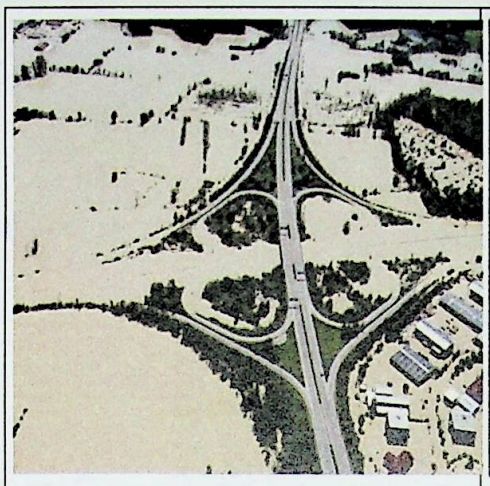
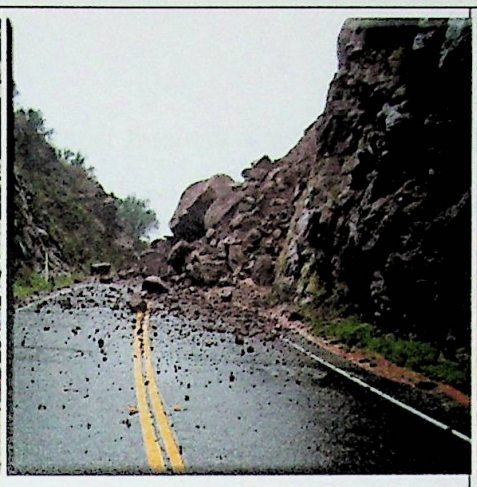
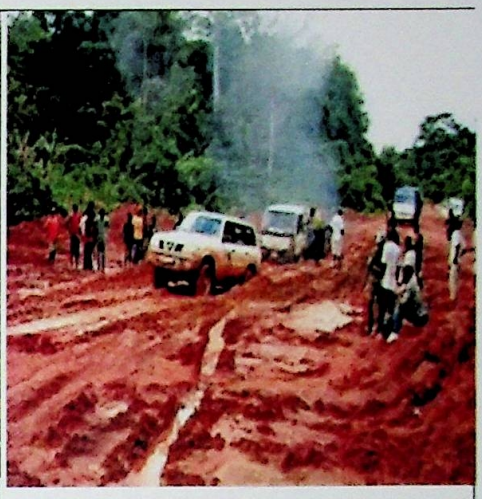
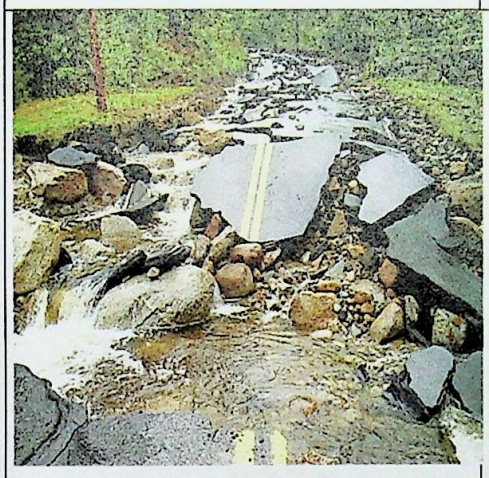
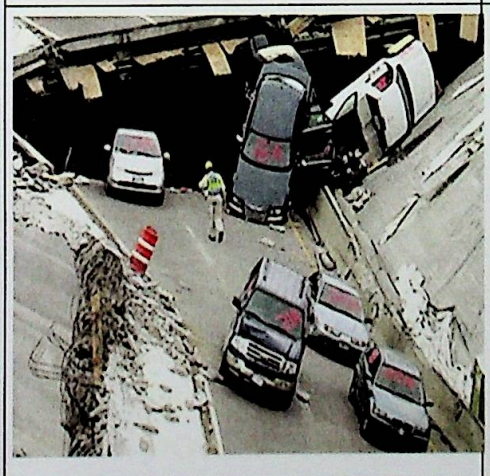
		
Overall flood inundation including highway-building structures & natural vegetation cover, (Central Europ)	*Rock & debris fallen on a highway*	*landslide & muddy flow on highway (Koslanda)*
		
The road completely demolished by the drains	*Highway has been damaged by the washed off*	*Embankment damages on highway and railway*
		
Highway infrastructure damage following an earth quack (USA)	*Highway infrastructures are damaged due to the flood*	*Railway is demolished by the Tsunami (Pereliya)*

Figure 1.1: The Disaster Events on Transportation Infrastructures

Flood and landslide are the most frequent disasters in Sri Lanka. For the reason that, the country is saturated with all three types of main precipitation ways; convectional, cyclonic & monsoonal rains. With the tropical climate and unstable land forms, coupled with deforestation, unplanned growth proliferation non-engineered constructions which make the disaster-prone areas mere vulnerable, tardy communication, poor or no budgetary allocation for disaster prevention, developing countries suffer more or less chronically by natural disasters (Rao, 2009). Thus, the Sri Lanka also can identify as a disaster prone area, including Tsunami disasters. After the 2004 Tsunami, the disaster management, prevention & resilience activities have been entered into a new level. As a result of this In July 2005 the Disaster Management Centre in Sri Lanka (DMC - SL), was established under the National Council for Disaster Management (NCDM) that function under the President of Sri Lanka. The Disaster Management Act No.13 of 2005 was enacted which provides the legal basis for instituting a disaster risk management system in the country. In order to the terms of the act, around ninety types of hazards have been come under the purview of Disaster Management (DMC Annual Report, 2009) that include,

1. Floods
2. Landslides
3. Industrial Hazards
4. Tsunami (Seismic Wave)
5. Earthquakes
6. Air Hazards
7. Fire
8. Epidemics
9. Explosions
10. Aid Raids
11. Civil or Internal Strife
12. Chemical Accidents
13. Radiological Emergency
14. Oil Spills
15. Nuclear Disaster
16. Urban and Forest Fire
17. Coastal Erosion
18. Lightning
19. Tornadoes and Thunder Storms

Overall coordination, monitoring and supervision works of disaster management projects, hazard mapping and risk assessment, information management, disaster mitigation, early warning dissemination, preparedness for effective response at

disaster situations, emergency operations management, management of the post-disaster activities after a disaster are the main responsibilities of DMC- SL

1.1.1 Natural Disasters on Transportation sector

The transportation sector is the backbone of the economy of a country. Towards the development of any country, the efficient tripartite transport media such as road, air, & sea transportation, is essential. Furthermore the road or land transport sector plays a vital role in a territory as compared to the sea or air transportation media. It is the most important and popular transport media for all countries around the world, due to its high capabilities to close with the utility of the people. This is due to, everyone unable to get the service by sea or air transportation. But, everybody can easily attend with the road transportation, as its low cost, easy access and spread eagled road network. For land transport, the transportation infrastructure i.e. highways, railways, bridges, culverts, terminals also should be considered. Efficiency really depends on the function of related infrastructure such as roads, bridges, culverts, and embankments. Moreover, the transportation infrastructure must reliable and perfect for ideal transportation. In order to that, the highway and railway engineers/ planners pay their keen attention to build more reliable, safe and efficient roads/ railways. Especially the roads and railways must be avoided from the disasters such as landslides and flood as far as possible. This is, highways and railways are badly affected by flooding and landslide disasters, especially in the tropical countries like Sri Lanka. (Figure 1.1)

Flood and landslide frequently occur in Sri Lanka during the rainy seasons rather than other months. Specially, South west monsoon (May to October) and north east monsoon (December to march) durations are the main flood seasons of the country. The landslides also activated in the hill country during these periods. As a result, land transport activates get affected. The government has to allocate large amounts of highways, railways, bridges, culverts, that inundated or, damaged due to floods & landslides. Though, Sri Lanka experience flood & landslides frequently, neither a scheduled process nor any other resilience assessment plan or concepts to anticipate and minimize the impacts are available as compared to the traditional disaster

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management process of rebuilding, awareness and evacuation. Nevertheless, going through the literature, it is seems, the disaster resilience practices are operated very primary level in Sri Lanka rather than the other countries of the world. The concept of "disaster resilience" has not been taken into consideration in massive level. Moreover, the most of developed and developing countries are used the modern technology, such as Geographical Information System (GIS), Remote Sensing (RS), digital terrain models & laser scanning techniques , as tools or strategies for disaster resilience and management practices. And they are keeping constantly updated database consists with the disaster records. But, the disaster resilience activities in Sri Lanka are handling very slow and primitive level, associating with the modern technological strategies, mentioned above.

Keeping disaster records and using modern technology, above mentioned, for the disaster resilience practices, are very useful to the country in many ways. Especially, keeping analyzed records and using modern technology are very important for making dictions in the planning stage of new constructions on the transportation sector, to avoid the disaster prone area.

The GIS software is a one of the solutions to identify the spatial differences, integrate and keeping geo- spatial database, including every type of attributes of features of the space. Using GIS technologies as a tool for disaster resilience is a practical solution to avoid loss of human life. Furthermore, using GIS, it is very easy to identify the disaster prone areas, the road / railway links that prone to the disasters, and finds suitable sites, traces for the new constructions on high way and railway. When constructing a new road, railway or their infrastructures, or when it is going to be repaired or extended an existing road/ railway link, the drainage characteristics among the area should be considered. Therefore a hydrological analysis would be done to determine the different flood return periods, flood gauge highs, water accumulation, inundate area, and flood risk of the considered area.

This research brings a simple methodology to identify correlations among the flood gauge high, discharge volume and, flood return periods as a main requirement of highway/ railway construction, development and extension practices. Furthermore, the disaster risk, derived by the flood and landslide risk would be considered.

1.2 Objective of the study.

The main objective of this research is to develop a systematic tool to integrate, analyze and update data and information pertaining to disaster resilience of transportation infrastructure.

Thus, this study attempted to achieve the following goals too,

- To identify geographic and demographic factors that will influence the impacts due to different natural disasters
- To develop a methodology to identify possible risk areas for flood and land slide, based on the information available using Spatial Analyst tool of Arc GIS
- To develop a GIS based tool for decision making and assess disaster resilient of land transport infrastructure.

1.3 Organization of thesis

This thesis includes following works carried out in this study.

The first chapter includes the objective of the research and an introduction of study with the importance of developing an **I**ntergraded **D**isaster **A**nalysis **T**ool (**IDAT**) to integrate, analyze and update data and information pertaining to disaster resilience of transportation infrastructure. Ratnapura catchment of the Kalu River in Sri Lanka is selected as a case study area (pilot site) of the research.

Second chapter covers detail literature review carry out. The relevant studies which have been done, pertaining to this research have been studied, and reviewed.

In the 3rd chapter, the research methodology is described. This includes, selecting the pilot site, the data collecting methods, data analyzing methods and strategies.

The case study and application is presented in chapter 4, also with the validation part of the study. The application part of the research has been done to convert the proposed methodology, into an applied methodology, through the case study. To evaluate the results of the case study, the validation part has been done, with a comparison; of all gathered data and information i.e. field collected data (primary data), recorded data (secondary data) and newly derived data by the study.

The 5th chapter consists of the concluding phase of the research. All research components, which were described in the early chapters, were concluded in this chapter, together with the output of the research.

CHAPTER 02

Literature Review

2.1 General

There are a number of tribulations on transportation infrastructures, currently in Sri Lanka, such as floods, washed out, embankment damages, bridges culvert & other structure overwhelm, high traffic congestion and fatal accidents, due to the natural disasters. Hence, it has been taken into consideration to develop a systematic approach for disaster resilience and management through an integrated tool, which is consisted with modern technology. To achieve this goal, the literature, which were reviewed in this study, to build an **I**ntergraded **D**isaster **A**nalysis **T**ool (**IDAT**) to Sri Lanka, using Geographical Information System (GIS), is described by this chapter.

2.2 What is a Disaster?

The word "*disaster*" implies a sudden overwhelming and unforeseen event. Although there is no universally accepted definition of a disaster, the following observations are coming close;

Konoorayar, (2006) says Disaster is derived from Greek meaning, "*bad star*".

Moe et al. (2007, pp 787) define the disaster as, *''a situation which overwhelms local capacity, necessitating a request to the national and international level for external assistance, or is recognized by a multilateral agency or by at least two sources, such as national, regional or international assistance groups and the media''.*

The disaster defined by the Oxford dictionary as "*A sudden accident or a natural catastrophe that causes great damage or loss of life*"

US disaster relief specialist Frederick Cuny (1944-1995) says "*A situation resulting from an environmental phenomenon or armed conflict that produced stress, personal injury, physical damage, and economic disruption of great magnitude.*"

The definition adopted by the World Health Organization (WHO) terms a disaster as "*The result of a vast ecological breakdown in the relations between man and*

his environment, a serious and sudden (or slow, as in a drought) disruption on such a scale that the stricken community needs extraordinary efforts to cope with it, often with outside help or international aid."

The US Federal Emergency Management Agency (FEMA) describes it as

"An occurrence of a natural catastrophe, technological accident, or human caused event that has resulted in severe property damage, deaths, and/or multiple injuries."

Quarentelly (1985) says *"Disaster is a crisis situation that far exceeds the capabilities"*

Coming across various definitions, the disasters can be identified as a sudden, hazardous event bringing great damage, loss, and destruction and devastation to life, property and livelihoods. The damage caused by disasters is immeasurable and varies with the geographical location, climate and the type of the earth's surface/degree of vulnerability. Thus, a disaster may have the following main features:-

- Unpredictability
- Unfamiliarity
- Speed
- Urgency
- Uncertainty
- Threat

2.3 Types of Disaster

Disasters are classified in various ways. United Nations (2006 cited Moe et al., 2007) further classified natural disasters in three as

- Hydro-meteorological disasters (floods, wave surges, storms, droughts, forest fire and extreme temperature)
- Geophysical disasters (earthquakes, tsunamis and volcanic eruptions)
- Biological disasters (epidemics and insect infestations).

Furthermore, the Emergency Disasters Database in 2006 classified disasters as natural or technological (Moe et al., 2007). Accordingly, technological disasters consist of industrial accidents, transport accidents and miscellaneous accidents.

Taking into consideration further classifications, generally the disasters can be divided into two types as

1. Natural disasters
2. Man-made disasters

2.3.1 Natural disasters

Billions of people in more than 100 countries are periodically exposed to at least one of natural disasters (Moe et al.,2007). A natural disaster is an act of weather or earth-related events that cause destruction. Additionally it is a major adverse event, resulting from natural processes such as, endogenous process of the earth's crust as tectonic activity, seismic activity, volcanism; and exogenitic forces of solar radiation, winds, waves, precipitation, and glacial ice; effecting on the Earth. Furthermore, based on the devastation, the natural disasters can be classified as major and minor natural disaster. As an example, earthquake, volcanic eruptions, earth slip, flood, cyclone, tornado, drought and tsunami are recognized as major natural disasters. Cold wave, avalanches, blizzards, thunderstorms, heat waves, mudslides, storm, solar flares, and gamma ray burst; can be identified as minor natural disasters. Table: 2.1 show the most vulnerable natural disasters that occurred during the last century, around the world.

The table represents, the more vulnerable and destructive results were given by the earthquakes, as compared to the Flood. The floods were the most vulnerable natural disaster all around the world, during the last century. Tsunami in 2004 was the deadliest natural disaster in the recent decade. Furthermore, the earthquake in 2010 in Haiti, Cyclone in 2008, in Nargis, earthquake in 2005 in Pakistan, Hurricane Katrina (2005), in USA are the significant disasters during the last decade. Annex 01 is consisted of the further Lists of natural disasters by cause.

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Table 2.1: Ten Deadliest Natural Disasters Since 1900

Rank	Death toll (estimate)	Event*	Location	Date
1.	1,000,000–4,000,000	1931 China floods	China	July 1931
2.	650,000–779,000	1976 Tangshan earthquake	China	July 1976
3.	500,000	1970 Bhola cyclone	East Pakistan (now Bangladesh)	November 1970
4.	234,117	1920 Haiyuan earthquake	China	December 1920
5.	230,000	2004 Indian Ocean Tsunami	Indian Ocean	26th December 2004
6.	229,000	Typhoon Nina—contributed to Banqiao Dam failure	China	August 7, 1975
7.	159,000	2010 Haiti earthquake	Haiti	January 12, 2010
8.	145,000	1935 Yangtze river flood	China	1935
9.	142,000	1923 Great Kanto earthquake	Japan	September 1923
10.	139,000	1991 Bangladesh cyclone	Bangladesh	April 29, 1991

Source: Wikipedia – 2014 May

2.3.2 Man–made disasters

Man-made disasters are disasters that relate to events caused by the actions of man and probably could have been prevented. Man-made hazards or anthropogenic hazard can come to fruition in the form of a man-made disaster. In this case, "anthropogenic" means threats having an element of human intent, negligence, or error; or involving a failure of a human-made system. It results in a huge loss of life and property. It farther affects a person's mental, physical and social well-being. In addition to this man-made disaster can be classified as major/minor scales in order to the magnitude of it. (NBRO - SL)

Global warming, deforestation, setting of fires, and wildfires, epidemics, chemical pollutions, war, crimes, and terrorism are the major man-made disasters.

Environmental pollution, industrial disasters/ crisis, road/ air/ train accidents, food poisonings, riots are considered as minor scale man-made disasters.

2.4 Sri Lanka as a Disaster Prone Area

2.4.1 General

Sri Lanka is prone to several types of natural disasters commonly caused by floods, cyclones, landslides, droughts and coastal erosion for generations with increasing losses to life and property in the recent few decades rather than the past. Earthquakes have been recorded over the past 400 years with relatively small magnitudes with no significant damage (Jayawardhana, 2006), but any future seismic damage to Sri Lanka cannot be excluded specially due to increased seismic activity in the region with a new tectonic boundary formed below Sri Lanka. The devastation caused by a massive earthquake of magnitude 9.0 in northern Sumatra in Indonesia, the Indian Ocean tsunami was originated on December 2004, however, took Sri Lanka by surprise warning that Sri Lanka is also vulnerable to low-frequency high impact events with extensive damage (Pheng et al.,2006, Sonak et al.,2008, Sirinivas &Nakagawa, 2008).

The disasters such as floods and landslides are the most frequent, major catastrophes, which bring severity on property, lives, and livelihoods in Sri Lanka. (Figure 2.1) The performances of these disasters are behaving in a cyclical process in order to chronologically, seasonally and spatially. In an another country though it is caused various types of factors to trigger such these disasters, in Sri Lankait is mostly associated with hydro- meteorological factors, such as precipitation, drainage, underground drainage, runoff , water discharge, flood levels etc. When it is going through the factors of the disasters, it should be considered the geographical location of Sri Lanka. Moreover, its geographical setting and geomorphologic and climatological conditions make it prone to several types of natural disasters (Fowze et al, 2006)

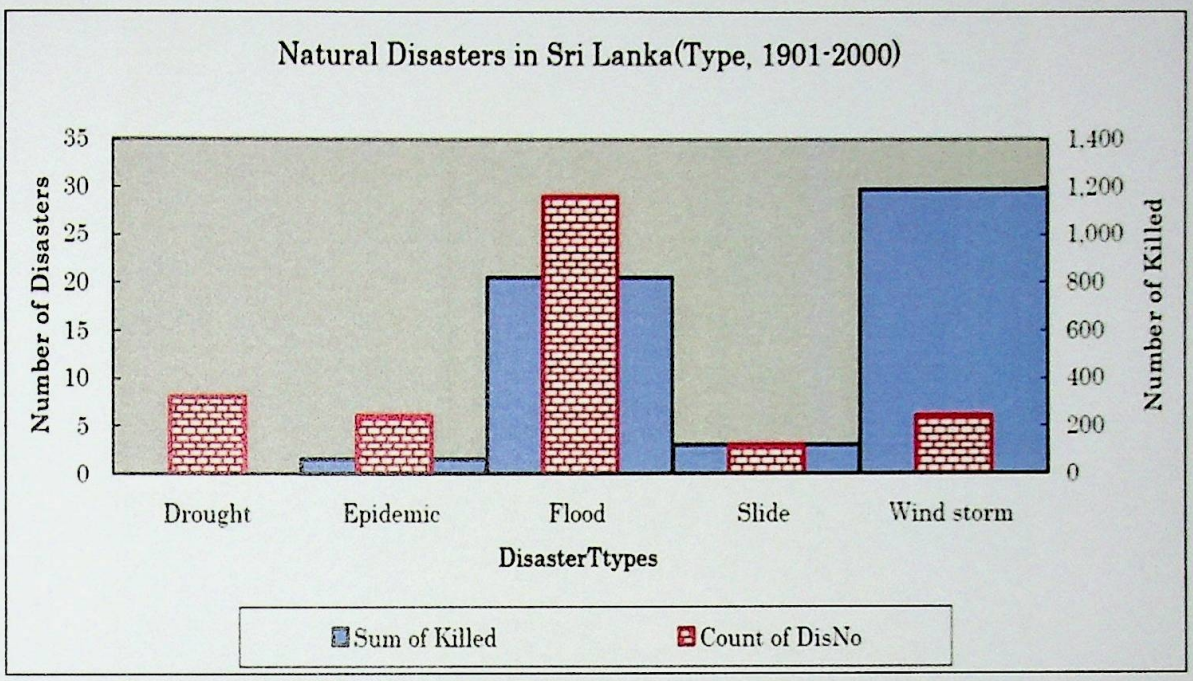


Figure 2.1: Natural Disasters in Sri Lanka (1901 - 2000)

Source: DMC – SL

Thus, the geographical features i.e. location, relief, precipitation, climate, and all other physical and demographical features of the country should be, taken into consideration, when it's going through the disasters in Sri Lanka.

2.4.2 The location of Sri Lanka

In order to the figure 2.2, Sri Lanka is a tropical country, located just above the equator between 5° 55'N - 9° 55' N and between the eastern longitudes 79° 42' - 81° 52' (department of meteorology SL, 2012) Geographically, is an island country in the Indian Ocean, to the south of India and separated from India by Palk Strait. The maximum length and width of Sri Lanka is 435 km and 225 km respectively. Total area of Sri Lanka is 65610 km^2, consisted with 64740 sq km of land area and, 870 sq km of water area. (National Atlas, 2007)



Figure 2.2: Location of Sri Lanka

Source: Survey Department Sri Lanka

(http://www.meteo.gov.lk/index.php?option=com_content&view=article&id=106&Itemid=81&lang=en).

As a tropical country, high temperature and heavy rainfall pattern are the main climatic fundamentals of the country. As a result of this, a number of disasters occurred in the country, which is mainly derived from water and its elements. Especially, the origin of flood and landslides are directly combined with the precipitation. Thus, it is essential to study the climate, precipitation and its forms among Sri Lanka, for this research.

2.4.3 Climate

The Climate of Sri Lanka is dominated by the topographical features of the country and the Southwest and Northeast monsoon regional scale wind regimes. Already, Sri Lanka has identified as a tropical island country. Its climate can be described as tropical, and quite hot. Its geographical position, endows the country with year-round warm weather, moderated by ocean winds and considerable moisture. The solar radiation & temperature, clouds & precipitation and atmospheric pressure & winds are the major elements of the climate of the country. The characteristics of those elements can be briefed as follows

2.4.3.1 Temperature

The mean annual temperature in Sri Lanka manifests largely homogeneous temperatures in the lowlands and rapidly decreasing temperatures in the highlands due to altitude, rather than to latitude (Department of meteorology SL, 2012). The mean temperature ranges from low of 16°C (60.8°F) in Nuwara-eliya in the central highlands and high of 32°C (89.6°F) in Trincomalee north east of the country. The average annual temperature for the country, as a whole ranges from 28 to 30 °C (82.4 to 86 °F). Day and night temperatures may vary by 4 °C (7.20 °F) to 7 °C (12.60 °F). January is the coolest month, especially in the highlands, where overnight temperatures may fall to 5 °C (41 °F). April – August, the hottest period, precedes the summer monsoon rains.

2.4.3.2 Humidity

Humidity is typically higher in the southwest and mountainous areas and depends on the seasonal patterns of rainfall. Therefore the humidity percentage can be varying in between 60% - 90% depending on the seasonal rainfall.

2.4.3.3 Rainfall

Sri Lanka being located in the Indian Ocean between the Bay of Bengal in the east and Gulf of Mannar in the west, pressure variations in the Bay of Bengal with high winds give rise to unexpected heavy rains (Nandalal. et al.,2010). The rainfall pattern

is influenced by the monsoon winds of the Indian Ocean and Bay of Bengal and is marked by four seasons (Department of meteorology SL, 2012).

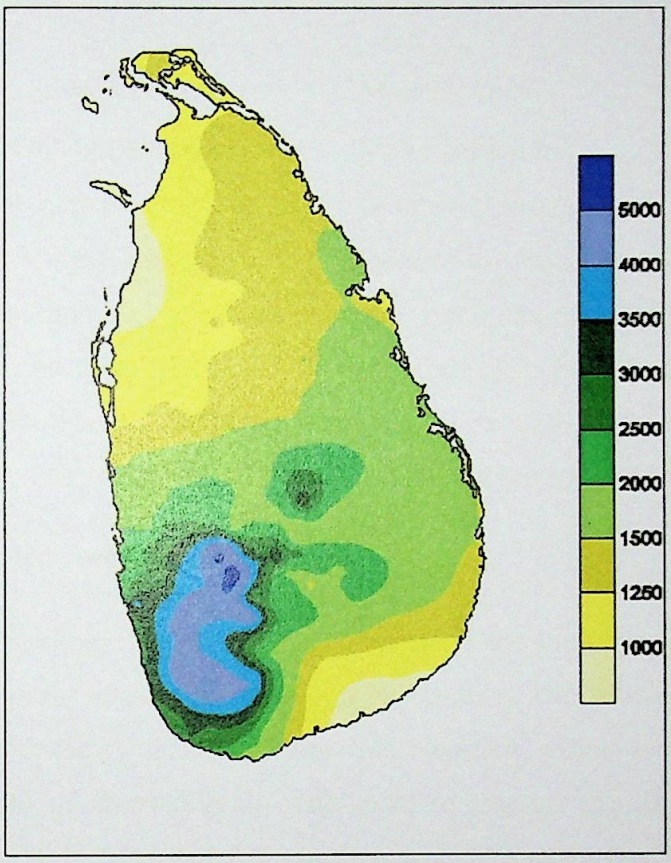


Figure 2.3: Annual Rainfall in Sri Lanka
Source: Department of meteorology – Sri Lanka

The mean annual rainfall varies from under 900mm in the driest parts such as southeastern and northwestern parts of the country to over 5000mm in the wettest parts such as Western slopes of the central highlands of the country. Above mentioned rainfall variations are describe by the Figure. 2.3. Depending on the figure, Manner, Puttlam and Hambantota districts can be identified as the driest area of the country; while the Nuwara – Eliya district is the wettest.

Sri Lanka experience three types of precipitation modes as follows.

- Convectional rains
- Cyclonic rain
- Monsoonal rain.

Considering the rainfall experienced during 12 months period in Sri Lanka, it has been characterized in to 4 climate seasons by the department of metrology Sri Lanka as follows.

- First Inter monsoon Season - March - April
- Southwest monsoon season - May - September
- Second Inter monsoon season - October - November
- Northeast Monsoon season - December – February

Depending on the climate seasons, the category, types and magnitude of the disaster can be changed as the characteristics of the climatic season may decide the magnitude of the disaster. Furthermore, the characteristics of rainfall of these main climatic seasons have been described by the Department of Meteorology Sri Lanka, as follow.

2.4.3.3.1 First Inter - monsoon Season

During March – April, the first inter monsoon occur in the country with thunderstorm-type rain, particularly during the afternoon or evening. The distribution of rainfall during this period shows that the entire Southwestern sector in the hill country receiving 250 mm of mean rainfall, with localize area on the southwestern slops experiencing rainfall in excess of 700 mm (Keragala 771 mm). Over most part of the island, the amount of rainfall varies between 100 and 250 mm, the notable exception being the Northern Jaffna Peninsula (Jaffna- 78 mm, Elephant pass- 83 mm). (Department of meteorology SL, 2012). The rainfall variations, mentioned above, of the 1st inter- monsoon season are shown by the Figure 2.4.

2.4.3.3.2 Southwest - monsoon Season

During May – September, the Southwest monsoon rains are experienced at some times of the day and night, sometimes intermittently mainly in the Southwestern part of the country. Amount of rainfall during this season varies from about 100 mm to over 3000 mm. The highest rainfall received in the mid-elevations of the western slopes. Rainfall decreases rapidly from these maximum regions towards the higher elevation. The variation towards the Southwestern coastal area is less rapid, with the Southwestern coastal belt experiencing between 1000 mm to 1600 mm of rain during

this period. Lowest figures are recorded from Northern and Southeastern regions of the island. (Department of meteorology SL, 2012). The rainfall variations, mentioned above, of the South- west monsoon season are shown by the Figure 2.5.

2.4.3.3.3 Second Inter - monsoon Season

The thunderstorm-type of rain, particularly in the afternoon or evening, is the typical climatic condition of this season, due to the influence of weather system like depression and cyclones in the Bay of Bengal, during October to November. Under such conditions, the whole country experiences strong winds with widespread rain, sometimes leading to natural hazards such as floods and unexpected landslides. The second Inter-monsoon period is the period with the most evenly balanced distribution of rainfall, excess of 400 mm, over Sri Lanka. The Southwestern slops further receiving higher rainfall in the range of 750mm to 1200 mm. (Department of meteorology SL, 2012). The rainfall variations, mentioned above, of 2nd inter monsoon season are shown by the Figure 2.6.

2.4.3.3.4 Northeast - monsoon Season

December to February, cold monsoon winds come from the northeast and Indian landmass bringing moisture from the Bay of Bengal, During this period, the highest rainfall figures are recorded in the North, Eastern slopes of the hill country and the Eastern slopes of the Knuckles/ Rangala range inundated with up to 1,250 mm. The maximum rainfall is recorded at Kobonella estate (1281 mm), and the minimum is in the Western coastal area around Puttalam (Chilaw- 177 mm) during this period. (Department of meteorology SL, 2012). The rainfall variations, mentioned above, of northeast monsoon season are described by the Figure 2.7.

As consequence of this precipitation pattern, hydro based natural hazards such as floods, landslides, rock felling etc.... can be occurred in the country. The Geo-morphological relief and geological and soil composition background also caused to accelerate such these natural hazards up to Natural disaster. Therefore, the geological and geomorphologic background of Sri Lanka should be considered.

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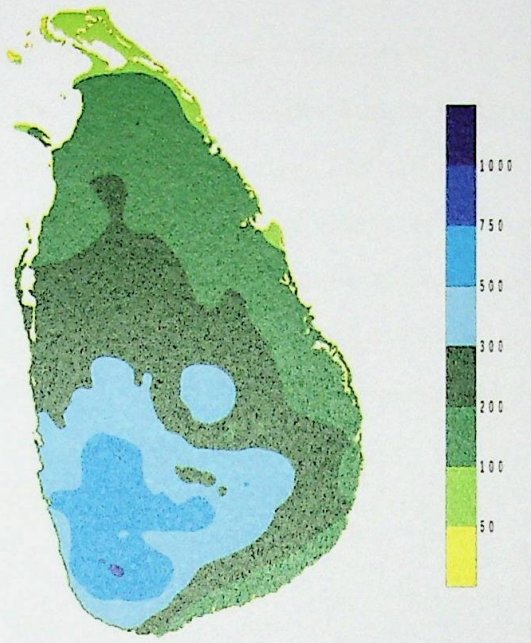


Figure 2.4: Rainfall in Sri Lanka
(First Inter- monsoon)
Source: Department of meteorology

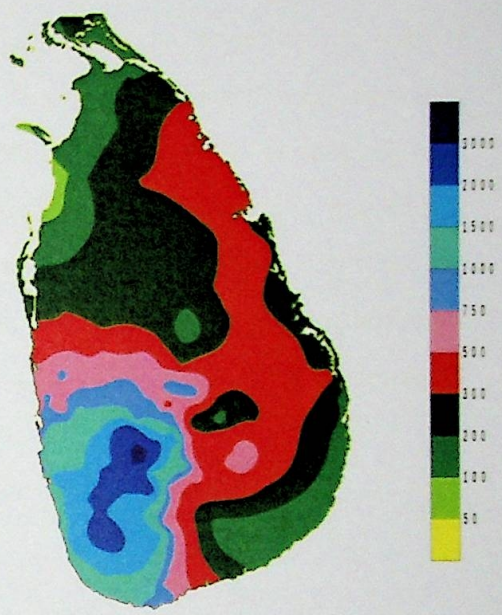


Figure 2.5: Rainfall in Sri Lanka
(South West monsoon)
Source: Department of meteorology

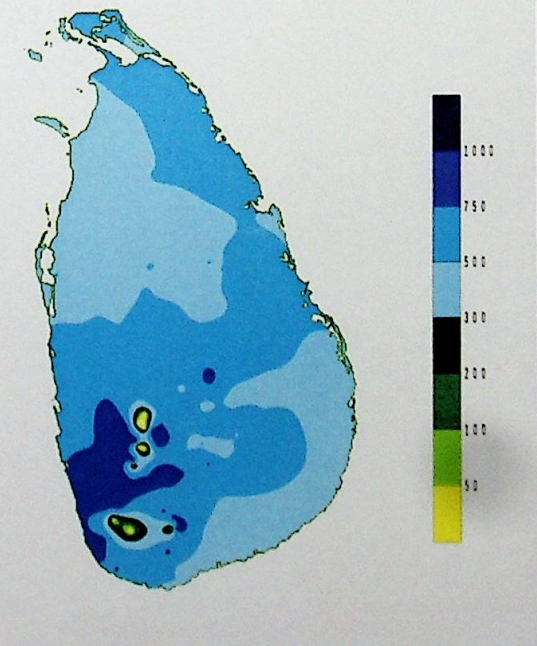


Fig. 2.6: Rainfall in Sri Lanka
(Second Inter- monsoon)
Source: Department of meteorology

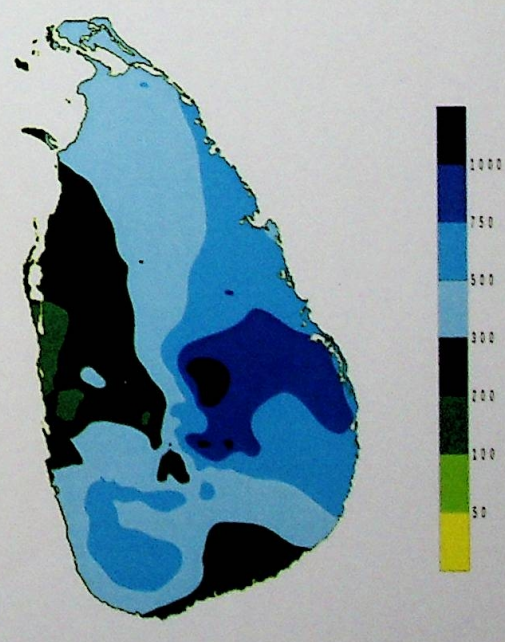


Fig. 2.7: Rainfall in Sri Lanka
(North Ease monsoon)
Source: Department of meteorology

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2.4.4 Geology of Sri Lanka.

Geological features and composition of a landmass, indirectly caused to the natural disasters, when it is collaborating with the other factors of disasters such as water, seismic waves and gravity. The structural composition of the land is reacted with those factors together and cause to the geological disasters such as, mudslides, landslides, rock felling, sinkholes, earthquakes, and volcanoes. These disasters are most common to the Sri Lanka except volcanoes and massive scale earthquakes. Therefore, studying geological regions and structural composition, of the landmass of Sri Lanka is very important.

The major geological divisions of the country are shown in Figure 2.8

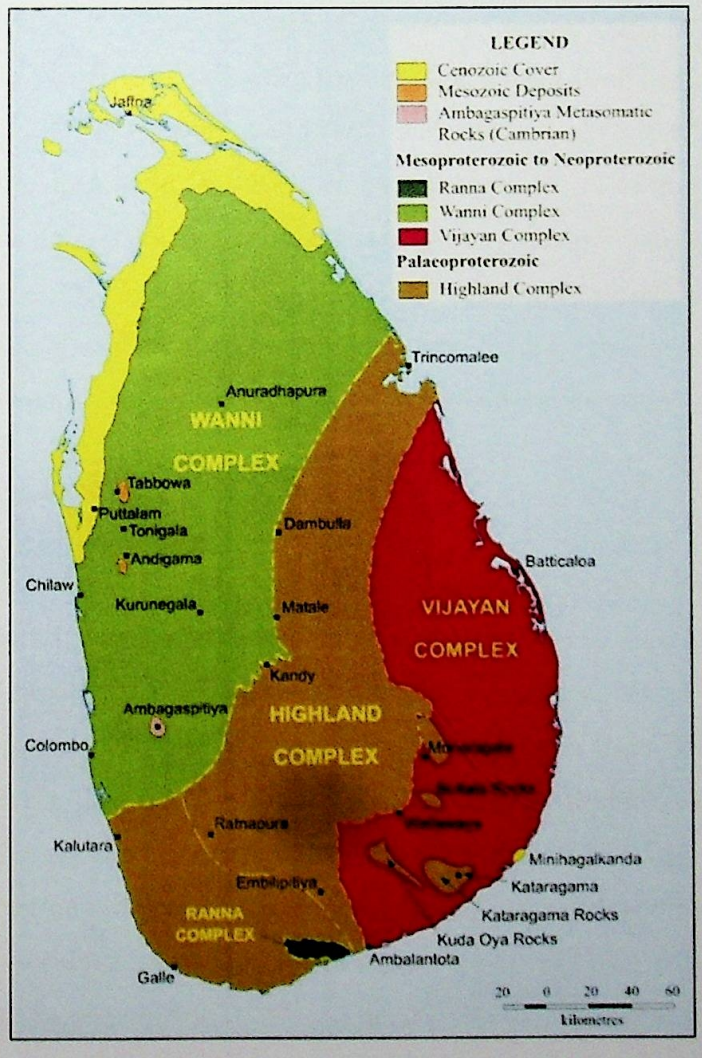


Figure 2.8: Major Geological Divisions of Sri Lanka

Source: Geological survey and mining bureau, National atlas 2007

Sri Lanka has been divided into five major geological divisions (Vadia , 1945) as follows

- Highland complex
- Vijayana Complex
- Wanni Complex
- Kadugannawa Complex
- Limestone complex

According to Dissanayake, (1981) nine tenths of Sri Lanka including the highland, Vijayan, Wanni & kadugannawa complexes, has been made up by highly crystalline, metamorphic rocks of Precambrian age. The rest of the island, north western region, is made up by Jurassic, Miocene and Quaternary sedimentary formations. The differences among these divisions have been studied by the geologists such as Wadia (1945), Vithanage (1972), Pathirathne (1980) and Dissanayake (1981). According to their findings, the geological features such as soil and mineral of those divisions are reacting with the natural forces such as, water, gravity, seismic waves, air and solar radiation. As a result of this, the strength of some compositions may be stronger than before, and some compositions may be lost than before. These variations of the compositions are caused to deriving various types of natural disasters in Sri Lanka.

2.4.5 Soil of Sri Lanka

According to Dokushew (1898) Parent materials formed by rock weathering react with organic material under various climatic conditions over a period of time and compose soil (Schoolnet. Lk). "The formation of soil happens over a very long period of time. It can take 1000 years or more. The soil is formed from the weathering of rocks and minerals. The surface rocks break down into smaller pieces through a process of weathering and is then mixed with moss and organic matter. Over time this creates a thin layer of soil. Decaying plant and animal matter makes the soil thick and rich. This continues until the soil is fully formed.
(http://library.thinkquest.org/J003195F/soil.htm)

The soil in Sri Lanka also been created as a result of weathering process by the physical, chemical & biological factors, among very long period. (Moormann and Panabokke, 1961). Panabokke (1961) has introduced 14 types of soil categories in Sri Lanka as follows (Figure 2.9)

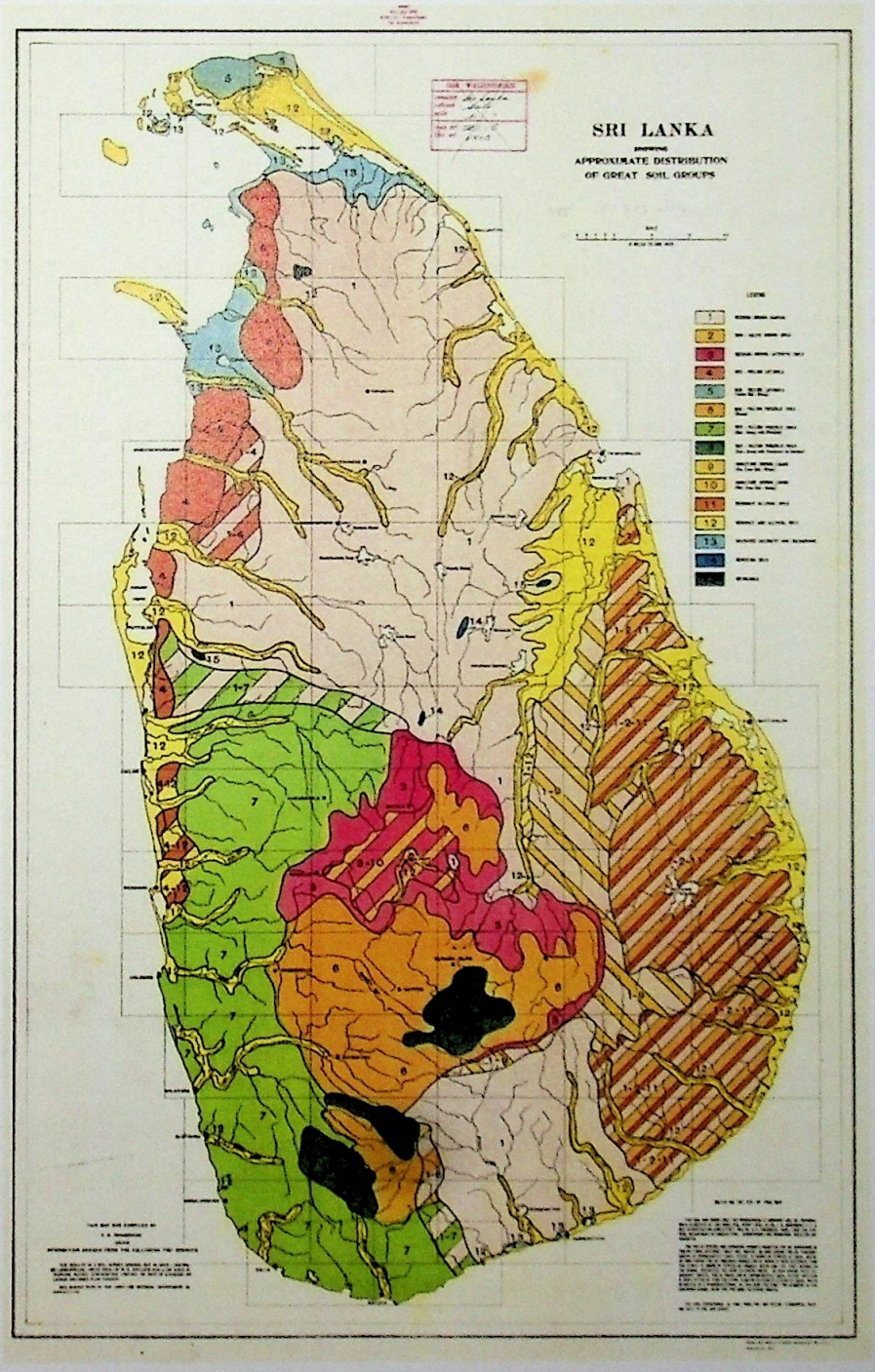


Figure 2.9: Soil Groups in Sri Lanka
Source: National Atlas 2007

1.Reddish brown earths
2. Noncalcic brown soils
3. Reddish brown lateritic soils
4. Red-yellow podzolic soils
5. Red-yellow latosols
6. Immature brown loams
7. Rendzina soils
8. Grumusols
9. Solodized solonetz
10. Low-humie gley soils
11. Meadow podzolic soils
12. Bog and half-bog soils
13. Alluvial soils
14. Regosols

According to Harr and Yee (1975), soil and hydrologic factors are directly affected to the stability of natural slopes of the land. According to the National Building Research Organization, in Sri Lanka (NBRO - SL), mud flows, debris flows, earth failures, and slope failurescan be triggered, by rain floods, run off and sub drainage. Due to the water saturated soil and clay minerals such as kaolinite, dickite, halloysite and Illite , the mud flows, earth slips or landslides can be activated. Mica, Graphite minerals also caused to the same results. Further, it can be recognized the contribution of soil and minerals for creating disasters in Sri Lanka.

2.4.6 Landforms of Sri Lanka.

According to the geomorphology of the island, Sri Lanka consists with a variety of physical features, called landforms, examples of which include mountains, plateaus, valleys, canyons, salient, cliffs, and plains, derived from endogenous and exogenitic process of the earth. According to the "Continental Drift theory" of Alfred Vegnar in 1912, before billions of years ago, in the pre-Cambrian age, the landmass Sri Lanka has been formed with India peninsula, as a part of "Gondwanaland", of the super continent called "Pangaea" (USGS). Sri Lanka though an island today, is an integral portion of the Carnatic genesis terrain of the Deccan peninsula of India only recently served from the mainland (Pathirana, 1980). According to the concept of landscape evolution called "erosion cycle", introduced by a famous geographer , W. M. Davis, the Sri Lanka landforms are modified by the combination of geologic processes that cause tectonic uplift and subsidence and surface processes , such as water, wind, solar

radiation, living things, chemical reactions that form soils , the force of gravity, and other factors.

Further extensive faulting and erosion over time have produced a wide range of topographic features in Sri Lanka. Thus, three zones are distinguishable by elevation such as

- Central Highlands (above 300m)
- Plains (125m – 300m)
- Coastal belt. (Below 125m) Shown by Figure 2.10

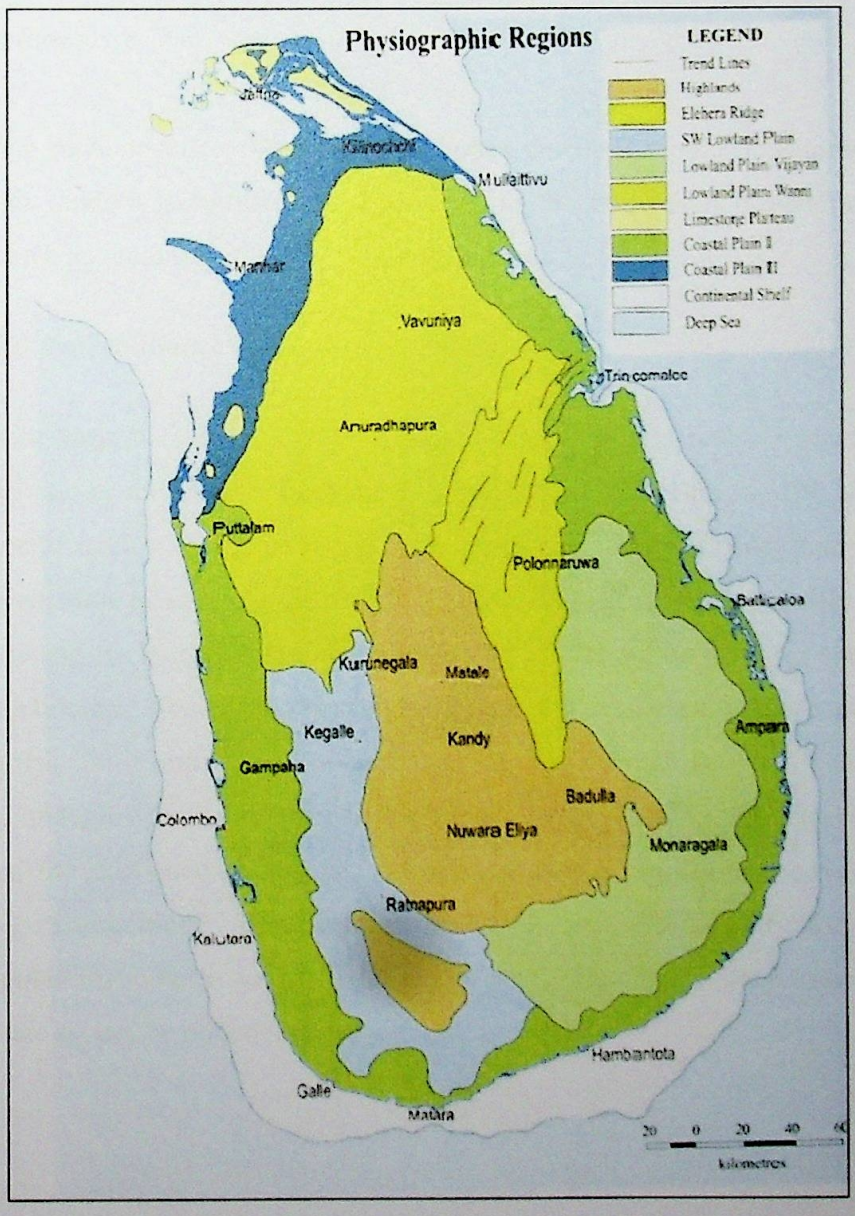


Figure: 2.10: Relief Map of Sri Lanka
Source: National Atlas Sri lank: 2007

As a result of weathering, erosion, denudation and sedimentation of the exogenitic process among several geological eras, such as Miocene, Pleistocene and Holocene, various types of land forms, geographically called "relief", has been originated among these topographical zones. They are different each other, among the zones. Joining with the major factors of the disasters, these reliefs are caused in numerous ways to develop disaster prone areas in Sri Lanka.

Further into the discussed physical elements such as its location, climatic characteristics, geological and soil structure, landforms, it can be identified as a disaster prone country, mainly affected by the disasters, derived from water and its numerous forms.

Considering such evidence, the disaster resilience practices should be launched in Sri Lanka with modern technology, as compared to the traditional disaster resilience practices such as reconstruction.

2.5 What is the Resilience?

American heritage® Dictionary (2000) says, "The ability to recover quickly from illness, change, or misfortune; buoyancy" is resilience. According to life science or environmental science, it can be taken as "Ecology the ability of ecosystem to return to its original state after being disturbed" (Collins English dictionary, 2003). Able to recoil or spring back into shape, after beginning stretching or bending compressed (Oxford dictionary, 2006). Plodinec in 2009 says the resilience is the capability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change (MHA). Considering these definitions, the resilience simply can be defined as the "ability to recover quickly from difficult condition". This research based on resilience activity for different environmental phenomena, such as natural disasters. Therefore, a good knowledge of the resilience should be added to this.

2.6 Transportation in Sri Lanka.

Sri Lanka's strategic location at the crossroads of Asian trading routes has contributed to its growth as a regional trading and transportation hub (web.worldbank.org) Road and rail transport accounts for an overwhelmingly large share of the movement of people and commodities within Sri Lanka, as compared to the air and water based transportation media.

Table 2.2: Road Statistics in Sri Lanka

Road Category	Length in Km
Expressways	159.78
A	4217.42
AA	*3720.31*
AB	*466.92*
AC	*30.19*
B	7955.77
C , D & E	15,500
Local authority	65000
Other roads*	24000

Source: RDA – SL 2014 December

* = *Roads owned or controlled by irrigation, wildlife, and other authorities*

Roads and railways are the backbone of the transport sector in the country. They are playing vitally an important role in integrating the country, facilitating economic growth, and ultimately reducing poverty. The table 2.2 describes the total lengths of each categories of the highway system in Sri Lanka when in 2014. According to the table, the Sri Lanka highway system is consisted with 159.78 km of expressways, (OCH is 29.2 km), 12173.19 km of A & B class (national) roads, 15500 km of C, D and E class roads and 89000 km of other local roads,*(RDA – SL, 2014)* carries over 70% of the traffic in Sri Lanka. According to the future prospects of "National Road master Plane", (2007), Rs. 238.3 billion has been estimated for constructing 594 km of new Expressways and Highways, as a solution for the competent transportation

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background for future Sri Lanka. Currently Sri Lanka, have 1380 km of railways (railway.gov.lk, 2011) and about 116,000 km, of road network (Figure- 2.11), which has been officially classified in to several groups.

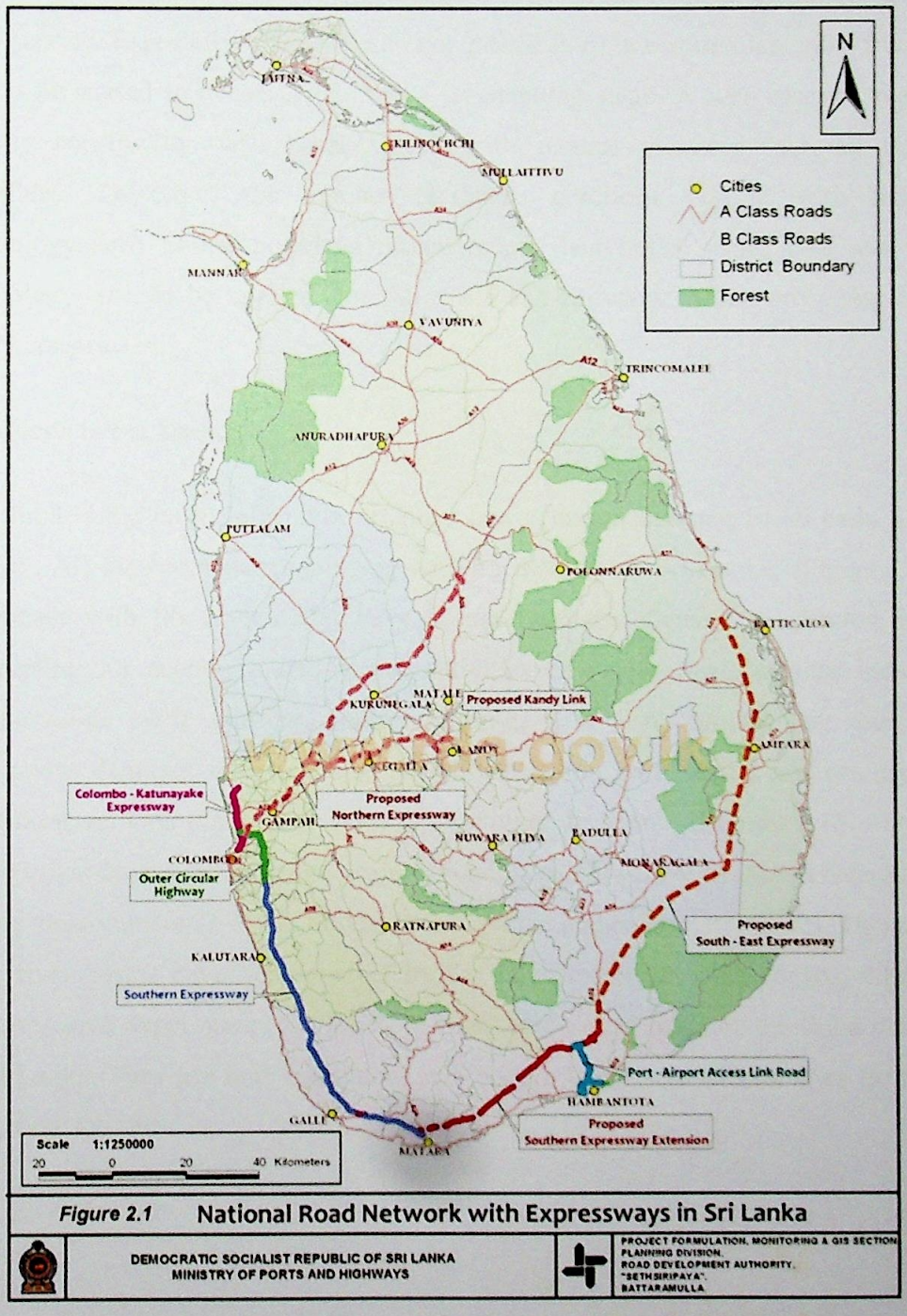


Figure 2.11 : Road Network of Sri Lanka

Source: RDA – SL, 2013

Though Sri Lanka is consists with such amount of railways, highways and relevant infrastructure, sometimes they are incapable to release their maximum operational strength, due to natural disasters

It is caused to deduct the actual operational strength of the road, as low travel speeds, poor service. Especially disaster resilience practices on transportation infrastructure, should be started from the beginning of its planning stage. A well planned road or railway construction will hardly faced with natural disasters such as floods, landslides. Therefore, the disaster resilience practices, consist with modern technology such as computerized digital maps, data bases, using GIS and GPS technology, should be applied, for the roads and railways, which are going to be newly constructed.

2.7 Floods in Sri Lanka.

The flood is the most vulnerable, frequent and common disaster, in all parts of the country. All nine provinces including with 25 districts of Sri Lanka, (Figure- 2.12) experience with flood regularly, have caused immense damage to affected areas, interrupting all economic and social activities i.e. agriculture, mining industry, transportation, cattle farming, poultry farming. It is also reported that there are tremendous damages to infrastructure facilities in the area. In the last century the flood disasters took the highest value among other disasters. (Figure. 2.13). Out of the 103 river basins in Sri Lanka Kalu, Kelani, Gin, Nilwala & Mahavali river basins are the most vulnerable to the floods, (Premarathne and Sonnadara, 2012). Therefore, those river basins have been studied by the flood expertise, hydrologists, who are doing research experiments on floods, to find solutions, to mitigate the flood disaster in Sri Lanka. They use both traditional and modern technological strategies for flood mitigation activities.

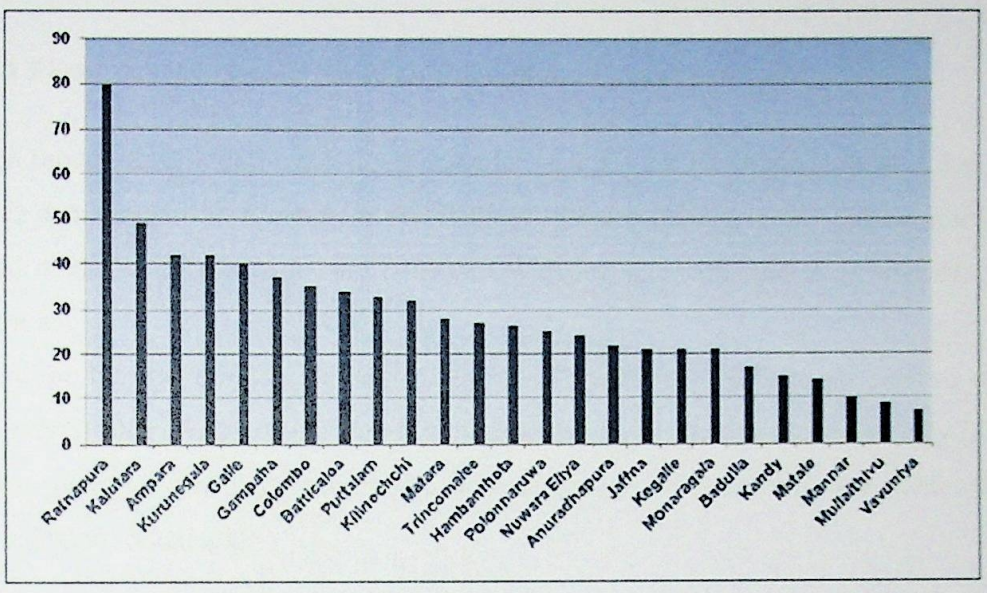


Figure 2.12: Flood Events by Districts 1999 – 2011
Source: DMC - SL

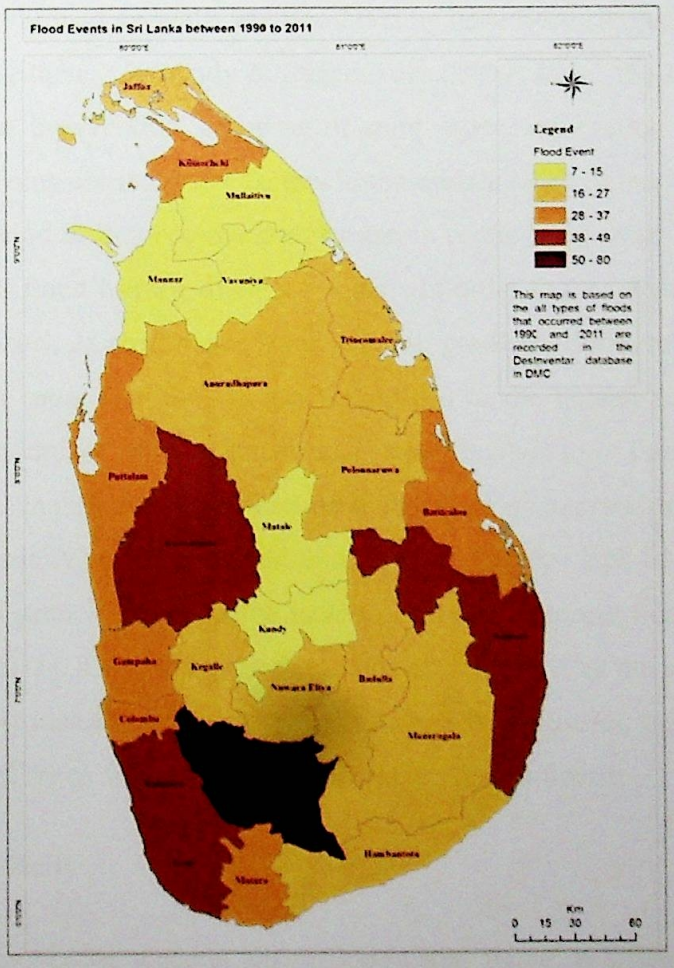


Figure 2.13: District based flood events in Sri Lanka from 1990 – 2011
Source: DMC - SL

2.7.1 Flood characteristics for ideal flood management practices.

Even though traditionally, the flood consider as a natural phenomena, now a day, the flood management is popular in the field of disaster management. Furthermore the flood management strategies are consisted with the scientific and neo- technological methods.

Therefore the hydrologists, scientists and other irrigation expertise are used to study the overall phenomena of the flood, including the flood factors, flood velocity, flood return periods, flood gauge height and discharge volume etc. for their flood management practices.

2.7.1.1 Causes of floods.

In spite of 103 river basins in Sri Lanka, most of flood studies have been done for five vulnerable river basins. Especially the flood factors have been studied by many of the expertise. Among them, Jayakody & Sugeeswara (2009) says, the human activities such as upstream intervention, dumping of solid waste, reservation encroachments, gem and sand mining are the major factors in the middle reach of the Kalu river, that's cause for flash flood in Ratnapura and downstream of the Kalu river. Dias (2006) has studied the major flood factors, of all five rivers. In order to the findings, mainly the physical factors such as catchment, zone, rainfall, gradient, flood velocity and basin shape have been caused by the flood as compared to the human activities such as urbanization, floodplain encroachment and land degradation. Furthermore, High intensity rainfall, unauthorized construction in reservations, narrow drains and canals, low retention capacity of wetlands and unauthorized fillings, lack of maintenance of reservations, and cannels, urbanization have caused for the recent floods in Sri Lanka (Hettiarachchi, 2011). Thus, it seems, the floods are triggered by the natural and man-made factors. Just identification of the flood factors is not useful, unless it is able to apply suitable resilience strategies to avoid damages due to floods.

2.7.1.2 Flood Velocity

Flood flow velocity is the speed at which floodwaters move. It is generally measured in feet per second (fps) or meters per second (ms^{-1}). Flow velocities throughout

riverine floods can easily reach 5 to 10 fps and, in some situations, such as flash floods or localized floods, it may be greater than that. Expressing velocities in fps is common in floodplain studies and engineering analyses. (Federal Emergency management agency, 1998). The velocity of a river is determined by many factors; slope of the stream channel and floodplain is the one of the most important factors. The other factors are the shape of the channel, volume of the water, roughness of the ground, the speed of the wind. The velocity can change at various points along the course of a river. (ehow.com). By using the current meter the velocity is measured (Deakin, 2004)

2.7.1.3 Flood discharge

Fluvial hydrologist, who studying the natural river systems can be defined as the discharge rate or flow rate; though an engineer operating a dump tank system can be defined as outflow, which contrasts with the influx. In hydrology, discharge is the volume rate of water flow, including any suspended solids (i.e. sediment), dissolved chemical species (i.e. $CaCO_{3(aq)}$) and/or biologic material (i.e. diatoms), which is transported through a given cross-sectional area (American Water, 2010). It is generally measured in cubic meter per second (m^3/s or CUMECS). Among the different methods such as Area Velocity Method, Slope Area Method, Weir Method and Volumetric Method, the most popular method , which use for calculating flood discharge volume is the Area Velocity method, (Deakin, 2004). Here the fallowing equation is and co estimate the discharge

$$Q = AV$$

Where

Q = is the discharge expressed in cubic meters per second (m^3/s) or cumecs

A = is the stream cross section area (m^2)

V = is the mean velocity of stream flow (m/s)

In the field of civil engineering and hydrology, the values of the discharge volume of a certain river or stream play a vital role in the decision making process, and estimating flood frequency, or flood return periods

2.7.1.4 Flood gauge height

Usually the height of a flood is obtained by measuring gauge height of a certain river or stream. The height of a flood measured by, in feet (ft) or meters (m) of the surface of a stream above a set height established at zero. This measurement can be used to identify the critical flood levels, where a river spills over its banks. (ehow.com) This is a useful statistic to define the flood intensity, flood contours, or it can use to predict the inundation area, when man-made structures near the waterway may be at risk of inundation.

2.7.1.5 Estimation of flood return periods

The accurate prediction of stream flow is essential to the planning of water resource systems (Fieldman, 1979). Moreover, the peak flood flow is an important hydrologic parameter in the determination of flood risk, management of water resources and design of hydraulic structures such as dams, spillways, bridges, culverts and irrigation ditches. Therefore there is a need, to estimate how often a specific flood event will occur, or how large a flood will be for a particular probability of exceedance or recurrence interval (Abida and Ellouze (2007).

Flood frequency is concept of the probable frequency of occurrence of flooding. (Duncan, 2005). The return period (occurrence interval) can be defined as the average time until the next occurrence of a defined event (Varathan et.al, 2010). It is a statistical measurement used for risk analysis, denoting the average recurrence interval over an extended period of time. The recurrence interval is based on the probability that the given event will be equaled or exceeded in any given year. Wikipedia, 2014 (http://en.wikipedia.org/wiki/Return_period) says a return period (recurrence interval) is an estimate of the interval of time between natural events like an earthquake, flood or a river discharge flow of a certain intensity or size. In a nutshell, all evaluations of the risks of extreme weather events, or natural phenomena, require methods to statistically estimate their return periods from the measured data. (Makkonen, 2005). In hydrological studies, the return period is one of the most significant parameters that need to be taken into account, when design a

hydraulic structure, to control flooding, as in the case of spillway dams for flood control, construction of bridges. (Urias et al, 2007)

Bengtson (2002) says, the statistical analysis of repeated observations of an event (e.g. Observations of peak annual flows) are based on the laws of probability. Therefore the probability of exceedance of a single peak flow, Q_A, is approximated by the relative number of exceedance of Q_A after a long series of observations, i.e.,

$$P_r = \frac{n_1}{n} = \frac{No.\,of\ exceedance\ of\ flood\ magnitude}{No.\,of\ observations\ (if\ large)}$$

Where,

n_1 = the frequency

n_1/n = relative frequency of Q_A.

P_r =peak annual flows

Especially, defining the recurrence interval for various types of extreme natural phenomena will help to make decisions of future constructions in the field of civil engineering.

The subjective research methodology is mainly based on the flood recurrence interval. Therefore, studying flood estimation methods is very essential for this research. There are many flood estimation and frequency analysis methods, such as Weibull method, Gumbell distribution, Log- Pearson type III method, Beared method, Hezain method, Log- normal method of bulletin 17B, Mixed distribution analysis, Skew coefficient, Regional flood analysis methods. (Corps of Engineers, 1998)

2.7.1.5.1 Gumbel's method for flood frequency estimation.

According to Faber (2010), flood risk management requires estimates of probability of extreme events with negative consequences. It is one of the most widely used probability analyses of extreme values in hydrologic and meteorological studies for prediction of floods and rainfall. (Mahanama, 2003) In 1966 the Wolf had summarized the different types of flood estimation methods adequately (Mashidani et.al, 1978). The Gumbel extreme value distribution, sometimes called the double-

exponential distribution of extreme values, can also be used to describe the distribution of hydrologic variables, especially peak discharges. (Bengtson, 2002). The significance of Gumbel's distribution of flood frequency evaluation has been taken into consideration. Details of Gumbel's method normally described in the literature can be written as follows:

$$Q_T = \bar{Q}\,(1 + KCv)$$

Where

Q_T = the probable discharge with a return period of T years

C_v = coefficient of variation = $\sigma/\bar{Q}$

$\bar{Q}$ = mean flood

K = frequency factor = $(y_T - y_n)/\sigma_n$

σ_n = standard deviation of data

y_T = - InIn(T/T- 1)

y_n, σ_n = expected mean and standard deviations of reduced extremes to be found from Gumbel's table.

Mashidani et.al, (1978) has evaluated the Powell's simplification practices of Gumbel's method. After several simplification steps it has simplified as follows.

$$T = \frac{N+1}{m}$$

Where

T = Recurrence interval (Return period).

N = Number of years on record.

M = The rank of the event being considered.

The Gumbel's method can be used to obtain the flood recurrence intervals. Nandalal et.al (2010) has obtained the flood return periods for Kalu River, by using the Gumbel's distribution. Fowze et.al (2008) has carried out the frequency analyses to determine peak discharges and return periods of Kelani River, by using Gumble's

method. Gumbel, Frechet, and Weibull distribution functions are the models that are commonly used for extreme value analysis (Varathan. et al, 2010). Among these three functions, the Gumbel distribution has been used to obtain an extreme value and return periods of the rainfall in Colombo, due to its limited requirements such as location and scale parameters, by Variation et.al (2010). Gumbel and Weibull distributions have been used to predict the extreme wave conditions for coastal and harbor structures in Sri Lanka, by Ranasinghe (2008). Fowze et.al (2008), Mahanama (2003) has used the Gumbel method to calculate the flood recurrence interval in Kelani River. Mujere (2011) also used the Gumbel's distribution for flood frequency analyzing in Nyanyadzi River in Zimbabwe.

Thus the Gumble's distribution is playing a vital role, in flood frequency analysis practices. Though, the Gumble's method will not use for the subjective research directly, the influence of it may be caused to the methodology, that's going to be applied to the subjective research.

2.7.1.5.2 Weibull method for flood frequency estimation.

The Weibull method also a popular flood frequency estimation method, which used all around the world, introduced by the Swedish physicist Waloddi Weibull in 1939.Over the last century, a number of plotting formulas and related computational methods for the extreme value analysis have been proposed and supported by empirical justification (Makkonen, 2005). Among these extreme value analysis methods, the Weibull formula is a simple modification of Gumble's method. (Selaman et.al, 2007). In order to Langbein in 1960, the Weibull formula has long been used by hydrologists in the United States for plotting flow duration and flood-frequency curves (Helsel & Hirsch, 1992). The main characteristic of Weibul method is similar to the Gumbel's distribution. By reason of, its limited parameters such as, amount (n) of the peak data, and data rank are the main requirements, to run the both functions to obtain the recurrence intervals. Weibull formula can be shown as follows.

$$P = \frac{m}{n+1}$$

Where;

P = Return period

n = Total number of years of record used

m = Magnitude or rank

Furthermore the equation can be described as follows (Selaman et.al, 2007).

$$P_x(X > x_m) = \frac{m}{n+1}$$

where P_x is the exceedance probability of the **m**-ranked observation, x_m and **n** = number of observations.

Selaman et.al, (2007) has utilized the Weibull distribution with Gumble's method, for flood frequency analysis. Waibull formula predicts much shorter return periods of extreme events than the other commonly used methods (Makkonen, 2005). Weibull distribution also studied for statistical modeling of daily extreme rainfall in Colombo, by Varathan et.al. (2010). The Weibull method is a one of the key method, which feed the methodology of the subjective research. Therefore studying the Weibull method is useful for the study

2.7.1.5.3 Gringorten method for flood frequency estimation.

Gringorten plotting position method also a one of widely used formula for the hydrologic frequency analysis practices. Gringorten formula is still the best plotting position method to be applied with Gumbel distribution (Selaman et.al, 2007). The Gringortain formula is as follows.

$$P_x(X > x_m) = \frac{m-a}{N+1-2a}$$

where P_x is the exceedance probability of the **m**-ranked observation, x_m and **N** = number of observations.

Where **a,** is a parameter that depends on the population distribution:

a = 0.335 *for normal or log normal distribution*

a = 0.44 *for Gumbel distribution*

a = 0.40 *for unknown distribution*

Thus, the Gringorten formula can be applied with different types of distributions, changing with its parameters. But, the Gringorten formula has been simplified by Duncan (2005) as follows.

$$T = \frac{n + 0.12}{m - 0.44}$$

Where;

T = Return period

n = Total number of years of record used

m = Magnitude or rank

Makkonen, (2005) has introduced this method for extreme value analysis in plotting positions. Duncan (2005) also introduced this method as a flood frequency estimation method. Gringortain method was a one of hydrologic data estimation method, used by Selaman et al. (2007), The Gringorten method is a one of key method, which feeds the methodology of the study. Therefore studying the Gringorten method is very useful for the study.

2.7.1.5.4 Hazen method for flood frequency estimation.

In 1914 Hazen has observed that the logarithms of the annual flood maximum were approximately normally distributed (Alexander, 2003). The Hazen method is another hydrological frequency estimation method used. This is popular among the regional flood frequency analyzing practices. Hazen alternative plotting position is a

traditional choice, since Hazen, originally, developed probability paper that simplifies the relationship among pluvial events, return periods and probability of occurrence. (Urias et al, 2007). The major requirements for the calculations of Hazen method are same as Gumble, Gringorten, Weibull methods. The Hazen formula can be shown as follows.

$$T = \frac{m - 0.5}{n}$$

By Mujumdar (1978) explains the Hazen method as follows.

$$P\,(X \geq x_m) = \frac{m - 0.5}{n}$$

Where;

T or P = Return period or Probability.

n = Total number of years of record used

m = Magnitude or rank

Selaman et al. (2007) have studied the reliability of the Hazen method for flood frequency analyzing practices. Using Hazen method, Ewemoje and Ewemooje (2011) have done a study for best distribution and plotting positions of daily maximum flood estimation at Ona River in Nigeria.

Urías et al. (2007) has done a flood risk assessment in Mexico, studying with the relationship between precipitation and return periods using Hazen method. The Hazen formula is used by Chambers et al. (1983) for comparing two or more data sets using Q-Q plots. Considering such these practical evidence, the magnitude of the Hazen method can be realized. It will help to calculate the flood return periods of the subjective research.

2.7.1.5.5 Beared method for flood frequency estimation.

Board's method is also a popular as a one of statistical frequency estimation method of hydro genetic natural phenomena, such as flood, precipitation. The Beareds'

formula can be used to obtain flood return period, or recurrence intervals of any other hydrologic extremes. This formula predicts much shorter return periods of extreme events than the other commonly used methods (Makkonen, 2005). The Beard formula can be shown as follows.

$$P = \frac{m - 0.31}{n + 0.38}$$

Where;

P = Probability (Return period).

n = Total number of years of record used

m = Magnitude or rank

Folland and Anderson (2002) have studied and realized the mathematical combination between Beared and Gumbel theory. They have recommended the Beareds' method as a plotting position method for extreme weather events. Makkonen, (2005) have considered the Beareds' method as a one of considerable method for calculating return periods on extreme weather events. Several flood estimation methods were reviewed by Oyegoke et al, (1983) including with Beard's method to study the synthetic stream flow sequences in West African rivers. The Beards' method is a one of key method, which feed the methodology of the study. Therefore studying the Beards' method is very useful for the study.

Thus, several popular flood frequency estimation methods can be identified for the literature. All of these methods are simple and easy to use. However the method is commonly considered the numbers of annual peak discharge or annual extreme values of the appropriate hydrologic event, and the rank or magnitude of the appropriate value, out of total numbers of the events, as the main factors of them. And it seems, all these methods mainly influenced by the Gumbel distribution method. But, the results of these methods are somewhat different from each other, due to the given

parameters. Such this flood estimation methods can be utilized to feed the methodology of this study.

2.7.1.6 Flood hazard mapping

Preparation the flood hazard maps is a one of nonstructural flood management strategy. But, it is directly related to the structural flood management practices. The flood hazard mapping is used to determine the areas prone to flooding when discharge of a stream exceeds the bank-full stage. Using historical data on river gauge height measurements and discharge volumes of previous floods, along with topographic data, the flood maps can be constructed to show areas expected to be flooded for various discharges or stages. (Figure 2.14)

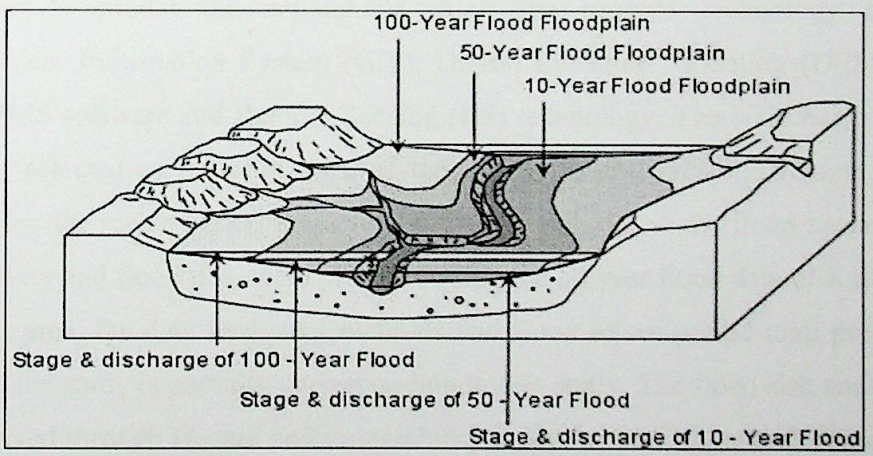


Figure 2.14 : Flood Stages
Source : Nelson 2011

Aerial photographs and satellite images of prior floods are widely utilized to determine the areas that would be covered, the developing phase of flood maps. The Fig.2.13 shows a possible risk map based on estimated flow rates or river stages for a theoretical flood return periods (i.e. 10-year flood, flood 50 years, and the 100-year flood). Furthermore, scale models are often constructed in areas prone to flooding (Nelson, 2011)

2.7.2 GIS intervention for flood management.

Advancements in the Geographic Information System (GIS) help in real time monitoring, early warning and quick damage assessment of flood disasters (Khanna et al, 2007). Dies (2010) have studied the structural and nonstructural approaches such as take water away from people and take people away from flood respectively, for flood mitigation practices using the GIS technology. In order to Dies (2010), the providing modern technology such as GIS, the instruments such as GPS, emergency response communication system, automated data collection system are helping to develop a flood warning system for most vulnerable rivers in Sri Lanka.

Most of the time, non-structural measures like flood forecasting, proper early warnings and conducting awareness programs among the flood affected community etc., can be very effective on flood resilience activities. Nandalal et.al, (2010) have concerned to model the watersheds using the modern technology such as Geographical Information System (GIS), Digital Elevation Modeling (DEM), HEC Geo – HMS software and Remote Sensing (RS) technology. The river basin of Kalu has been selected as the pilot area, of their study. Using GIS and remote sensing technology, the return period maps for 10, 20, 50 and 100 years, flood hazard, flood vulnerability and flood risk, were prepared using the 50 year flood data of Kalu River. The pilot area, the data analyzing methods and flood return period map preparation works of the study is partially corresponding to this study. The flood risk analysis has been derived through Hazard and vulnerability analysis data. In general, flood hazard is classified as low, medium and high according to the United Nations (1991) criteria. Defining the flood return periods, preparation the correspondent flood maps and defining the flood intensity levels of this study can be influenced by the study of Nandalal et.al, 2010

Mahanama (2003) has used the GIS as a tool, to map the flood inundation plots for the Kelani River in Colombo area. there contour map creation, find out flood levels (gauge) for different return periods by frequency analysis, creating flood inundation maps corresponding to the different flood levels and different flood return periods, were the main activities. The research methods, objectives, and outcomes of that research are similar to the research method and case study, of this study.

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Fowze et.al (2008) has done a research on flood hazard mapping in the lower reach of Kelani River. Hydrologic Engineering Center's River Analysis System (HEC-RAS) which is designed for applying in floodplain management and flood insurance studies has been utilized to study the geometry of the Kelani river. Utilizing, Digital elevation model (DEM) collaborating with 3D analysis of Arc view software, the flood maps were prepared.

By using the Gumble distribution, the flood return periods have been obtained, and 35 years annual peak discharge data of Kelani River has been used to it. Water levels corresponding to the above discharges were estimated at the downstream station using the rating curve collected from the Irrigation Department.

The core simulations of this research are partially matched with the object of this study. This research will show the way to define the flood return periods, flood discharges corresponding to different flood levels, rating curves and flood map preparation practices of current study.

2.7.3 Other flood related studies.

Many studies have been done, relating to the flood and flood related events. Many of them are flood management and mitigation practices. Various types of flood mitigation models, management plans, technological/ mathematical experiments and explanations, have been developed.

Hawkes (2005) has done a research on coastal flood risk calculations in UK, to define the flood return periods and corresponding flood extremes using Joint Probability method. This analysis gives the probability of the relevant source variables taking high values simultaneously and thus creating a situation where flooding may occur in the coastal area in the UK. This can be considered as a new dimension in flood studies.

The methodologies and the case studies are developed is fully dependent on the historical flood data. The review of historical information can lead to a better understanding of the factors that lead to extreme flood events (Bayliss & Reed, 2001). Therefore, the study that is done by Bayliss & Reed, regarding the flood frequency

estimation, using historical flood data, in the UK can be considered as an important study.

After doing some studies about uniform flood frequency guidelines in Australia, and southwestern USA , Vogal et al, (1993) recommended the log Pearson type 3 (LP3) distribution as a one of best accurate and robust method for flood frequency estimation, as compared to the Gumbel, Log- normal, Normal, Pearson, exponential distributions, etc. Although these studies are not relevant to the current study, the comparison part of the flood estimation methods is important to develop the methodology of this study. .

The study of probability distribution of flood flows in Tunisia, using historical flood flow data, was done by Abida and Ellouze (2007) is an another similar practice for flood estimation. In, this study L-moment diagrams have been used to select the flood frequency distribution that best fits the annual maximum flood flows.

Furthermore, regarding the flood hydrograph and predicting the peak discharge has been investigated by Fieldman (1979), using statistical relationships, empirical equations and watershed models. Frequency analysis of historical stream flows, statistical equations (e.g. Gumbels method), empirical formulas (e.g. Rational formula), single and continuous watershed models have been considered widely through this research as peak flow estimation techniques. Hence, the flood frequency estimation methods, practiced by Fieldman, can be used to develop the research methodology.

Thus several types of flood relevant studies, pertinent to the current research can be described.

2.8 Land Slides.

The landslide is a one of the significant natural disaster (Rathnayake, 2006), with more destructive events on lives property, physical infrastructures of both natural and man-made environments. Due to landslides, economically important facilities have also been affected, especially water distribution pipes, hydro electricity generating

centers, highways, railway and its pertaining infrastructures and communication systems (Bandara, 2005)

United States Search and Rescue Task Force (http://www.ussartf.org/landslides.htm) defined the landslides as a "*rock, earth, or debris flows on the slopes due to gravity*".

"*A landslide is the movement of rock, debris or earth down a slope by the force of gravity. Landslides are known also as landslips; earth Slips, slumps or slope failure*" (Geoscience, 2012). (www.ga.gov.au/hazards/landslide/landslide-basics/what.html)

"*A landslide is a downward or outward movement of soil, rock or vegetation, under the influence of gravity*" (Weerasinghe et al, 2006).

According to the above definition, the landslide can be defined as a geological phenomenon which includes a wide range of ground movement, such as a fall, topple, slide, spread or flow of the earth which can occur in offshore, coastal and onshore environments (Weerasinghe et al, 2006).

"The movement of a considerable mass of rock and / or soil along with the vegetation and structures thereon from a higher to a lower elevation under the influence of gravity may be termed as a landslide" (Bandara, 2005).

By the United States Search and Rescue Task Force, the landslides have introduced as "mass wasting" due to its wide variety of mass movement processes that wear away at the Earth's surface. Anyway, according to these definitions, it seems the landslide directly caused to overwhelm the physical landscape of a certain area, including with the property, physical infrastructures, and lives belongs to it.

2.8.1 Landslide disaster in Sri Lanka

Sri Lanka, comprising 20% of the total land area in the central highlands of the country, is often threatened by landslides during the rainy season. (Werasinghe et al, 2006). Conventionally it had been considered as a minor type, uncommon disaster, in Sri Lanka. Until the year 2002, the annual average number of landslide records did

not exceed 50. However, it shows a sudden increase in the occurrence of landslides during the period after 2003. (Figure 2.15)

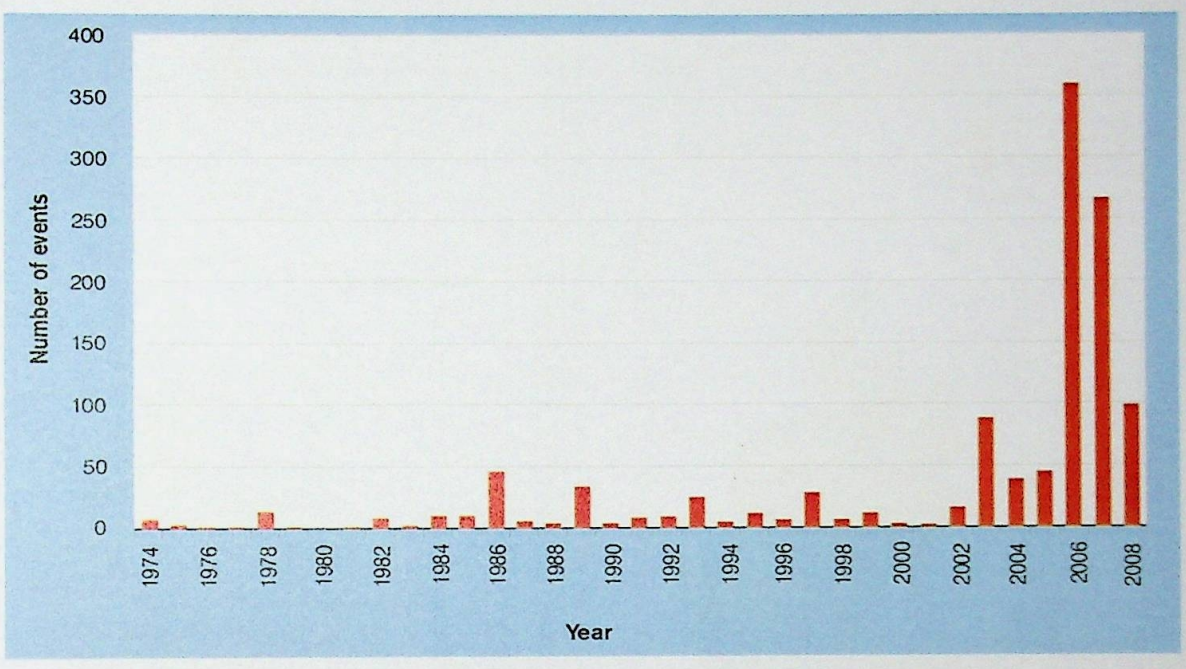


Figure 2.15: Annual Time Series Distribution of Landslides in Sri Lanka

Source: (www.desinventar.lk)

20 - 30% of Sri Lanka's land area, encompassed around 10 districts named, Kalutara, Galle, Hambantota, Nuwara Eliya, Matale, Kandy, Kegalle, Ratnapura, Matara and Badulla have been declared as the area that are prone to landslides, by the National Building Research Organization (NBRO) - Sri Lanka. (Figure 2.16).

During the last ten years it has become evident that the most devastating landslide events tend to occur as a result of comparatively short duration, high intense rainfall in Sri Lanka. (Rathnaweera et al, 2012). Bandara (2005) has identified mainly 3 parts of a landslide, namely Crown, Body and Toe, from uppermost part, middle part, and the lowermost part of the sliding respectively. Weerwsinghe et.al. (2006) and Bandara (2005), have categorized landslides into several types such as Slump, Rock fell, Rock slide, Debris fell, Creep, Debris flow. (Figure 2.17). Thus the main types and the behavior of the landslides can be referring by the figures below.

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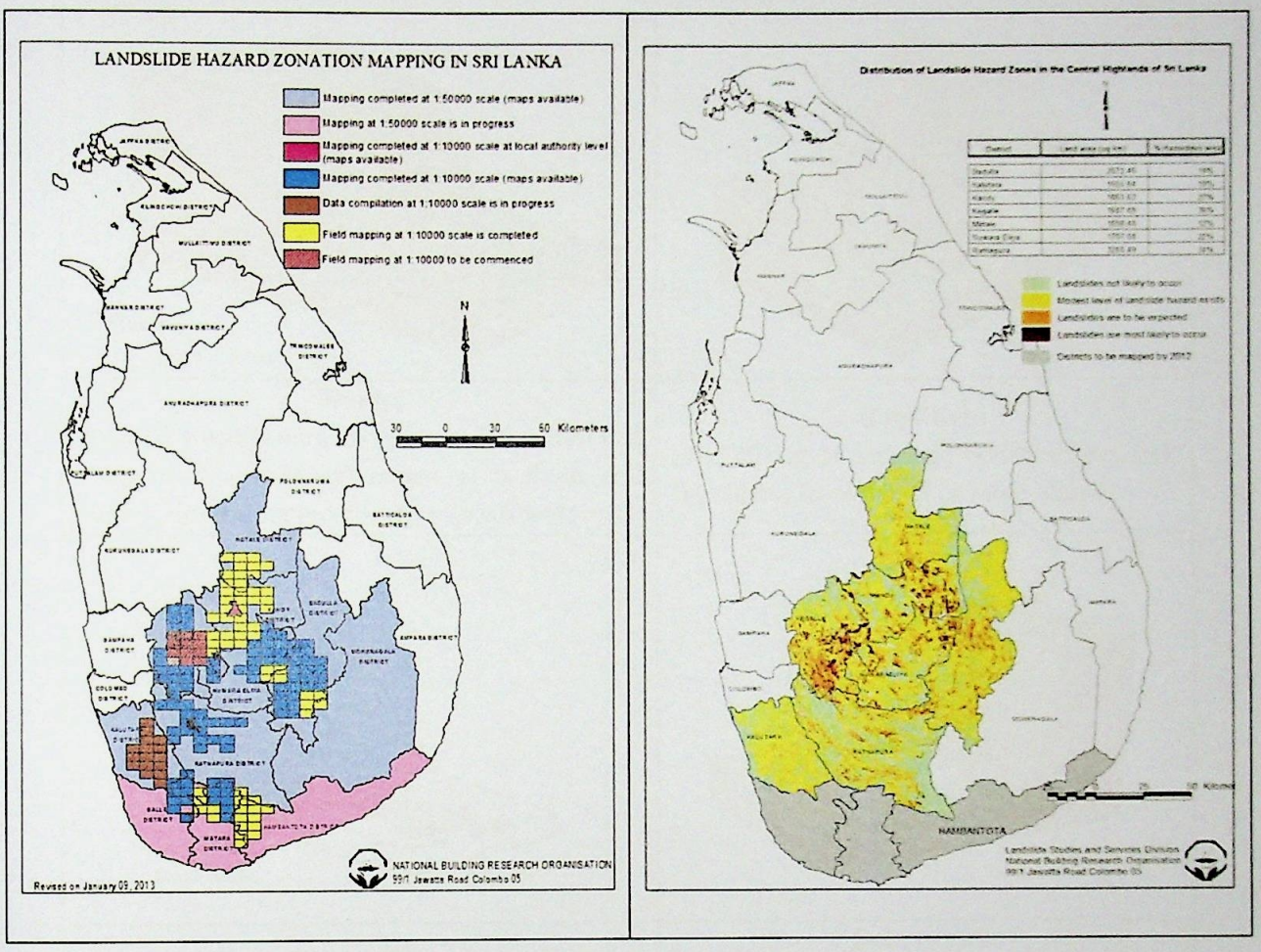


Figure 2.16: Landslides Potential Area of Sri Lanka

Source: NBRO and DMC SL

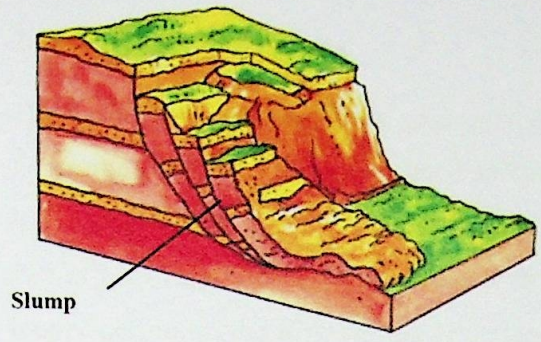
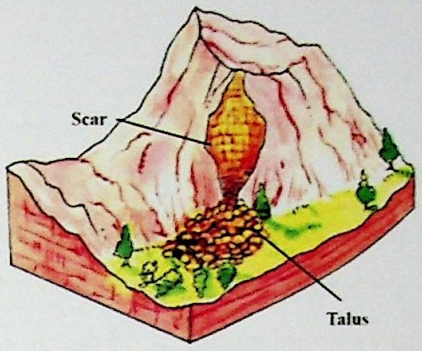
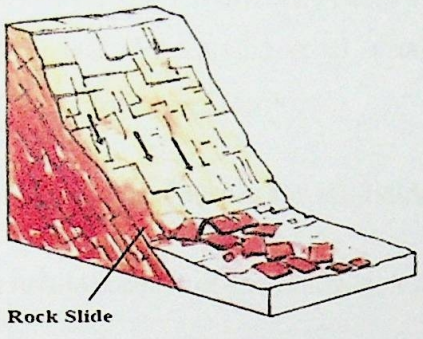
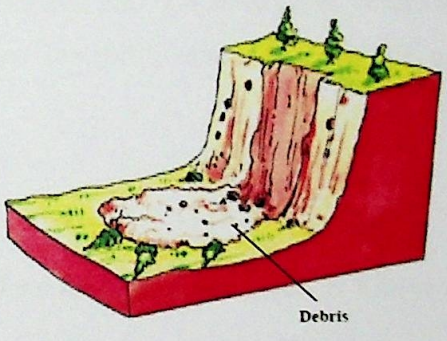
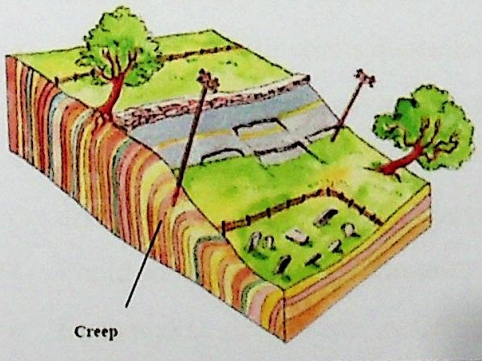
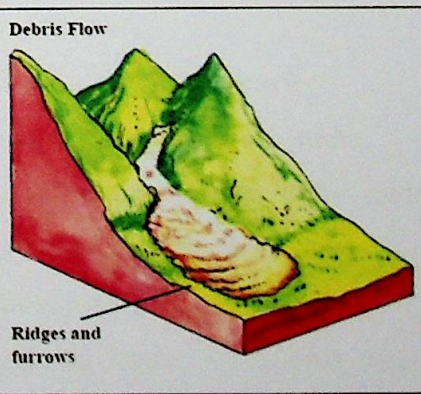
<table>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Slump:
Type of slope failure in which a downward and outward rotational movement of rock or soil occurs along a curved concave up surface</td>
<td>Rock Fall:
Free falling of detached bodies of bedrock (boulders) from a cliff or steep slope</td>
</tr>
<tr>
<td>
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</tr>
<tr>
<td>Rock Slide:
Sudden down slope movement of detached masses of bedrock is called a rockslide.</td>
<td>Debris Fall:
Free falling is not only rock but also overlying sediments and vegetation is known as debris fall.</td>
</tr>
<tr>
<td>
</td>
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</td>
</tr>
<tr>
<td>Creep:
Imperceptibly slowdown slope movement of earth cove or regolith. Utility poles, fence posts and gravestones etc. appear tilted or deformed on the surfaces where affected by creep</td>
<td>Debris Flow:
Down slope movement of collapsed, unconsolidated material typically along a stream channel.</td>
</tr>
</table>

Figure 2.17: Types of Landslides.

Source: National Building Research Organization (NBRO).

2.8.2 Causes of landslides.

The occurrence of landslides generally depends on complex interactions among a large number of partial interrelated factors (Pan et al., 2008). Though the cause of landslides is usually related to instabilities in slopes (Werasinghe et al 2006), it is the nett effect of multi reasons consisted with several processes and factors persisting for longer period on the hilly terrain (Bandara, 2005). It can be triggered by many often concomitant causes, which triggers the movement of slope material will be an increase in pore water pressure from rainfall or leaking infrastructure. Other triggers include earthquakes, vibrations caused by human activities, and undercutting of slopes by fluvial erosion or artificial excavation. (Middelmann, 2007) According to Bandara, (2005), and Werasinghe et al. (2006), the slope instability can occurred due to, Natural or Man-made factors.

2.8.2.1 Natural Factors for landslides

The natural causes or factors, which influence to lead landslides, are given as follow.

- Steepness of hill slope
- Type of rock material and Geological structure of rock or soil formation
- Decomposition of rock material and the depth of the weathered rock.
- Density of the joint pattern and the structure of the rock.
- Thickness of colluviums deposits collected down slope due to gravity.
- Poor drainage conditions leading to excessive water seepage in sub strata.
- High intensity of precipitation (caused to raise the ground water table; decrease the soil strength and increases weight of associated material.)
- Rapid snowmelt in the mountains {not common in Sri Lanka}.
- Earthquakes or volcanic activities as a triggering factor. – (In areas where there is an existing volcano, volcanic ash deposits , called as lahars deposits are prone to erosion and subjected to mud flows due to intense rainfall) {not common in Sri Lanka}.
- Flood and reservoirs in hilly areas, which impact to the ground water regimes
- Fluctuation of water levels due to the tidal action.

- Deposition of loose sediments in delta areas.

Thus, the natural factors can be identified as the endogenous process, and external factors, of the physical environment of the earth.

2.8.2.2 Man-made factors for landslides.

Man made or anthropogenic factors are derived as a result of day to day human activities. Unnecessary human intervention or encroachments on the natural environment, strongly influences to the incidence of landslides. Some wanton land use practices can be mentioned as follows.

- The use of land without proper planning manners.
- Denudation of forest areas exposes the topsoil, which affects the stability of slopes.
- The soil cracks and is eroded by the rains causing landslide.
- Constructions on hilly terrain, without due investigation or engineering design.
- Quarrying for metal without due investigation and adherence to norms.
- Obstruction of natural water paths and storage of water on high ground.
- Farming practices

These activities may cause to increase the slope instability, or significant changes in surface and ground water regimes adding to the landslides.

Thus the factors, which cause to the landslides, can be presented, as it is a requirement of sub objectives of this research.

2.8.3 Landslide management and mitigation practices using GIS

At present, the landslide prevention and management practices are taking into consideration widely, then the past. As well as the neo- technological integrated mechanisms are commonly implemented for landslide prevention and management practices, as compared to the traditional disaster management practices. Both structural and non structural mitigation practices can be implemented as landslide management practices (Weerasinghe et al, 2006). In spite of such these practices, the

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intervention of GIS and Remote sensing technology is a one of significant dimension in landslide and other disaster mitigation practices.

Landslide Hazard Mapping Program (LHMP) has been conducted since 1995 by NBRO- Sri Lanka, using GIS technology to identify the distribution of landslide potential in the central highlands of Sri Lanka (Bhanbari, 1995), (Weerasinghe et al, 2006). Furthermore, the landslide hazard zonation maps have been prepared; in order for the potential of the factors are spatially integrated; based on this cumulative hazard potential, different hazard zones are allocated to the threatened area. PC based GIS model for preparation of hazard zonation maps, have been developed using both AUTO CAD and PC ARC/INFO software (Bhandari, 1995, Weerasinghe, 1997). The landslide hazard zonation maps, prepared by Bhandari and Weerasinghe, are very useful.

The Study of Baldiviezo et al (2004) was to develop and test a heuristic approach to predict the spatial distribution of landslide hazards using GIS and variables such as slope, aspect, proximity and type of current land cover. They have showed that the probability of the landslide was significantly influenced by the slope and land cover. Their model was effective in predicting landslide hazard and landslide hazard map generation. Their findings are useful to determine a strategy to identify the probability to occurring landslide in relation to the slop of a given area.

Furthermore, using Digital Terrain Model (DTM) of GIS and multivariate regression analysis methods, the independent factors of landslide, such as geology, slope angle, land use and soil, has been analyzed, to develop a landslide prediction tool, by Pan et al. (2008). Although this is not directly related to the proposed approach, the factor identification through DEM and GIS is somewhat important.

Another study of Weereainghe et al, (2007) was to map the landslide propensity of Ratnapura town area using the deterministic slope stability analysis model called Stability INdex MAPping (SINMAP), and Digital Elevation Model (DEM), together with the Arc View GIS for data analyzing works. Due to Ratnapura is the pilot areas of this (current) research, the findings of Weereainghe et al, are very important.

The experience of Lan et al. (2009) for managing and assessing landslide data using web-based GIS shows a new dimension of using GIS as a disaster management strategy. It is useful for the future developments of the study.

2.8.4 Identification of the risk of Landslides.

Landslides are characterized by their spatial and temporal occurrence and by their intensity. Intensity can be defined by the volume of the displaced material (in link with landslide depth) and by the velocity of the movement. In order to these factors the risk level can identify.

The United States Search and Rescue Task Force has defined landslide prone and the safer area based on basic factors of the landslides. The places

- On existing landslides, old or recent
- On or at the base or top of slopes
- In or at the base of minor drainage hollows
- At the base or top of an old fill slope
- At the base or top of a steep cut slope

Have identified as the area, prone to landslides. The areas

- On hard, non-jointed bedrock that has not moved in the past
- On relatively flat-lying areas away from slopes and steep river banks
- At the top or along the nose of ridges, set back from the tops of slopes,

Have defined as the safer area from landslides.

Depending on the risk level, the landslide has been divided into four groups by the national building research organization (NBRO) - Sri Lanka as follows. (Operation professional Combine, 2003)

1. High risk
2. Moderate risk
3. Low risk
4. Very low risk

The risk levels have been categorized in order to the number of cases, total effected families of the area and volume of the displaced material. In order to these four types

of risk levels, the landslide prone districts in Sri Lanka were categorized based on the risk levels, and mapped them by NBRO Sri Lanka (Bhandari, 1995, Weerasinghe, 1997).

2.9 Data Processing Systems

At present there are lots of data processing systems for corresponding with the data types and requirements. Data-processing systems typically manipulate raw data into information. The process may be automated and run on a computer. It involves recording, analyzing, sorting, summarizing, calculating, disseminating and storing data, or otherwise converts data into usable information (Wikepedia.com). Several data processing systems are used for the subjective research, among the plenty of data processing systems in the world.

2.9.1 GIS

The term GIS (Geographical Information System) is frequently used to mean a computerized geographic database system. However, some definitions of GIS also accommodated, the maps, the much older analogue geographical information system. Cartographers and spatial scientist rendered geographical information into maps, which are also a means of storing and presenting geographic information in a manner comparable in some aspect to the modern geographical information system (Wickramagamage, 2002).

Even though there are so many different definitions of GIS in different areas and disciplines, all GIS definitions recognize that spatial data are unique since geographic location is an important attribute of activities, policies, strategies, and plans (Eldrandaly, 2007). Following are some of these definitions.

In 2004 Worboys and Duckham defined GIS as "A computer-based information system that enables capture, modeling, storage, retrieval, sharing, manipulation, analysis, and presentation of geographically referenced data" (Tylar, 2007).

In order to Tylar (2007), Ducker (1979) defined GIS as " a special case of information systems where the database consists of observations of spatially distributed features, activities or events, which are definable in space as points, lines,

or areas. A geographic information system manipulates data about these points, lines, and areas to retrieve data for ad hoc queries and analysis".

Furthermore, Burrough and McDonnell (1998) defined GIS as "a powerful set of tools for storing and retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes".

Clarke (2001) defined GIS as "an automated system for the capture, storage, retrieval, analysis, and display of spatial data".

Star and Estes (1990) defined GIS as "an information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially–referenced data, as well as a set of operations for working with the data".

Davis (2001) defined GIS as "A computer–based technology and methodology for collecting, managing, analyzing, modeling, and presenting geographic data for a wide range of applications."

Whereas Longley et al. (2005) defined GIS as "A special class of information systems that keep track not only of events, activities, and things, but also of where these events, activities, and things happen or exist."

2.9.1.1 ArcGIS

It is a collection of a group of geographic information system and its software products has been produced by (Environmental Systems Research Institute) ESRI. ArcGIS based on a common library of GIS software components called as Arc Objects [ArcGIS Developer Guide, ESRI]. All ArcGIS 9 ,9.1, 9.2, 9.3, 10 versions consist of four main key parts which are Desktop GIS, Embedded GIS, Server GIS, and Mobile GIS. Figure 2.18 shows the structure of ArcGIS family.

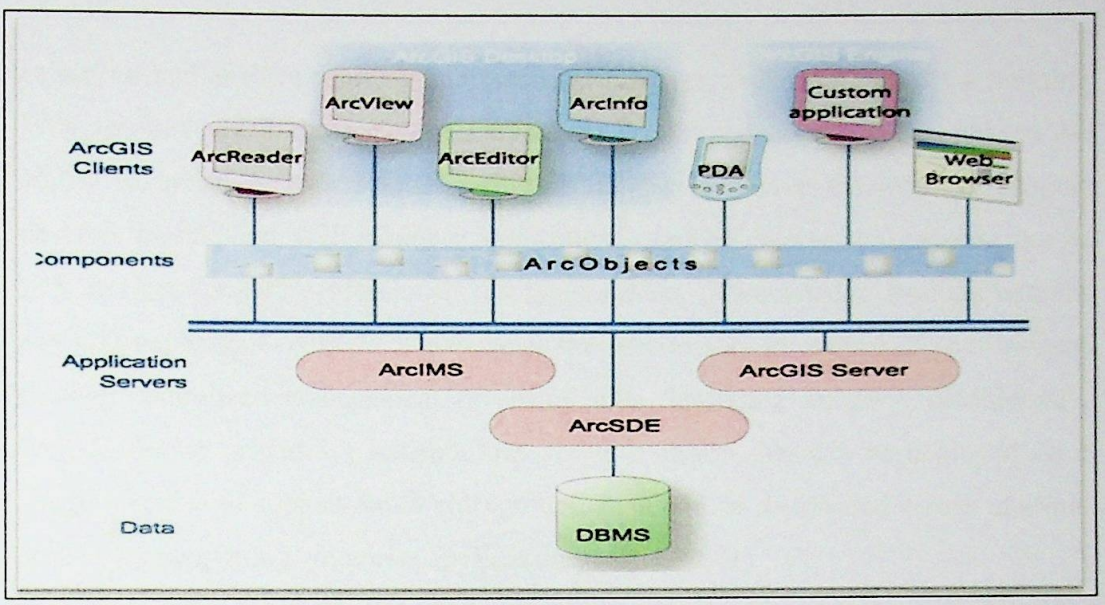


Figure 2.18: ArcGIS Family ,

Source: ArcGIS Developer Guide, Published by ESRI

2.9.1.1.1 Desktop GIS

In order to the ArcGIS Developer Guide of ESRI, Desktop GIS is an integrated application which is developed for advanced GIS applications. At the level of desktop GIS, ArcGIS has ArcView, which allows to view spatial data, create layered maps, and carry out basic spatial analysis; ArcReader, which allows to view and query maps created with the other Arc products; ArcEditor which, in addition to the functionality of ArcView, includes more advanced tools for manipulation of Geo-databases and shape files; or ArcInfo, for data manipulation, editing, and analysis.

2.9.1.1.2 Embedded GIS

In order to the ArcGIS Developer Guide of ISRI it is an Embeddable GIS component library which is used for building custom applications using C++, COM, .NET, Java & Python programming languages. (Silva, 2011)

2.9.1.1.3 Server GIS

According to the ArcGIS Developer Guide of ISRI Server GIS is a shared library of GIS software objects which are used to build server side GIS applications in

enterprise and Web computing frameworks. Moreover, this can be used for building Web services and Web applications using .NET/ASP and Java/JSP. It is able to the ability to create, manage, and distribute GIS services over the Web to support desktop, mobile and Web mapping applications. ArcGIS Server simplifies access to GIS services for GIS professionals, mobile workers, or knowledge workers without any GIS experience. ArcGIS Server helps the user to stay in control of your content through centralized management of spatial data, including imagery. Additionally, ArcGIS Server provides a scalable GIS server platform that can be deployed on a single machine to support small workgroups, or it can be distributed across multiple servers for supporting enterprise applications. (Silva, 2011)

2.9.1.1.4 Mobile GIS

ArcGIS Mobile helps to deliver GIS capabilities and data from centralized servers to a range of mobile devices. It can also deploy sensitive and productive mobile GIS applications to increase the accuracy and improve the currency of GIS data across an organization. (Silva, 2011)

2.9.1.2 ArcGIS customization

This study attempt to develop a model using Visual Basic 6.0 to enhance the efficiency of the GIS application to analyze the flood and landslide data. Therefore, it is important to have a good knowledge of how to customize the ArcGIS software using VB 6.0.

2.9.1.3 Customizing the ArcGIS

Customizing options are very helpful for large organization where a lot of workers engaged in GIS background. Everyone in an organization does not need the same GIS interface to do their tasks easily, and it is more efficient to have customized work environment for each person. ArcGIS can be customized in order to the user preference; due to it is user friendly software. Although, the ArcGIS and ArcCatalogue consisted with several toolbars, menus, short keys and so on, to do lots of customization tasks in GIS without writing a single line of code, ArcGIS helps user

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to create new toolbars to organize commands that often use together or to contain buttons that run the custom scripts. (Silva, 2011) There are many ways to customize ArcGIS to do the required work very easily. Some of the said capabilities of customizing ArcGIS can be given as follows

- Position toolbars in a specific area of the application.
- Group commands in a way that works best for you.
- Add new macros or load custom commands from another source.

2.9.1.4 Customizing the ArcGIS Desktop applications

This allows the user, to write own code using ArcObjects to perform some customization in their desktop application. ArcGIS Desktop applications use set of software products which share objects called ArcObjects to do its tasks. The graphical user interface (GUI) in each application is developed using the same objects, contains with, menus, commands, toolbars, and tools that have the same look and feel. The interfaces can also be easily manipulated in terms of adding and removing toolbars, docking toolbars, adding and removing commands, and so on [ESRI Developer Network, EDN Discussion Forum]. By the using of following options, ArcGIS desktop can be customized.

- User interface customization
- VBA macros
- VBA UI controls
- Framework components
- Extensions
- Custom Objects

2.9.2 Google Earth,

Google Earth is a virtual globe, map and geographical information program that was originally called Earth Viewer 3D, and was created by Keyhole, Inc, in the USA, by using 3D modeling program software. Google Earth allows traveling the world

through a virtual globe and view satellite imagery, maps, terrain, 3D buildings, and much more. It is considered as a hub of knowledge as well as a Geo database, consisting with all attribute data and satellite images of the features in the real world, (Figure 2.19) consisting with the data updating facility. Therefore it is useful for many day-to-day and other purposes.

If Google supplies up-to-date images, it can be used to view areas subjected to widespread disasters such as flood, Landslide, Volcanic eruption, Earthquake. For example after the January 12, earthquake images of Haiti were made available on January 17.

Google Earth can be used as a soft component in all planning, teaching and implementation works in the field of industry (Wikipedia.com). Due to its superimposing facility, the files created by, ArcGIS CAD can be opened on the Google Earth interface. It is a one of the most important feature to match or realize the differences between the real world and created maps or plane. Therefore the subjective research is going to be used the Google earth application, to verify the result that derived.



Figure 2.19 Google Earth Interface ,

Source: Google Earth .com

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2.9.3 MS Excel

Microsoft Excel is spreadsheet application developed by Microsoft for Microsoft Windows and Mac OS. It has the basic features of all spreadsheets, using a grid of *cells* arranged in numbered *rows* and letter-named *columns* to organize data manipulations like arithmetic operations. It has a battery of supply functions to answer statistical, engineering and financial needs, with a macro programming language called Visual Basic for Applications. In addition, it can display data as line graphs, histograms, charts, and with a very limited three-dimensional graphical display. (Wikipedia) (Figure 2.20)

The subjective research is widely used MS Excel 2007 for its data calculations and graphical representation of the combinations of the appropriate data.

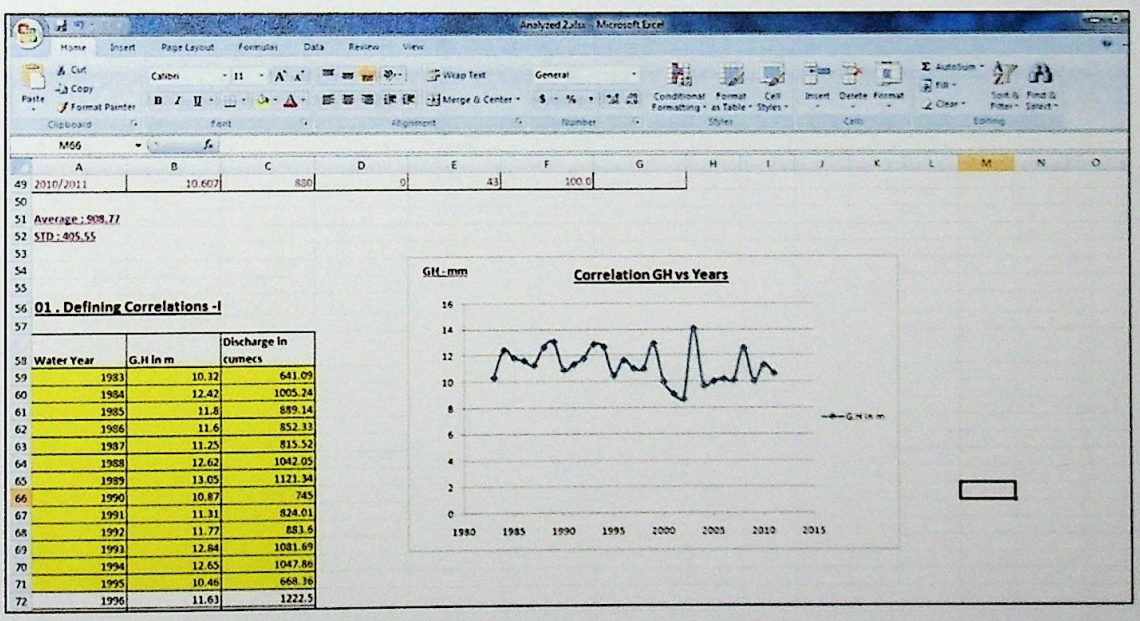


Figure 2.20: MS Excel Interface ,

2.9.4 FindGraph

FindGraph (Figure 2.21) is a comprehensive graphing, curve fitting, and digitizing software that can generate Cartesian X-Y plots, digitize the data and extract data values from a published graph, and simplify the task of curve fitting and regression analysis. (bestshareware.net) It offers 12 generic fits, including linear regression,

logistic functions, Fourier approximation, rationales, neural networks, B-spines and parametric curves least squares approximations, plus a library of over 300 industry-specific 2D formulas. (findgraph.software.r-tt.com/) By using Find Graph, it can be taken any graph or data from any source (Web or PDF document, for example), add the comments, and perform any manipulations, like nonlinear regression or curve fitting. It even can manipulate the data, include it in another graph, and find the best curve to fit the data. The latest version includes an auto regression (ARIMA) model. The software enables you to smooth, interpolate, apply FFT and Wavelet filters, subtract, differentiate, integrate, transform data and curves, and to apply Procreates analysis. As its capability to find the best curve to fit the data, it has been used by the subjective research.

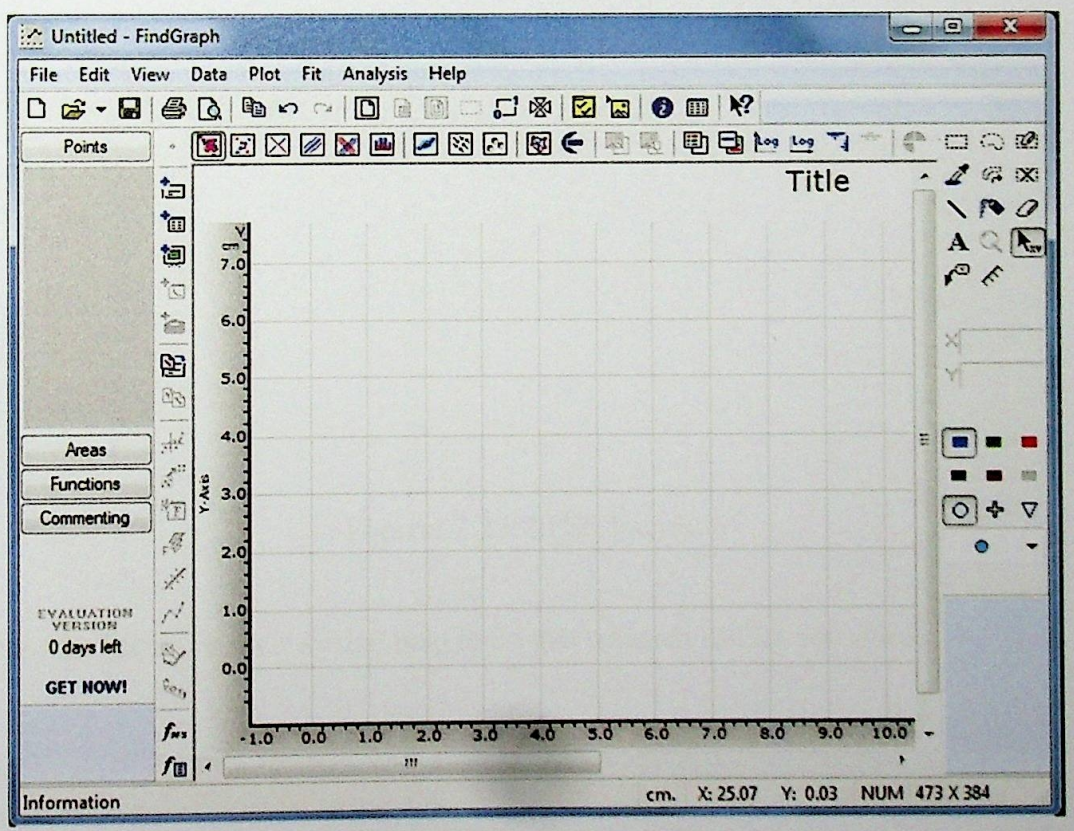


Figure 2.21: FindGraph Interface

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2.9.5 SPSS software.

Statistical Product and Service Solutions **(SPSS)** (officially named "IBM SPSS Statistics") is a software package used for statistical analysis. (Figure 2.22) It is a software, most widely used for statistical analysis in the field of social science. It is used by market researchers, health researchers, survey companies, government, education researchers, marketing organizations and others (Wikipida.com). In the data manipulation part of the Subjective research, the SPSS software is partially used for more reliable outcomes.

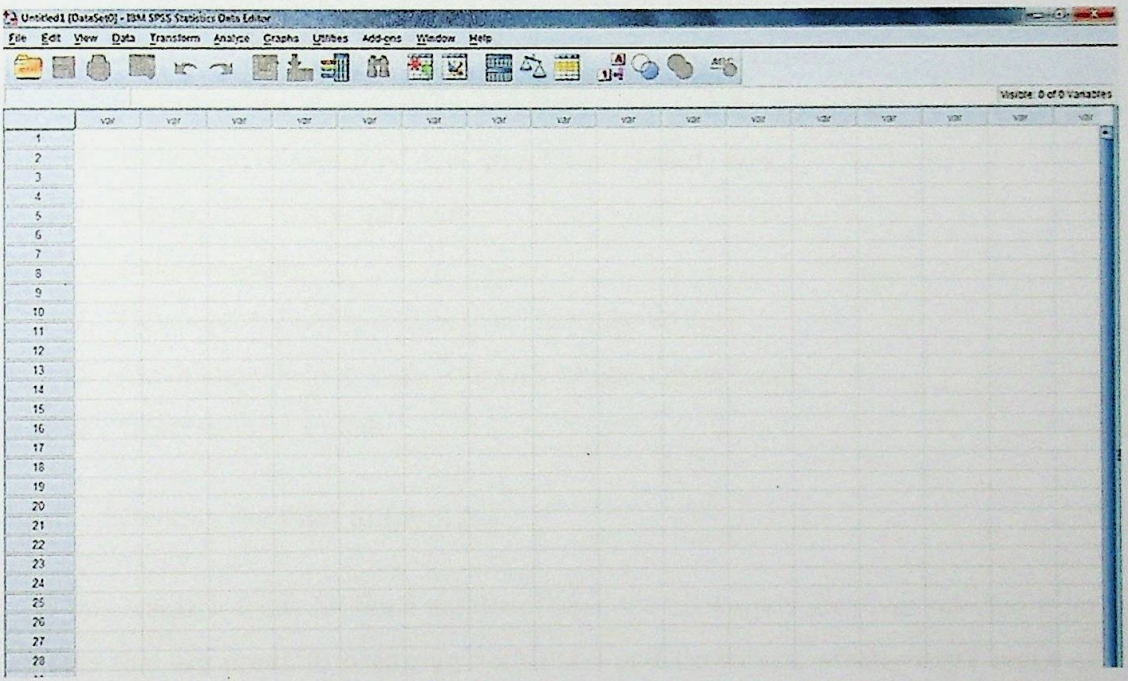


Figure: 2.22: SPSS Interface

Thus, the literature reviews that help to do this research can be described.

CHAPTER 03

03 Methodology

3.1 General

An attempt is made to develop a methodology to identify disaster risk on the limited information available on floods and landslide occurrence.

The methodology of this research is mainly associated with the following steps.

1. Pilot area selection.
2. Identification of appropriate data, for model development.
3. Identification of appropriate software, for model development.
4. Collection of identified data from the pilot study area.
5. Preparation of row data base.
6. Data analyzing.
7. Development of the data base using analyzed data.
8. Manipulate the data base with GIS integration methods
9. Generation of output

3.2 Selecting the Pilot Study Area.

As this research focus on flood and landslides, the pilot study area was selected from places that are prone to occurring both flood and landslides. Mostly these types of disaster prone areas can be identified along with the river basins of Sri Lanka. Mountainous areas, which are consisted with the steepest gradient and un- interrupted heavy rain, are mostly vulnerable to the landslides, rather than the floods.

The country consists with radial drainage system, possessed of 103 rivers. Figure 3.1 shows the major river basins of Sri Lanka. The radial drainage system of Sri Lanka can be identified by referring the same figure.

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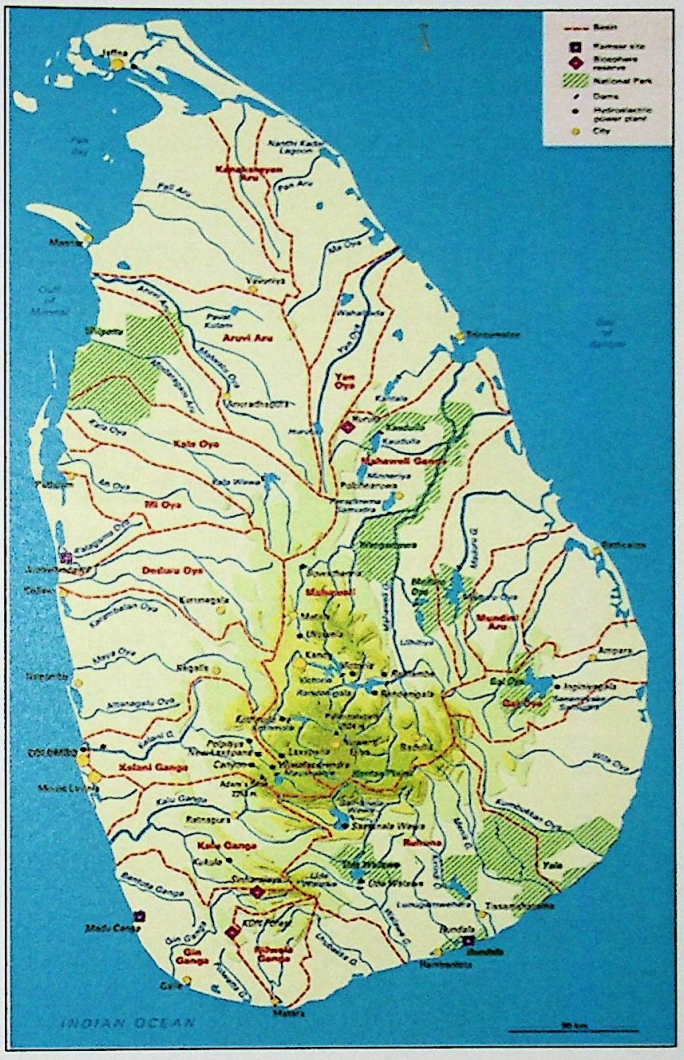


Figure 3 .1: The Radial Drainage System in Sri Lanka and Major River Basins.

Source: National Atlas – 2007

Some of these rivers are perennial rivers, which are most prone to the flood havoc, 3-4 times per year. Kalu, Kelani, Gin, Nilwala, and Mahawelley river basins are most vulnerable to the frequent floods in Sri Lanka (Weerakoon et.al, 2007). Among these, the Kalu river basin is one of the frequently vulnerable, river basins for the flood havoc in Sri Lanka. As same as the Ratnapura can be identified as a one of landslide prone district, among the 10 most vulnerable districts to landslides, declared by the National Building Research organization in Sri Lanka (NBRO - SL)Therefore, Kalu□Ganga River basin at the Ratnapura district in Sri Lanka is selected as the study area for landslides and flood studies.

Kalu River catchment (Figure 3.2) located on the western slopes of the island accumulates most of the monsoon high rainfall and consists of steep gradient in the upper catchment. Mild gradient in the lower part of the river, inadequate to create higher velocities and the bottle necks in the river at downstream locations making the river basin vulnerable to frequent floods. Its watershed covers 2658 km^2 as the second largest river basin in Sri Lanka. The valley is dominant by forest, residential plots and agricultural cropland land use types.

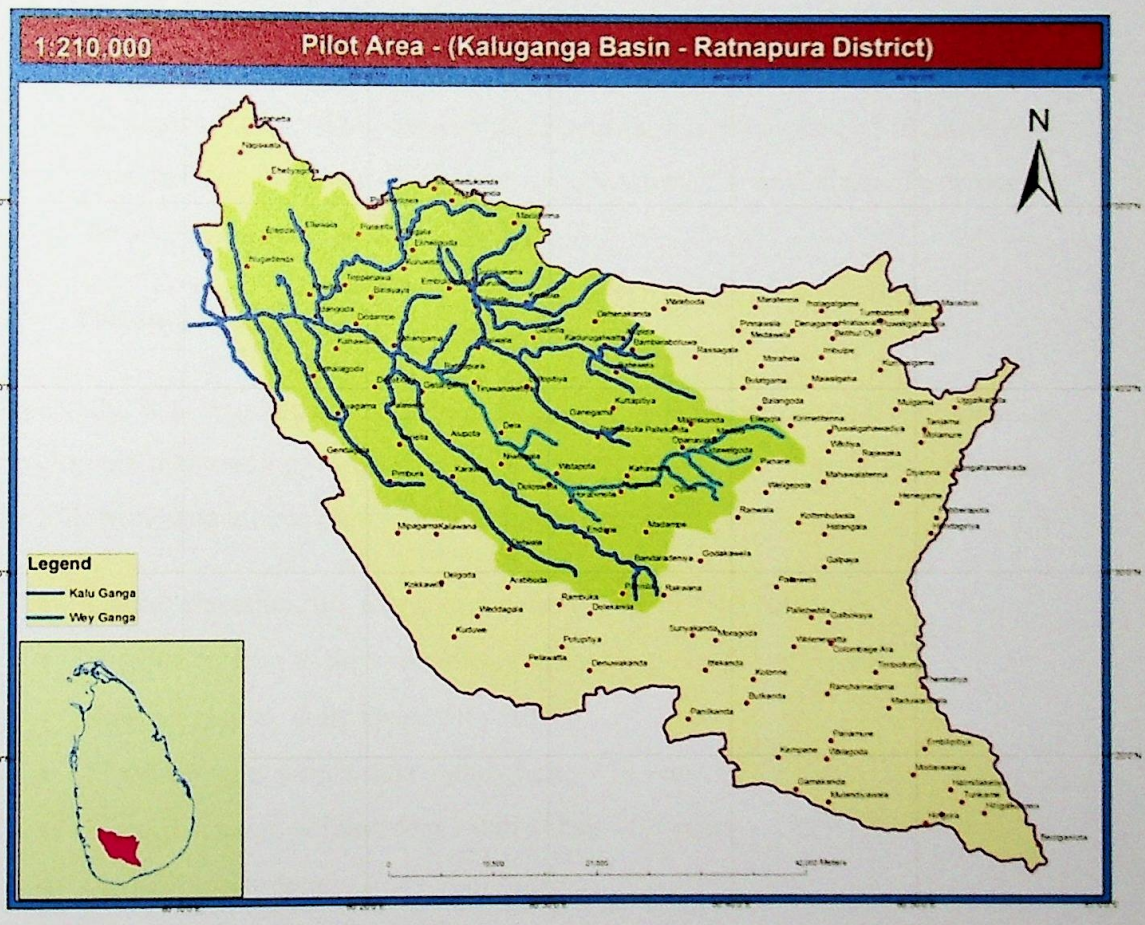


Figure: 3 .2: Kalu River Basins in Ratnapura District

The Kalu river basin and its surrounding area within Ratnapura district are more vulnerable to the landslides as compared to other areas of the country. The main factors that are contributing to increase in dreadful landslides can be identified within this area, due to its precipitation, drainage pattern, steep gradient, and geological background. Therefore, Kalu Ganga River basin in Ratnapura district is considered as the pilot study area of this research.

Reasons for selecting Ratnapura, as the pilot study area are as follows.

- It is a area frequently vulnerable to Floods & Landslides
- Kalu Ganga is the second largest river basin in Sri Lanka, consisting with 2720 km^2 catchment area.
- Geo-morphologically Ratnapura consisted with significant relief, steep gradient, hydrological & topographical characteristics, mostly prone to natural disasters.
- One of proposed major railway development project, "Kelani valley railway extension", up to Hambantota from Kottawa, has been planned to go through this area and Proposed "Ruwanpura Expressway " is also planned to cross the area.

3.3 The data requirement

Especially, it is required the hydrological data landslides data and elevation data to develop the methodology. According to the literature and preliminary investigations, the following data are required to do a detailed research.

- Digital elevation data of the entire study area, in 1:10,000 scale.
- Satellite Images of the study area, representing dry & wet season
- Rainfall data in, daily basis -50 years
- Flood Gauging height data – daily basis - 50 years
- Flood discharge volume data – daily basis - 50 years
- Flood velocity data
- Flood Rating Curves
- Cross section data of the catchment.
- Flood inundation maps of the pilot area
- Digital data of landslides & its intensity data (L/S Zonal maps)
- Defined flood intensity heights.
- Historical records of the flood & landslides, affected road links.

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As the estimation will be reliable with the amount historical data, at least 50 year data on floods will be required for this research. Further 1:10,000 scale elevation data in digital media also required. Other demographic and relevant data can be collected from updated reports, issued by the department of Senses and Statistics.

Though the above information is require to the research, various types of constraints limit the data collecting range. The identified constraints are as follows.

- Lack of the flood gauge height & discharge volume data; and poor availability of the data.
- Non systematic record keeping of the flood levels & discharge volume data.
- Cost of the data.
- Non- defined problems of the data issuing process of the appropriate institutes such as irrigation department, NBRO and survey department of Sri Lanka

Therefore the level the data collection was independent as follows.

- Digital elevation data of Ratnapura sub catchment area, in 1:10,000 scale.
- Digital elevation data of Ratnapura district, in 1:50,000 scales.
- Annual peak flood Gauging Height data for 33 years (only available)
- Annual peak flood flow rate data (Discharge Volume) for 33 years (only available)
- Digital data of landslides & its intensity data (L/S Zonal maps)
- Defined flood intensity heights by the department of Irrigation Sri Lanka.
- In addition the data collected from field observation and interviews, were also used for calibration and testing of the developed methodology.

3.3.1 Data collection

Data collection was carried out from various sources. Collected data can be categorized into two main categories.

- Primary data
- Secondary data

3.3.1.1 Primary data

Primary data are the data which were collected by field surveys and interviews with people of the pilot site. Collected data were;

- Information on flood occurrences
- Flood heights (approximate inundation levels)
- Flood affected areas (approximately)
- Flood risk areas
- Places where landslides occurred

Those data were recorded in a field book and GPS coordinates of those places were recorded using a GPS receiver. Primary data were used to identify the temporal and spatial changes, in respect of natural disasters by analyzing them with maps.

3.3.1.2 Secondary data

Firstly, libraries and internet were referenced in order to collect information regarding flooding and landslides related to the study area, from books, articles research papers etc. Secondly, data were collected from responsible institutions with respect to natural disasters. Data were collected by interviewing officials and from inventories maintained by those institutions.

Names of those institutions and the data collected from them are shown by table: 3.1, as follows.

Table: 3.1 Names of the Institutions and the Collected Data

No	Institute	Collected data
1	Disaster management center (DMC)	• Information on natural disasters (places and dates occurred)
2	Department of irrigation	• Peak flood levels • River gauges heights & flow rates
4	National building research organization (NBRO)	• Landslide data (places and dates occurred) • Landslide risk maps
5	Department of surveying	• Digital maps of study area (land use, roads, contours, hydrology etc.)

3.3.2 Preparation of initial database

All the collected data were entered into the computer using MS Excel application. There the data were categorized under two sub datasets. Each sub dataset was entered to separate spreadsheets. Those sub datasets were;

1. Geographical data
2. Demographic data

3.3.2.1 Geographical data

The geographical data are the collection of information that can describe objects and things with reference to space. Often this is indexed using x, y coordinates or longitudes and latitudes, with altitude (z) . The geographical data, which were used for this research, are as follows.

- Hydro-meteorological data
- Topographical data
- Landslide data

➢ **Hydro-meteorological data**

Information gathered from river gauging stations and rainfall gauging stations within the study area was included.

E.g.: River gauge height, discharge volume, rainfall data.

➢ **Topographical data**

Almost all the data under this category are map borne. Most of these data are in the form of digital data (shape files, geo-databases and images). There were some graphs and charts as non-digital data too. Especially the contours and topographical data were extracted from this source.

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- **Landslide data**

Information regarding occurred landslides within the study area was included.

E.g.: Locations of landslide occurred, locations at risk, landslide intensity data

3.3.2.2 Demographic data

Information regarding the administrative and population data, within the study area was included.

E.g. : province, district, DS division, GN division, population data, population density data.

For the data analyzing purpose, those collected data were gathered in to the computer in several file types. Those file types are shown by Table: 3.2

Table : 3.2 File Types Used for the Final Analysis.

Database	File type
FGH/MSL	MS Excel spreadsheet
FRP	MS Excel spreadsheet
Flood intensity	MS Excel spreadsheet
Flood occurrence	MS Excel spreadsheet
Extrapolated contours	MS Excel spreadsheet & Shape files
Socioeconomic demography	MS Excel spreadsheet & Shape files
Landslides	MS Excel spreadsheet & Shape files

3.4 Data Analysis

The intention of data analysis is to create or produce new data by manipulating collected or existing data via various technical tools such as the software and applications like ArcGIS, MS Excel, Find graph, SPSS . Thus, information with respect of disasters such as magnitude, temporal and spatial behavior, frequency, can

be estimated by analyzing the collected data. In this task; simple statistics and specify were used.

When considering floods which are derived from various natural and man-made factors, a fluctuation of floods can be identified with the time. That fluctuation exhibits an array of temporal and spatial variation of the considered event. A circular pattern of flood levels against the time can be observed

By determining the circulatory pattern of floods which is called the Flood Return Period (FRP), occurrences of future floods can be estimated to a certain extent. The validity of those estimations will depend on the quality of the collected data set. It is much more successful to forecast based on data for long time period rather than based on the data for shorter time period. (Bayliss & Reed, 2001)

3.4.1 Hydrology associated with Kalu Ganga

Kalu Ganga basin was studied in detail as catchments rather than concerning the basin as a whole. Basically four main catchments of Kalu Ganga basin can be identified in Ratnapura District (Figure: 3.3). Those catchments are;

I. Dela sub catchment
II. Malwala sub catchment
III. Ratnapura sub catchment
IV. Ellagawa sub catchment

Each of those catchments covers a tributary of Kalu Ganga. In order to monitor the water discharge data of those catchments, River Gauging Stations have been established by the Department of Irrigation. There are altogether seven river gauging stations located in the Kalu Ganga basin as shown in Figure: 3.4

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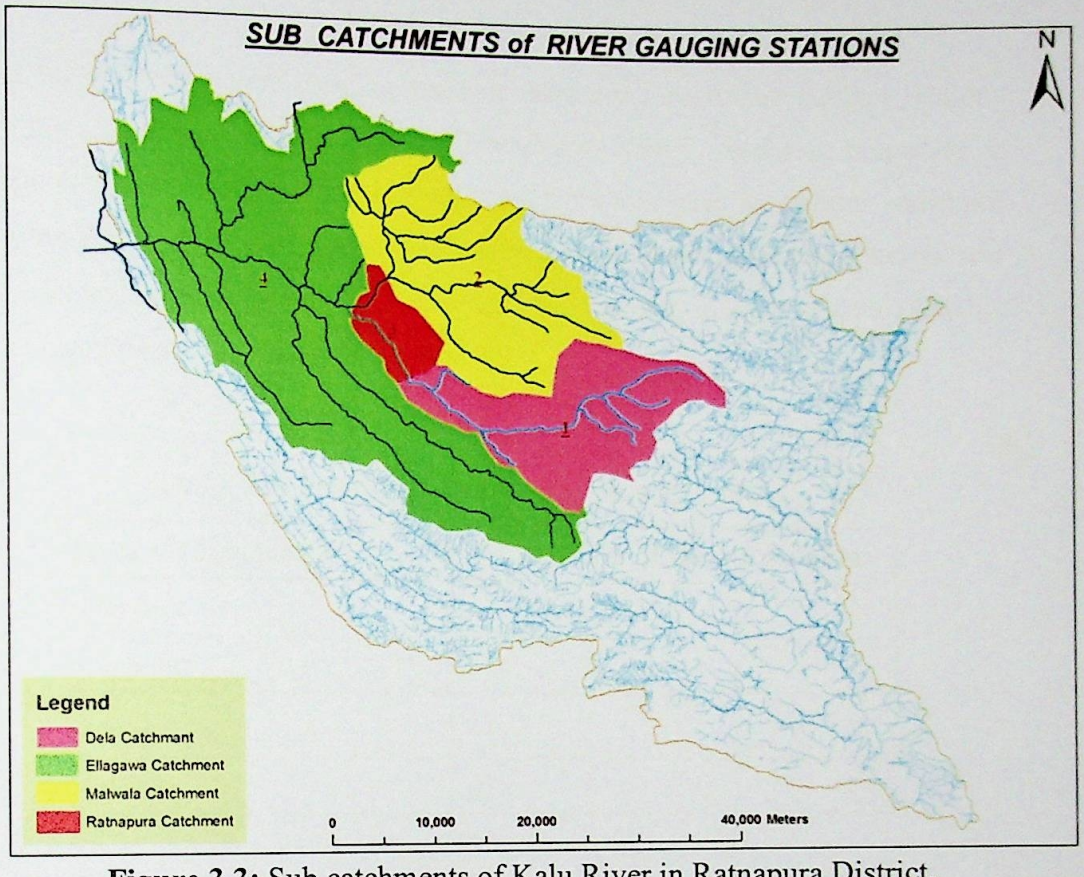


Figure 3.3: Sub catchments of Kalu River in Ratnapura District.

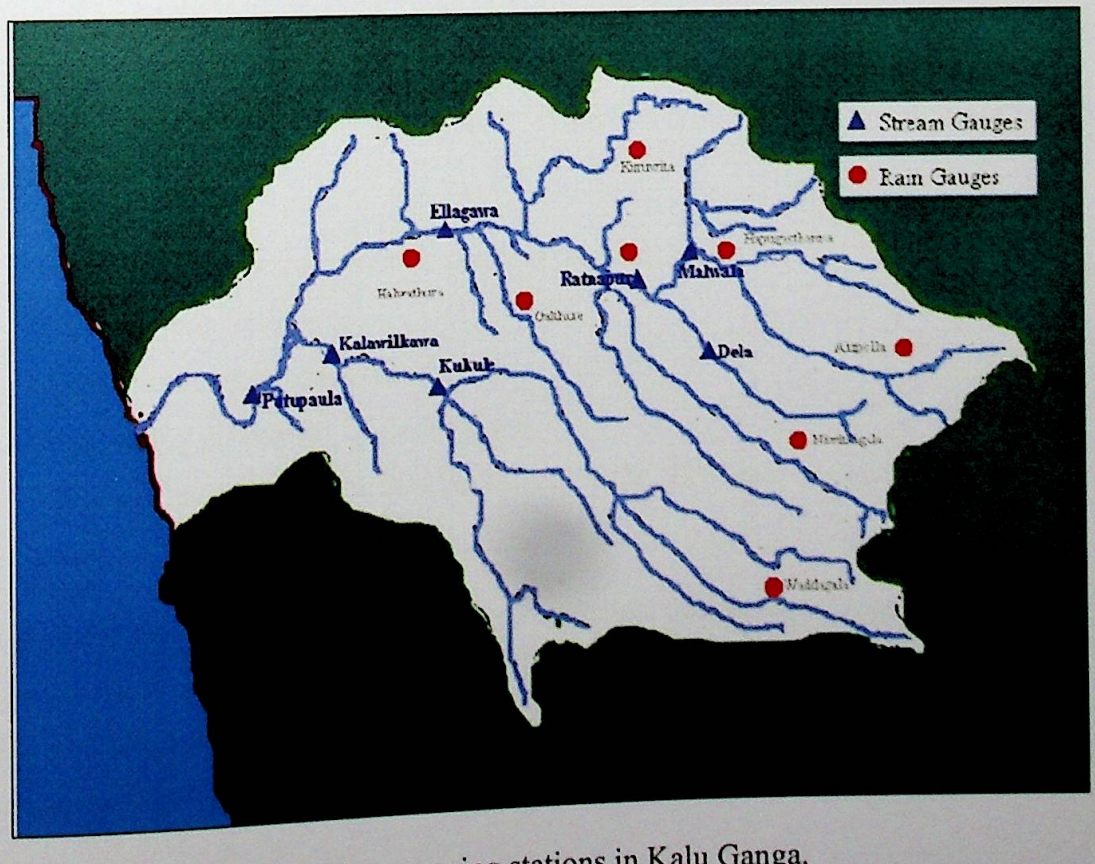


Figure 3.4: River gauging stations in Kalu Ganga.

Out of those seven stream gauging stations, there are four stream gauging stations within the study area. In this study, it is intended to identify discharge properties of the Kalu Ganga by analyzing the data collected from four gauging stations which are within the limits of the study area. The relationship between river gauge height and flood discharge volume has to be determined. The number of years of data available for each gauging station is shown in Table 3.3

Table 3.3: Data availability of the gauging stations.

River Gauging Station	No. of Years of Data Available
Ellagawa	43
Ratnapura	33
Dela	27
Malwala	07

3.4.1.1 Identification of hydrological characteristics of sub catchments.

Out of these four stations, Ratnapura station is more significant due to following reasons.

- Ratnapura is the main economic center in the study area
- Relatively populated area
- Directly affected by flood disasters
- Has a higher probability of flash floods
- There are more proposed development projects for Ratnapura and adjacent areas.

Specify correlation analyzing between flood gauge height and flood discharge volume indicated a linear relationship was observed between flood gauge height and flood discharge volume for all stations (Figure 3.5 & 3.6)

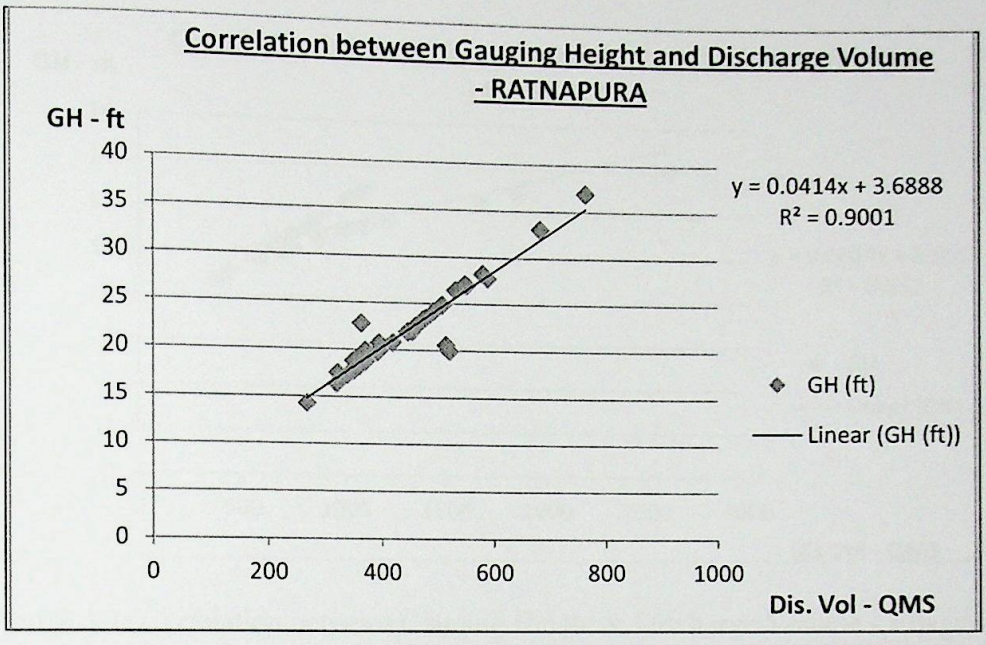


Figure 3.5: Correlation between Gauging Height & Discharge Volume - Ratnapura

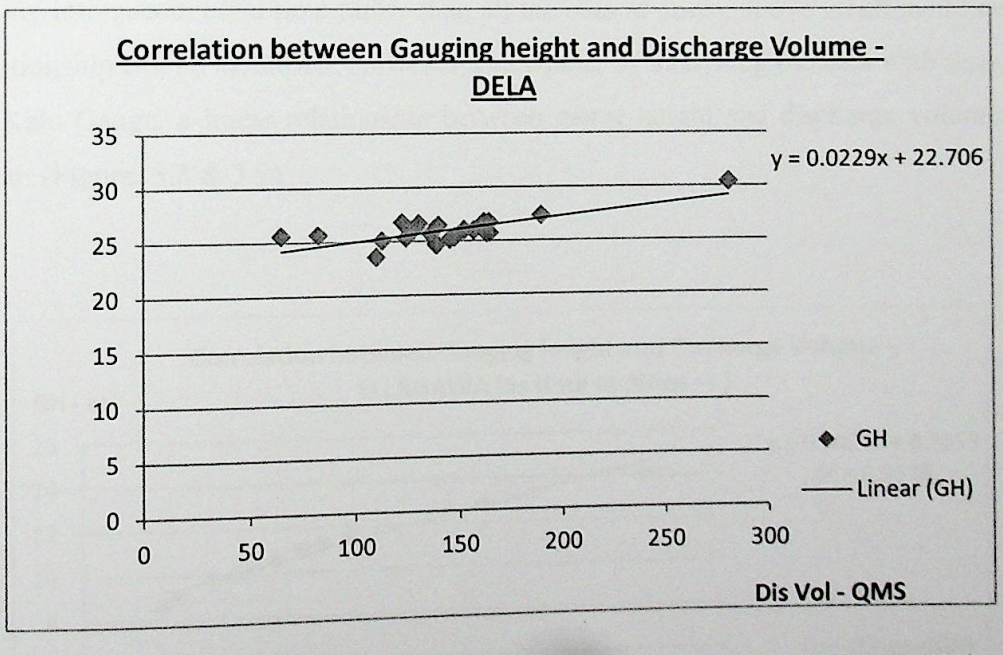


Figure 3.6: Correlation between Gauging Height & Discharge Volume – Dela

Perhaps a linear relationship could not be observed for a long period of time. That is due to temporal changes in flood pattern. Altering river cross sections due to development projects may change the flood pattern. This fact can be illustrated with the data with respect to Ellagawa station. Basically a linear relationship between gauge height and discharge volume, is not there. (Figure: 3.7)

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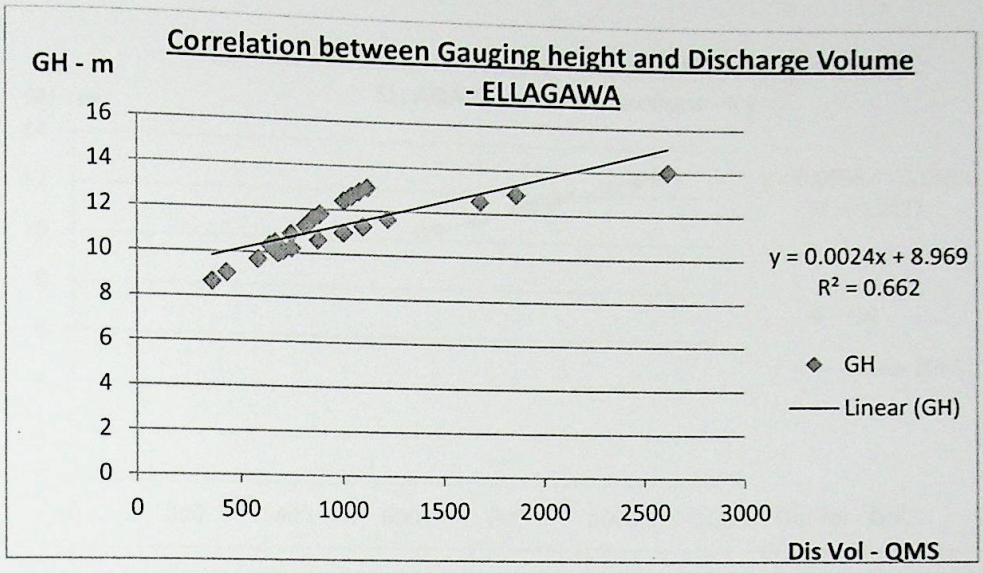


Figure 3.7: Correlation between Gauging Height & Discharge Volume - Ellagawa

However, by studying the data as time sections (i.e. data of few number of years taking into account at a time rather than all the data at once), above mentioned linear relationship can be identified. However as a whole, by analyzing the data with respect of Kalu Ganga, a linear relationship between gauge height and discharge volume is clear. (Figure: 3.8 & 3.9)

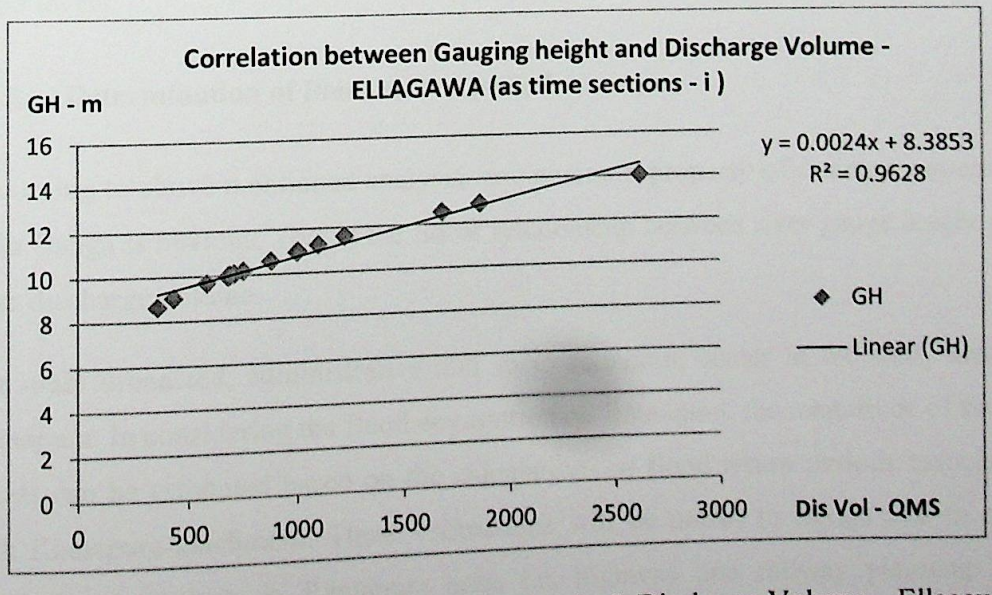


Figure 3.8: Correlation between Gauging Height & Discharge Volume – Ellagawa (As Time Section - i)

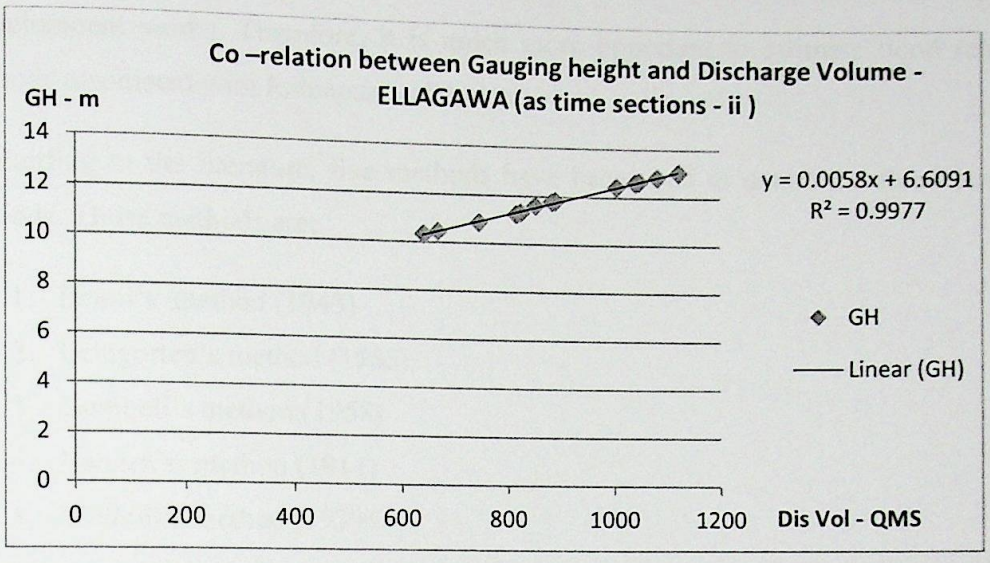


Figure 3.9: Correlation between Gauging Height & Discharge Volume – Ellagawa (As Time Sections – ii)

Based on that relationship, rating curves can be plotted. Using the rating curves, developed flow rates (discharge volumes) and gauging heights can be estimated. In order to fill the gaps in collected data those estimations are very important.

For the calculation of flood return period, flood discharge volume is an important datum. Therefore the estimation of flood discharge volume is another intention of this study, which is required to calculate flood return period corresponds to annual peak flood levels.

3.4.2 Determination of flood return period

According to above mentioned analysis, one common property of drainage pattern of Kalu Ganga is obvious. That is the linear relationship between river gauge height and river discharge volume.

The main urbanized, administrative and socio-economic center in the study area is Ratnapura. In considering the flood devastation on Ratnapura, the magnitude of future floods can be estimated based on the calculations of flood return periods associated with Ratnapura catchment. Those estimations will be useful to design and to plan development projects in Ratnapura area, i.e. highway and railway planning and

development works. Therefore, it is much more important to estimate flood return periods associated with Ratnapura catchment.

According to the literature, five methods have been used to determine flood return periods. Those methods are;

1. Beard's method (1943)
2. Gringorten's method (1963)
3. Gumbell's method (1958)
4. Hanzen's method (1914)
5. Weibull's method (1939)

3.4.2.1 Determination of flood return period according to Gumbell's method

The formula derived from this method is complex as stated below.

$$Q_T = \bar{Q}\,(1 + KC_v)$$

Q_T = the probable discharge with a return period of T years

C_v = coefficient of variation = $\sigma / \bar{Q}$

$\bar{Q}$ = mean flood

K = frequency factor = $(y_T - y_n)/ \sigma_n$

y_T = $- \ln(T/T- 1)$

y_n, σ_n = *expected* mean and standard deviations of reduced extremes to be found from Gumbel's table.

However, above complex formula can be converted to a simpler one as follow.

$$T = \frac{N + 1}{m}$$

T = Recurrence interval (Return period).

N = Number of years on record.

m = The rank of the event being considered.

The only information required to calculate the return period using simplified Gumbell's formula is annual peak flood discharge value. In order to calculate flood return periods, following steps has to be followed.

1. Arrange annual peak flood discharge volume values in a descending order
2. Give ranks to annual peak flood discharge volume values (highest rank to maximum value)
3. Calculate flood return period by applying the data to the formula

Flood return periods calculated for Ratnapura catchment using simplified Gumbell's formula is shown by Table: 3.1

According to confirm the calculated flood return period values, return periods were studied using Recurrence Interval Calculation Formulas. Each and every formula commonly follows two steps (descending arrangement and ranking) followed for Gumbell's method. By doing so, the application of data to those formulas was done.

3.4.2.2 Determination of flood return period according to Weibull's method

Formula for calculating flood return period using Weibull's method is given below.

$$P = \frac{m}{n+1}$$

Where;

P = Return period

n= Total number of years of record used

m = Magnitude or rank

Flood return periods calculated for Ratnapura catchment by Weibull's formula is shown by Table: 3.1

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3.4.2.3 Determination of flood return period according to Gringorten's method

Formula for calculating flood return period using Gringorten's method is given below.

$$T = \frac{n + 0.12}{m - 0.44}$$

Where;

T = Return period

n = Total number of years of record used

m = Magnitude or rank

Flood return periods calculated for Ratnapura catchment by Gringorten's formula is shown by Table: 3.1

3.4.2.4 Determination of flood return period according to Beard's method

Formula for calculating flood return period using Weibull's method is given below.

$$P = \frac{m - 0.31}{n + 0.38}$$

Where;

P = Return period

n = Total number of years of record used

m = Magnitude or rank

Flood return periods calculated for Ratnapura catchment by Beard's formula is shown by Table: 3.1

3.4.2.5 Determination of flood return period according to Hanzen's method

Formula for calculating flood return period using Weibull's method is given below.

$$T = \frac{m - 0.5}{n}$$

Where;

T = Return period

n = Total number of years of record used

m = Magnitude or rank

Thus the flood return periods calculated for Ratnapura sub catchment by using these formulas is shown by Table: 3.4. In their 33 year annual peak flood data were used.

At a glance, it can be understood that, five methods have given five different flood return period values for same discharge volume value. In order to have one return period value average of the five different values were taken.

Flood **G**auge **H**eight (FGH) corresponds to, calculated return period can be determined, using discharge volume associated with it. The studied relationship between FGH and discharge volume can be used for that task. Thus variation of FGH can be worked out according to different **F**lood **R**eturn **P**eriod (FRP) values.

Table 3.4: Defined Flood Return Periods in Ratnapura Sub Catchment Area.

Water Year	GH	DIS. Vol in Descending	Rank	Nos of Data	RP Gumbells	RP Weibull	RP Beard	RP Gringorten	RP Hazen	RP Average
1988/1989	11.28	764.54	1	33	34.0	34.0	48.4	59.1	66.0	48
2002/2003	10.1	682.88	2	33	17.0	17.0	19.8	21.2	22.0	19
1993/1994	8.47	589.06	3	33	11.3	11.3	12.4	12.9	13.2	12
1981/1982	8.63	579.15	4	33	8.5	8.5	9.0	9.3	9.4	9
1998/1999	8.23	552	5	33	6.8	6.8	7.1	7.3	7.3	7
2007/2008	8.25	547.27	6	33	5.7	5.7	5.9	6.0	6.0	6
1987/1988	6.34	531	7	33	4.9	4.9	5.0	5.0	5.1	5
1978/1979	6.1	520.31	8	33	4.3	4.3	4.3	4.4	4.4	4
1985/1986	6.28	513.48	9	33	3.8	3.8	3.8	3.9	3.9	4
1983/1984	7.57	506.58	10	33	3.4	3.4	3.4	3.5	3.5	3
1989/1990	7.38	492.78	11	33	3.1	3.1	3.1	3.1	3.1	3
1995/1996	7.16	477.9	12	33	2.8	2.8	2.9	2.9	2.9	3
1984/1985	7.09	472.59	13	33	2.6	2.6	2.6	2.6	2.6	3
2004/2005	6.89	459	14	33	2.4	2.4	2.4	2.4	2.4	2
1992/1993	6.89	458.79	15	33	2.3	2.3	2.3	2.3	2.3	2
1980/1981	6.71	453.06	16	33	2.1	2.1	2.1	2.1	2.1	2
1991/1992	6.71	446.05	17	33	2.0	2.0	2.0	2.0	2.0	2
1997/1998	6.34	419	18	33	1.9	1.9	1.9	1.9	1.9	2
1986/1987	6.08	395.43	19	33	1.8	1.8	1.8	1.8	1.8	2
2010/2011	6.33	395.33	20	33	1.7	1.7	1.7	1.7	1.7	2
2001/2002	6.03	392	21	33	1.6	1.6	1.6	1.6	1.6	2
1990/1991	5.73	370.99	22	33	1.5	1.5	1.5	1.5	1.5	2
1977/1978	6.1	370.94	23	33	1.5	1.5	1.5	1.5	1.5	1
2009/2010	5.97	368.45	24	33	1.4	1.4	1.4	1.4	1.4	1
1996/1997	6.95	363.04	25	33	1.4	1.4	1.4	1.3	1.3	1
1994/1995	5.58	360.37	26	33	1.3	1.3	1.3	1.3	1.3	1
2008/2009	5.77	353.75	27	33	1.3	1.3	1.3	1.2	1.2	1
2003/2004	5.43	350	28	33	1.2	1.2	1.2	1.2	1.2	1
1979/1980	5.73	349.71	29	33	1.2	1.2	1.2	1.2	1.2	1
1982/1983	5.27	339.14	30	33	1.1	1.1	1.1	1.1	1.1	1
2006/2007	5.33	322.02	31	33	1.1	1.1	1.1	1.1	1.1	1
1999/2000	5	320	32	33	1.1	1.1	1.1	1.0	1.0	1
2000/2001	4.36	268	33	33	1.0	1.0	1.0	1.0	1.0	1

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3.4.3 Determination of correlation between FRP and FGH

The Correlation between **F**lood **R**eturn **P**eriod (FRP) and **F**lood **G**auge **H**eight (FGH) can be used to determine FRP corresponds to any GH value and to determine GH corresponds to any FRP value. This relationship is significant to this research study. This correlation was determined using three different statistical applications which are MS Excel, Findgraph and SPSS. The results obtained from that software are as follows. (Figure: 3.10, 3.11, 3.12)

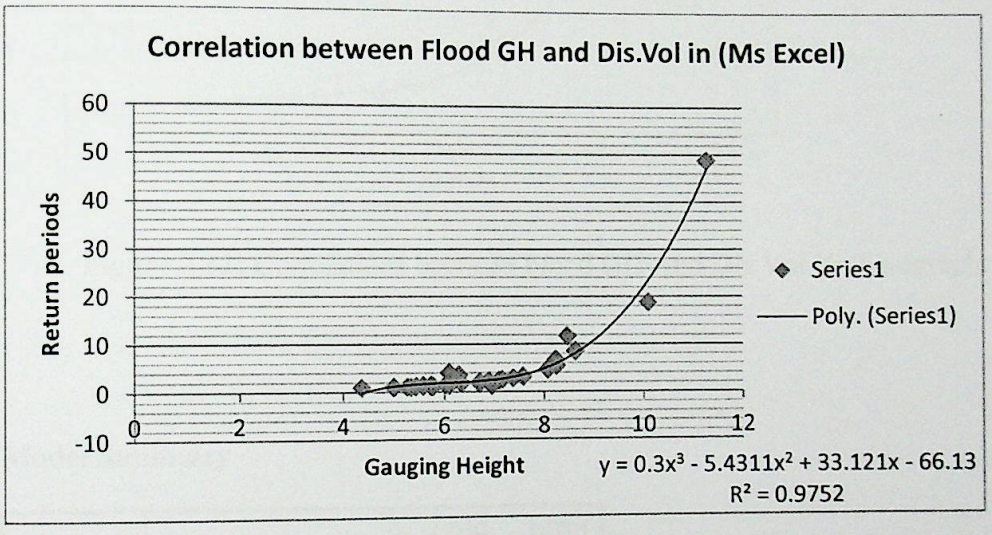


Figure 3.10: Correlation between GH & Dis VOL (in MS Excel)

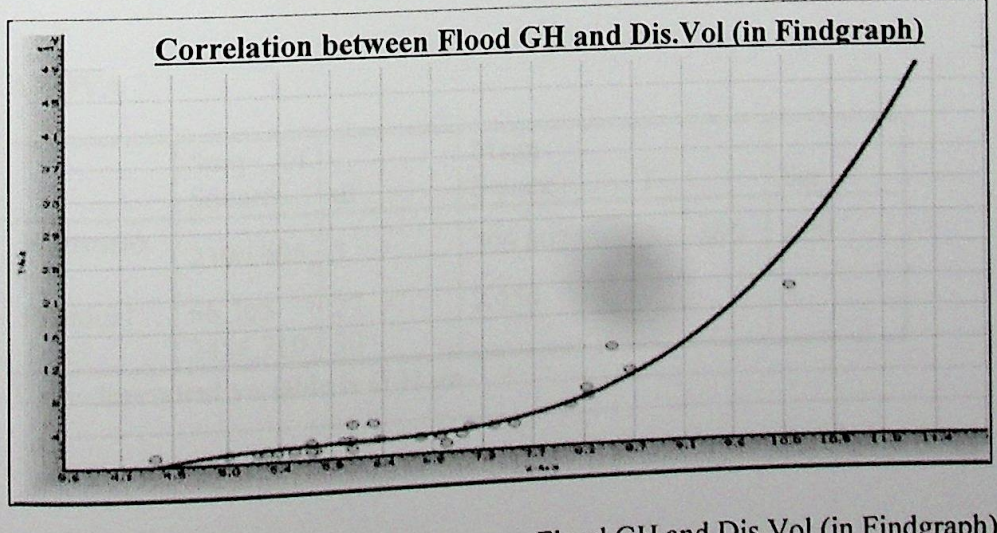


Figure 3.11: Correlation between Flood GH and Dis.Vol (in Findgraph)

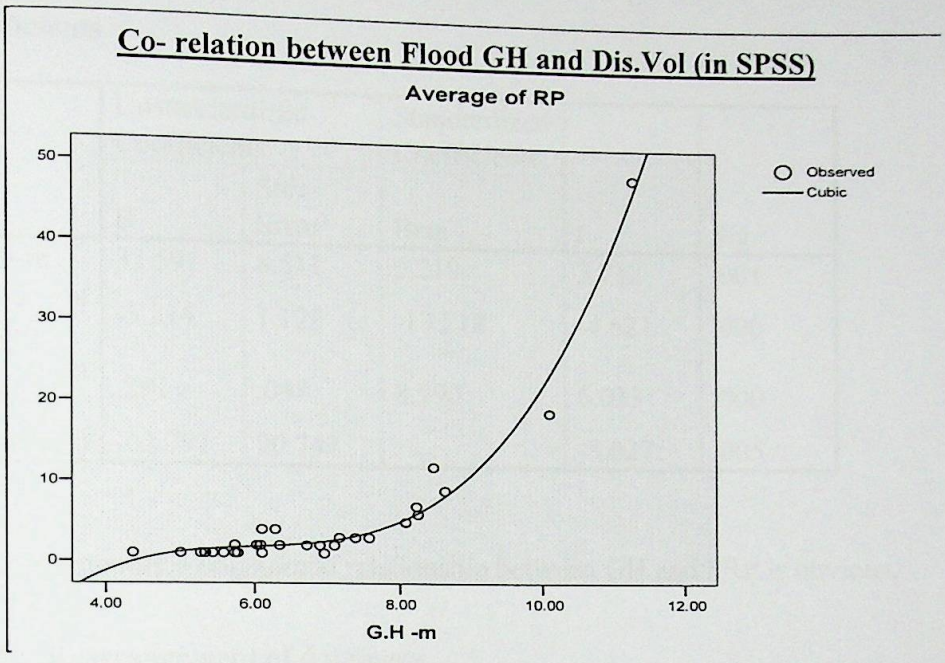


Figure 3.12: Correlations between Flood GH And Dis.Vol (In Findgraph.

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.986	.973	.970	1.567

The independent variable is G.H -m.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	2390.405	3	796.802	324.465	.000
Residual	66.305	27	2.456		
Total	2456.710	30			

The independent variable is G.H -m.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
G.H -m	31.591	8.511	5.219	3.712	.001
G.H -m ** 2	-5.214	1.128	-13.218	-4.621	.000
G.H -m ** 3	.291	.048	8.990	6.033	.000
(Constant)	-62.791	20.747		-3.027	.005

Hence commonly a polynomial relationship between GH and FRP is obvious.

3.4.4 Rearrangement of databases

As mentioned at the beginning of this report, a raw database has been established based on field data, literature and inventories of institutions. However, newy created simulated data were created from that raw database for different requirements.

E.g.: Calculation of discharge volume of GH data

Regarding those created simulated data, following data classes can be identified.

- Flood GH data
- Flood discharge volume data
- Flood return period data

In addition, flood intensities associated with each catchment (gauging station) has been calculated by the Department of Irrigation. Those flood intensities are different from station to station. Gauge zeros of individual gauging stations of the study area are given in Table: 3.5

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Table: 3.5: The Gauge Zero Values (MSL) of The Selected Gauging Stations.

Gauging station	Gauge Zero values (m)
Ellagawa	0
Ratnapura	13.49
Dela	17.12
Malwala	18.17

Source: Irrigation Department SL

According to the records maintained by each gauging station, flood intensity levels have been defined by the Department of Irrigation Sri Lanka. There are five flood intensity levels.

1. Alert level
2. Minor flood level
3. Medium flood level
4. Major flood level
5. Critical flood level

Given below (Table 3.6) is the flood intensity levels estimated for Ratnapura sub catchment.

Table 3.6 : Flood Intensity Levels Estimated for Ratnapura Sub Catchment.

Flood category	Flood level from gauge zero (m)	Gauge zero from MSL (m)	Flood level from MSL (m)
Alert level	3.65	*13.49*	17.14
Minor flood level	6.1	*13.49*	19.59
Medium flood level	7.9	*13.49*	21.39
Major flood level	11.0	*13.49*	24.49
Critical flood level	>11	*13.49*	>24.49

Those flood intensity data were incorporated into the database. Thus, gauge height and flood intensity level can be determined for a certain return period.

When the water level of the river increases, flood risk also increases. When the water level of the river passes alert level, it is the beginning of a flood. When it is grown up to and are beyond the critical level, it might be a catastrophic flood. This can be well understood by studying a river cross section. (Figure: 3.13)

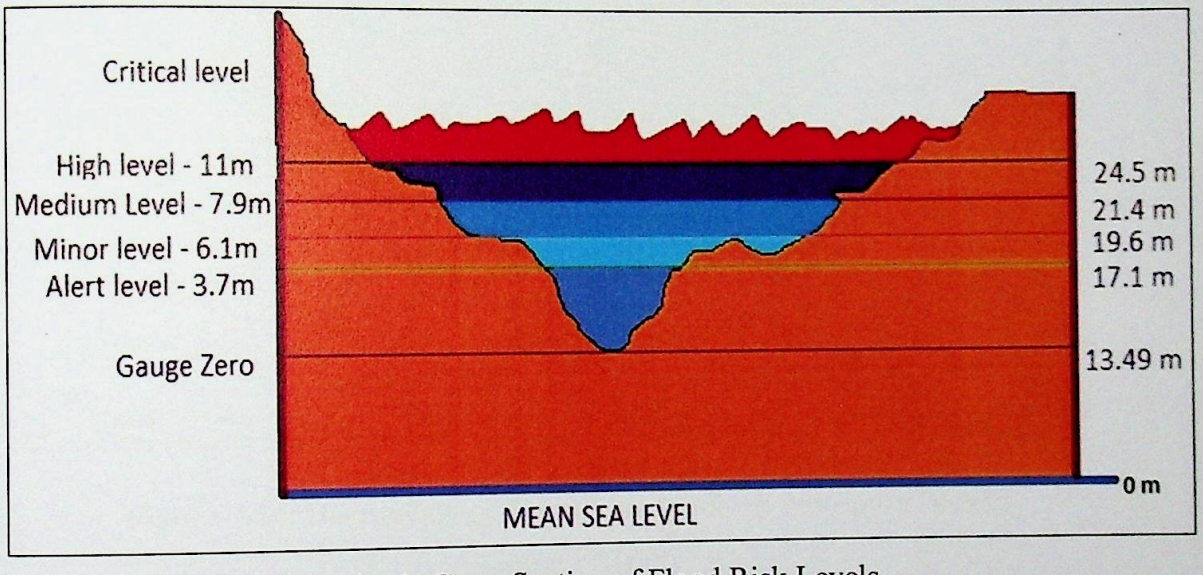


Figure 3.13: Cross Section of Flood Risk Levels.

As a matter of fact that, there is a long return period for low flood risk area where as, there is a short return period for the high flood risk area. Thus there is a somewhat reciprocal proportionality between return period and flood risk.

3.4.5 Landslide risk levels.

Furthermore, National Building Research Organization- Sri Lanka has defined four landslide risk levels.

1. No risk
2. Low risk
3. Moderate risk
4. High risk

Distribution of those risk levels in Ratnapura district is shown in Figure: 3.14

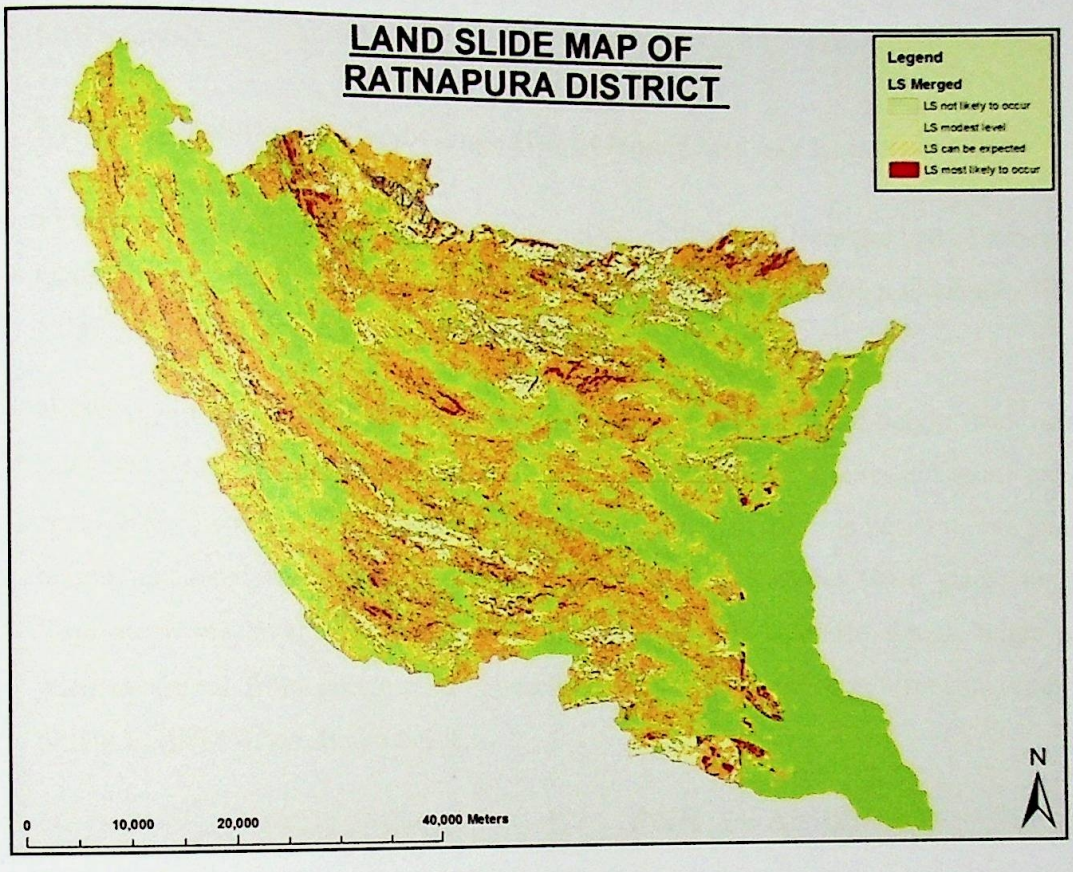


Figure 3.14: Distribution of Those Risk Levels in Ratnapura District

Source : NBRO

Hence another two new sets of data can be incorporated into the main database. Those are;

- Flood risk levels
- Landslide risk levels

3.4.6 Finalizing database for integrate with GIS

This is the most important part in this research. As mentioned earlier, a raw database was established using collected data (primary and secondary). Using mathematics and simple statistics, some newly created data called simulated data such as flood return period, flood risk level, landslide risk level, were created from that raw database. Thus a new database was established by incorporating simulated data to the raw

database. This modified database was analyzed further and it was fine tuned for the final analysis.

3.4.7 Calculation of Flood Gauge Height from Mean Sea Level (GH/MSL)

Flood gauge height in the database is the height of the flood from the bed of the river. Gauge zero is the height to the riverbed from mea sea level (MSL). Generally flood height is expressed as the height from gauge zero.

However, in this study it is essential to determine the flood gauge height from mean sea level. (i.e. Expressing flood gauge height from mean sea level not from gauge zero). Hence contours are measured from the mean sea level, it is better to use gauge height measured from mean sea level for this study. Hereafter flood gauge height from mean sea level is expressed as FGH(MSL). In the database, gauge height has been measured from gauge zero. Therefore, those values were adjusted in order to obtain FGH(MSL)as shown below.

$$\textbf{FGH (MSL)} = \textbf{FGH} + \textbf{Altitude}$$

According to the Ratnapura gauging station, flood intensity levels in FGH (MSL) are as follows.

a. Alert level - 17.1 m
b. Minor flood level - 19.6 m
c. Medium flood level - 21.4 m
d. Major flood level - 24.5 m
e. Critical flood level - >24.5 m

3.4.8 Database for Flood Return Period (FRP) Vs FGH (MSL)

Based on the relationship between FRP and FGH, a new dataset was created by calculating FRP for 0.1 m height sections. This calculation was done up to 1000 m from 0 m (MSL). This calculation can be done beyond 1000 m according to the

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requirement. After the calculation FRP for each 0.1 m section, the corresponding FGH value was converted to FGH (MSL)

3.4.9 A total flood possibility, can be occurred in a year or in a certain location

Here, the possibility of being flooded of a certain location was calculated. The minimum possible flood level which can occur at that particular location was calculated based on the elevation of that particular location. Any flood greater than the calculated minimum possible flood level, can inundate that particular location. If a certain location got inundated, based on the elevation of that location, return period of that flood can be estimated. Hence those predictions are important for building and construction industry.

Furthermore, one certain location can be exposed more than one flood at once, it is possible to complete more than one return period at the same time. Under these circumstances, flood risk can be pre-identified in order to execute precautions.

Thus, another new database was established which contains elevation, minimum possible flood level, total return periods which are going to be completed in the concerning year and intensity levels of those floods. By dealing with this database, return period wise flood occurring periods and high flood risk periods can be identified.

Moreover, another data set which contains socioeconomic data of the study area was incorporated into the above mentioned database. This data set is important to have an idea with respect to socioeconomic background when estimating flood risk of a particular location.

3.4.10 Extrapolation of contours

Contours of 1:50,000 and 1:10,000 maps which were taken from Department of Surveying were used for this task. In maps there are only contour intervals available. Therefore elevation of a location which lies between two contour lines cannot be obtained. Hence, mapping of flood risk areas using those contours will be

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unsuccessful. Therefore a methodology has to be developed in order to obtain at least approximate elevation of every place using those contours.

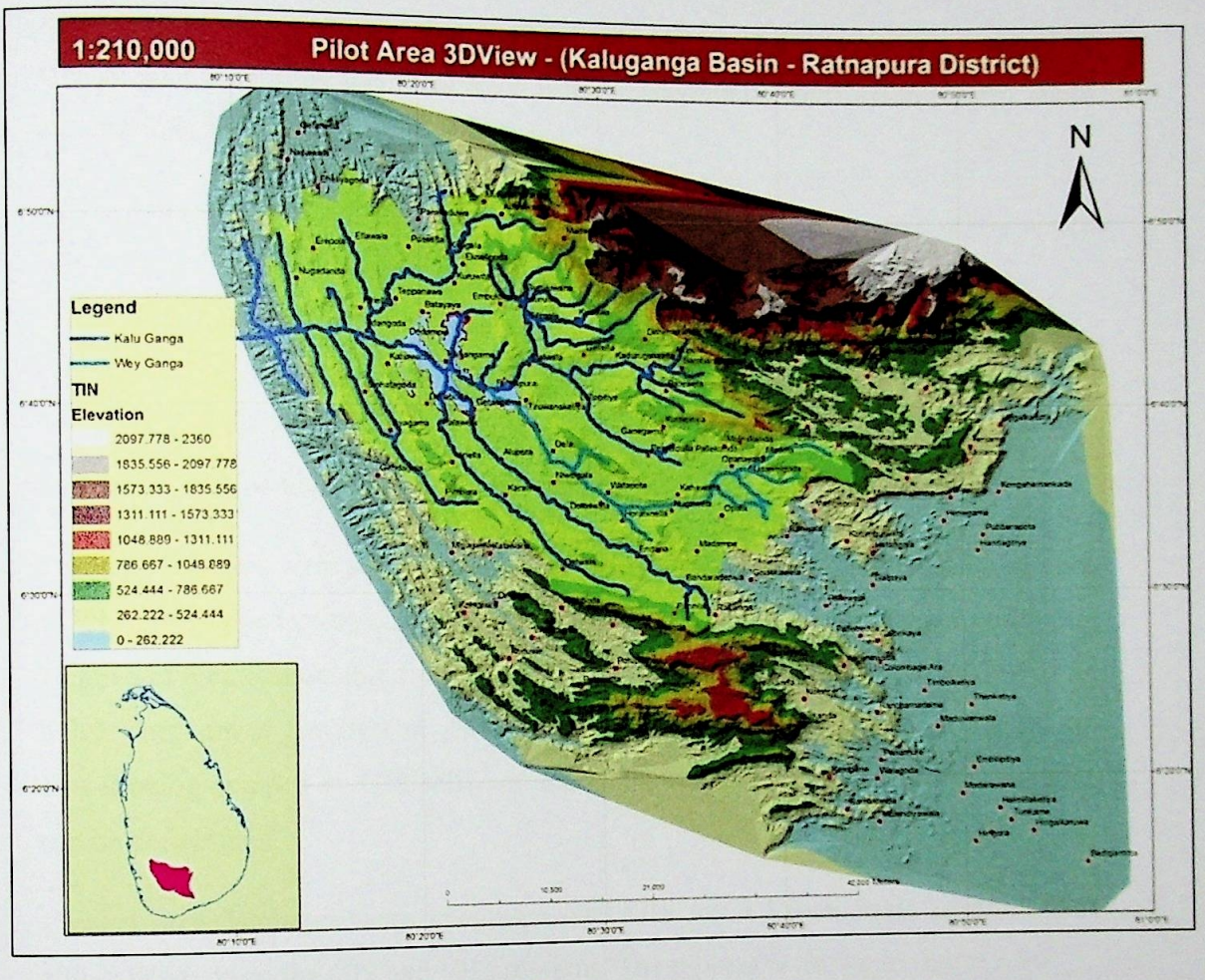


Figure 3.15: 3D View of the Pilot Study Area

In order to overcome this problem, 3D analysis tools in GIS software were used. Firstly using existing contours a 3D map (TIN) of a study area was developed (Figure: 3.15). Elevation of any location of the study area can be obtained from this map; and contours too. Secondly developed TIN (3D map) was converted to a raster file. This conversion was carried out in order to prepare an attribute table which contains extrapolated elevation values.

One pixel in the raster image map represents 20 m x 20 m area on the earth. Those pixel values represent the location heights. This information is essential for this research study.

3.5 Integration of Databases with GIS

Accuracy of this integration relies on the quality of collected data and the accuracy of created data. Therefore this integration was executed under some assumptions. Those assumptions are;

I. Under a flood all locations within the catchment (river basin / alley) which have an elevation equal or more than FGH are inundated.
II. Rainfall received by a certain catchment is uniform.
III. No temporal changes of land use pattern within the concerned catchment.
IV. The River cross section is fixed.
V. No erosion and sedimentation associated with river.

Created databases were separately incorporated into the GIS. There FGH corresponds to FRP are mapped using contours. Furthermore, main FRPs are considered and gauge height and area responsible for those FRPs are mapped. Mapping is carried out using height contours or 1 m by 1 m. Thus the new contour system which has an interval of 1 m is being mapped by GIS software. Hence an inundated area due to a certain FRP can be determined.

Created new databases were integrated with GIS via a Visual basic program. The output depends on the GIS and VB programs. The process is shown in figure 3.16

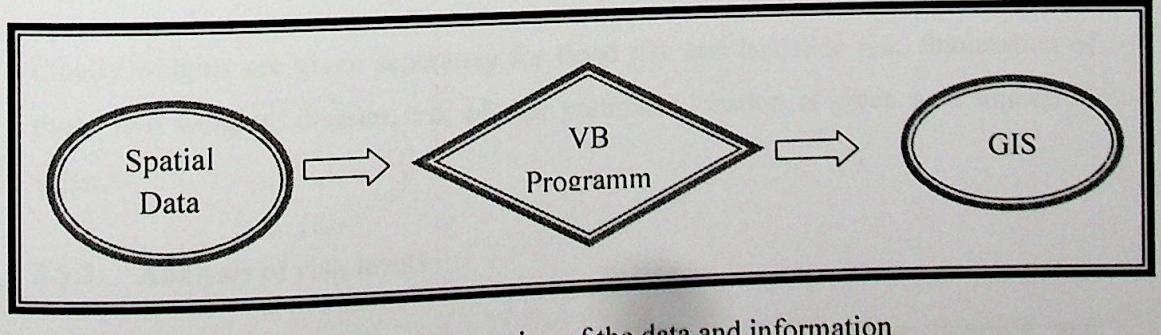


Figure 3.16: Integration of the data and information

There are diverse types of spatial data such as text, graphics, spreadsheets, shape files etc. Most types of spatial data cannot be directly incorporated to GIS, as GIS has been created by programming languages such as VB, C, C++, Java etc. Using one of those programming languages (VB) spatial data was integrated with GIS and process.

In developing a disaster analyzing tool, according to research objectives a program written in VB was used. All databases were linked to the program. When the program runs, it manipulates the databases and the output is given via GIS.

3.5.1 The behavior of the program

This program behaves as a disaster analyzing tool. When commands are given to the databases via VB, output is given which is visible in the program interface. This tool analyses the disaster risk, basically floods and landslides regarding a certain (given) location.

In order to run this tool, GIS and VB program should be loaded to the computer. Then a location in the study area should be clicked. Hence the tool identifies XY coordinates and height (Z) of the selected (clicked) location. Thus the spatial location of the selected point is identified at first. Then socioeconomic information about that particular place is displayed on the screen. That is the first step of the program.

In the second step, flood possibility of that location is determined by calculating return periods based on elevation. Both return periods and flood risk levels are displayed on the screen.

There after landslide risk associated with selected location and its adjacent areas is displayed on the screen.

Finally weights are given separately for flood risk and landslide risk. Summation of those two weights, disaster risk of that particular location is given as a numerical value.

3.5.2 Analysis of risk levels

In predicting disaster risk for a location, information regarding flooding and landslides is separately studied. Considering the magnitude of risk for both disasters, total disaster risk is assessed.

Institutions responsible for floods and landslide monitoring, have introduced intensity levels in order to address the magnitude of floods and landslides.

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Department of irrigation has introduced 05 flood intensity levels namely Alert level, Minor flood level, Major flood level, High flood level and Critical flood level.

A critical level flood possesses a higher GH value and it has a return period of 50-100 years or more. Though that type of floods can be catastrophic, the risk of that type of flood is less, as its occurrence almost once in 100 years. However, minor, major and high floods posses return periods such as 1, 2, 5, 10 years. Therefore, occurrences of these types of floods are relatively frequent. As a result, risk is high regarding floods with shorter return periods.

The alert level is the maximum water level that a river can retain. Therefore it cannot be addressed as a risk. Thus four out of five flood intensity levels, introduced by the department of irrigation are considered more ion this study. Those are;

- Minor
- Major
- High
- Critical

Hence, when the intensity level of a flood increased, its risk level is decreased. Therefore there is a reciprocal relationship between flood intensity and flood risk.

Minor floods have the highest risk; therefore value 01 can be assigned to minor floods as the weight. Critical floods bear the lowest risk. Therefore value 04 can be assigned for critical floods as the weight. Therefore the weights assigned for different flood intensity levels are;

- Minor = 04
- Major = 03
- High = 02
- Critical = 01

Likewise national building research organization has introduced intensity ranks for landslides on risk, namely,

- High risk
- Moderate risk
- Low risk
- No risk

Areas which have stronger rocks and soil layers and ground with low gradient or relatively flat lands have been ranked as no risk or low risk. Areas with relatively weaker rocks and soil layers and ground with a high gradient has been ranked as high risk areas. Therefore, high risk areas get weight value 01 and no risk areas get weight value 04

3.5.3 Determination of disaster risk rank

The output of this research is to express disaster risk of a location by a numerical value, by combining flood and landslide risk levels. Therefore separately weighed risk levels of floods and landslides are combined together in order to obtain a single value for disaster risk. Table 3.7 shows the risk levels & assigned weights on them.

Table 3.7: Risk Levels & Assigned Weights on Them.

Flood		**Land Slide**	
Risk	**Assigned Weight**	**Risk**	**Assigned Weight**
Critical	01	High	01
High	02	Moderate	02
Major	03	Low	03
Minor	04	No	04

Considering weights assigned for floods and landslides, 16 combinations of disaster risks can be obtained. Hence the probability of disaster risk of a certain location is 1/16. That is more evident in Figure: 3.17

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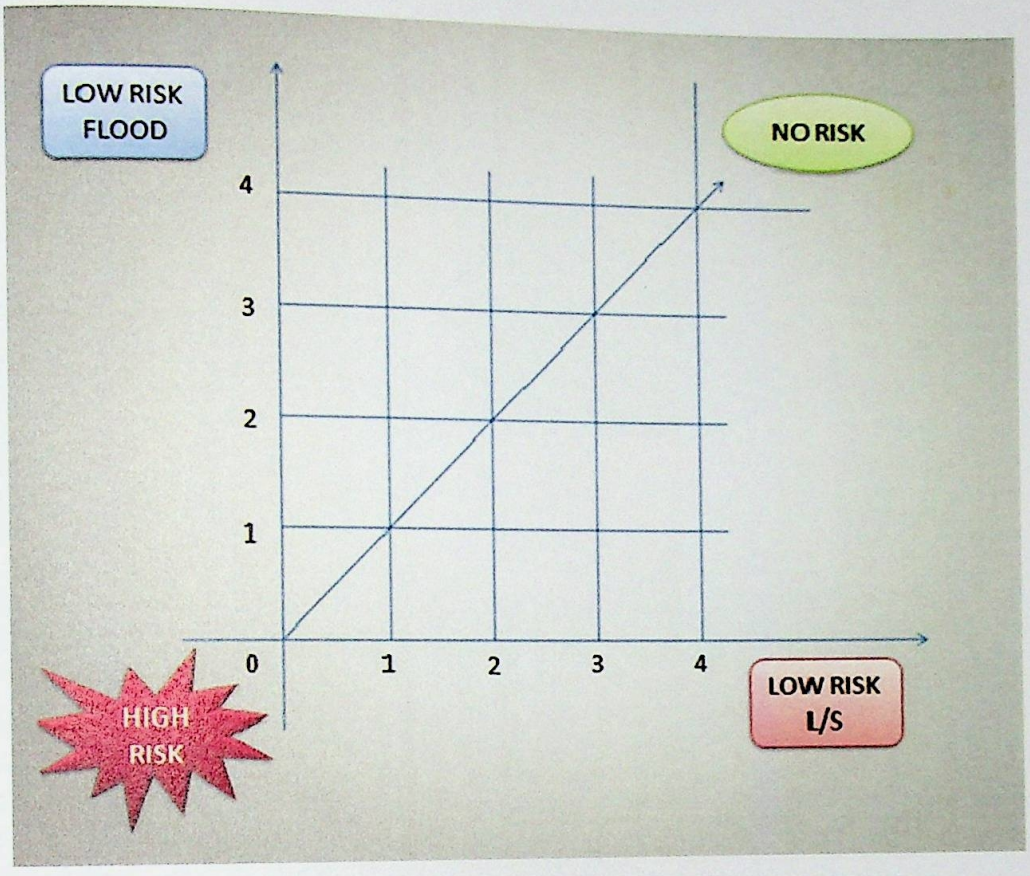


Figure 3.17: Probability of Disaster Risk of a Certain Point - I

According to graph coordinate 1,1 represents the maximum disaster risk where as coordinate 4,4 represents the minimum disaster risk.

Thus, fore main levels of disaster risks zones can be introduced. (Figure: 3.18)

No risk (4,4)

Low risk (3,4 / 3,3 / 4,3)

Moderate risk (4,2 / 3,2 / 2,2 / 2,3 / 2,4)

High risk (4,1 / 3,1 / 2,1 / 1,1 / 1,2 / 1,3 / 1,4)

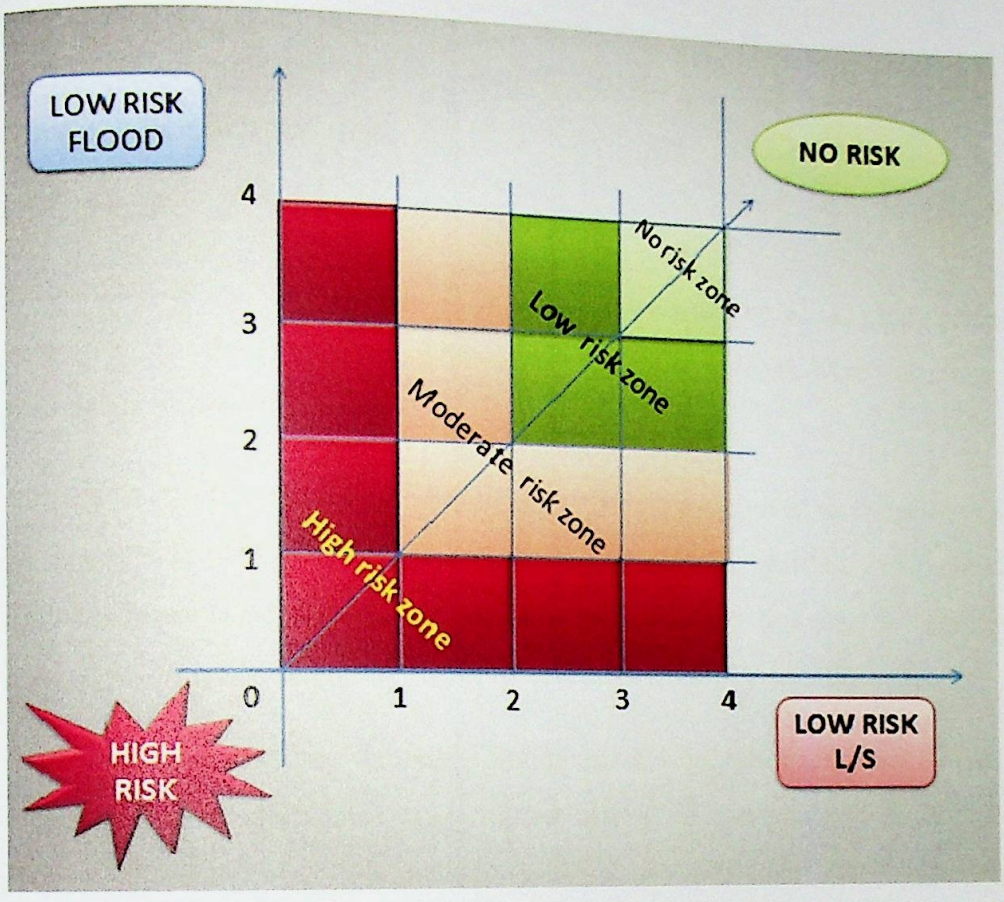


Figure 3.18: Probability of Disaster Risk of a Certain Point - II

Thus the disaster risk of the pilot area can be identified.

In order for these steps the methodology of the research can be discussed.

CHAPTER 04

Application and Validation.

4.1 General

In this chapter, the proposed methodology is to be tested by a case study and validated based on the actual field data. This covers the entire process, from selecting the pilot site to data validation.

As mentioned in the chapter 3, Ratnapura district was selected as the pilot area, due to the magnitude of its physical, demographical & disaster profiles. This area subject to frequent flood and landslide havocs every year. Further, this area is highlighted as a focal point of centralizing the regional development of the country.

As it is difficult to study the entire Ratnapura district, due to the lack of field data & information, the study area was limited to the Kalu river basin in the Ratnapura district. Then, by dividing the whole basin area into four sub catchments; Dela, Ratnapura, Malwala & Ellagawa, the hydrological characteristics were studied.

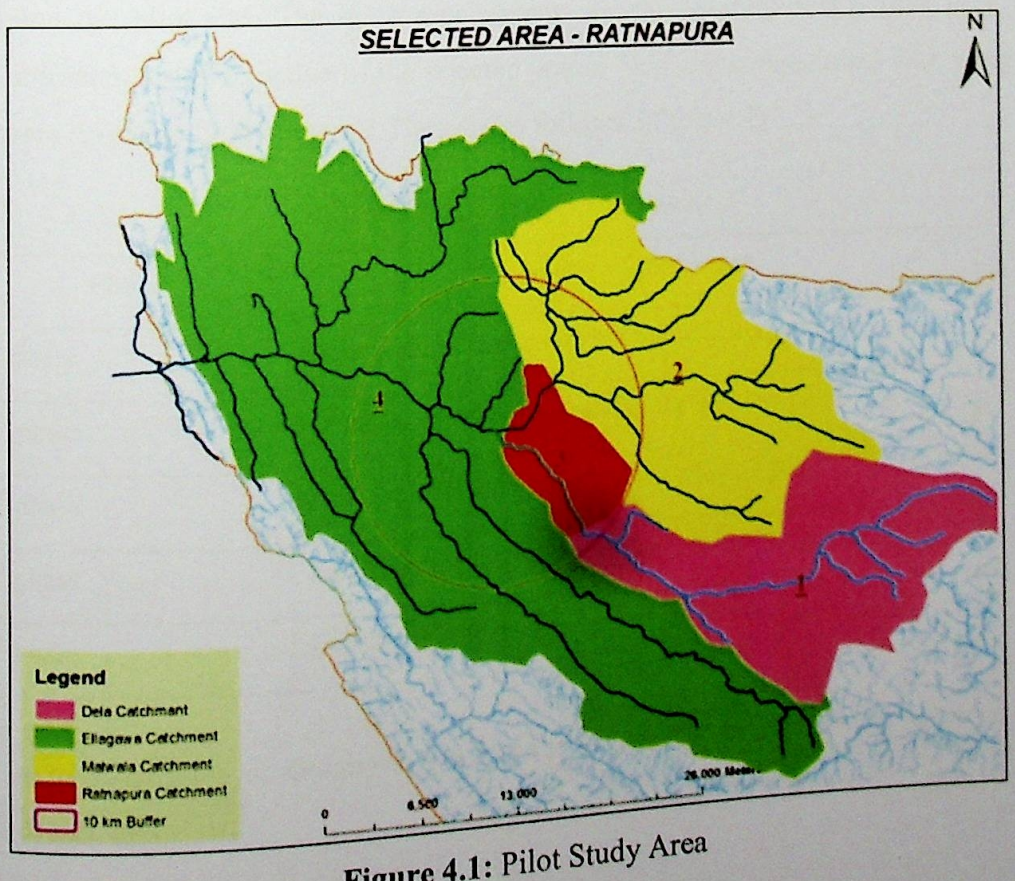


Figure 4.1: Pilot Study Area

Finally by considering the all hydrological characteristics in all four sub catchments, a 10km circular area of Ratnapura town, including with the Ratnapura sub catchment, was selected as the "pilot study area" for a case study of the research.

4.2 Applying VB on proposed methodology

Thus, in the application the spatial data of the pilot site together with all physical and demographic data i.e., elevation data, flood data, landslides data, population data, administrative data were gathered and prepared a raw database. By using this raw database, the new data series such as flood return period data, flood risk levels and risk ranking data, landslides risk ranking data were derived. All those raw and newly derived data were integrated and processed by ArcGis and Visual basic software, to obtain automatically the disaster risk of the selected place of the field, as the final output. The GIS database, called Geo database is handled by the Visual Basic programming. As a result a user friendly data process and implementation tool has been developed in the Arc Map interface, called **Integrated Disaster Analysis Tool (IDAT)**. By using this tool, the disaster risk can be evaluated, in any of location among the pilot site. The input requirements are the location details such as x, y coordinates and the z value of the selected point. This tool is functioned with several phases up to the final outcome. They are as follows. (Table 4.1)

Table 4.1: The IDAT Behavior

Phase	Nature of the output.
1st phase	Geographical background of the selected point
2nd phase	Demographical background of the selected point
3rd phase	Flood related background of the selected point
4th phase	Landslide related background of the selected point
5th phase	Disaster related background of the selected point

A short description of the above five steps is very useful to identify the behavior of the IDAT tool.

4.2.1 IDAT- Geographic data analysis

Identifying the absolute location of a selected place is very important in the industry of construction as well as disaster management and resilience activities. A physical location can determine by Longitude (*Y*), Latitude (*X*), & Terrain (*Z*). The 1st phase of the IDAT tool has been programmed to identify the *X, Y, and Z* of the pointed place, on the map, which is Geo-coded on GIS interface. Moreover, when it is click on a certain place on the map, the corresponding x, y and z coordinates are appearing automatically. (Figure: 4.2)

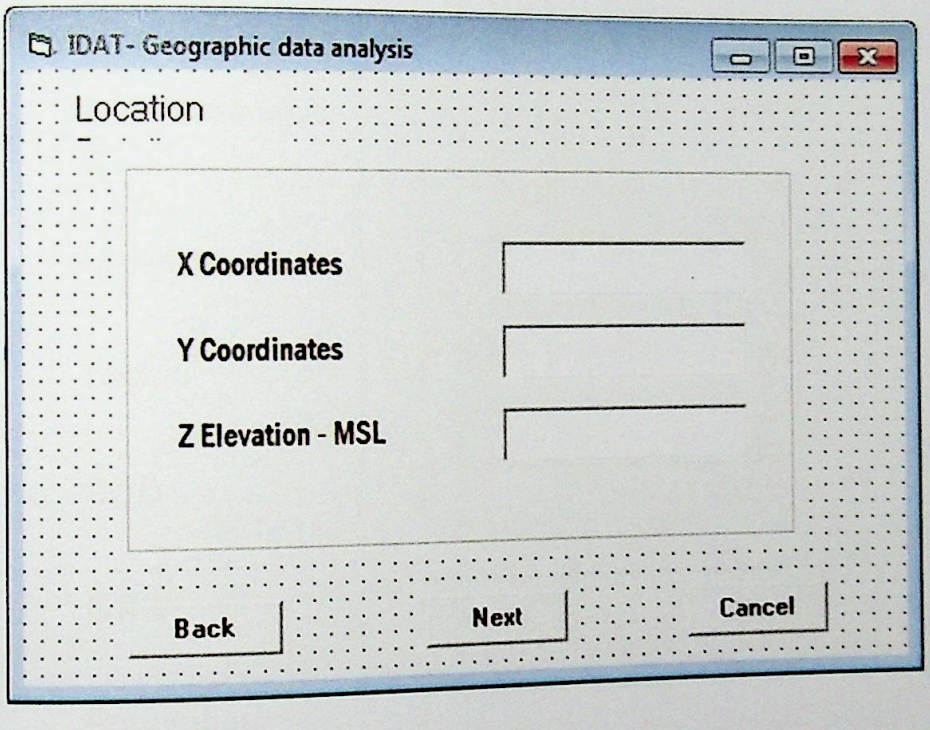


Figure 4.2: IDAT 1st Phase

By using this feature, the physical profile of a selected location on the map can be determined easily.

4.2.2 IDAT- Demographic data analysis

In the second phase, the demographic and administrative data and information corresponds to the above selected point such as province, district, DSD, GND, population, & population density of the relevant GND of the selected location, are given by the program. (Figure: 4.3) This information is very essential for road /

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railway construction works and disaster management works. Using this feature, the affected people, and property or land area can be extracted easily. As The same data profile can be used to define the effected or benefited administrative areas and their population, by a new road/ railway construction work. The database prepared by using demographic and administrative data and information on the pilot area, has been processed through VB programming, to obtain the output, mentioned above on GIS interface.

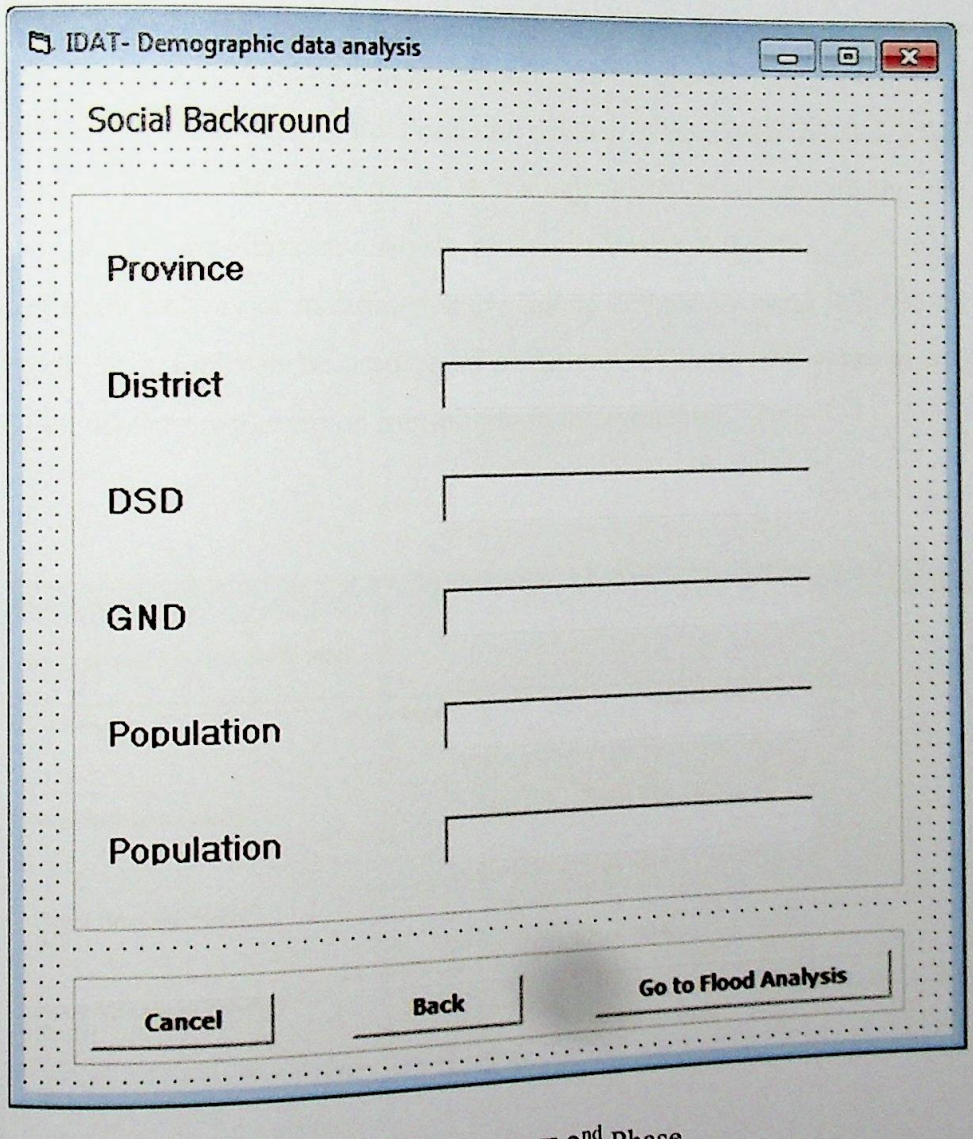


Figure 4.3: IDAT 2nd Phase

4.2.3 IDAT- Flood analysis

In the 3rd interface, the flood related data, such as flood gauge height, discharge volume, flood return period, flood risk level, past and future flood occurrence, that correspondence to the selected point will be given. Predefined and analyzed overall flood information on the pilot area, have been saved into a systematic database. Then by using VB programming, the system database is joined with the GIS, as a Geo database. When click on a selected place on GIS map, the flood related data corresponds to the selected place will be appeared on IDAT interface. (Figure: 4.4) Thus the tool is capable to illustrate the minimum flood risk level, its gauge height, discharge volume, flood return period, according to the elevation of the selected point. According to the magnitude of the flood, the risk levels have been defined in both text and numeric format. This numeric value is amalgamated together with the program, until the end of the disaster analysis process. Consequently, the flood risk on a proposed road/ railway or its infrastructure can be defined by using this phase of the IDAT tool. This tool can be used to be avoid process those risk areas as a one of strategy on disaster resilience on transportation infrastructure.

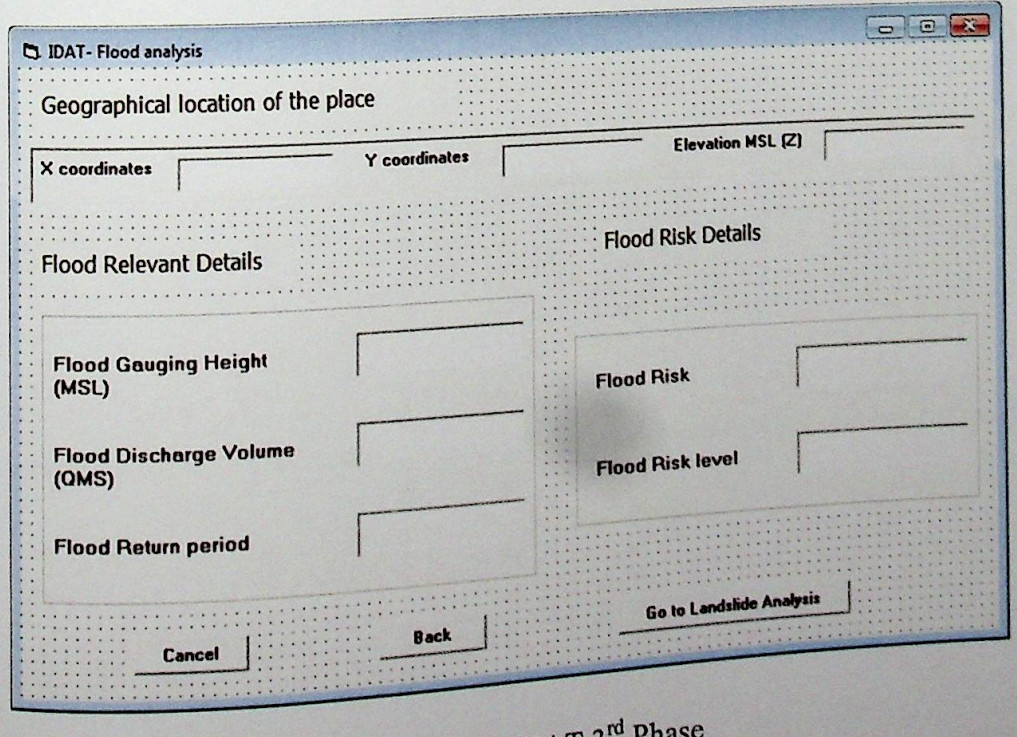


Figure 4.4: IDAT 3rd Phase

4.2.4 IDAT- Landslides analysis

In the 4th phase, the landslide risk of the selected location is shown by the VB interface (Figure: 4.5) The risk levels of the landslides; High, moderate, low, and very low or no risk, has been defined by the NBRO. Those risk levels have been given a numeric value, and added to the system database for easy identification for the program. When clicked on a particular place, the operative risk level of the landslide on those places is given on the interface as its 4th phase. Therefore the landslide risk on a proposed road/ railway or its infrastructure can be defined and evaluated by using this phase of the IDAT tool, separate risk levels can be avoided those risk areas as a one of strategy on disaster resilience on transportation infrastructures.

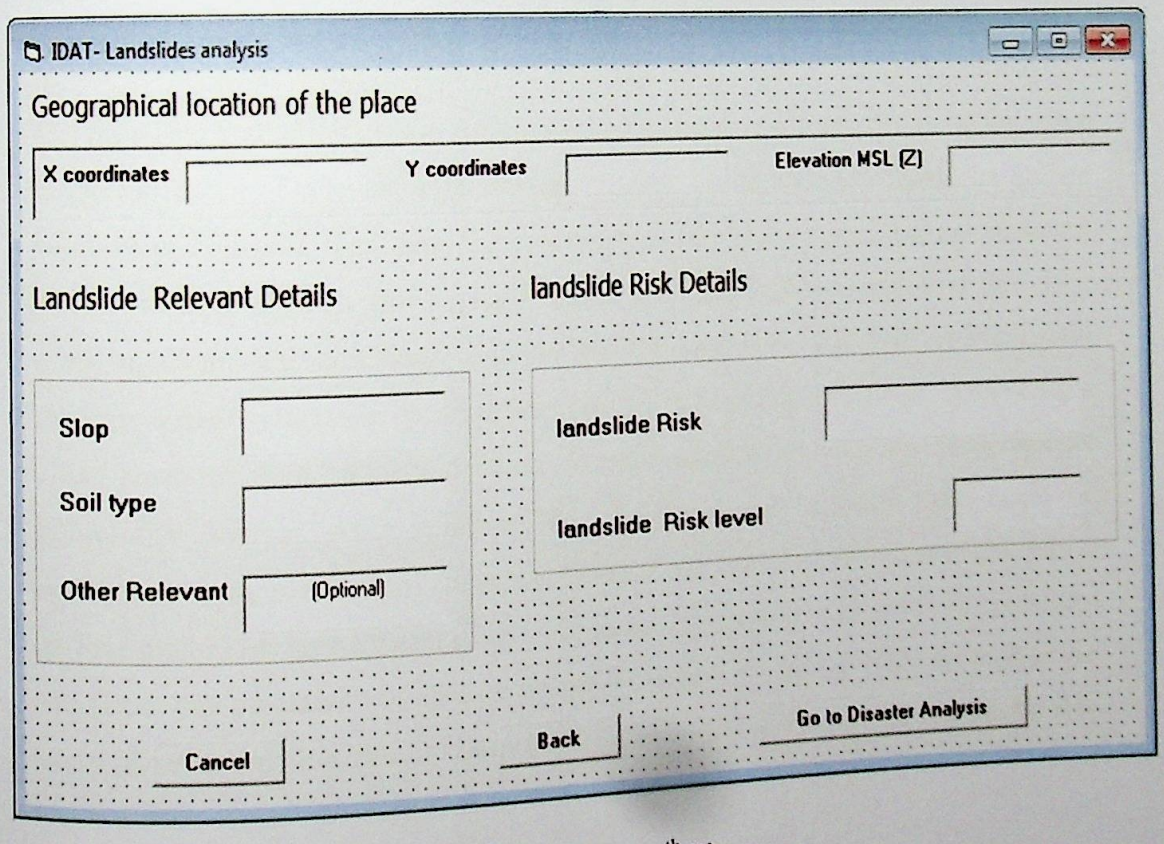


Figure 4.5: IDAT 4th Phase

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4.2.5 IDAT- Disaster analysis

This is the final and most important phase of the VB interfaces. The objective of the research is realized here. The overall disaster risk of selected location is defined automatically, by the program. It was defined in the physical and demographic background of a selected location in the GIS map, through the1st and 2nd phases. Then the flood and landslide risks are evaluated of selected location by 3rd and 4th phases. According to the numeric values given on the each risk level of both flood and landslide hazards, the disaster risk of the given place is evaluated by the 5th interface. (Figure: 4.6) Accordingly disaster risk level coordinates the risk zones; High, Moderate, Low, and No risk are defined automatically by the program. Furthermore, the disaster risk and also the zone can be found very easily through this program. The accuracy and liability of the outcome are depending on the accuracy of the source data and systematic preparation of the Geo- database.

The proposed methodology was developed based on several types of assumptions, due to the limitation of relevant data and information. In its train, by using the limited numbers of collected field data, the raw database has been created. By extrapolating those raw data, such as flood gauge height, discharge volume, and landslide data, using mathematical equations, defined by the expertise, and GIS technological strategy, a new systematic database was created, named Geo- database. By writing a visual basic program on Geo- database, it could amalgamate with the Geographical Information System. As a result of that, the flood and landslide risks could be evaluated, in any place of the pilot site. When it is evaluating the disaster risk based on four major risk types such as high, moderate, low, and no risk, of both landslides and flood, the, propensity of disaster risk of any place, is equal to 1/16. As well as the every place in the pilot site, is comprised of any of risk zones, out of four major risk types.

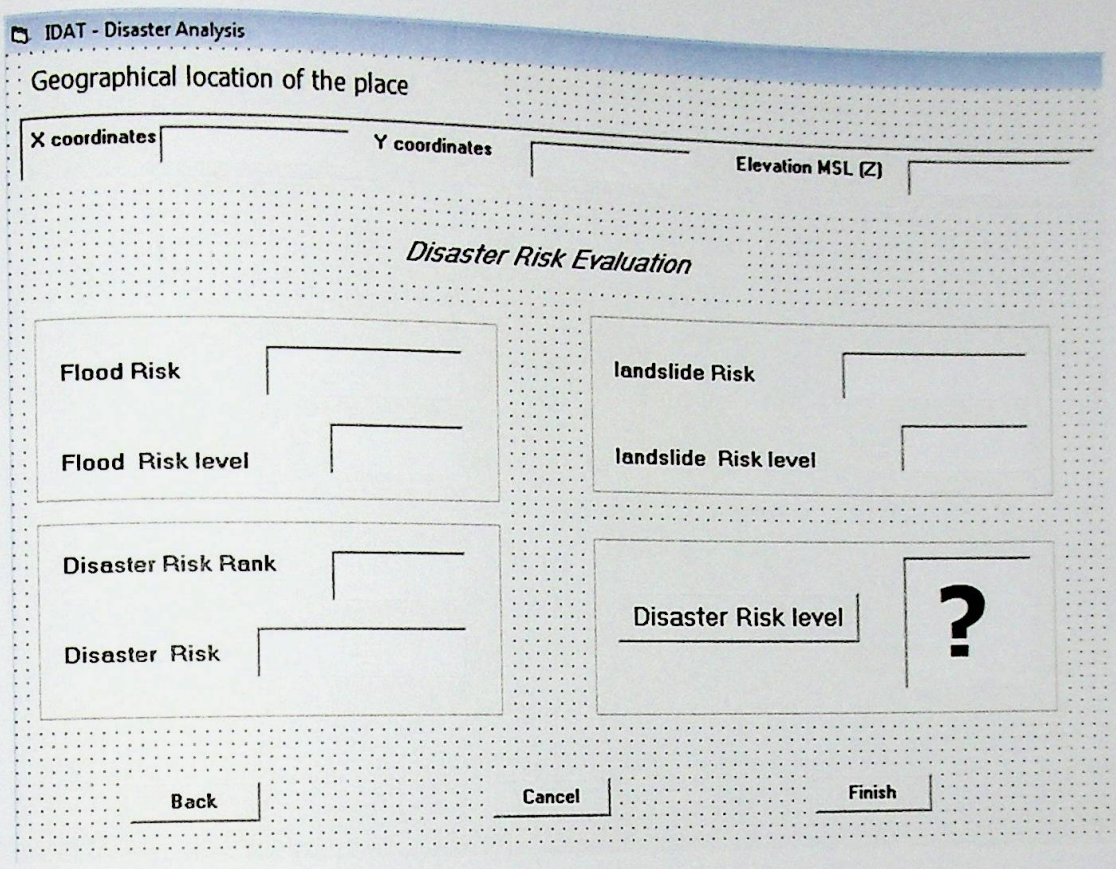


Figure 4.6: IDAT 5th Phase

4.3 Case Study

A total of twenty five of selected places were considered to evaluate the disaster risk within the pilot site. Some of those places were selected along the Kelani valley railway extension trace, which is planned to be constructed up to Hambantota, from Kottawa. (Figure 4.7)

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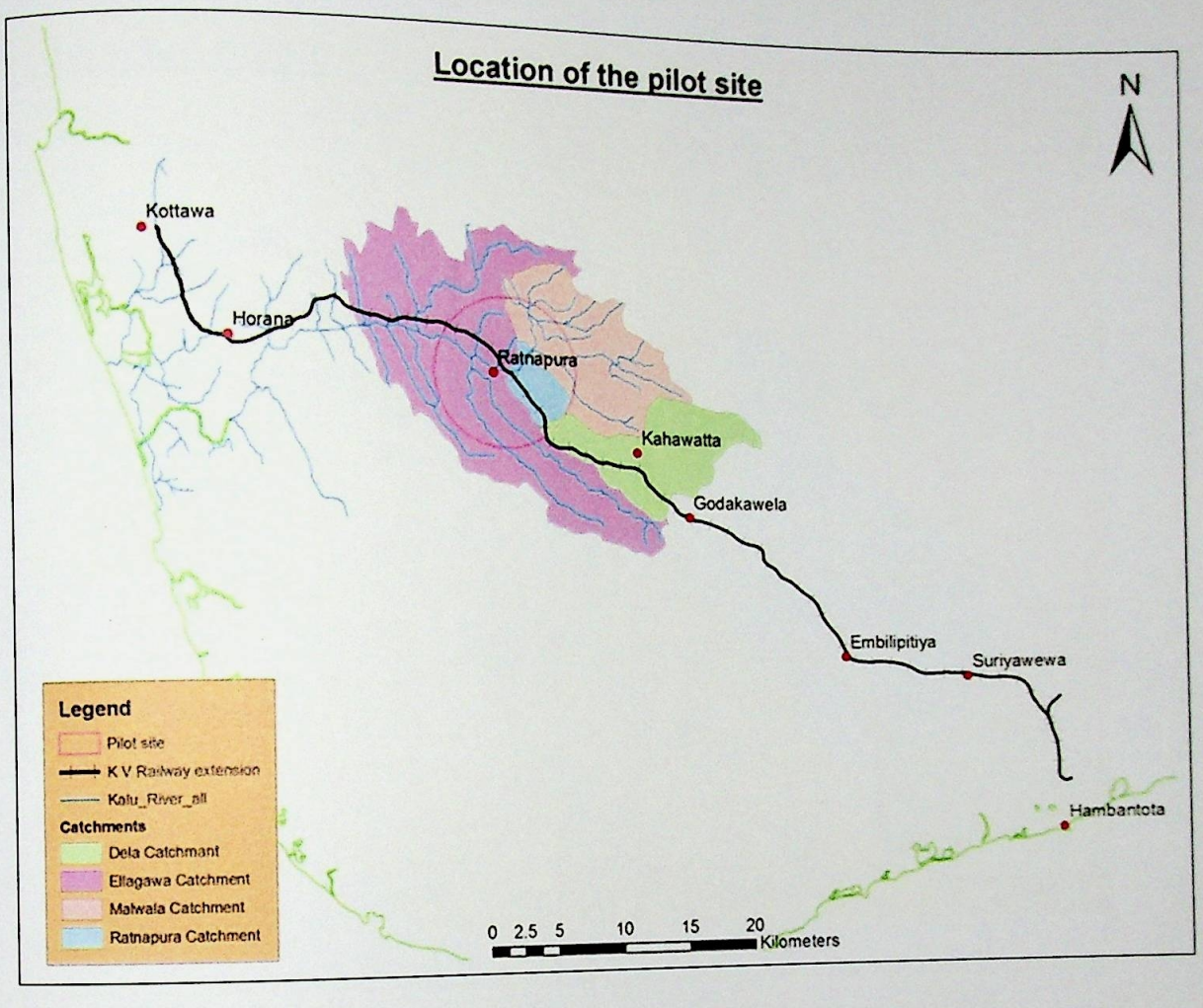


Figure 4.7: Proposed Kelani Valley Railway Extension

The other places were in the bordering points in the Ratnapura urban area that are associated especially with the A & B class roads and suspected places for critical disasters. After determining the disaster risk of those places, using the proposed method, it is compared with the actual data and information, gathered by Irrigation Department, NBRO, and field visits, validate the developed IDAT tool.

4.3.1 Selecting locations for the case study.

Ten locations were selected, along the proposed railway track in 2325m (2.3km) intervals, by using the Hawth's tool of ArcGIS. And other fifty locations were selected randomly, within the pilot study area as mentioned earlier in the case study. (Figure 4.8)

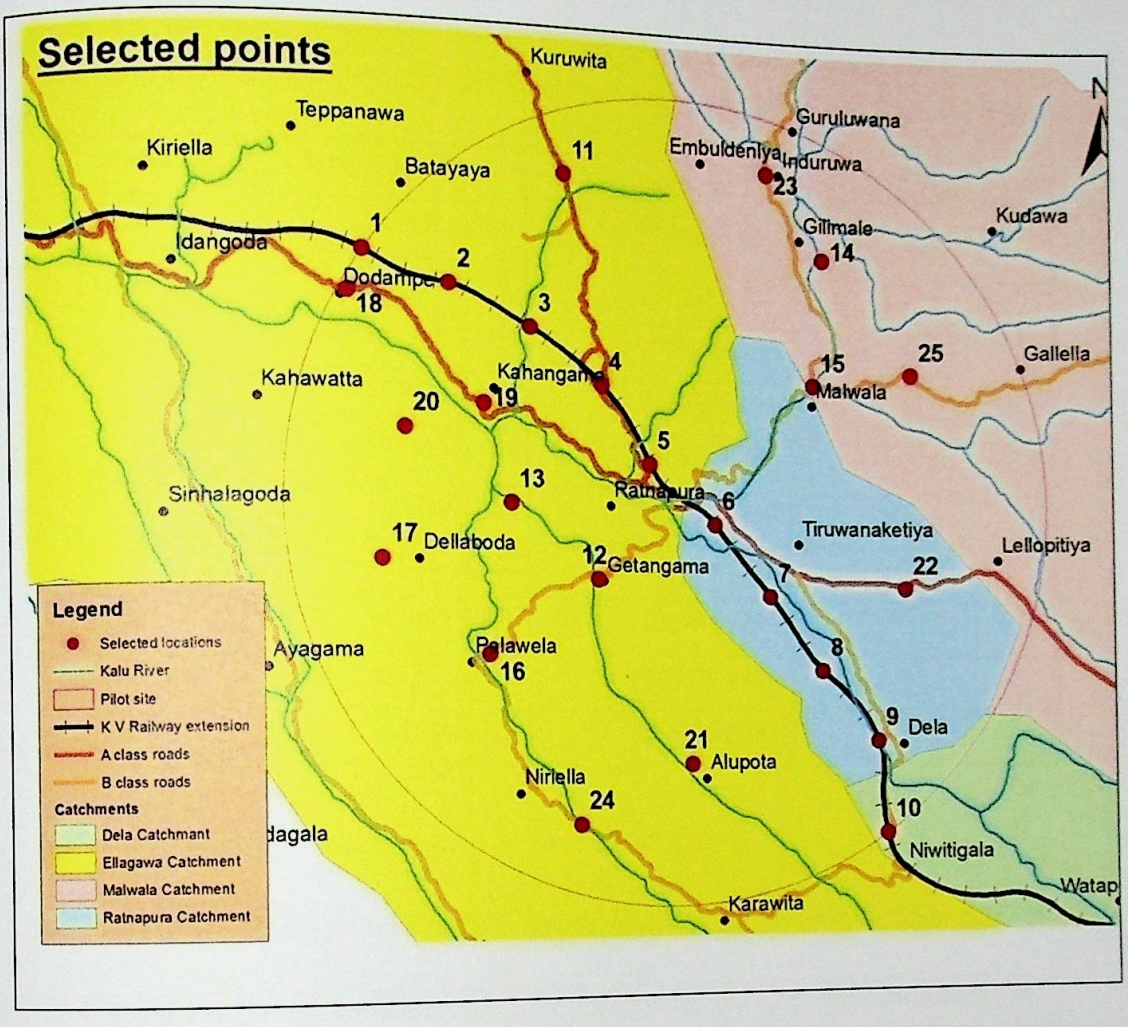


Figure 4.8: Selected Locations for the Case Study.

4.3.2 IDAT second phase of the case study.

According to the first phase of IDAT tool, the coordinates of the geographical location of those selected points were as follows. (Table: 4.2 and 4.3)

Table 4.2: Location Data of the Selected Points along the Proposed Railway Trace.

Point No	X coordinates	Y coordinates	Elevation MSL- m
1	150896.0024	170633.1501	56.8
2	153070.5574	169881.5964	53.1
3	155160.7746	168885.6533	20.0
4	157035.4101	167526.825	50.2
5	158313.9274	165603.488	20.0
6	160050.7147	164141.9759	15.9
7	161526.8354	162346.2224	34.2
8	162912.9433	160484.6944	20.0
9	164373.3921	158719.1409	23.5
10	164588.5212	156423.6992	59.6

Table 4.3 shows the other selected points of case study.

Table 4.3: Location Data of Other Selected Points among the Pilot Site.

Place No	X coordinates	Y coordinates	Elevation MSL- m
11	156084.4202	172675.9458	30.0
12	156886.6755	162741.6748	20.0
13	154620.9242	164578.2172	27.2
14	163036.2869	170848.7076	30.0
15	162742.9863	167662.0182	25.0
16	154027.0728	160866.2833	30.0
17	151327.5003	163196.997	24.4
18	150522.5396	169637.0717	24.4
19	153938.2307	166991.8863	27.4
20	151924.6893	166378.192	25.0
21	159354.4522	158173.5244	24.3
22	165154.444	162567.0374	117.2
23	161540.3638	172946.7571	64.3
24	156359.2747	156704.2329	138.5
25	165382.6388	167995.47	169.7

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4.3.3 IDAT second phase of the case study.

In the second phase of IDAT, the demographic data for the selected locations were extracted as follows. (Table: 4.4)

Table 4.4: Demographic Data of Selected Points of the Pilot Site.

Place No	Province	District	DSD	GND	Population of GND	Pop..Den of GND
1	Sabaragamuwa	Ratnapura	Kiriella	Dodampe	2727	4
2	Sabaragamuwa	Ratnapura	Kuruvita	Kithulpe	3313	4
3	Sabaragamuwa	Ratnapura	Ratnapura	Amuthagoda	1713	7
4	Sabaragamuwa	Ratnapura	Ratnapura	New Town	5080	8
5	Sabaragamuwa	Ratnapura	Ratnapura	Weralupa	6546	30
6	Sabaragamuwa	Ratnapura	Ratnapura	Batugedara	1707	18
7	Sabaragamuwa	Ratnapura	Pelmadulla	Marapana	2829	7
8	Sabaragamuwa	Ratnapura	Pelmadulla	Marapana	2829	7
9	Sabaragamuwa	Ratnapura	Nivitigala	Noragalla	3420	4
10	Sabaragamuwa	Ratnapura	Nivitigala	Noragalla	3420	4
11	Sabaragamuwa	Ratnapura	Kuruwita	Kahengama	4370	10
12	Sabaragamuwa	Ratnapura	Elapatha	Kotamulla	1495	9
13	Sabaragamuwa	Ratnapura	Elapatha	Karandagoda	2209	5
14	Sabaragamuwa	Ratnapura	Ratnapura	Pagoda	1760	3
15	Sabaragamuwa	Ratnapura	Ratnapura	Malwala	2312	4
16	Sabaragamuwa	Ratnapura	Elapatha	Niriella	2332	3
17	Sabaragamuwa	Ratnapura	Elapatha	Weragama	1555	3
18	Sabaragamuwa	Ratnapura	Kiriella	Dodampe	2727	4
19	Sabaragamuwa	Ratnapura	Kiriella	Holeepitaya	918	5
20	Sabaragamuwa	Ratnapura	Elapatha	Raddella	1801	4
21	Sabaragamuwa	Ratnapura	Pelmadulla	Niralgama	1992	3
22	Sabaragamuwa	Ratnapura	Pelmadulla	Gallinna	2174	5
23	Sabaragamuwa	Ratnapura	Ratnapura	Gileemale North	1579	2
24	Sabaragamuwa	Ratnapura	Elapatha	Digana	1356	2
25	Sabaragamuwa	Ratnapura	Ratnapura	Durekkanda	2800	5

According to the table, the demographic data of the selected pilot/site are given. These data, such as Province, District, DSD, GND can utilize as the characteristics of the selected location/point, for the new road, railway or infrastructure constructions, or the place that is faced for the disaster. As same as, the corresponding population and the population density of those locations, can utilize for the resilience activities of the disaster. And can be identified the magnitude of the places, when it is given the priority for the resilience activities.

4.3.4 IDAT third phase of the case study.

According to the predefined strategy the flood related data were given by the IDAT program, on its third phase as follows. (Table: 4.5).

Table 4.5: The Flood Possibility of the Selected Points.

Place No	Elevation (MSL)	Flood Return period	Flood intensity rank
1	56.8	15124.7	4
2	53.1	11060.5	4
3	20.0	2.1	2
4	50.2	8440.7	4
5	20.0	2.1	2
6	15.9	-13.0	1
7	34.2	934.9	4
8	20.0	2.1	2
9	23.5	22.4	3
10	59.6	18787.7	4
11	30.0	344.5	4
12	20.0	2.1	2
13	27.2	138.7	4
14	30.0	344.5	4

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15	25.0	53.0	4
16	30.0	344.5	4
17	24.4	38.5	3
18	24.4	38.5	3
19	27.4	149.5	4
20	25.0	53.0	4
21	24.3	36.3	3
22	117.2	399913.9	4
23	64.3	26189.0	4
24	138.5	676466.7	4
25	169.7	1275541.3	4

According the table, the elevation column represents the actual elevation of the selected point of the pilot area in meters from the mean sea level (msl). In order to the elevation of the selected points, the corresponding average flood return periods have been calculated by using five frequency estimation methods, mentioned in the third chapter. In order to the given parameter by the Department of Irrigation –SL, the flood intensity levels were declared, for the each selected location. A flood intensity ranks have been given by the study for the processing purpose through the VB programming, such as 1, 2, 3 & 4 for the alert, medium, high & critical flood levels respectively. The flood intensity rank column shows the corresponding flood intensity ranks of the selected locations.

4.3.5 IDAT fourth phase of the case study.

In the fourth phase of IDAT, the landslide risk levels were defined by the program, by using the Geo- database. (Table: 4.6)

Table 4.6: The Landslide Possibilities of the Selected Points.

Place No	Slope	Defined L/S Risk Level	Defined L/S Risk Rank
1	23.467	Low risk	3
2	18.102	No risk	4
3	0	Low risk	3
4	16.189	No risk	4
5	0	No risk	4
6	1.862	No risk	4
7	22.873	No risk	4
8	0	No risk	4
9	3.466	No risk	4
10	7.403	No risk	4
11	0	No risk	4
12	0	No risk	4
13	15.697	No risk	4
14	0	No risk	4
15	0	No risk	4
16	0	No risk	4
17	8.498	No risk	4
18	11.878	No risk	4
19	12.462	Moderate risk	2
20	0	No risk	4
21	4.751	No risk	4
22	33.799	Moderate risk	2
23	10.655	High risk	1
24	20.549	Moderate risk	2
25	20.712	Low risk	3

According to the table, the landslide risk of the selected locations was defined. In order to the given criteria by the NBRO – SL, the landslide risk levels were defined and the risk ranks were given to them, for the studying purpose. The slop of the selected locations were defined by the 3D analyst tool of ArcGIS.

4.3.6 IDAT fifth phase of the case study.

After considering all physical, demographic, flooding & Landslide data, the IDAT tool is attended to its fifth phase. It is the most important phase of the case study. Considering both flooding and landslide risk ranks, of those selected points, the disaster risk, corresponded to the each point was given by the program. The derived disaster risks of the selected points as follow. (Table: 4.7)

Table 4.7: The Disaster Risks of the Selected Points

Place No	Flood risk rank	Landslide risk rank	Disaster risk rank	Disaster risk %	Disaster risk level	Disaster risk rank
01	4	3	4,3	87.5	Low risk	3
02	4	4	4,4	100	No risk	4
03	2	3	2,3	62.5	Moderate risk	2
04	4	4	4,4	100	No risk	4
05	2	4	2,4	75	Moderate risk	2
06	1	4	1,4	62.5	High risk	1
07	4	4	4,4	100	No risk	4
08	2	4	2,4	75	Moderate risk	2
09	3	4	3,4	87.5	Low risk	3
10	4	4	4,4	100	No risk	4
11	4	4	4,4	100	No risk	4
12	2	4	2,4	75	Moderate risk	2
13	4	4	4,4	100	No risk	4
14	4	4	4,4	100	No risk	4
15	4	4	4,4	100	No risk	4
16	4	4	4,4	100	No risk	4
17	3	4	3,4	87.5	Low Risk	3
18	3	4	3,4	87.5	Low Risk	3
19	4	2	4,2	75	Moderate risk	2
20	4	4	4,4	100	No risk	4
21	3	4	3,4	87.5	Low Risk	3
22	4	2	4,2	75	Moderate risk	2
23	4	1	4,1	62.5	High Risk	1
24	4	2	4,2	75	Moderate risk	2
25	4	3	4,3	87.5	Low risk	3

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The percentages of the disastrous possibility were calculated in order to the disaster rank given by the program. The disaster risk rank was derived by considering the given weights for the each category, such as high, moderate, low or no risk. The high values of the percentages mention the low disaster risk, while the low value mentions the high disaster risks.

Thus the disaster risk of the selected points in the Ratnapura area can be evaluated by using this approach, using GIS; VB programming, as a disaster resilience strategy. By using this methodology, the new highway, railway or any other transportation infrastructures that going to be constructed in the study area, disaster risk levels of the selected location, once the risk level can be identified. The structural, non structural disaster management practices can be utilized in the optimum level on disaster resilience of the transportation infrastructures.

4.4 Validation.

Disasters can be identified as a disturbance, especially in the transport sector. Utilization of the traditional disaster prevention and resilience methodologies are not a permanent solution in the transport sector. Therefore a systematic methodology, which is integrated with modern technology, was developed, for disaster prevention and resilience on transportation infrastructure such as this. A case study was done based on Ratnapura urban area, to make out the capability on disaster resilience of the development methodology. It was given multiple answers among 5 steps, in its program.

In the validation proven model outputs were compared with the actual observations of selected locations. As mentioned in the third chapter, following base data was utilized to validate the outcomes given by the program.

Data	Source
33year flood gauging height and discharge volume	Irrigation Department, SL
Landslide data	NBRO, SL
Topological & Contour maps (1:50 000 and 1: 10 000)	Survey departments
Google Earth software	Keyhole, Inc. - USA
Arc GIS software	ESRI - USA
Field observations & discussions	By researcher.

4.5 Validate the location factor.

As the 1st phase of the validation, the geographical locations of the selected points were compared with the topographical maps and the Google earth software. The results are shown in the Table no: 4.8.

Table 4.8: The Location Data for the Validation.

Place No.	from the case study			By Topological maps of survey department			By Google Earth		
	x	*y*	*z*	*x*	*y*	*z*	*x*	*y*	*z*
1	150896.0024	170633.1501	56.8	150896.0024	170633.1501	56.8	80°19'46.31"E	6°44'6.12"N	53
2	153070.5574	169881.5964	53.1	153070.5574	169881.5964	53.1	80°20'57.15"E	6°43'41.72"N	60
3	155160.7746	168885.6533	20.0	155160.7746	168885.6533	20.0	80°22'5.24"E	6°43'9.35"N	20
4	157035.4101	167526.825	50.2	157035.4101	167526.825	50.2	80°23'6.32"E	6°42'25.17"N	57
5	158313.9274	165603.488	20.0	158313.9274	165603.488	20.0	80°23'48.00"E	6°41'22.59"N	22
6	160050.7147	164141.9759	15.9	160050.7147	164141.9759	15.9	80°24'44.59"E	6°40'35.05"N	25
7	161526.8354	162346.2224	34.2	161526.8354	162346.2224	34.2	80°25'32.69"E	6°39'36.62"N	49
8	162912.9433	160484.6944	20.0	162912.9433	160484.6944	20.0	80°26'17.87"E	6°38'36.05"N	26
9	164373.3921	158719.1409	23.5	164373.3921	158719.1409	23.5	80°27'5.45"E	6°37'38.60"N	33
10	164588.5212	156423.6992	59.6	164588.5212	156423.6992	59.6	80°27'12.51"E	6°36'23.88"N	81
11	156084.4202	172675.9458	30.0	156084.4202	172675.9458	30.0	80°22'35.22"E	6°45'12.77"N	38
12	156886.6755	162741.6748	20.0	156886.6755	162741.6748	20.0	80°23'1.60"E	6°39'49.38"N	32
13	154620.9242	164578.2172	27.2	154620.9242	164578.2172	27.2	80°21'47.78"E	6°40'49.11"N	29

14	163036.2869	170848.7076	30.0	163036.2869	170848.7076	30.0	80°26'21.65"E	6°44'13.46"N	34
15	162742.9863	167662.0182	25.0	162742.9863	167662.0182	25.0	80°26'12.17"E	6°42'29.70"N	40
16	154027.0728	160866.2833	30.0	154027.0728	160866.2833	30.0	80°21'28.54"E	6°38'48.25"N	45
17	151327.5003	163196.997	24.4	151327.5003	163196.997	24.4	80°20'0.58"E	6°40'4.05"N	33
18	150522.5396	169637.0717	24.4	150522.5396	169637.0717	24.4	80°19'34.18"E	6°43'33.69"N	34
19	153938.2307	166991.8863	27.4	153938.2307	166991.8863	27.4	80°21'25.48"E	6°42'7.67"N	43
20	151924.6893	166378.192	25.0	151924.6893	166378.192	25.0	80°20'19.94"E	6°41'47.63"N	39
21	159354.4522	158173.5244	24.3	159354.4522	158173.5244	24.3	80°24'22.06"E	6°37'20.73"N	37
22	165154.444	162567.0374	117.2	165154.444	162567.0374	117.2	80°27'30.81"E	6°39'43.89"N	115
23	161540.3638	172946.7571	64.3	161540.3638	172946.7571	64.3	80°25'32.89"E	6°45'21.72"N	85
24	156359.2747	156704.2329	138.5	156359.2747	156704.2329	138.5	80°22'44.58"E	6°36'32.82"N	147
25	165382.6388	167995.47	169.7	165382.6388	167995.47	169.7	80°27'38.12"E	6°42'40.62"N	182

It is very useful, that check the accuracy of the values, given by the different manners. The characteristics of a certain location should almost be same, though it is derived from the different manner. If the data are almost same, the liabilities of the used techniques are increased. In its train, the field observed data and recorded data should be same with the defined data by the study, for extra liability of the module developed.

In there the X, Y coordinates and the altitude (Z) factors were considered, to validate the geographical locations of the selected 25 points, by the case study. The digital data, derived by the survey department Sri Lanka, are used for all requirements of the mapping and data analyzing works by using ArcGIS software.

By using the 3D analysis tool of ArcGIS, a TIN (Triangulated Irregular Network) feature has been created, to determine the altitude factor in any place of the study area. In its train, the resulted X, Y, Z values, by the research and X, Y, Z values determined from the topographical maps, were almost same, due to its, common source files.

But, a very little value difference can be seen with the values given by Google earth software, in order to its WGS 84 coordinate system and sensing methods with a remote object. In its train, the Google earth X Y coordinates are given as Longitudes

and Latitudes, with degree, minutes & seconds, while it was in meters of local projection system, of topological maps of survey department Sri Lanka. After converting the WGS 84 coordinates into the local coordinate, most of the X & Y coordinate values are same each other. But, the elevation values consist with little changes in each other.

The factors such as satellite altitude, focal length - angle of the camera, EMS (Electro Magnetic Spectrum), etc.... can be affected, for these differences in the values of the elevation. As same as, the value extrapolation methods of the TIN files, of ArcGIS, also may be given the different values, each other. Even though, these value differences, between Google earth and local map values, a common scale variation with equal intervals can be identified by the following Chart: 4.9.

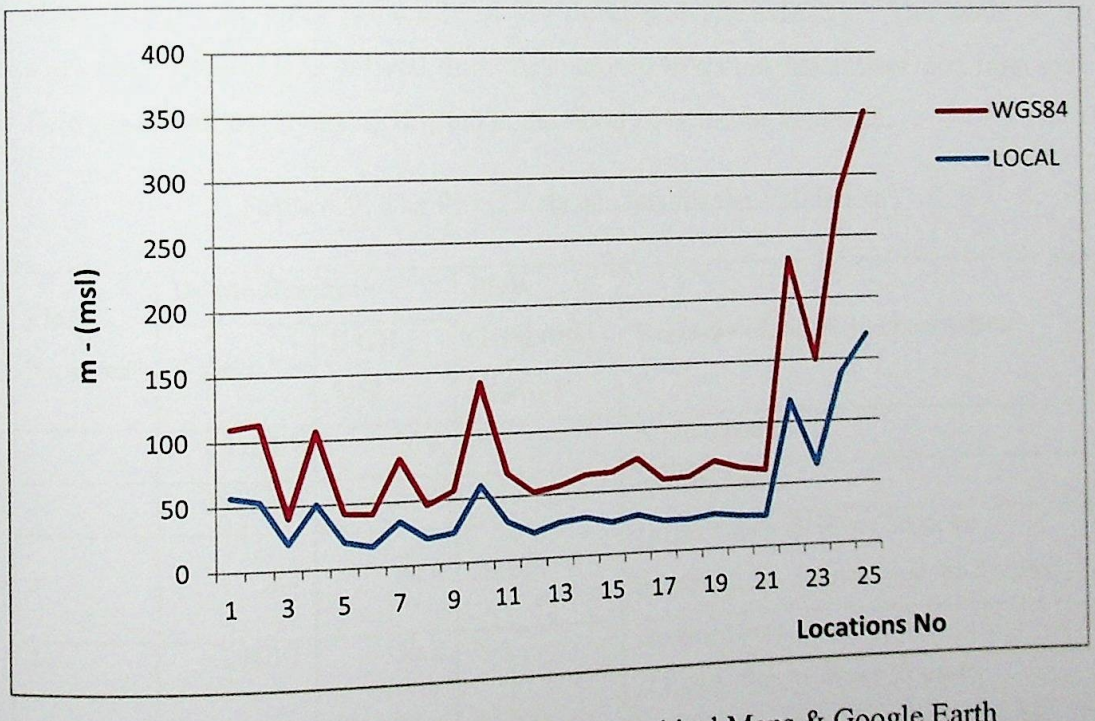


Figure 4.9: Given Elevation by Topographical Maps & Google Earth

According to the variation pattern of the chart, the values derived and the values given by Google earth can be generalized. The x & y location data are accurate as compared to the elevation (z) values. For the reason that, the x, y & elevation represented by the Google earth, using remotely sensed method. It is a satellite image. The focal lengths of the camera, satellite angular, the speed of the satellite, are

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directly engaged with the accuracy of the image. However the variation of the both local and WGS 84 are really constant. Usually the locale coordinates system is being used in Sri Lanka. Therefore, the given IDAT elevation levels were also be calculated according to the local coordinate system. As these matters, the local coordinate curve can be considered as the accurate curve in this study.

Thus the geographical location can be validated.

4.6 Validate the Flood related date.

The flood return periods and corresponded flood gauging heights were calculated by using developed methodology. Those given flood levels also be compared with the flood levels recorded by the irrigation department and, gathered from the field observations, for extra reliability of the developed methodology. The table: 4. 9 shows the flood details derived from the research, Irrigation department, and from the field observations. By using this table, the flood risks can be validated.

Table 4.9: The Flood Related Data for the Validation.

Place Number	By the Research		FGH (Irrigation Dept...)	Remarks of the Field observation
	F RP	F GH-MSL		
1	15124.7	56.8	NA *	No flood here
2	11060.5	53.1	NA *	No flood here
3	2.1	20.0	20.200	(13.49 + 6) = 19.49m / 50 years , Inundated 2 – 3 times / year by 2 – 3m
4	8440.7	50.2	NA *	No flood here
5	2.1	20.0	20.200	(13.49 + 7) = 21.49m / 50 years, Inundated 2 – 3 times / year by 2 – 3m
6	-13.0	15.9	NA *	Flooded 2 – 3 times annually.
7	934.9	34.2	NA *	No flood here
8	2.1	20.0	20.200	(13.49 + 5) = 18.49m / 50 years Inundated 2 – 3 times / year by 2 – 3m
9	22.4	23.5	23.49	(13.49 + 7) = 20.49 / 50 years
10	18787.7	59.6	NA *	No flood here

11	344.5	30.0	NA *	No flood here
12	2.1	20.0	20.200	(13.49 + 6) = 19.49m / 50 years Inundated 2 – 3 times / year by 2 – 3m
13	138.7	27.2	27.19	No flood here
14	344.5	30.0	NA *	No flood here
15	53.0	25.0	24.99	1-2m flood / 50 year
16	344.5	30.0	NA *	No flood here
17	38.5	24.4	24.39	1-2m flood / 50 year
18	38.5	24.4	24.39	1-2m flood / 50 year
19	149.5	27.4	27.39	No flood here
20	53.0	25.0	24.99	1- 2 ft flood / 50 year
21	36.3	24.3	24.29	1-2m flood / 50 year
22	399913.9	117.2	NA *	No flood here
23	26189.0	64.3	NA *	No flood here
24	676466.7	138.5	NA *	No flood here
25	1275541.3	169.7	NA *	No flood here

*NA * = Not Available*

According to the table a considerable difference cannot be seen among the gauge heights, given by the program, by the irrigation department, or the data collected by the field visit. But, a considerable deviation at least 5% - 10%, can be seen between the irrigation data and the data gathered by the field visit.

The field data cannot be considered as 100% accurate data. Informal field conversations and field measurements can be deferred by the systematic records. The people are explaining their past experience on disasters, with considerable affectation. Therefore, the field data can be deferred by the systematic data. But the risk levels can be extrapolated by using the field data. In that way, the field data can be superimposed with the systematic data. The systematic data, such as irrigation data and the outcomes of the research are almost superimposed. Thus, the flood risk levels can be validated. Therefore the validity of the proposed methodology of the research is realized.

Chapter 05

Conclusion

5.1 The importance of the research among the research literature.

Several numbers of common dimensions can be identified of the research literature, as follows.

Mainly, a single hazard has been studied broadly, rather than the multiple hazards, like current study.

In there, a single hazard has been selected to study deeply, i.e. Flood, landslide, drought etc. But, the researches, which are considered several hazards at once, are very few. But this research has been taken into consideration both flood and landslides, at one stretch, and attempted to estimate the disaster risk at a given place by considering both flood and landslides as its parameters. Therefore, this research turns a new chapter of the research literature.

The disaster risk has not been evaluated broadly for a road / railway, and its infrastructure, on its planning stage, as compared to the existing road / railway & its infrastructures.

A lot of research on disaster resilience on transportation; have been done for existing roads, railways or its infrastructures, considering with its river basins, rivers/ tributaries, terrain patterns and soil type. But, it has not been taken into consideration to study regarding the disaster risk of a new route, at the planning stage. Using this methodology a route that will have minimal risk of exposure natural disasters could be found. This method is studied the disaster risk at the planning stage of a road, railway or there infrastructures, amalgamating with the available information of the considering factors such as floods, landslides and defined risk levels. A tool that integrating with the GIS is developed to evaluate the disaster risk in any location,

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It shows a new dimension on calculating recurrence interval of a disaster.

The proposed tool is capable of estimating the return period or recurrence interval for a large area or a single point in the field. It is one of the most important part of this research.

The specialty of calculating return periods

The tool is capable of estimating flood return period using five widely used methods of average value in considered on the estimated return periods. By doing so, the reliability of the calculated return periods is protected.

The database preparation method.

The all most database is consisted with extrapolated data and information by using the limited data source and appropriate computer applications.

5.2 The specialty of the research methodology.

The methodology that is carried out by the research consisted with unique characteristics on its own. Selecting the pilot site, database preparation, data analyzing part and the output were consisted with unique characteristics. As the identified significant reasons such as hydrological, demographical and other physical and man-made characteristics, the pilot study area was limited in to 10km cercal area, in the Kalu River basin around the Ratnapura town.

This methodology was able to develop a simulated database by extrapolating the limited amount of data in the field. In its train, thirty three year flood gauging height and discharge volume data were extrapolated and the simulated database was prepared to determine the corresponded flood gauge heights and discharge volumes. The defined leaner combination between the flood gauging height and discharge volume,

$$\underline{Y= 0.0414x + 3.6888}$$

gives the correspondent gauge heights of any of discharge volumes. (Annex: 01)

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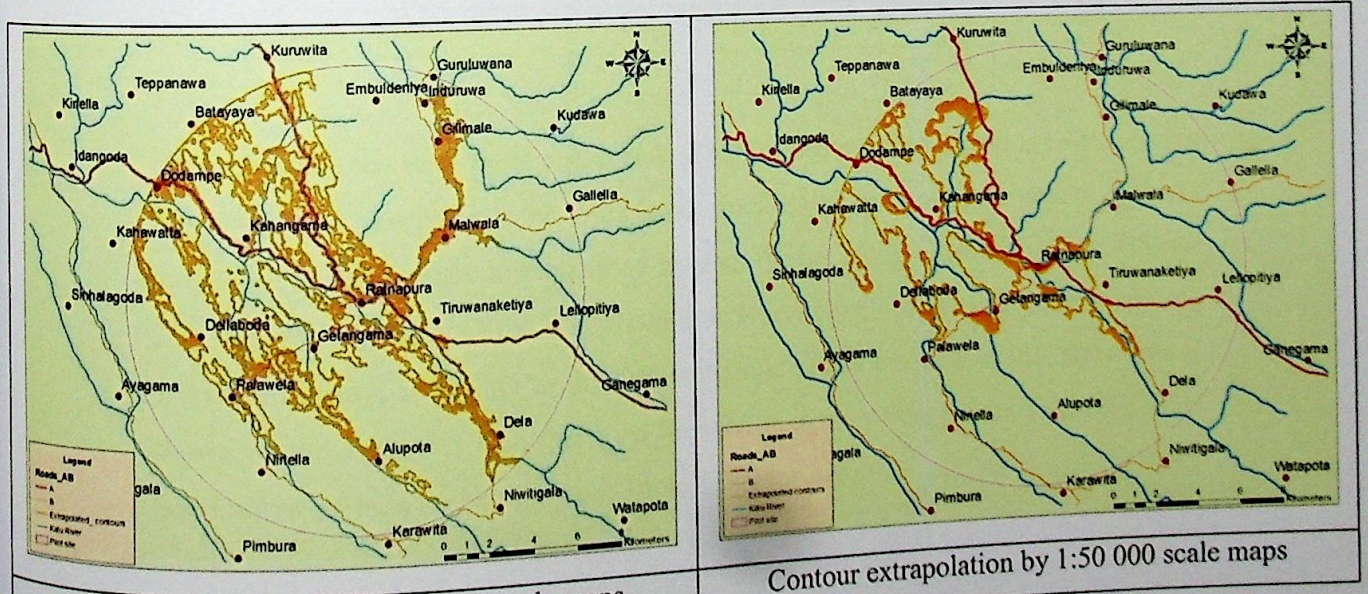
And the polynomial combination between the flood gauging height and flood return period

$$Y = 0.3x3 - 5.4311x^2 + 33.121x - 66.13$$

gives the correspondent return periods of any flood gauge height. (Annex: 02)

The correspondent inundation area of flood return periods and proposed & existing road links that can be inundated by the different flood levels also were calculated and implemented by the map media using GIS. The minor contours corresponded with different flood levels have been extrapolated by using the 3D Analysis tool of GIS.

For the liability of the extrapolated contours, the scale factors of source contours were considered. Moreover 1:10 000 shape files, were used to obtain the minor contour, considering their 5m contour interval, as compared to the 20m interval of the 1:50 000 contours. According to the used method, the extrapolated contours using 1:10000 shape files are more accurate rather than the 1:50 000 contours. (Figure- 5.1)



Contour extrapolation by 1:10 000 scale maps

Contour extrapolation by 1:50 000 scale maps

Figure 5.1: The Area Covered by the 1:10000 Contour Extrapolations is Greater Than 1: 50000 Contour Extrapolation in the Pilot Area.

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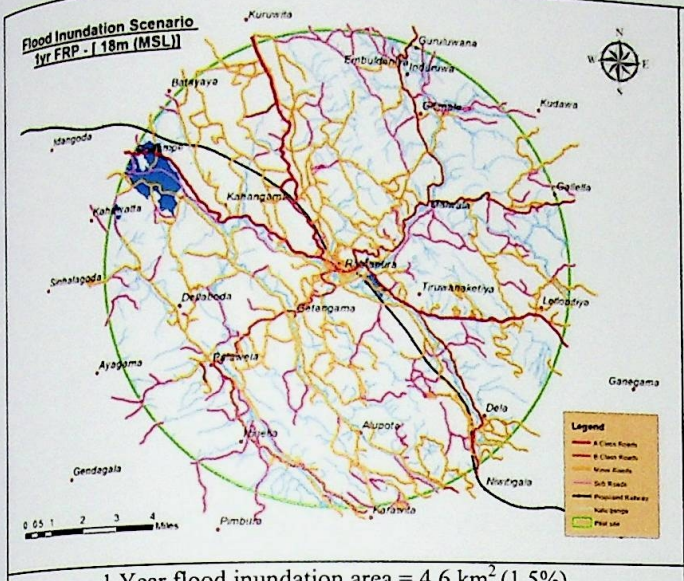
Simple statistical methods & applications such as, average, maximum , minimum, & scatter charts were used for the data analyzing works. Using Gumbel's, Gringroaten's, Hanzen's, Bleard's, & Weibul's frequency estimation methods, the average flood return periods in the pilot area were calculated. It is a kind of different strategy that used in the world for frequency estimation on a natural process.

The GIS intervention of the research work is also playing a vital role in all over the research. Table 5.1 describes the total lengths of the existing and proposed highway / railway among the study area were identified by using ArcGIS software.

Table 5.1: Existing & Proposed Highway / Railway statistics in the study area

Road Category	In m	In km	As %
A class roads	36241	36.2	6.0
B class roads	54235	54.2	9.1
Sub Roads	345275	345.3	57.6
Minor roads	163515	163.5	27.3
Total length	***599266***	***599.3***	***100.0***
Proposed Railway	20927	20.9	13.8

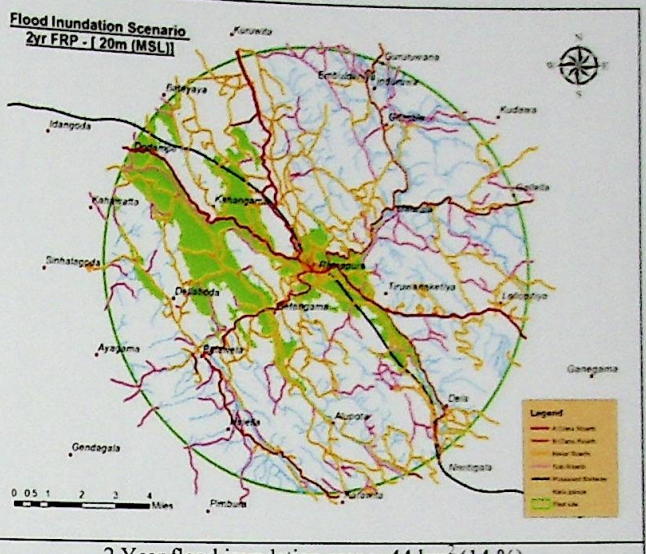
By processing the both flood risk levels & extrapolated contours, the inundation area of each flood levels and the inundated road links (proposed & existing) were evaluated, and they were implemented by map media, using GIS technology. (Figure 5.2). And the summery of the total flood inundation lengths on existing highways and proposed railway, according to the different flood return periods, in the study area is shown by the Table 5.2, and the flood inundation area correspondent to the different flood return periods is shown by the Table 5.3 respectively



1 Year flood inundation area = 4.6 km^2 (1.5%)

FGH = 18m by MSL

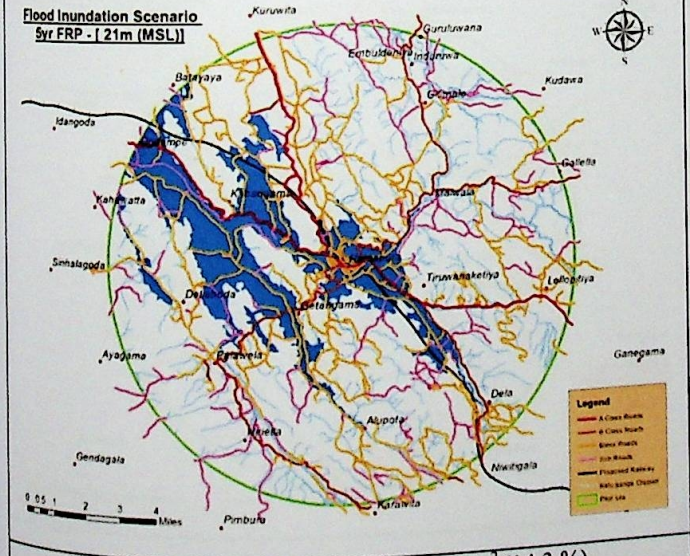
Road Category	Length in km	As a % by the total	Total (kms) can be inundated
A class	0.9	2.5	11.9
B class	0.0	0.0	
Sub roads	6.2	1.8	
Minor roads	4.8	2.9	
Railway	0.3	1.4	1.4



2 Year flood inundation area = 44 km^2 (14 %)

FGH = 20m by MSL

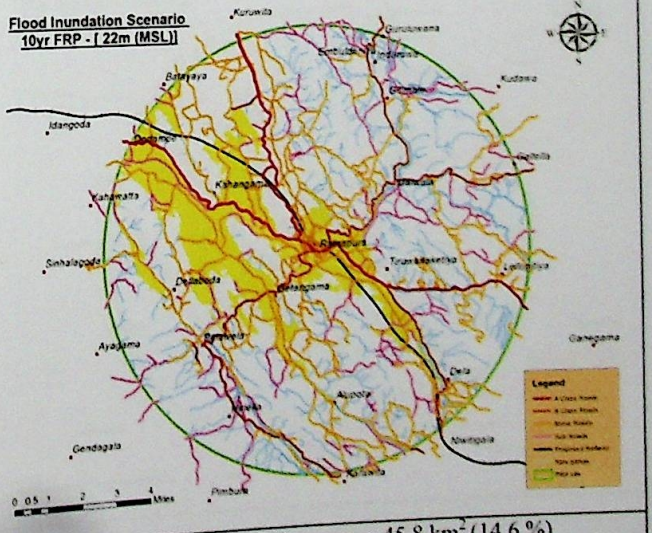
Road Category	Length in km	As a % by the total	Total (kms) can be inundated
A class	11.8	32.7	110.7
B class	5.0	9.1	
Sub roads	74.1	21.5	
Minor roads	19.7	12.1	
Railway	8.8	41.9	41.9



5 Year flood inundation area = 44.9 km^2 (14.3 %)

FGH = 21m by MSL

Road Category	Length in km	As a % by the total	Total (kms) can be inundated
A class	12.0	33.2	113.4
B class	5.3	9.7	
Sub roads	75.9	22.0	
Minor roads	20.2	12.4	
Railway	9.0	43.1	43.1

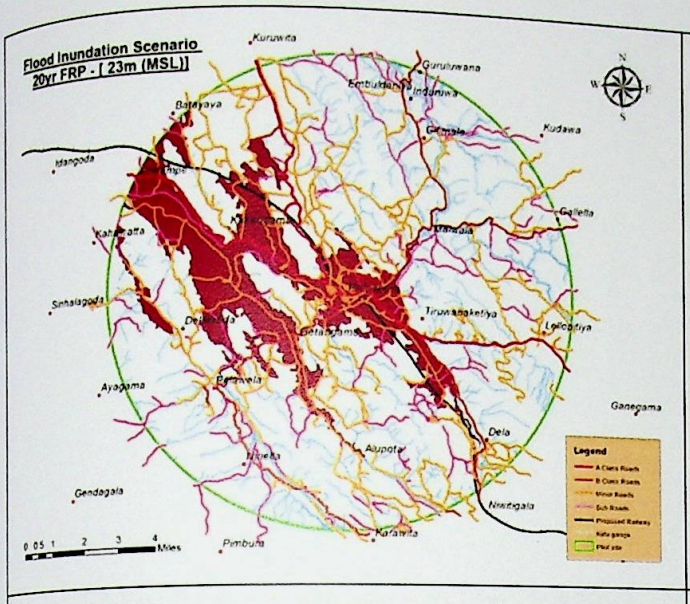


10 Year flood inundation area = 45.8 km^2 (14.6 %)

FGH = 22m by MSL

Road Category	Length in km	As a % by the total	Total (kms) can be inundated
A class	12.3	33.8	116.0
B class	5.8	10.7	
Sub roads	77.3	22.4	
Minor roads	20.6	12.6	
Railway	9.2	43.9	43.9

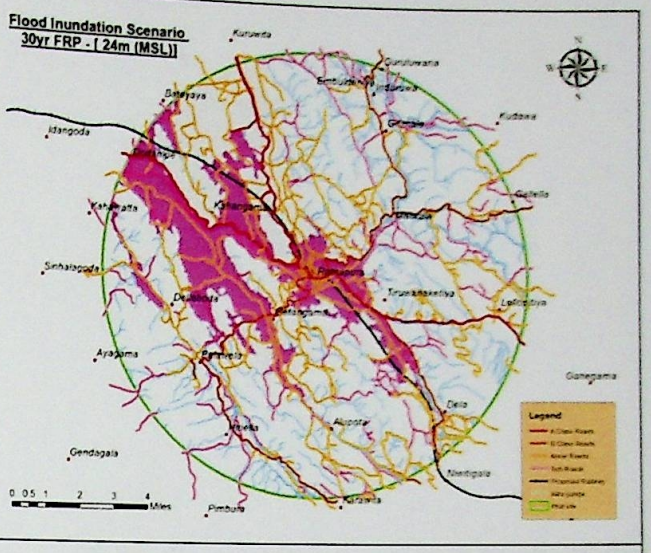
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20 Year flood inundation area = 46.7 km^2 (14.9 %)

FGH = 23m by MSL

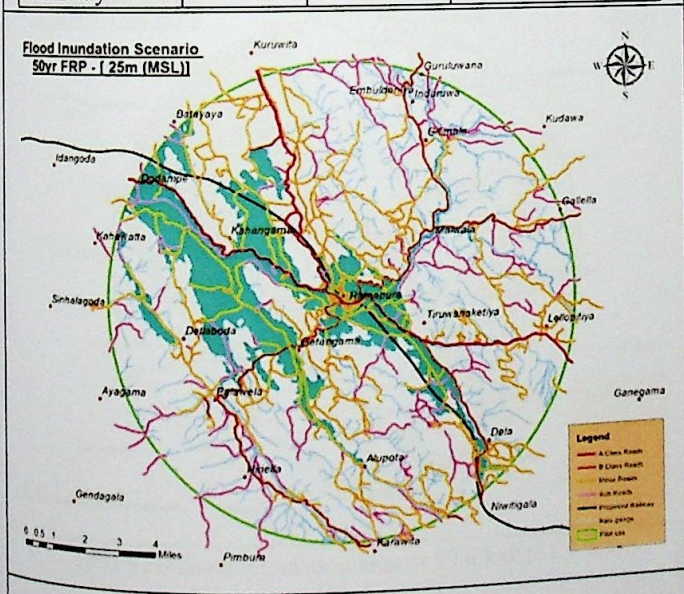
Road Category	Length in km	As a % by the total	Total (kms) can be inundated
A class	12.5	34.6	118.5
B class	6.2	11.4	
Sub roads	78.9	22.8	
Minor roads	21.0	12.8	
Railway	9.3	44.5	44.5



30 Year flood inundation area = 47.6 km^2 (15.2 %)

FGH = 24m by MSL

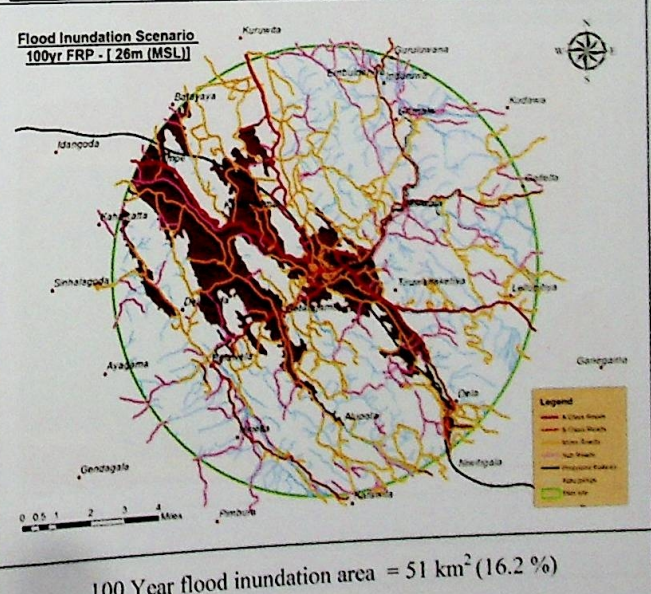
Road Category	Length in km	As a % by the total	Total (kms) can be inundated
A class	12.9	35.5	121.6
B class	6.8	12.5	
Sub roads	80.6	23.3	
Minor roads	21.4	13.1	
Railway	9.4	45.1	45.1



50 Year flood inundation area = 49.9 km^2 (15.9 %)

FGH = 25m by MSL

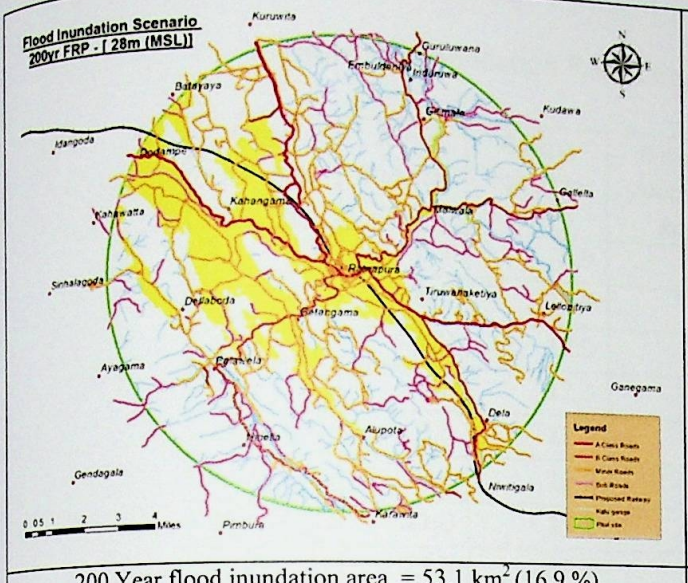
Road Category	Length in km	As a % by the total	Total (kms) can be inundated
A class	13.2	36.5	128.8
B class	8.9	16.3	
Sub roads	84.4	24.4	
Minor roads	22.3	13.7	
Railway	11.0	52.6	52.6



100 Year flood inundation area = 51 km^2 (16.2 %)

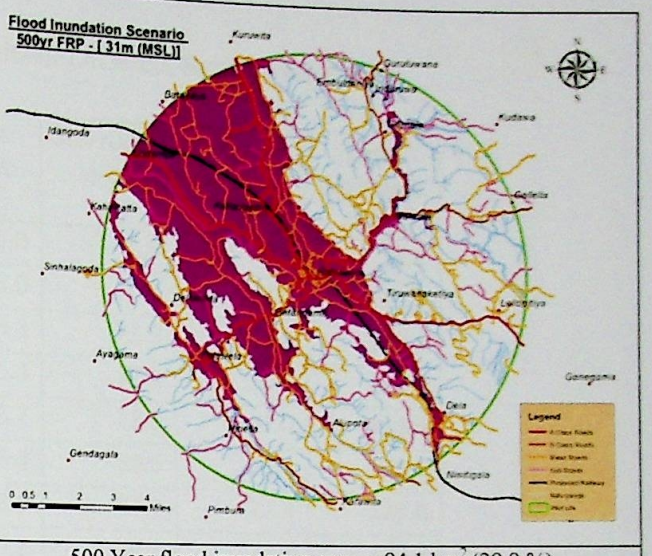
FGH = 26m by MSL

Road Category	Length in km	As a % by the total	Total (kms) can be inundated
A class	13.6	37.4	132.8
B class	9.6	17.7	
Sub roads	86.8	25.1	
Minor roads	22.8	14.0	
Railway	11.0	52.6	52.6



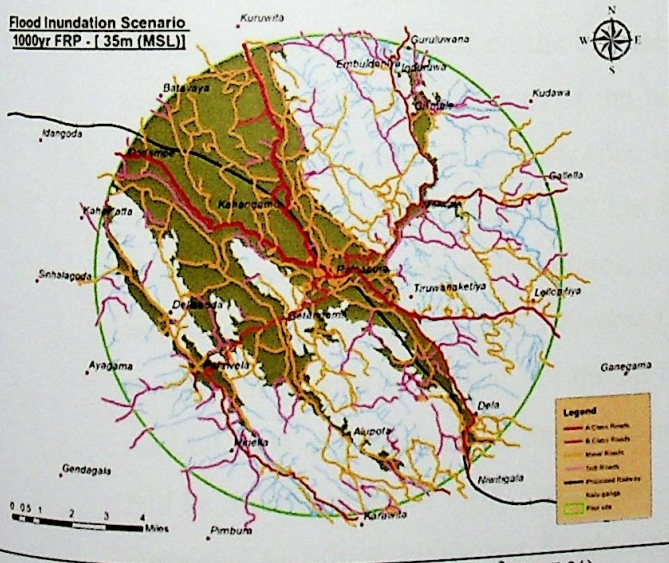
200 Year flood inundation area = 53.1 km^2 (16.9 %)
FGH = 28m by MSL

Road Category	Length in km	As a % by the total	Total (kms) can be inundated
A class	14.2	39.2	139.9
B class	10.6	19.5	
Sub roads	91.3	26.4	
Minor roads	23.8	14.5	
Railway	11.9	56.7	56.7



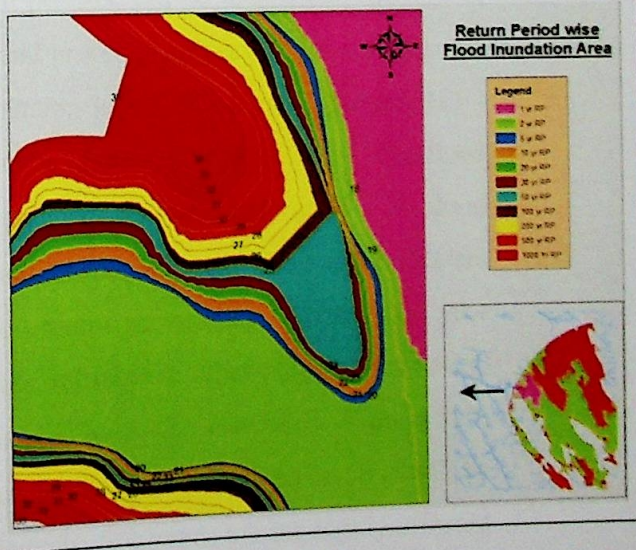
500 Year flood inundation area = 94.1 km^2 (29.9 %)
FGH = 31m by MSL

Road Category	Length in km	As a % by the total	Total (kms) can be inundated
A class	28.1	77.5	231.7
B class	16.9	31.2	
Sub roads	153.1	44.3	
Minor roads	33.5	20.5	
Railway	17.8	85.3	85.3



1000 Year flood inundation area = 99.6 km^2 (31.7 %)
FGH = 35m by MSL

Road Category	Length in km	As a % by the total	Total (kms) can be inundated
A class	28.2	77.8	248.5
B class	19.9	36.7	
Sub roads	161.6	46.8	
Minor roads	38.9	23.8	
Railway	18.8	89.7	89.7



Return period wise flood inundation scenario

Figure 5.2: The Scenario of the Flood Gauge Heights and Correspondent Inundation Area of Different Flood Return Periods in the Pilot Site

Table 5.2: Inundation Road Lengths of Different Return Periods.

Flood Return period	*Total Railway in km*	*A class roads in km*	*B class roads in km*	*Sub roads in km*	*Minor Roads in km*	***Total highways in km***
1	0.3	0.9	0.0	6.2	4.8	**11.9**
2	8.8	11.8	5.0	74.1	19.7	**110.7**
5	9.0	12.0	5.3	75.9	20.2	**113.4**
10	9.2	12.3	5.8	77.3	20.6	**116.0**
20	9.3	12.5	6.2	78.9	21.0	**118.5**
30	9.4	12.9	6.8	80.6	21.4	**121.6**
50	11.0	13.2	8.9	84.4	22.3	**128.8**
100	11.0	13.6	9.6	86.8	22.8	**132.8**
200	11.9	14.2	10.6	91.3	23.8	**139.9**
500	17.8	28.1	16.9	153.1	33.5	**231.7**
1000	18.8	28.2	19.9	161.6	38.9	**248.5**

In order to the Table 5.2, the lengths of the all four roads categories, which are prone to be inundated by the different flood return periods, can be identified. The annual flood is not badly affected on the highway and proposed railway. However, the two year flood is started the growth of the inundation levels of the area. Around 111 - 118.5 km of highways in all categories is to be inundated within 2 - 20 year flood return period. Moreover, 122 - 129 km is going to be inundated by 30 - 50 flood return period. Furthermore, it assumes, around 133 km of roads in all categories are trending to be flooded by the 100-year flood return period. 200, 500 & 1000 year floods will be strictly critical, for the all roads, railways & other physical structures. Around 44% of proposed rail line to be inundated by 2 - 30 year flood. Around 52% will be inundated by 50 - 100 year floods. Around 85% & 90% of the rail line will be inundated by 500 & 1000-year floods, respectively. Sub roads are the highly effected category by the floods, while the B class roads are the minimum category. A class & the minor roads are affected in intermediately.

Table 5.3: Inundation Land Areas of Different Return Periods.

Return Period	Flood Gauge Height (MSL)	Inundation area km^2	Total considered area km^2	Inundation Area %
1	18	4.6	314.2	1.5%
	19	5.0	314.2	1.6%
2	20	44.0	314.2	14.0%
5	21	44.9	314.2	14.3%
10	22	45.8	314.2	14.6%
20	23	46.7	314.2	14.9%
30	24	47.6	314.2	15.2%
50	25	49.9	314.2	15.9%
100	26	51.0	314.2	16.2%
	27	52.1	314.2	16.6%
200	28	53.1	314.2	16.9%
	29	54.2	314.2	17.3%
	30	93.1	314.2	29.6%
500	31	94.1	314.2	29.9%
	32	95.0	314.2	30.2%
	33	95.9	314.2	30.5%
	34	96.8	314.2	30.8%
1000	35	99.6	314.2	31.7%

The table describes the correspondent FGH (MSL) of different FRPs. Furthermore the inundation land area also been calculated by the system as km^2 wise and percentage wise. In its train, around 1.5% - 1.6% of land area, lower than 19m (MSL), out of the total land area, is most vulnerable to inundated annually. 30 year flood covers 15.2% (47.6km^2) land area, while the 100 year flood covers 16.2% of the land area by the total land area. 200, 500, & 1000 year return periods inundate 16.9% (53.1 km^2), 29.9% (94.1 km^2), & 31.7% (99.6km^2) respectively. The existing highway and proposed railway that can be affected by the different risk levels of land slide were also determined using GIS. The roads & railways that can be threatened by the landslides in the pilot site are given by the Table 5.4.

Table 5.4: Road & railway that can be threatened by the landslides

Landslides Risk Level	Total land area in km^2	A class road in km	B class road in km	Sub roads in km	Minor roads in km	Rail road in km
HIGH Risk	**5.7**	-	0.8	0.6	2.6	0.1
MODERATE Risk	**60.8**	1.9	10.7	34.4	25.8	1.6
LOW Risk	**65.7**	3.4	6.9	52.9	25.0	18
NO Risk	**182.4**	29.8	32.1	236.1	91.2	17.4

According to the table, it can realize, the almost roads & railways has been avoiding the high risk zones. The A class roads have completely avoided the high risk zones. The majority of the highway has been constructed among the Low risk & No risk areas. The proposed railway has also been planned associating with the Low risk & No risk areas of the pilot site.

A polynomial combination can be shown between the FRP & FGH of the pilot area. (Figure 5.3)

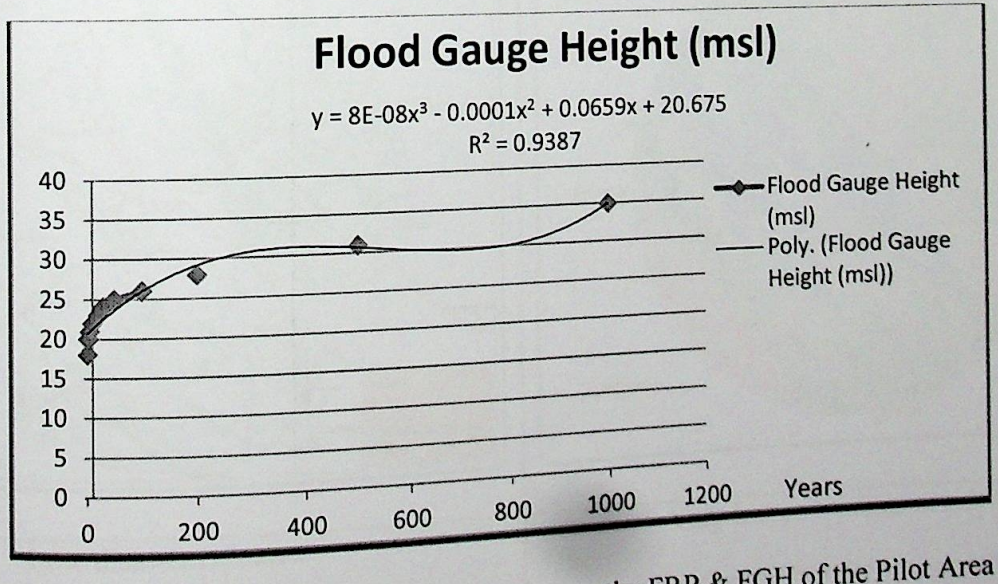
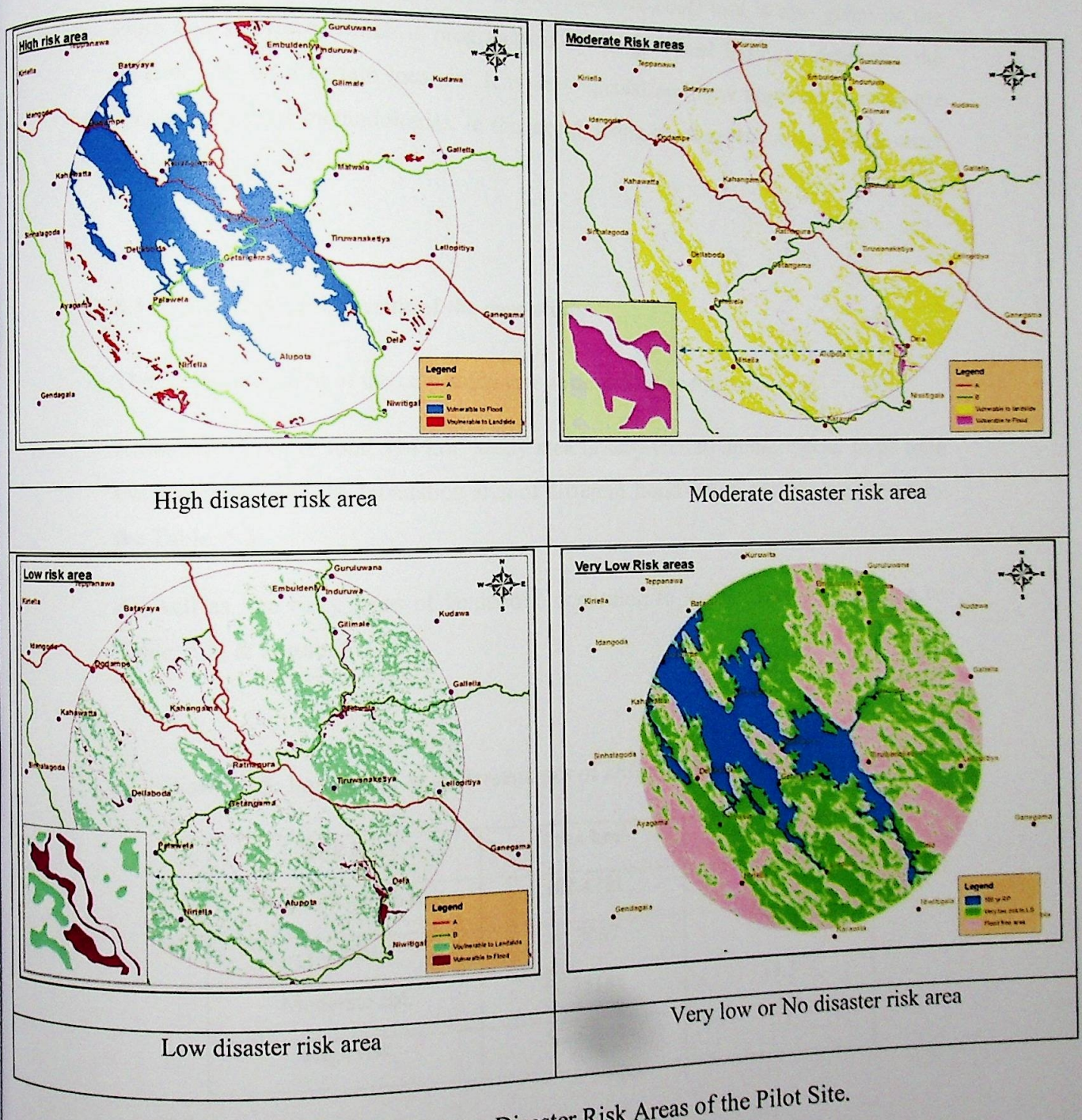


Figure 5.3: Polynomial Combination between the FRP & FGH of the Pilot Area

Then the flood risk levels and landslide risk levels were overlapped each other, and obtained the disaster risk levels mainly into 04 groups, i.e. High risk, Moderate risk,

Low risk, Very low or No risk. Using ArcGIS the corresponding maps for four disaster risk areas also were prepared. (Figure: 5.4)



High disaster risk area

Moderate disaster risk area

Low disaster risk area

Very low or No disaster risk area

Figure 5.4: Four Major Disaster Risk Areas of the Pilot Site.

The used methodology of the study can be considered as a different methodology, among the other methodologies have been applied on disaster resilience. Using this

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methodology, the disastrous possibility can be predicted on a large area as same as a single location.

A user friendly IDAT *(Integrated Disaster Analysis Tool)* tool is also given on the same GIS interface, which is programmed by using Visual basic, to determine the disaster risk on a certain location. It is very special and new approach, among the contemporaneous methodologies, in the world, using modern technology, on disaster resilience up to now.

5.3 Conclusion of the result of the case study

The final conclusion of the case study can be described as follows.

Around 30% out of total 314 km^2 study area is subjected to annual flood. In its train the percentage and the inundation area of different flood return periods are shown by the Table: 5.3

As well as, the risky areas of landslides, according to its risk levels are shown by Table: 5.5. & Figure: 5.5

Table 5.5: Land Area & its Percentages of Different Landslide Risk Levels.

Risk level	Area km^2	Area as %
Very low or No risk	182.4381	58.1
Low risk	65.7067	20.9
Moderate risk	60.75185	19.3
High risk	5.262446	1.7

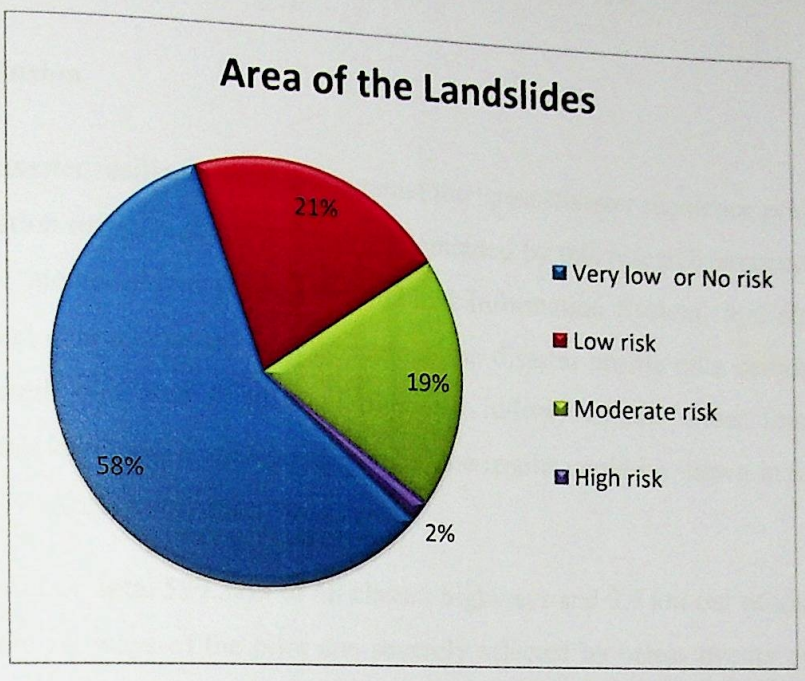


Figure 5.5: Area of different landslide risk levels.

According to this, 182.4 km^2 land area (58.1%) out of 314.2km^2 can be identified as landslide free area. 2% of the study area (5.3km^2) is consists with high risk or most prominent to the landslide. Nearby half of the rest of area, 21% is consists with moderate risk, while the 19% is consists with low risk by the landslides.

According to the study, the areas consist with 1 – 20 return period and high risk landslides, are the most vulnerable to the frequent floods and landslides. Therefore, those areas can be identified as "High risk area". As same as the areas consists with 20– 50 return period and moderate landslide risk, are identified as "Moderate risk area". 50 – 100 return period and low risk landslide areas are considered as "Low risk area" and greater than 100 (>100) and very low or No risk landslide areas can be identified as the "Very low risk or No risk" areas by the disasters.

By superimposing the different landslide and flood risk levels, above mentioned, using ArcGIS software, the disaster risks can be visualized under 4 risky groups, i.e. High disaster risk area, Moderate disaster risk area, Low disaster risk area & very low or No disaster risk area. (Figure 5.4)

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5.4 Conclusion

A "pre- disaster resilience strategy" against the "post-disaster resilience practices", on transportation infrastructure has been implemented by this research successfully. The developed methodology, using Geographical Information System, hydrological and geophysical characteristics, was represented the disaster profile on a certain location. The affected land area & affected highway, railway lengths under four different disaster risk levels were calculated. Finally, the results could be shown in map media, by using the ArcGis software.

118.5km out of total 599.3km of all classes highways and 9.6 km out of total 20.9 km of proposed railways of the pilot are, severely affected by below twenty year floods, in the defined high disaster risk zone. 128.8 km of highways and 11km of proposed railways will be affected by twenty to fifty year floods, in the defined Moderate disaster risk zone. The roads & proposed railways which are in the Low disaster risk zone that is between fifty to hundred year flood return periods will be affected by 132.8 km and 11 km respectively. And the highways and proposed railways, sited in the Low/No risk area, in the flood zone above hundred years, will be affected more than 132.8 km & 11 km respectively.

Most of the highways & proposed railroads are sited in Low risk and landslide free area, while they are limited to a few kilometers in the Moderate & High risk landslide zones.

Finally, it could be found that, 58.1%, (182.4 km^2 out of 314.28km^2 pilot site) is belonging to very low (or No risk) risk area, while other low risk, moderate risk and high risk areas were 20.9% (65.7 km^2), 19.3% (60.8 km^2) and 1.7% (5.3 km^2) respectively in the study area.

Thus the findings can be concluded in order to the proposed methodology of the research.

5.5 Presumption

Thus around the 1/3 of the study area is vulnerable to the flash flood and critical landslide disasters. Therefore, it is recommended to evaluate the disaster risk on every suspected area and places, where the new road / railways or their infrastructures are going to be established. As well as, it is recommended to utilize the defined low risk and no risk areas for the construction & development works of infrastructures of the transport sector, as a pre-disaster resilience strategy on transportation infrastructure.

The developed methodology is recommended, to utilize as a pre-disaster resilience strategy, for surface analysis/ risk analysis against the natural disasters on the transportation infrastructures.

Hence, according to the defined methodology, the disaster resilience can be evaluated any location of the country or all around the world, by changing the appropriate attributes of the features of the considered location.

5.6 Future developments of the research.

The future developments of the research work can be arrayed as follows.

- The research factors on disasters should be extended, further than two, for more reliable output than the current study. (This research has considered only flood & landslides characteristics as the main factors)
- It is proposed to develop the IDAT as an online disaster analysis tool, and proposed an online updating system for the database.

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Annex. 01

Ten deadliest natural disasters in the world

Rank	Death toll (estimate)	Event named as	Location	Date
1	145,000–4,000,000*	1931 - China floods	China	July, August - 1931
2	900,000–2,000,000	1887 - Yellow River flood	China	September, October - 1887
3	830,000	1556 - Shaanxi earthquake	China	January 23 - 1556
4	242,000–779,000	1976 - Tangshan earthquake	China	July - 1976
5	500,000-1,000,000	1970 - Bhola cyclone	East Pakistan (now Bangladesh)	November 13 - 1970
6	300,000	1839- India Cyclone	India	November 25 - 1839
6	300,000	1737 - Calcutta cyclone	India	October 7 - 1737
8	273,400	1920 - Haiyuan earthquake	China	December 16 - 1920
9	250,000–300,000	526 - Antioch earthquake	Byzantine Empire	May - 526
10	260,000	115 -Antioch earthquake	Byzantine Empire	December 13 - 115

* Estimate by Nova's sources are close to 4 million and yet Encarta's sources report as few as 1 million. Expert estimates report wide variance.

Ten deadliest natural disasters since 1900

Rank	Death toll (estimate)	Event named as	Location	Date
1.	1,000,000–4,000,000	1931 - China floods	China	July - 1931
2.	650,000–779,000	1976 - Tangshan earthquake	China	July - 1976
3.	500,000	1970 - Bhola cyclone	East Pakistan (now Bangladesh)	November - 1970
4.	234,117	1920 - Haiyuan earthquake	China	December - 1920
5.	230,000	2004 - Indian Ocean Tsunami	Indian Ocean	26th December - 2004
6.	229,000	Typhoon Nina—contributed to Banqiao Dam failure	China	August 7 - 1975
7.	159,000	2010 - Haiti earthquake	Haiti	January 12 - 2010
8.	145,000	1935 - Yangtze river flood	China	1935
9.	142,000	1923 - Great Kanto earthquake	Japan	September - 1923
10.	139,000	1991 - Bangladesh cyclone	Bangladesh	April 29 - 1991

Does not include industrial or technological accidents or epidemics nor the 1938 Yellow River flood.

Lists of natural disasters by cause

Ten Deadliest avalanches

Rank	Death toll (estimate)	Event named as	Location	Date
1.	20,000	1970 - Huascarán avalanche; triggered by the 1970 Ancash earthquake	Peru	1970
2.	4,000	1962 - Huascarán avalanche	Peru	1962
3.	265	Winter of Terror	Austria-Switzerland	1951
4.	172	2010 - Salang avalanches	Afghanistan	2010
5.	125	Kolka - Karmadon rock ice slide	Russia	2002
6.	102	2010 - Kohistan avalanche	Pakistan	2010
7.	96	Wellington, Washington avalanche	United States	1910
8.	90	Frank Slide	Canada	1903
9.	62	1910 - Rogers Pass avalanche	Canada	1910
10.	59	1993 - Bayburt Üzengili avalanche	Turkey	1993

Ten deadliest blizzards

Rank	Death toll (estimate)	Event	Location	Date
1.	4,000	1972 - Iran blizzard	Iran	1972
2.	3,000	Carolina Death March	Sweden	1719

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Rank	Death toll (estimate)	Event	Location	Date
3.	926	2008 - Afghanistan blizzard	Afghanistan	2008
4.	400	Great Blizzard of 1888	United States	1888
5.	318	1993 - North American Storm Complex	United States	1993
6.	235	Schoolhouse Blizzard	United States	1888
7.	199	Hakko-da Mountains incident	Japan	1902
8.	154	North American blizzard of 1996	United States	1996
9.	144	Armistice Day Blizzard	United States	1940
10.	133	2008 - Chinese winter storms	China	2008

Ten deadliest tropical cyclones

Rank	Death toll	Event	Location	Date
1.	500,000	1970 - Bhola cyclone	East Pakistan (Bangladesh)	November 13, 1970
2.	300,000	1839 - India Cyclone	India	November 25, 1839
2.	300,000	1737 - Calcutta cyclone	India	October 7, 1737
4.	229,000	Super Typhoon Nina—contributed to Banqiao Dam failure	China	August 7, 1975
5.	200,000	Great Backerganj Cyclone of 1876	India (now Bangladesh)	October 30, 1876
6.	138,866	1991 - Bangladesh cyclone	Bangladesh	April 29, 1991
7.	138,366	Cyclone Nargis	Myanmar	May 2, 2008

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Rank	Death toll	Event	Location	Date
8.	100,000	1882 - Bombay cyclone	India	1882
9.	80,000	1874 - Bengal cyclone	India	October, 1874
10.	75,000	1847 - Bengal cyclone	India	October, 1847

50 Deadliest earthquakes

Rank	Death toll (estimate)	Event	Location	Date
1.	830,000	1556- Shaanxi earthquake	China	January 23, 1556
2.	650,000–779,000	1976 - Tangshan earthquake	China	July 28, 1976
3.	273,400	1920 -Haiyuan earthquake	China	December 16, 1920
4.	250,000–300,000	526 - Antioch earthquake	Byzantine Empire	May 526
5.	260,000	115 - Antioch earthquake	Byzantine Empire	December 13, 115
6.	230,000	2004 - Indian Ocean earthquake	Indonesia	December 26, 2004
7.	230,000	1138 - Aleppo earthquake	Syria	October 11, 1138
8.	200,000	1303 - Hongdong earthquake	China	September 17, 1303
9.	200,000	856 - Damghan earthquake	Iran	December 22, 856
10.	200,000	1780 - Tabriz earthquake	Iran	January 8, 1780
11.	170,000	896 - Udaipur earthquake	India	896

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Rank	Death toll (estimate)	Event	Location	Date
12.	159,000	2010 - Haiti earthquake	Haiti	January 12, 2010
13.	150,000	893 - Ardabil earthquake	Iran	March 23, 893
14.	142,807	1923 - Great Kanto earthquake	Japan	September 1, 1923
15.	130,000	533 - Aleppo earthquake	Syria	November 29, 533
16.	123,000	1908 - Messina earthquake	Italy	December 28, 1908
17.	110,000	1948 - Ashgabat earthquake	Turkmen SSR, Soviet Union (now Turkmenistan)	October 5, 1948
18.	100,000	1290 - Chihli earthquake	China	September 27, 1290
19.	100,000	1970 - Ancash earthquake	Peru	May 31, 1970
20.	100,000[29]	2005 - Kashmir earthquake	Pakistan (Azad Kashmir)	October 8, 2005
21.	87,587	2008 Sichuan earthquake	China	May 12, 2008
22.	80,000	1721 Tabriz earthquake	Iran	April 26, 1721
23.	80,000	458 Antioch earthquake	Turkey & Syria	September 458
24.	80,000	1667 Shamakhi earthquake	Azerbaijan	November 1667
25.	80,000	1854 Great Nankaidō earthquake	Japan	November 1854
26.	80,000	1169 Aleppo earthquake	Syria	1169
27.	77,000	1727 Tabriz earthquake	Iran	November 18, 1727
28.	73,000	1718 Gansu earthquake	China	June 19, 1718
29.	70,000	1033 Ramala earthquake	Palestine	December 10, 1033
30.	70,000	847 Damascus earthquake	Syria	847
31.	70,000	1868 Ecuador earthquakes	Ecuador	August 15,

Rank	Death toll (estimate)	Event	Location	Date
				1868 and August 16, 1868
32.	60,000	587 Antioch earthquake	Byzantine Empire	September 30, 587
33.	60,000	1101 - Iran earthquake	Iran	1101
34.	60,000	1268 - Cilicia earthquake	Armenian Kingdom of Cilicia (now Turkey)	1268
35.	60,000	1693 - Sicily earthquake	Italy	January 11, 1693
36.	60,000	1935 - Balochistan earthquake	British India (now part of Pakistan)	May 31, 1935
37.	50,000	844 - Damascus earthquake	Syria	September 18, 844
38.	50,000	1042 - Tabriz earthquake	Iran	November 4, 1042
39.	50,000	1783 - Calabrian earthquakes	Italy	1783
40.	50,000	1990 - Manjil-Rudbar earthquake	Iran	June 21, 1990
41.	40,000–50,000	1755 - Lisbon earthquake	Portugal	November 1, 1755
42.	45,000	850 - Iran earthquake	Iran	July 15, 850
43.	45,000	856 - Corinth earthquake	Greece	December 856
44.	45,000	856 - Tunisia earthquake	Tunisia	December 3, 856
45.	42,571	1668 - Shandong earthquake	China	July 25, 1668
46.	40,900	1927 - Gulang earthquake	Gansu, China	1927
47.	40,000	342 - Antioch earthquake	Syria	342
48.	40,000	662 - Damghan earthquake	Iran	April 26, 662

Rank	Death toll (estimate)	Event	Location	Date
49.	40,000	1455 - Naples earthquake	Italy	December 5, 1455
50.	40,000	1754 - Cairo earthquake	Egypt	September 2, 1754
51.	40,000	1755 - Tabriz earthquake	Iran	June 7, 1755
52.	40,000	1797 - Riobamba earthquake	Ecuador	1797

Ten deadliest floods / landslides

(Note: Some of these floods and landslides may be partially caused by humans, for example, the dams, levees, seawalls and retaining walls failure.)

Rank	Death toll	Event	Location	Date
1.	2,500,000–3,700,000	1931 - China floods	China	1931
2.	900,000–2,000,000	1887 - Yellow River (Huang He) flood	China	1887
3.	229,000	Failure of 62 dams, the largest of which was Banqiao Dam, result of Typhoon Nina.	China	1975
4.	145,000	1935 - Yangtze river flood	China	1935
5.	more than 100,000	St. Felix's Flood, storm surge	Netherlands	1530
6.	100,000	Hanoi and Red River Delta flood	North Vietnam	1971
7.	up to 100,000	1911 - Yangtze River flood	China	1911
8.	50,000–80,000	St. Lucia's flood, storm surge	Netherlands	1287
9.	60,000	North Sea flood, storm surge	Netherlands	1212

Rank	Death toll	Event	Location	Date
10.	36,000	St. Marcellus flood, storm surge	Netherlands	1219

Deadliest heat waves

Rank	Death toll	Event	Location	Date
1.	70,000	2003 - European heat wave	Europe	2003
2.	56,000	2010 Russian heat wave	Russia	2010
3.	5,000–10,000	1988 United States heat wave	United States	1988
4.	1,700-5,000	1980 United States heat wave	United States	1980
5.	1,718	2010 Japanese heat wave	Japan	2010
6.	1,500	2003 Southern India heat wave	India	2003
7.	946	1955 Los Angeles heat wave	United States	1955
8.	891	1972 New York City heat wave	United States	1972
9.	739	1995 Chicago heat wave	United States	1995
10.	475	1900 Argentina heat wave	Argentina	1900

Deadliest lightning strikes

Rank	Death toll	Event	Location	Date
1.	4,000	Palace of the Grand Master Explosion, Rhodes	Greece	1856
2.	3,000	Church of San Nazaro Explosion, Brescia	Italy	1769

Deadliest limnic eruptions

Rank	Death toll	Event	Location	Date
1.	1,744	Lake Nyos	Cameroon	1986
2.	37	Lake Monoun	Cameroon	1984

10 deadliest storms (non-cyclone)

Rank	Death toll	Event	Location	Date
1.	15,100	Torrential rains and mudslides	Venezuela	1999
2.	1,000	Rio de Janeiro floods and mudslides	Brazil	2011
3.	500	Lofoten, Heavy storm	Norway	1849
4.	250	Great Lakes Storm of 1913	United States and Canada (Great Lakes region)	1913
5.	242	1996 - Amarnath Yatra tragedy	India	1996
6.	210	Trøndelag, storm ("Follastormen")	Norway	1625
7.	189	Eyemouth, Scotland, storm ("Black Friday")	United Kingdom	1881
8.	140	Trøndelag, storm ("Titran disaster")	Norway	1899
9.	128	2008 - Santa Catarina floods and mudslides	Brazil	2008
10.	96	Lofoten, storm	Norway	1868

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10 deadliest tornadoes

Rank	Death toll	Event	Location	Date
1.	1,300	The Daulatpur-Salturia Tornado	Manikganj, Bangladesh	April 26, 1989
2.	923	1969 - East Pakistan Tornado	East Pakistan, Pakistan (now Bangladesh)	1969
3.	695	The Tri-State Tornado	United States (Missouri–Illinois–Indiana)	March 18, 1925
4.	681	1973 - Dhaka Tornado	Bangladesh	1973
5.	600	The Valletta, Malta Tornado	Malta	1551
6.	500	The Sicily Tornadoes	Sicily, Two Sicilies (now Italy)	1851
6.	500	The Narail-Magura Tornadoes	Jessore, East Pakistan, Pakistan (now Bangladesh)	1964
6.	500	The Comoro Tornado	Comoro	1951
9.	440	The Tangail Tornado	Bangladesh	1988
10.	400	The Ivanovo-Yaroslavl, Russia, Tornado	Soviet Union (now Russia)	1984

10 deadliest tsunamis

Rank	Death toll	Event	Location	Date
1.	230,000	2004 - Indian Ocean tsunami	Sumatra	December 26, 2004

Rank	Death toll	Event	Location	Date
2.	123,000	1908 - Messina earthquake	Italy	December 28, 1908
3.	36,417–120,000	1883 - eruption of Krakatoa	Indonesia	August 26, 1883
4.	40,000–50,000	1755 - Lisbon earthquake	Portugal	November 1, 1755
5.	40,000 (est.)	Minoan Eruption	Greece	2nd Millennium BCE
6.	31,000	1498 - Meiō Nankaidō earthquake	Japan	September 20, 1498
7.	30,000	1707 - Hōei earthquake	Japan	October 28, 1707
8.	27,122	1896 - Meiji-Sanriku earthquake	Japan	June 15, 1896
9.	25,674	1868 - Arica earthquake	Chile	August 13, 1868
10.	23,024	1293 - Kamakura earthquake	Japan	May 27, 1293

A 1782 possible tsunami causing about 40,000 deaths in the Taiwan Strait area may have been of "meteorological" origin (a cyclone)

10 deadliest volcanic eruptions

Rank	Death toll	Event	Location	Date
1.	92,000	Mount Tambora (see also Year Without a Summer)	Indonesia	April 10, 1815
2.	36,000	Krakatoa	Indonesia	August 26–27, 1883
3.	33,000	Mount Vesuvius	Pompeii and Herculaneum, Italy	August 24, 79 A.D.

Rank	Death toll	Event	Location	Date
4.	29,000	Mount Pelée	Martinique	May 7 or May 8, 1902
5.	23,000	Nevado del Ruiz (Armero tragedy)	Colombia	November 13, 1985
6.	15,000	Mount Unzen	Japan	1792
7.	10,000	Mount Kelud	Indonesia	1586
8.	9,350	Laki. Killed about 25% of the population	Iceland	June 8, 1783
9.	6,000	Santa Maria	Guatemala	1902
10.	5,115	Mount Kelut	Indonesia	May 19, 1919

10 Deadliest wildfires / bushfires

Rank	Death toll	Event	Location	Date
1.	1,200–2,500	Peshtigo Fire, Wisconsin	United States	October 8, 1871
2.	1,200	Kursha-2 Fire	Soviet Union	August 3, 1936
3.	453	Cloquet Fire, Minnesota	United States	October 12, 1918
4.	418	Great Hinckley Fire, Minnesota	United States	September 1, 1894
5.	282	Thumb Fire, Michigan	United States	September 5, 1881
6.	273	Matheson Fire, Ontario	Canada	July 29, 1916
7.	240	Sumatra and Kalimantan Fires	Indonesia	1997
8.	230	Landes region	France	1949
9.	213	Black Dragon Fire	China	May 1987
10.	173	Black Saturday bushfires	Australia	Feb7 – March 14, in 2009

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Annex: 02

Co- relation between FGH and FD Volume

F.G.H (m)	F.D. Volume (CUMECS)	F.G.H (m)	F.D.Volume (CUMECS)	F.G.H (m)	F.D.Volume (CUMECS)	F.G.H (m)	F.D.Volume (CUMECS)
1	39.47	5	323.03	9	606.60	13	890.16
1.1	46.56	5.1	330.12	9.1	613.69	13.1	897.25
1.2	53.65	5.2	337.21	9.2	620.78	13.2	904.34
1.3	60.74	5.3	344.30	9.3	627.87	13.3	911.43
1.4	67.83	5.4	351.39	9.4	634.96	13.4	918.52
1.5	74.91	5.5	358.48	9.5	642.04	13.5	925.61
1.6	82.00	5.6	365.57	9.6	649.13	13.6	932.70
1.7	89.09	5.7	372.66	9.7	656.22	13.7	939.79
1.8	96.18	5.8	379.75	9.8	663.31	13.8	946.88
1.9	103.27	5.9	386.84	9.9	670.40	13.9	953.97
2	110.36	6	393.93	10	677.49	14	961.06
2.1	117.45	6.1	401.01	10.1	684.58	14.1	968.15
2.2	124.54	6.2	408.10	10.2	691.67	14.2	975.23
2.3	131.63	6.3	415.19	10.3	698.76	14.3	982.32
2.4	138.72	6.4	422.28	10.4	705.85	14.4	989.41
2.5	145.81	6.5	429.37	10.5	712.94	14.5	996.50
2.6	152.89	6.6	436.46	10.6	720.03	14.6	1003.59
2.7	159.98	6.7	443.55	10.7	727.11	14.7	1010.68
2.8	167.07	6.8	450.64	10.8	734.20	14.8	1017.77
2.9	174.16	6.9	457.73	10.9	741.29	14.9	1024.86
3	181.25	7	464.82	11	748.38	15	1031.95
3.1	188.34	7.1	471.91	11.1	755.47	15.1	1039.04
3.2	195.43	7.2	478.99	11.2	762.56	15.2	1046.13
3.3	202.52	7.3	486.08	11.3	769.65	15.3	1053.21
3.4	209.61	7.4	493.17	11.4	776.74	15.4	1060.30
3.5	216.70	7.5	500.26	11.5	783.83	15.5	1067.39
3.6	223.79	7.6	507.35	11.6	790.92	15.6	1074.48
3.7	230.88	7.7	514.44	11.7	798.01	15.7	1081.57
3.8	237.96	7.8	521.53	11.8	805.09	15.8	1088.66
3.9	245.05	7.9	528.62	11.9	812.18	15.9	1095.75
4	252.14	8	535.71	12	819.27	16	1102.84
4.1	259.23	8.1	542.80	12.1	826.36	16.1	1109.93
4.2	266.32	8.2	549.89	12.2	833.45	16.2	1117.02
4.3	273.41	8.3	556.98	12.3	840.54	16.3	1124.11
4.4	280.50	8.4	564.06	12.4	847.63	16.4	1131.20
4.5	287.59	8.5	571.15	12.5	854.72	16.5	1138.28
4.6	294.68	8.6	578.24	12.6	861.81	16.6	1145.37
4.7	301.77	8.7	585.33	12.7	868.90	16.7	1152.46
4.8	308.86	8.8	592.42	12.8	875.99	16.8	1159.55
4.9	315.94	8.9	599.51	12.9	883.08	16.9	1166.64

17	1173.73	21.5	1492.74	26	1811.75	30.5	2130.76
17.1	1180.82	21.6	1499.83	26.1	1818.84	30.6	2137.85
17.2	1187.91	21.7	1506.92	26.2	1825.93	30.7	2144.94
17.3	1195.00	21.8	1514.01	26.3	1833.02	30.8	2152.03
17.4	1202.09	21.9	1521.10	26.4	1840.11	30.9	2159.12
17.5	1209.18	22	1528.19	26.5	1847.20	31	2166.21
17.6	1216.26	22.1	1535.28	26.6	1854.29	31.1	2173.30
17.7	1223.35	22.2	1542.36	26.7	1861.38	31.2	2180.39
17.8	1230.44	22.3	1549.45	26.8	1868.46	31.3	2187.48
17.9	1237.53	22.4	1556.54	26.9	1875.55	31.4	2194.57
18	1244.62	22.5	1563.63	27	1882.64	31.5	2201.65
18.1	1251.71	22.6	1570.72	27.1	1889.73	31.6	2208.74
18.2	1258.80	22.7	1577.81	27.2	1896.82	31.7	2215.83
18.3	1265.89	22.8	1584.90	27.3	1903.91	31.8	2222.92
18.4	1272.98	22.9	1591.99	27.4	1911.00	31.9	2230.01
18.5	1280.07	23	1599.08	27.5	1918.09	32	2237.10
18.6	1287.16	23.1	1606.17	27.6	1925.18	32.1	2244.19
18.7	1294.25	23.2	1613.26	27.7	1932.27	32.2	2251.28
18.8	1301.33	23.3	1620.35	27.8	1939.36	32.3	2258.37
18.9	1308.42	23.4	1627.43	27.9	1946.45	32.4	2265.46
19	1315.51	23.5	1634.52	28	1953.53	32.5	2272.55
19.1	1322.60	23.6	1641.61	28.1	1960.62	32.6	2279.63
19.2	1329.69	23.7	1648.70	28.2	1967.71	32.7	2286.72
19.3	1336.78	23.8	1655.79	28.3	1974.80	32.8	2293.81
19.4	1343.87	23.9	1662.88	28.4	1981.89	32.9	2300.90
19.5	1350.96	24	1669.97	28.5	1988.98	33	2307.99
19.6	1358.05	24.1	1677.06	28.6	1996.07	33.1	2315.08
19.7	1365.14	24.2	1684.15	28.7	2003.16	33.2	2322.17
19.8	1372.23	24.3	1691.24	28.8	2010.25	33.3	2329.26
19.9	1379.31	24.4	1698.33	28.9	2017.34	33.4	2336.35
20	1386.40	24.5	1705.41	29	2024.43	33.5	2343.44
20.1	1393.49	24.6	1712.50	29.1	2031.51	33.6	2350.53
20.2	1400.58	24.7	1719.59	29.2	2038.60	33.7	2357.62
20.3	1407.67	24.8	1726.68	29.3	2045.69	33.8	2364.70
20.4	1414.76	24.9	1733.77	29.4	2052.78	33.9	2371.79
20.5	1421.85	25	1740.86	29.5	2059.87	34	2378.88
20.6	1428.94	25.1	1747.95	29.6	2066.96	34.1	2385.97
20.7	1436.03	25.2	1755.04	29.7	2074.05	34.2	2393.06
20.8	1443.12	25.3	1762.13	29.8	2081.14	34.3	2400.15
20.9	1450.21	25.4	1769.22	29.9	2088.23	34.4	2407.24
21	1457.30	25.5	1776.31	30	2095.32	34.5	2414.33
21.1	1464.38	25.6	1783.40	30.1	2102.41	34.6	2421.42
21.2	1471.47	25.7	1790.48	30.2	2109.50	34.7	2428.51
21.3	1478.56	25.8	1797.57	30.3	2116.58	34.8	2435.60
21.4	1485.65	25.9	1804.66	30.4	2123.67	34.9	2442.68

35	2449.77	39.5	2768.78	44	3087.80	48.5	3406.81
35.1	2456.86	39.6	2775.87	44.1	3094.88	48.6	3413.90
35.2	2463.95	39.7	2782.96	44.2	3101.97	48.7	3420.99
35.3	2471.04	39.8	2790.05	44.3	3109.06	48.8	3428.07
35.4	2478.13	39.9	2797.14	44.4	3116.15	48.9	3435.16
35.5	2485.22	40	2804.23	44.5	3123.24	49	3442.25
35.6	2492.31	40.1	2811.32	44.6	3130.33	49.1	3449.34
35.7	2499.40	40.2	2818.41	44.7	3137.42	49.2	3456.43
35.8	2506.49	40.3	2825.50	44.8	3144.51	49.3	3463.52
35.9	2513.58	40.4	2832.59	44.9	3151.60	49.4	3470.61
36	2520.67	40.5	2839.68	45	3158.69	49.5	3477.70
36.1	2527.75	40.6	2846.77	45.1	3165.78	49.6	3484.79
36.2	2534.84	40.7	2853.85	45.2	3172.87	49.7	3491.88
36.3	2541.93	40.8	2860.94	45.3	3179.95	49.8	3498.97
36.4	2549.02	40.9	2868.03	45.4	3187.04	49.9	3506.05
36.5	2556.11	41	2875.12	45.5	3194.13	50	3513.14
36.6	2563.20	41.1	2882.21	45.6	3201.22	50.1	3520.23
36.7	2570.29	41.2	2889.30	45.7	3208.31	50.2	3527.32
36.8	2577.38	41.3	2896.39	45.8	3215.40	50.3	3534.41
36.9	2584.47	41.4	2903.48	45.9	3222.49	50.4	3541.50
37	2591.56	41.5	2910.57	46	3229.58	50.5	3548.59
37.1	2598.65	41.6	2917.66	46.1	3236.67	50.6	3555.68
37.2	2605.73	41.7	2924.75	46.2	3243.76	50.7	3562.77
37.3	2612.82	41.8	2931.83	46.3	3250.85	50.8	3569.86
37.4	2619.91	41.9	2938.92	46.4	3257.93	50.9	3576.95
37.5	2627.00	42	2946.01	46.5	3265.02	51	3584.04
37.6	2634.09	42.1	2953.10	46.6	3272.11	51.1	3591.12
37.7	2641.18	42.2	2960.19	46.7	3279.20	51.2	3598.21
37.8	2648.27	42.3	2967.28	46.8	3286.29	51.3	3605.30
37.9	2655.36	42.4	2974.37	46.9	3293.38	51.4	3612.39
38	2662.45	42.5	2981.46	47	3300.47	51.5	3619.48
38.1	2669.54	42.6	2988.55	47.1	3307.56	51.6	3626.57
38.2	2676.63	42.7	2995.64	47.2	3314.65	51.7	3633.66
38.3	2683.72	42.8	3002.73	47.3	3321.74	51.8	3640.75
38.4	2690.80	42.9	3009.82	47.4	3328.83	51.9	3647.84
38.5	2697.89	43	3016.90	47.5	3335.92	52	3654.93
38.6	2704.98	43.1	3023.99	47.6	3343.00	52.1	3662.02
38.7	2712.07	43.2	3031.08	47.7	3350.09	52.2	3669.10
38.8	2719.16	43.3	3038.17	47.8	3357.18	52.3	3676.19
38.9	2726.25	43.4	3045.26	47.9	3364.27	52.4	3683.28
39	2733.34	43.5	3052.35	48	3371.36	52.5	3690.37
39.1	2740.43	43.6	3059.44	48.1	3378.45	52.6	3697.46
39.2	2747.52	43.7	3066.53	48.2	3385.54	52.7	3704.55
39.3	2754.61	43.8	3073.62	48.3	3392.63	52.8	3711.64
39.4	2761.70	43.9	3080.71	48.4	3399.72	52.9	3718.73

Annex : 03

Flood Return Periods of Flood gauging heights

F.G.H	F.R.P	F.G.H	F.R.P	F.G.H	F.R.P	F.G.H	F.R.P
1.00	-36.124	4.80	0.855	8.60	8.122	12.40	81.368
1.1	-33.964	4.9	1.007	8.7	8.785	12.5	85.059
1.20	-31.888	5.00	1.141	8.80	9.495	12.60	88.864
1.3	-29.897	5.1	1.257	8.9	10.254	12.7	92.784
1.40	-27.986	5.20	1.359	9.00	11.065	12.80	96.822
1.5	-26.156	5.3	1.446	9.1	11.928	12.87	99.719
1.60	-24.404	5.40	1.522	9.20	12.845	13.00	105.256
1.7	-22.728	5.5	1.588	9.3	13.819	13.1	109.656
1.80	-21.127	5.60	1.645	9.40	14.850	13.20	114.179
1.9	-19.598	5.7	1.696	9.5	15.941	13.3	118.829
2.00	-18.141	5.80	1.741	9.60	17.094	13.40	123.607
2.1	-16.753	5.9	1.784	9.7	18.310	13.5	128.513
2.20	-15.433	6.00	1.825	9.80	19.590	13.60	133.551
2.3	-14.179	6.1	1.867	9.9	20.937	13.7	138.722
2.40	-12.989	6.20	1.911	10.00	22.353	13.80	144.028
2.5	-11.861	6.3	1.958	10.1	23.838	13.9	149.470
2.60	-10.794	6.40	2.011	10.20	25.396	14.00	155.050
2.7	-9.786	6.5	2.072	10.3	27.027	14.1	160.769
2.80	-8.835	6.60	2.141	10.45	29.615	14.20	166.631
2.9	-7.940	6.7	2.222	10.5	30.517	14.3	172.636
3.00	-7.098	6.80	2.314	10.60	32.379	14.40	178.785
3.1	-6.309	6.9	2.422	10.7	34.322	14.5	185.082
3.20	-5.569	7.00	2.545	10.80	36.347	14.60	191.527
3.3	-4.878	7.1	2.686	10.9	38.456	14.7	198.123
3.40	-4.234	7.20	2.847	11.00	40.651	14.73	200.131
3.5	-3.635	7.3	3.028	11.1	42.934	14.9	211.772
3.60	-3.079	7.40	3.233	11.20	45.306	15.00	218.829
3.7	-2.564	7.5	3.463	11.3	47.769	15.1	226.044
3.80	-2.090	7.60	3.719	11.40	50.324	15.20	233.417
3.9	-1.653	7.7	4.003	11.5	52.975	15.3	240.951
4.00	-1.252	7.80	4.318	11.60	55.721	15.40	248.648
4.1	-0.887	7.9	4.664	11.7	58.566	15.5	256.509
4.20	-0.553	8.00	5.043	11.80	61.510	15.60	264.536
4.3	-0.251	8.1	5.458	11.9	64.556	15.7	272.731
4.40	0.022	8.20	5.910	12.00	67.705	15.80	281.095
4.5	0.267	8.3	6.401	12.1	70.958	15.9	289.630
4.60	0.486	8.40	6.932	12.20	74.319	16.00	298.339
4.7	0.682	8.5	7.505	12.3	77.788	16.1	307.222

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16.20	316.282	20.60	916.100	25.1	2041.266	29.6	3841.630
16.3	325.520	20.7	934.907	25.2	2073.350	29.7	3890.524
16.40	334.938	20.80	953.970	25.30	2105.770	29.80	3939.831
16.5	344.538	20.9	973.291	25.4	2138.526	29.9	3989.554
16.60	354.321	21	992.873	25.5	2171.621	30	4039.694
16.7	364.289	21.10	1012.716	25.60	2205.057	30.10	4090.253
16.80	374.444	21.2	1032.824	25.7	2238.834	30.2	4141.232
16.9	384.788	21.3	1053.197	25.8	2272.956	30.3	4192.634
17.00	395.323	21.40	1073.836	25.90	2307.423	30.40	4244.459
17.1	406.049	21.5	1094.745	26	2342.238	30.5	4296.711
17.20	416.970	21.6	1115.925	26.1	2377.401	30.6	4349.390
17.3	428.086	21.70	1137.376	26.20	2412.916	30.70	4402.499
17.40	439.399	21.8	1159.102	26.3	2448.783	30.8	4456.039
17.5	450.912	21.9	1181.104	26.4	2485.005	30.9	4510.011
17.60	462.626	22.00	1203.384	26.50	2521.582	31.00	4564.419
17.7	474.542	22.1	1225.943	26.6	2558.518	31.1	4619.262
17.80	486.662	22.2	1248.783	26.7	2595.813	31.2	4674.544
17.9	498.989	22.30	1271.906	26.80	2633.469	31.30	4730.265
17.91	500.233	22.4	1295.313	26.9	2671.489	31.4	4786.428
18.00	511.524	22.5	1319.007	27	2709.873	31.5	4843.034
18.1	524.268	22.60	1342.989	27.10	2748.624	31.60	4900.085
18.20	537.224	22.7	1367.260	27.2	2787.743	31.7	4957.583
18.3	550.392	22.8	1391.824	27.3	2827.232	31.8	5015.530
18.40	563.776	22.90	1416.680	27.40	2867.093	31.90	5073.926
18.5	577.376	23	1441.832	27.5	2907.328	32	5132.775
18.60	591.195	23.1	1467.280	27.6	2947.938	32.1	5192.078
18.7	605.233	23.20	1493.027	27.70	2988.925	32.20	5251.836
18.80	619.494	23.3	1519.075	27.8	3030.290	32.3	5312.051
18.9	633.977	23.4	1545.424	27.9	3072.037	32.4	5372.726
19.00	648.687	23.50	1572.077	28.00	3114.165	32.50	5433.861
19.1	663.623	23.6	1599.036	28.1	3156.677	32.6	5495.458
19.20	678.788	23.7	1626.302	28.2	3199.576	32.7	5557.520
19.3	694.184	23.80	1653.877	28.30	3242.861	32.80	5620.048
19.40	709.812	23.9	1681.763	28.4	3286.536	32.9	5683.043
19.5	725.674	24	1709.961	28.5	3330.602	33	5746.508
19.60	741.771	24.10	1738.474	28.60	3375.061	33.10	5810.444
19.7	758.107	24.2	1767.302	28.7	3419.914	33.2	5874.853
19.80	774.681	24.3	1796.448	28.8	3465.163	33.3	5939.737
19.9	791.497	24.40	1825.914	28.90	3510.810	33.40	6005.097
20.00	808.555	24.5	1855.701	29	3556.857	33.5	6070.935
20.1	825.858	24.6	1885.811	29.1	3603.306	33.6	6137.253
20.20	843.407	24.70	1916.245	29.20	3650.157	33.70	6204.053
20.3	861.204	24.8	1947.007	29.3	3697.414	33.8	6271.336
20.40	879.251	24.9	1978.096	29.4	3745.077	33.9	6339.105
20.5	897.549	25.00	2009.515	29.50	3793.149	34.00	6407.360