FLOOD INUNDATION MAPPING USING GIS AND REMOTE SENSING TECHNIQUES

M.Tech (Geoinformatics)

MODABBIR ALAM

2023

A DISSERTATION

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE
OF

MASTER OF TECHNOLOGY
IN

CIVIL ENGINEERING
(With Specialization in Geoinformatics Engineering)

Submitted By:

MODABBIR ALAM

(2K21/GEO/03)

Under the supervision of

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CANDIDATE'S DECLARATION

I, **Modabbir Alam**, Roll No. 2K20/GEO/03 of M.Tech Geoinformatics, hereby declare that the project dissertation titled "**Flood Inundation Mapping Using GIS and Remote Sensing**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Associateship, Fellowship, or other similar title or recognition.

Place: Delhi **Modabbir Alam**

Date:

CIVIL ENGINEERING DEPARTMENT
DELHI TECHNOLOGICAL UNIVERSITY
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CERTIFICATE

I hereby declare that the Project Dissertation titled "**Flood Inundation Mapping Using GIS and Remote Sensing**" which is submitted by **Modabbir Alam**, Roll No 2K20/GEO/03 [Civil Engineering] Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master in Technology, is a record of the project work carried by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this university or elsewhere.

Place: Delhi
Date:

PROF. K C Tiwari
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ABSTRACT

Floods are water-induced disasters that cause temporary inundation of dry land, causing serious damage in the affected area such as loss of life, property, and infrastructure destruction. Knowing that floods are a natural part of human life and that they cannot be completely controlled, it is critical to focus on this issue and improve knowledge about damage prevention. To accomplish this goal, a more specific and scientific model for understanding flooding phenomena and their related geographical, hydrological, and geomorphologic causes must be developed. The global impact of floods on people has resulted in resident mitigation to reduce the associated risk of floods to a manageable level, if not eliminate its negative impact. The identification of flood-prone areas is the first step in flood risk management. The scientific technique of GIS was used in this study to identify flood-risk areas in Delhi. The purpose of this thesis is to develop flood inundation mapping for South Delhi using GIS and remote sensing techniques. The primary goal of this research is to create an accurate and reliable flood inundation map for Delhi by combining GIS and remote sensing.

The global impact of floods on people has resulted in the mitigation of residents to reduce the associated risk of floods to a manageable level, if not eliminate its negative impact. Flood risk management begins with the identification of flood-prone areas. This study used the scientific technique of GIS to identify flood-risk areas in Delhi. This thesis focuses on the creation of flood inundation mapping for South Delhi using GIS and remote sensing techniques. The primary goal of this research is to create an accurate and dependable flood inundation map for Delhi by combining GIS and remote sensing.

The results of this study demonstrate that the proposed methodology is effective for creating accurate and reliable flood inundation maps using GIS and remote sensing techniques. The validation results indicate that the developed flood inundation map has a high level of accuracy. The findings of this study could be useful for flood management and disaster preparedness planning in Delhi and other similar areas. The study also sheds light on the vulnerability of critical infrastructure in Delhi to flooding, such as transport networks, power plants, and hospitals.

ACKNOWLEDGEMENTS

First and foremost, I would like to convey my heartfelt appreciation to **Prof. K C Tiwari**, Department of Civil Engineering, for his continual advice, guidance, motivation, and encouragement during the duration of this effort. Their constant availability for advice, educational remarks, concern, and support have been essential.

Modabbir Alam

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
AMC	Antecedent Moisture Condition
C	Criteria
CI	Consistency index
cms	centimetres
CN	Curve Number
CR	Consistency Ratio
CV	Consistency Vector
DDA	Delhi Development Authority
DEM	Digital Elevation Model
DGP	Director General of Police
DWG	AutoCAD drawing format
E	East
ESRI	Environmental System Research Institute
Etc.	Et cetera
FA	Flow Accumulation
GCC	Greater Chennai Corporation
GIS	Geographical Information System
Govt.	Government
GPS	Global Positioning System
GWP	Global Water Partnership
HSG	Hydrologic Soil Group
IDW	Inverse Distance Weightage
IITM	Indian Institute of Tropical Meteorology
IMD	Indian Meteorological Department

INRAS	Input Raster
IRS	Indian Remote Sensing
IT	Information Technology
Km	Kilometres
KM^2 / sq. km	Square Kilometres
Kmph	Kilometres Per hours
KSNDMC	Karnataka State Natural Disaster Monitoring Centre
LISS	Linear Imaging Self Scanning
LiDAR	Light Detection and Ranging
LULC	Land Use Land Cover
M	Meter
MCDA	Multi Criteria Decision Analysis
mm	Millimetres
M3	Cubic meter
MSL	Mean Sea Level
N	North
NA	Not Available
NCCR	National Centre for Coastal Research
NDMA	National Disaster Management Authority
NRCS	Natural Resources Conservation Service
OMR	Old Mahabalipuram Road
OSDMA	Odisha State Disaster Management Authority
OUTRAS	Output Raster
P	Precipitation
PDF	Portable Document Format
RISAT	Radar Imaging Satellite

SCS	Soil Conservation Service
SIPCOT	State Industries Promotion Corporation of Tamil Nadu
SoI	Survey of India
SRM	Sri Ramaswamy Memorial University
SRTM	Shuttle Radar Topographic Mission
SWD	Storm Water Drain
TIFF	Tag Image File Format
TIN	Triangulated Irregular Network
TNSDMA	Tamil Nadu State Disaster Management Authority
Topo	Toposheet
TWI	Topographic Wetness Index
UNITAR	United Nations Institute for Training and Research
UNLV	University of Nevada Las Vegas
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
W	Weight
WGS	World Geodetic System
WMO	World Meteorological Organisation

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Floods are the most common natural disaster that many countries face, out of all the natural disasters that occur around the world. Flooding occurs when a large amount of water infiltrates a dry land area (Wikipedia, 2021). Floods can occur for a variety of reasons, including phenomena such as heavy rain, storms, overflow of rivers and dams, climate change, and poor planning and development. Floods caused by poor planning and development are referred to as urban floods (FloodSite, 2008). The early civilisations are thought to have settled along river valleys and waterbodies such as the Euphrates and Tigris Valleys in Mesopotamia, the Nile Valley in Egypt, the Indus Valley in India, and so on. Because of its rich soils, good water supply, and transportation options, the River Plain has a high development potential. Avinash (2009) (pp. 48-51) The expanding human population not only established settlements along the river and other bodies of water, but also gradually encroached on them to build their homes and communities. Humans' uncontrolled and ill-planned development gradually clogged the natural drainage system. According to (Sieker, 2008, pp. 303-304), the process of urbanisation includes the following steps: sealing the natural landscape with buildings, other utilities, and transportation networks. He mentions how agricultural areas contribute to flooding by increasing runoff on agricultural land. In both urban and rural areas, human intervention in the natural drainage system in the name of development has resulted in numerous disasters, the most serious of which is flooding.

Not only does urbanisation cause flooding; there are numerous other factors that contribute to the disaster. Floods have extreme consequences as a result of urbanisation, deforestation, population growth, climate change, and sea level rise. It is also predicted that the number of people at risk of flooding will rise in the coming years (Avinash, 2009, pp. 48-51). Many urban areas are experiencing flash floods as a result of heavy rainfall for a short period of time. Cities are especially vulnerable to flooding because they are mostly built with impervious surfaces such as asphalt, concrete, and bricks. Rainfall that falls on the ground often runs off in these areas where the majority of the surface is impervious. When it rains, the runoff increases dramatically, and when the existing drainage system cannot handle the excess runoff, a flood occurs. It is strongly advised to use appropriate flood management technology and techniques.

Nepal, India's neighbour, had used GIS during the 2015 earthquake. During the emergency, the government used technology to identify people who were at risk, guiding emergency workers to the victims. The government recognised the importance of technology and prepared a Post Disaster Need Assessment Report. It is stated that as part of urban recovery, Hazard Mapping, Participatory Planning, risksensitive urban planning, rapid urban expansion studies, and facilitated management are required (NPC, 2015, pp. 1-5).

Floods have affected millions of people worldwide, and India is particularly vulnerable to flooding. In terms of Natural Disasters, India is ranked 14th in the world.

India's 7500-kilometer-long coastline is vulnerable to tropical cyclones originating in the Bay of Bengal and the Arabian Sea (Aggarwal et al., 2009, pp. 145-158). According to the National Disaster Management Authority, 40 million hectares of India's total geographical area is prone to flooding (NDMA, unknown). The regular occurrence of flooding prompted various government departments to employ relevant technologies throughout the stages of disaster prevention, preparedness, response, and recovery.

GIS is a technology that can visualise all topographic features in terms of their location (latitude and longitude) as well as altitude. GIS has the ability to visualise and analyse precise spatial data, providing greater insights into disaster preparedness and response planning. During the cyclones Hud-Hud, Gaja, Amphan, and Nisarga,Tautktae that hit India between 2019 and 2022, GIS played a critical role in emergency response, planning, and analysis.

During the 1999 floods, the Odisha State Disaster Management Authority used GIS-based satellite remote sensing. Flood GIS assisted the department at various stages. The officials used GIS to determine the best location for a multipurpose food shelter and to identify weak points in order to begin the rescue operation. The system was improved further to create district an The system was further improved in order to create district and gramme panchayat level vulnerability maps for future preparedness (OSDMA, 2019, pp. 21-28).

1.2 PROBLEM STATEMENT

South Delhi is located in the Yamuna River basin, which is prone to flooding as a result of heavy rain and dam releases. The region has previously experienced several devastating floods, including floods in 1978, 1995, 2010, and 2018, which caused significant damage to property and infrastructure as well as loss of life. Earth Interact.

2016, 20, 1-29) (Jain, M.; Dimri).Due to heavy rainfall, Delhi experienced severe flooding in various parts of the city in 2018. According to the Central Water Commission of India, the Yamuna river at the Delhi Railway Bridge in the North district stood at 206.05 metres, well above the danger level of 204.83 metres.Around 10,000 people have been displaced, mostly from Delhi settlements near the river.

Floods are a significant hazard in urban areas, particularly in developing countries like India. Delhi, the capital city of India, is also facing the issue of flooding due to inadequate drainage systems and the urbanization process. Flood inundation mapping using GIS and remote sensing techniques is an effective method for identifying and managing flood risks in urban areas (Biswas, A.K.; Saklan et.al 2016). This technology can help policymakers and city planners in the development of targeted flood management strategies to minimize the impacts of floods. Floods are a major concern in many parts of the world, including the city of Delhi, India.

Yamuna has crossed the danger level of 204.83 m at Old railway bridge (ORB) 37 times in the last 53 years, from 1963 to 2015. depicts the Yamuna River at the ORB in Delhi during the 2010 flood, when a maximum water level of 207.11 m was recorded. The major contributors to the increase in peak flow magnitude are large-scale urbanisation, a reduction in catchment holding capacity, the confining of the river spread by embankment construction, and the climate change phenomenonIncreases in impermeable surface during urbanisation increase peak flow, decrease concentration time, and thus make the area more flood prone (Wheater and Evans 2009). According to Krellenberg et al. (2013), conversion of green space into built-up areas in Santiego, Chile, increased flood risk. In comparison to regions further upstream in the basin, the rate of urbanisation is relatively high in the Upper Yamuna region just upstream of Delhi. The 2011 census of India

(Chandramouli et al. 2011) clearly shows an increase of more than 40% in the urban population of three states in the Upper Yamuna region.

Encroachment on flood plains Paleochannels, meander cutoffs, terrace markers, and river migration plains show that in the nineteenth century, the Yamuna only flowed on the eastern side of Narela and Wazirabad. Embankments were built in 1955-1956 to prevent flooding in the surrounding areas. It resulted in rapid urbanisation in protected areas. Sabhapur, Sadatpur, Usmanpur, and Garhi Mandu, villages with average ground levels of 207, 206, 204.5, and 205 metres, respectively, were submerged during the Yamuna's high floods. There was less encroachment on the flood plain between 1807 and 1980 than between 1980 and 2014, when it was used for settlements, civic buildings, roads, bridges, flyovers, metros, and other construction (Khan and Bajpai 2014). The decrease in flood plain from 1807 to 2014 is depicted in.

1.3 LITERATURE REVIEW

1.3.1 Causes of Flooding-

The world is currently experiencing flooding, which is a very common natural disaster. Flooding has primarily become more frequent and intense over the past few years. The major causes of flooding in urban areas, according to many literature papers, are land use change, or urbanisation and climate change.

Dehradun experiences urban flooding frequently, according to the author of the paper "Causes and Impact of Urban Flooding in Dehradun" (Bansal et al., 2015, pp. 12615–12627). The buildings were constructed in close proximity to one another due to the city's rapid urbanisation, which caused the storm water drains to close and become clogged. Due to encroachments, the streets were also made very narrow, which prevented rainwater runoff from reaching storm water drain outlets. Even for a low intensity rainfall, the area floods and becomes inundated as a result of these man-made scenarios. The author analysed historical data, conducted a field survey of locals, and considered a number of variables, including topography, elevation, slope, rainfall, runoff volume, river bed encroachment, failed embankments, urban storm water drains, road width, river pollution, vulnerable urban infrastructures, building vulnerability classification based on building material, classify buildings based on age, historical flooding water depths, and congested streets during flooding. In order to determine the causes of flooding in an urban area, all of these factors were examined. According to the study's findings, which include the common and widespread causes of urban flooding—high demographic growth, unplanned urbanisation, and the impact of climate change—flood risk is generally higher in cities.

In the context of urban areas, a study by Devaraju et al. (2021) assessed the flood risk in Bangalore city in India. The study used GIS and multi-criteria decision-making techniques to identify areas at high risk of flooding. The study found that the high-risk areas were mainly located in the low-lying areas, and recommended the development of a flood management plan, including infrastructure development and awareness campaigns.

1.3.2 Flood Risk Management

In a document on managing urban flood risks that the WMO/GWP has released, the use of GIS technology is recommended for risk assessments of flood-prone areas. While performing a risk assessment, a number of factors must be taken into account. Risk assessment heavily relies on historical data regarding hazards, their intensity, losses, exposure, and the society's vulnerability. It also takes into account future development plans, the potential for urbanisation, and waterbodies that are on the verge of extinction (WMO, 2008).

In the paper, "Flood risk and context of land-uses: Chennai city case" (Gupta & Nair, 2010, pp. 365–372), the author used GIS techniques to assess the pattern of land use change in Chennai with respect to the loss of hydrological features, encroachment of waterbodies like rivers, streams, lakes, and ponds, and uncontrolled development of buildings. The National Institute of Disaster Management conducted a national level study in India that included 8 important cities: Bangalore, Bhopal, Chennai, Kolkata, Hyderabad, Mumbai, Bhopal, and Surat. This study was based on the technical report of that study. The city's infrastructure, current drainage, geoenvironmental, hydrological, and socioeconomic profiles were examined in this context.Dahiya et al. (2021) provide valuable insights into the vulnerability of flood-prone areas in Delhi and emphasize the need for a risk-based insurance policy to ensure adequate coverage for high-risk areas. By using a vulnerability assessment index, the study was able to identify areas that are most vulnerable to flooding and prioritize insurance coverage accordingly. This approach can help reduce the financial burden on both individuals and the government in the event of a flood and ensure a timely and efficient response to the disaster.

Based on experiences and observations made at a flood site, the book "Flood Risk Assessment and Flood Risk Management" (Klijn Frans, 2009) was developed. Although it is stated clearly that a flood cannot be prevented, its aftereffects may be avoided or reduced if the appropriate steps are taken. This book includes a variety of strategies for reducing the severity of flood impacts in vulnerable areas, including spatial planning, flood control, and flood defence strategies. A combination of all the measures, such as geospatial, mechanical, infrastructure, electrical, etc. must be coordinated to achieve the best flood risk management plan, it is also mentioned that a single measurement approach cannot solve the flood risk management purpose.

In many flood-related studies, such as flood risk mapping, flood prediction, mitigation measures, and rescue operation and planning, GIS methods and tools are found to be extensively used. For better outcomes in various studies, GIS is also combined with various models. This thesis used GIS tools in conjunction with additional approaches and models to produce better flood risk mapping results.

1.3.3 AHP and GIS Approach

Estimating flood risks in expanding urban areas is the goal of the paper "Urban Flood Vulnerability and Risk Mapping Using Integrated Multi- Parametric AHP and GIS: Methodological Overview and Case Study Assessment" (Ouma & Tateishi, 2014, pp. 1515–1545). To estimate the results, the author used GIS that was integrated with AHP techniques. The study was conducted in Kenya's Eldoret Municipality. Since the past ten years, the Municipality has experienced frequent flooding. Unplanned urban development, the encroachment of low-lying areas, drainage blockages, precipitation, water logging, and soil erosion are the main contributors to flooding in the municipality. Between 1912 and 2013, the municipality's area grew primarily from 12 square kilometres to 248 square kilometres. To determine the flood risk zones, this study used a variety of factors that affect urban flooding. Rainfall distribution, elevation and slope, drainage network and density, landuse/land cover, and soil type are the criteria that were used in this study. Historical flood reports were used to cross-check the results. 92% of the real-time results during the flood were matched by the results, with the most vulnerable flood zones only experiencing an 8% maximum error.

The author discusses the value of geospatial technology in the phases of preparation, monitoring, and flood mitigation in the article "Remote Sensing and GIS Applications in Flood Management" (Aggarwal et al., 2009, pp. 145–158). This study was conducted in rural Orissa (Kendrapara) utilising geospatial analysis tools and a community-based methodology. The study states that the GIS database created during the preparation phase must include information on agriculture, socioeconomics, communication, population, and infrastructure. This will serve as the fundamental information needed to plan the rescue efforts during the mitigation phase. In order to create flood risk maps and identify flood-vulnerable areas and streets, this data will also be integrated with historical precipitation and storm data.

The objective of this research, titled "Flood Susceptibility Assessment through GIS-Based Multi-Criteria Approach and Analytical Hierarchy Process (AHP) in a River Basin in Central Greece" (Lappas & Kallioras, 2019), is to locate flood-prone areas within the Atalanti drainage basin in Central Greece. Intensity of rainfall, slope of the river basin, land use and cover, local topography, soil type, proximity to the drainage system, Topographic Wetness Index (TWI), and Digital Elevation Model (DEM) were used as criteria for this study. Studies on flood risk management used the final flood risk map. The outcome assisted the authorities in building the necessary infrastructure in the risk zones.

The objective of the paper, "Flood Vulnerable Zones in the Rural Blocks of Thiruvallur District, South India" (Periyasamy et al., 2018, p. 21), is to use GIS technology to map the flood vulnerable zones in the study area. Tectonic map, drainage, geology, geomorphology, land use, land cover, slope, and data from Resourcesat-2 LISS IV - 2014 and Shuttle Radar Topographic Mission (SRTM) were used in the study. To create the flood vulnerable map, the data was classified and a weighted overlay analysis was run in ArcGIS.

The purpose of the paper "Mapping Storm Water Sewer System using GIS" (Subramanian et al., 2015, pp. 23–32) is to use GIS to find the best location to construct storm water drains. A field survey using GPS was done to map the current storm water drainage system. The author has mapped the existing infrastructures and Land use features using open source satellite imagery. To create the SWD classification Map, the SWD data is combined with this Land use data. The information about the flood-prone areas was gathered from the relevant departments and mapped using the Google Earth platform.

1.4 RESEARCH GAPS

Lack of high-resolution and up-to-date satellite imagery for flood mapping on the other hand the availability of various remote sensing data, including optical and radar imagery, the lack of high-resolution and up-to-date data hinders the accuracy and effectiveness of flood inundation mapping in Delhi (Pandey et al., 2019).

Limited studies on the accuracy and reliability of flood mapping models. while several flood mapping models have been proposed for Delhi, limited studies have been conducted to assess their accuracy and reliability, which is essential for effective decision-making (Kumar et al., 2021).

Inadequate consideration of socio-economic factors in flood mapping. many flood mapping studies focus simply on physical and environmental factors, neglecting the significant influence of socioeconomic factors on flood risk. Therefore, there is a need to integrate socio-economic data into flood mapping studies in Delhi (Khanduri et al., 2021).

Lack of research on the impact of climate change on flood inundation. with the changing climate patterns, there is a need to investigate the potential impact of climate change on flood inundation in Delhi. However, limited research has been conducted on this topic (Ravindranath et al., 2018).

Limited studies on the effectiveness of flood mitigation measures. although various flood mitigation measures have been implemented in Delhi, there are limited studies on their effectiveness in reducing flood risk and preventing losses (Singh et al., 2021).

1.5 OBJECTIVES

Considering the research gaps, this work has been based on the following objectives.

Objective 1- Assessing the Vulnerability of Areas Prone to High-Impact Floods.

Objective 2- To create map of an area susceptible to flooding using AHP MCDA.

1.6 THESIS OVERVIEW

This thesis presents an overview in chapter 2 Methodology of To create map of an area susceptible to flooding using AHP MCDA , chapter 3, and the results obtained with analysis and discussion in chapter 4. The study concludes in Chapter 5, with concluding remarks on the research effort and its outcomes.

CHAPTER 2

To Create a Map of an Area Susceptible to Flooding

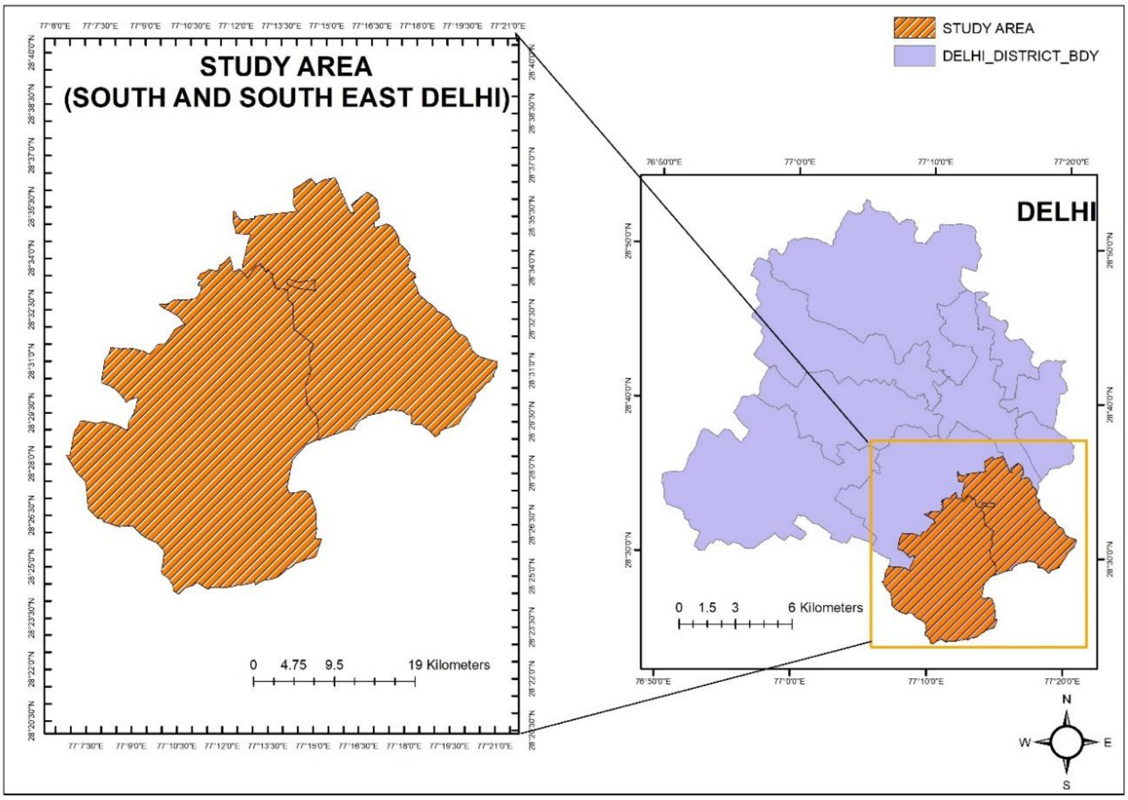
2.1 STUDY AREA

This study's study area is South and South East Delhi (Map-1). It is situated in the Yamuna River basin, which is prone to flooding as a result of heavy rains and dam releases. Delhi is divided into three major drainage basins that eventually drain into the Yamuna River: the Najafgarh, Barapulaah, and Shahdara basins. The Yamuna River enters Delhi from the northeast near Palla at an elevation of 210.3 m and exits Delhi at an elevation of 198.12 m near Jaitpur in the south after a 40-kilometer journey. Almost every year, the Yamuna River floods, with the intensity of the flood varying according to the classification established by the Irrigation and Flood Control Department, Delhi government (I&FC). When the gauge levels fall below 204.22 m, it is considered a low flood, according to the I&FC department. Floods between 204.22 m and 205.44 m are classified as medium, and floods above 205.4 m are classified as high.

South Delhi is a district in Delhi's National Capital Territory. It is bounded to the east by the Yamuna River, to the south by the state border of Haryana, to the north by the districts of New Delhi and Central Delhi, and to the west by the districts of West Delhi and Southwest Delhi. South East Delhi is another district in India's National Capital Territory of Delhi. It is situated east of South Delhi. The administrative divisions determine the boundaries of South East Delhi. Greater Kailash, Kalkaji, Lajpat Nagar, Defence Colony, Jasola, Nehru Place, Sarita Vihar, Okhla, and parts of Vasant Kunj are all included.

From July to September, South Delhi experiences a monsoon season. The region receives the majority of its annual rainfall during this time. The monsoon brings relief from the summer heat, but it also brings heavy rain, which can cause flooding in some areas. During this time, South Delhi receives an average of 650 to 800 millimetres (25 to 31 inches) of rain.

The Delhi NCT, which covers 1483 square kilometres, is located between latitudes 282401500 and 285300000 N and longitudes 765002400 and 772003000 E, with an average elevation of 233 metres (ranging from 213 to 305 metres) above mean sea level. According to the 2011 census, the NCT of Delhi has three statutory towns, 110 census towns, and 112 villages. During the decade from 2001 to 2011, the population of Delhi increased at a rate of 2.1% per yearDelhi has the highest population (13.8 million), while Lakshadweep has the lowest population (60,650) among union territories. Delhi's population has increased from a meagre 405,800 in 1901 to a staggering 16,753,200 in 2011, making it one of the world's fastest growing cities. When compared to other states, the Delhi region received the highest share of foreign direct investment (FDI).



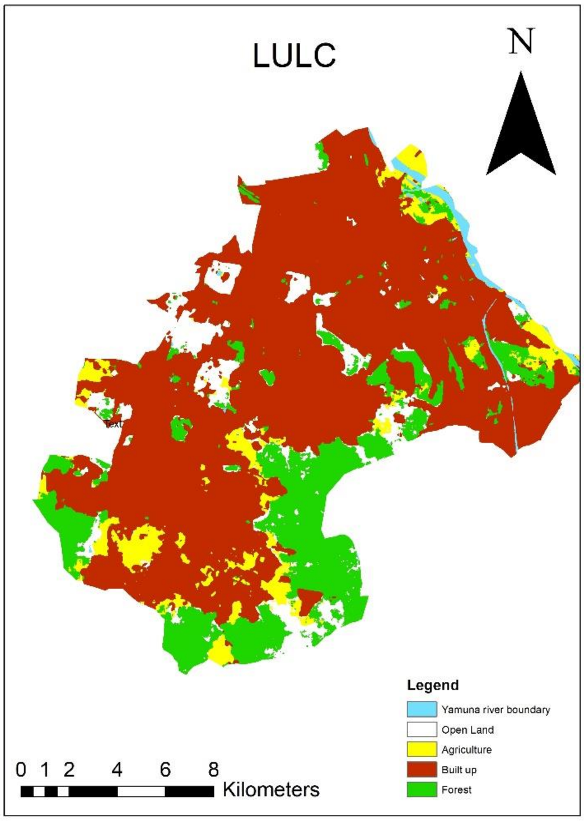
Map 1- Study Area

In general, the National Capital Region is part of the well-integrated drainage system of the Ganga basin. The degrading activities of the streams and drains are limited by the area's remarkably moderate gradient, which is almost completely pervasive. The region that makes up Delhi's metropolitan area is almost entirely made up of plain land, with a long, rocky ridge roughly extending from south-west to north-east and a river that enters from the territory's north-eastern edge and flows across its south-eastern edge.The Ridge serves as the neighbourhood watershed, dividing the drainage system of the region into two sections. In Delhi, the overall slope of the ground is from north to south. The western region drains directly into the Yamuna, whereas the eastern region drains through the Najafgarh drain. Based on geographical features, the National Capital Territory of Delhi has been divided into five primary drainage basins: the Najafgarh basin, the Alipur basin, the Shahadra basin, the Kushak-Barrapullah basin, and the Mehrauli basin. Through this drainage system, all water collected by the main drains, link drains, and tiny rivulets is eventually released directly or indirectly into the Yamuna.

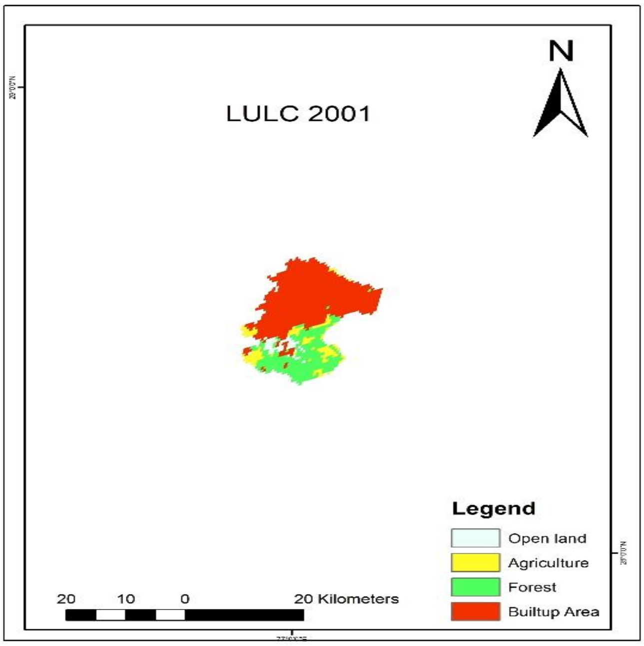
Table 1 Details of the study area

Site Number	Location Name	Actual Flood Level Value [1]
1	Palla Village	212.30 m
2	jhangola Village	211.15 m
3	, Jagatpur Bund	209.35 m
4	WajirabadBarrage	208.05 m
5	Old Delhi Railway Bridge	207.11 m
6	Yamuna Barrage	205.06 m
7	Okhla Barrage	200.10 m
8	Jaitpur Village	198.07 m

A study on the South Delhi and South East Delhi metropolitan region examined development between the two time periods (2001 and 2022) using Landsat images from 2001 and 2022. This research is based on Landsat 8 temporal data, which was used to detect changes in the urban land cover surrounding Delhi. The findings indicated that land use and cover had changed rapidly. It was discovered that the amount of developed land in watersheds, the amount of forest cover lost, and the amount of agricultural land changed dramatically.



Map 2 – LULC of 2022



Map 3 – LULC Map of 2001

2.2 METHODOLOGY

The goal of this thesis is to use GIS and other assisting tools and technology to create a flood Inundation map and flood forecast for the study area. The project's goals include interpreting flood-prone areas, locating flood risk zones, and carrying out flood prediction studies. These goals were accomplished through the use of GIS, MCDA, mathematical computations, and hydrological modeling approaches. The methods used in this study are explained in depth in this chapter.

The chapter is divided into the following section-

- Data Used
- Interpretation of Flood Prone Areas and Structures
- Multi-Criteria Decision Analysis
- Software Used

To identify the locations that are susceptible to flooding and the structures there, Geographical Information System (GIS) technology and the necessary data must be used. Additionally, the information will be utilized to examine the current drainage system and forecast floods using mathematical formulas and unit hydrographs.

This study and the resulting maps can assist Delhi Development Authorities (DDA), the planning and development agency of Delhi, in making educated judgements about where to construct and where development should be supported with unique landscape architecture . The disaster management department will utilise the findings to design the search and rescue operation and the remediation steps.

2.2.1 DATA USED

Raster and vector data were abundantly utilised in this project to conduct the research. From the MCD's official records, some data were received as papers and AutoCAD DWG files. These files were then transformed to shapefile formats using ArcGIS, GoogleEarth, and World Imagery Base map of ESRI. Other information was gathered from freely accessible government sources, including the webpages of the Delhi Government, USGS Earth Explorer, and Bhuvan (an Indian web utility portal). The processing and analysis of the data were done in ArcGIS 10.8 software.

Table 2: Data Used and Source

Base Layers		
Data Description	**Data Type**	**Source**
Indian State Boundary	Vector - Polygon	Survey of India (http://www.surveyofindia.gov.in/pages/downloads)
Administrative Boundary of Delhi	Vector - Polygon	Open source data from Data Meet (http://projects.datameet.org/maps/districts/)
South-Delhi and South-East Delhi	Vector - Polygon	Derived from the District Boundary.Area of the Study area is 314 sq.km
Raster Data		
Data	**Format**	**Source**
Aerial Imagery	Raster Data with 10m resolution	World Imagery Base map of ESRI\ USGS
Digital Elevation Model	Raster TIFF with 30m accuracy	USGS

Soil Data	Raster	Digitized from Soil Survey of India Maps
Vector Data		
Data	**Format**	**Source**
Water Bodies	Vector Polygon	Open source data from Map Cruzin (https://mapcruzin.com/free-india-country-city-placegis-shapefiles.htm) The data was cross checked with Google Earth and the missing Waterbodies were digitized as Polygons from the Google Earth application
LULC	Vector Line and Polygon	The Land Use Land Classification will be generated from Aerial Imagery.
SWD (Storm Water Drain)	Vector Line	The data shall be digitized as points and lines from the High resolution Aerial Imagery
Rainfall Data	Excel sheet	The data was procured from IMD, Pune

The collected data were aligned to a common coordinate and projection system in the GIS software as mentioned in Table 3. Doing this shall avoid unnecessary errors while doing the GIS analysis.

Table 3: Coordinate and Projection system

Coordinate System:	:	WGS 1984 UTM Zone 44N
Projection:	:	Transverse Mercator
Datum:	:	WGS 1984
Units:	:	Meter

2.2.2 Interpretation of Flood Prone Areas and Structures

This approach of determining the area that is susceptible to flooding and the nearby buildings that are susceptible to flooding is not scientific. Digitalization of the 2001 toposheet was used to determine the land use and cover of the research area. In this study, we're going to refer to this as old land usage. Digital copies of the Orthophoto's updated land use and cover data have been made. This shall be termed as new land use land cover. To locate the structures that are located in flood-prone locations, the current building layer is superimposed over the old toposheet.

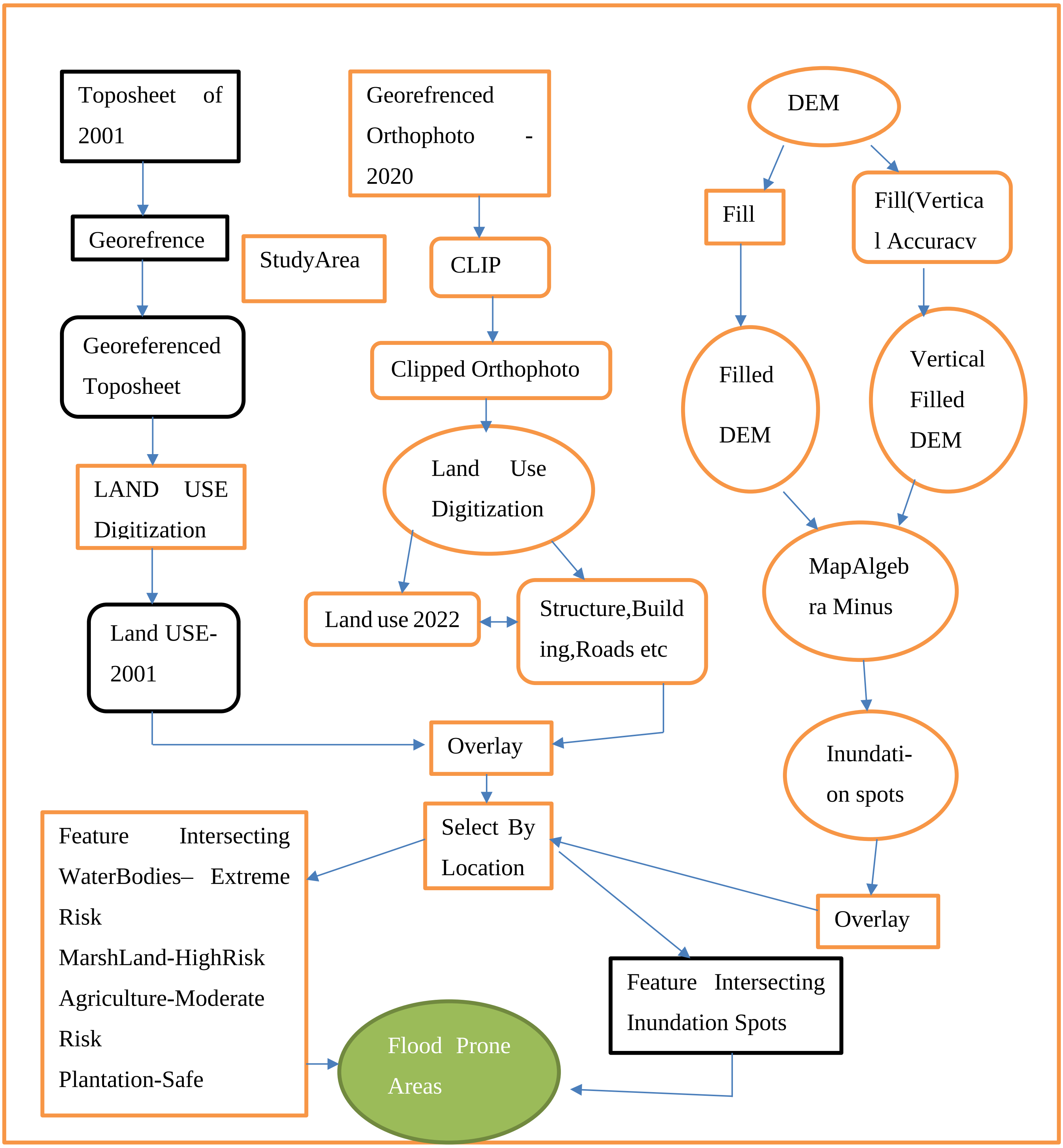


Figure 1 : Methodology of Identifying Flood Prone Areas and Flood Prone Structures.

2.2.3 Multi-Criteria Decision Analysis

This study used a GIS-based AHP methodology to identify flood-risk areas in South and South-East Delhi. GIS, also known as a geographic information system, is a theoretical technology that enables us to map geographical and spatial data and analyse that data using a variety of tools to produce a spatial solution. In research on natural disaster management, GIS techniques were utilised to determine risk and risk zones, spatially visialises features, and provide results that were remarkably accurate. The most suited strategy, GIS - AHP Multi Criteria Decision Analysis (MCDA), was chosen after studying numerous similar publications from journals with high impact factors. In my work, I combined the AHP technique with GIS to discover the flood hazard zones in the study region while taking into account a variety of different factors.

The analytical hierarchy process (AHP), which is based on mathematics and psychology, is a structured method for organising and understanding difficult decisions. Thomas L. Saaty created it in the 1970s (Wikipedia, 2020). AHP (Analytical Hierarchy Process) has been suggested as a systematic method for establishing priorities and figuring out how much weight to give to each criterion. The criteria are compared pair-by-pair using the AHP (Analytical Hierarchy Process). According to Saaty's fundamental scale (Saaty, 2000), the criteria are ranked. To create the Flood Prone Buildings map, the criteria are merged and given the appropriate weighting. The pairwise comparison matrix is normalised to arrive at the weightage of each criterion. The weights are then applied to the criteria in ESRI's ArcGIS 10.8 software to conduct the weighted overlay analysis. Buildings located in these zones have been assessed as being vulnerable to floods.

The selection of the study's criteria was based on socioeconomic and environmental considerations. Then, based on the chosen parameters, each criterion was regraded on a scale of 1 to 5. According to the AHP technique, a pairwise comparison matrix was created.The normalised pairwise matrix was created, and the weighted standards were determined based on the literature study and professional judgement. The consistency ratio was tested, and it should be smaller than 0.10. The weighted criteria were used after the consistent value had been obtained.Below are the steps for calculating AHP.

- Pairwise Comparison Matrix: By evaluating the criterion in a matrix on a scale of 1 to 9, the matrix is created to determine the relative importance of the criteria.

Table 4: Saaty's Fundamental Scale

Intensity	Importance	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Moderate Importance	Experience and judgement slightly favour one activity over another
3	Strong Importance	One activity is greatly preferred over another by experience and judgement.
4	Very Strong Importance	A particularly strong preference for one activity over another is seen in practise.
5	Extreme Importance	The highest level of affirmation is used to describe the evidence preferring one action over another.

Source(Satty,2007)

a) Calculation of the consistency vector, consistency measure, and eigenvalue((λ_{max}) of the criteria,

$$\begin{bmatrix} C11 & C12 & C13 \\ C21 & C22 & C23 \\ C31 & C32 & C33 \end{bmatrix} \times \begin{bmatrix} W11 \\ W22 \\ W33 \end{bmatrix} = \begin{bmatrix} Cv11 & Cv12 & Cv13 \\ Cv21 & Cv22 & Cv23 \\ Cv31 & Cv32 & Cv33 \end{bmatrix} \quad \text{eq3.1}$$

Where,
C = Criteria
W = Weight
Cv = Consistency vector

Ratio is calculated to arrive at the eigenvalue (λ_{max})

$$R = \sum_{i}^{j} (C_v \div W) \quad \text{eq3.2}$$

$$\lambda_{max} = (\sum_{i}^{j} R) \div n \quad \text{eq. 3.3}$$

$$CI = (\lambda_{max} - n) \div (n - 1) \quad \text{eq. 3.4}$$

$$CR = CI \div RI \quad \text{eq3.5}$$

Where R=Ratio

n= no. of criteri

CI= Consistency Index

CR= Consistency Ratio

Table 5: Consistency Ratio Random number Index by Saaty

n	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56

$$CR = \begin{cases} < 0.1, & acceptable \\ \geq 0.1, & unacceptable \end{cases}$$

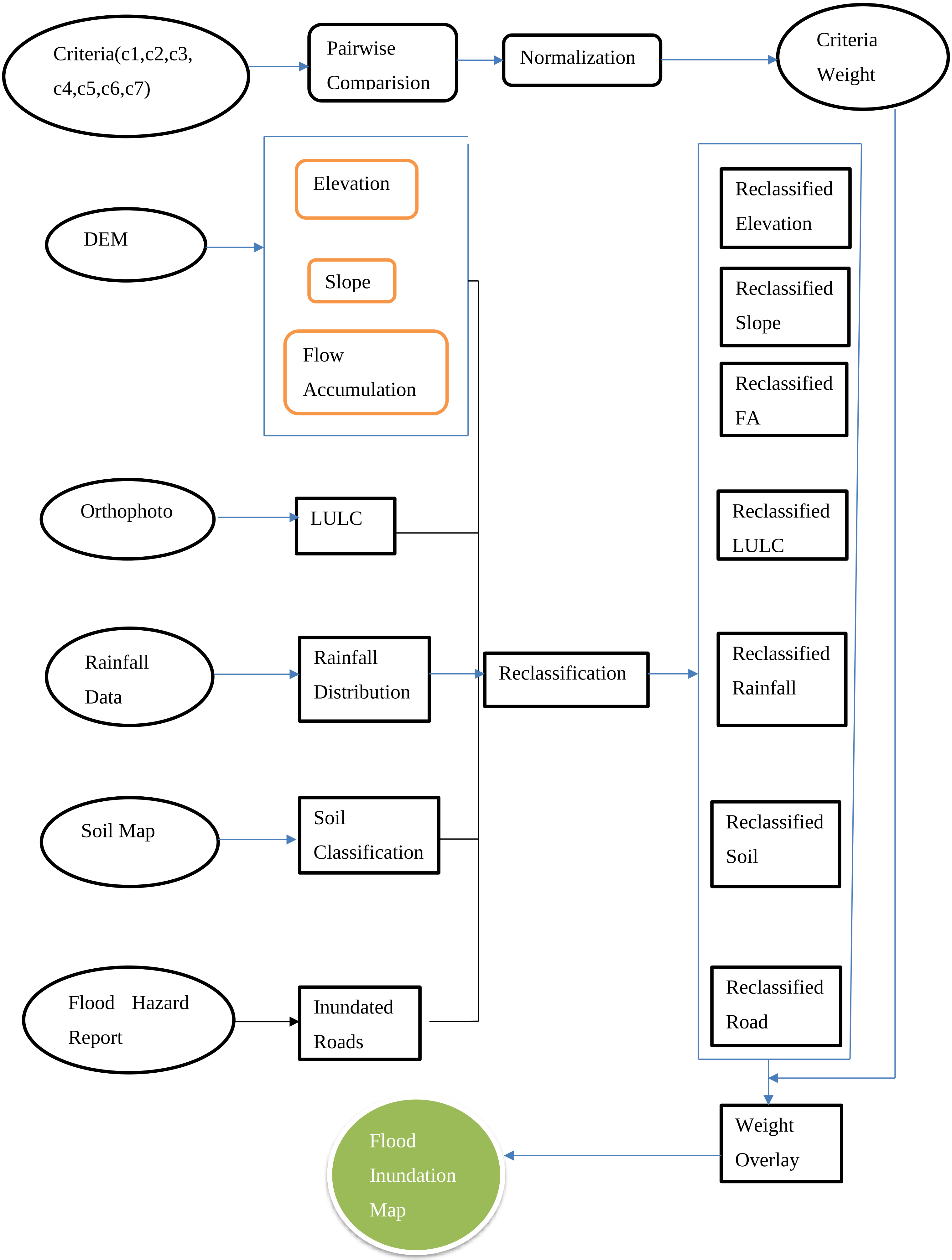
2.2.3.1 Criteria Used-

The goal of this research is to identify the flood risk zones within the study region using GIS techniques in conjunction with an AHP Multi Criteria Decision Approach. Elevation, slope, soil information, rainfall information, flow buildup, inundated highways, and land use are among the factors taken into account in this study to identify inundation risk zones. Environmental and socioeconomic factors were taken into consideration when choosing these criteria. The environmental criteria include elevation, slope, soil information, rainfall information, and flow accumulation. Inundated roads and land usage are socioeconomic factors that were taken into account in this study. Due to the accelerated urbanisation and rising land prices, the poor population began establishing their communities in and near flood-prone areas. The criteria are briefed below,

- Elevation Range
- Degree of slope
- Maximum amount of Rainfall distribution in the study area
- Flow Accumulation in the study area derived from the DEM
- Soil data classified as per their infiltration capacity
- Distance to Inundated Roads
- Land use types classification

The flood Inundation maps will be classified to five classes,

1 – Extreme Risk, 2 – High Risk, 3 – Moderate risk, 4 – Safe, 5 – Very Safe.



Criteria(c1,c2,c3, c4,c5,c6,c7)
Pairwise Comparision
Normalization
Criteria Weight
DEM
Elevation
Slope
Flow Accumulation
Orthophoto
LULC
Rainfall Data
Rainfall Distribution
Soil Map
Soil Classification
Flood Hazard Report
Inundated Roads
Reclassification
Reclassified Elevation
Reclassified Slope
Reclassified FA
Reclassified LULC
Reclassified Rainfall
Reclassified Soil
Reclassified Road
Weight Overlay
Flood Inundation Map

Figure 2: Methodology of MCDA

2.2.4 Software used

ArcGIS 10.8 was the GIS programme used for this study.The Environmental Systems Research Institute (ESRI) maintains ArcGIS, a geographic information system for working with maps and geographic data (Wikipedia, 2020). Spreadsheets with Microsoft Excel from the Microsoft Office software were used to calculate AHP. Spatial data that was not accessible from any sources was abstracted using Google Earth Pro. The project report's references are cited using the software programme End Note.

CHAPTER 3

Processes and Results

This chapter describes the procedures followed in the research area in relation to the approaches and information supplied in Chapter 3. The stages of the method in detail as well as the outcomes for each study objective are described in this chapter.

The following sections make up this chapter:.

- Flood prone Areas and Structures
    - DEM based result
- Flood Risk Mapping using MCDA

3.1 Flood prone Areas and Structures:

3.1.1 Identifying Flood prone Structures using DEM-

The elevation information of a landscape is contained in the pixels of a digital elevation model (DEM), which is a raster file. In GIS, DEM are typically used for hydrological analysis. In this study, DEM is utilised to identify the areas that will likely experience flooding following a cloudburst.

Aerial imagery is used to obtain the DEM for this study. The DEM has a 30 metre accuracy. The ArcMap Fill Tool was used to fill the first sinks. Following the delineation of the watershed from the DEM, flow direction was determined. The DEM was used to determine the likely inundation areas. Buildings in this area were noted as being vulnerable to flooding (Periyasamy et al., 2018, p. 21). The flood areas were determined using the DEM in Model Builder in ArcGIS. The model builder used for this step is taken from the ESRI training session "Find areas at risk of flooding in a cloudburst" (ESRI, 2021), and the model is then changed in accordance with the study's objectives.

The Hydrology tool 'fill' under the Spatial Analyst Tool of the Arc Tool box is used to fill the DEM with respect to its vertical accuracy to arrive at the True DEM.Then fill function is used to fill all the sinks in the DEM. The True DEM is subtracted from the Filled DEM using Minus Tool to arrive at the Blue spots i.e., the probable flood risk zones.

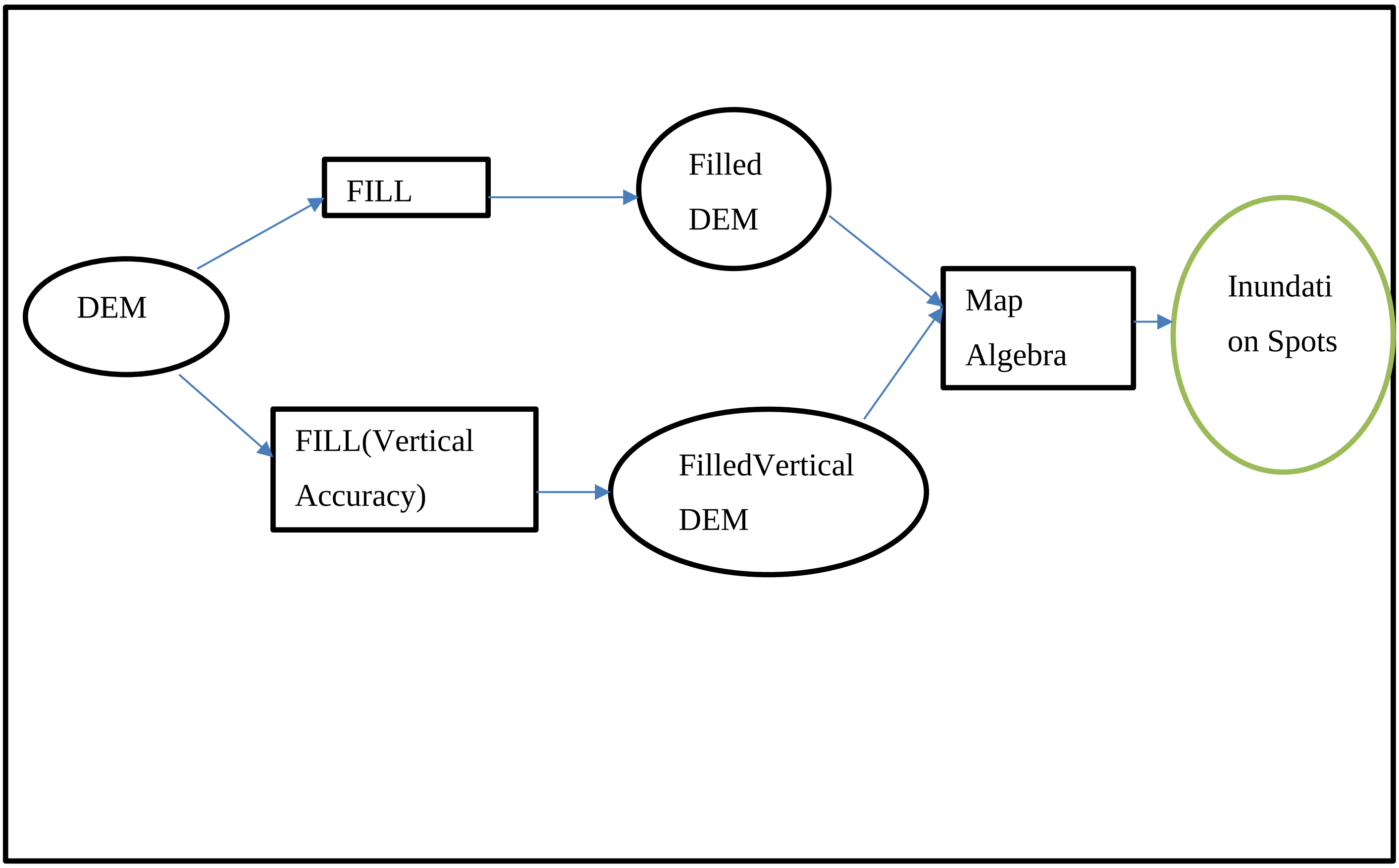
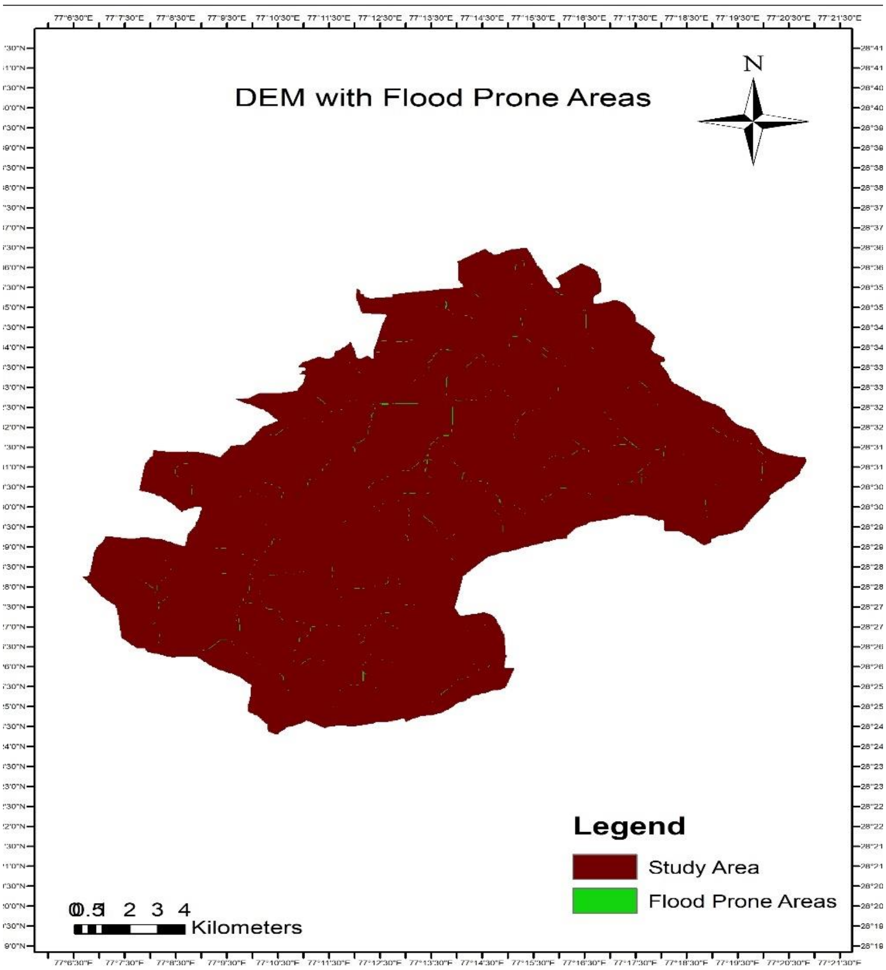


Fig 3 - Steps to Find Flood Prone Areas Using DEM



Map 4 – DEM with Flood Prone Areas

The flood prone areas of the study area were found using this method, and the result of the same are displayed in Map . The buildings under the risk of inundation are derived using the results obtained in the previous stages. Select by Location function in ArcGIS was used to obtain the buildings that intersect with the Probable Inundation spots.

3.2 Flood Risk Mapping using MCDA

3.2.1 Criteria Evaluation and Reclassification

There are 8 significant factors used in this study to identify the inundation risk zones, as described in section 3.2.2.1. Regarding the information learned from articles published in high impact factor journals and the development criteria from the Master Plan for the DDA,(MPD-2041)), these criteria are categorised according to the distance range and various other qualities. The flow chart below shows the criteria that were employed in this investigation. The environmental and socioeconomic parameters employed in this study are directly related to the flood risks before, during, and after a flood occurrence.

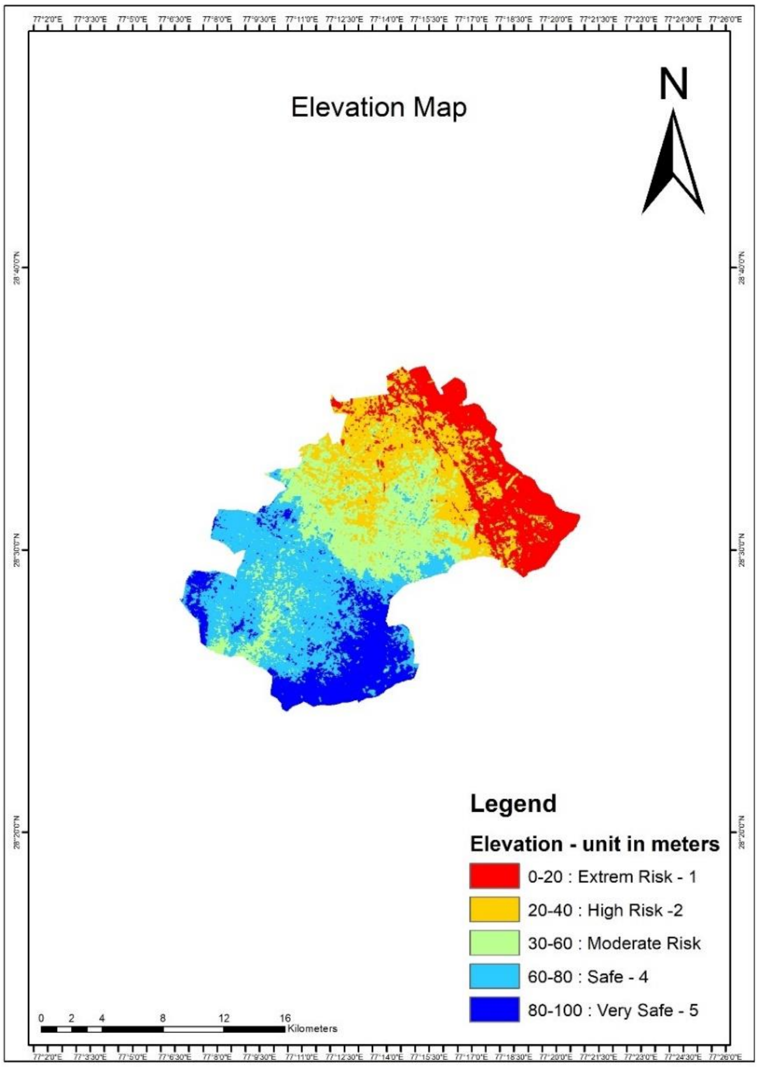
Criteria	Unit	Suitability Level				
		1	2	3	4	5
Elevation	Meters	20	40	60	80	100
Slope	Degrees	5	15	25	40	85
Soils	Infiltration Capacity Inches/hour	< 0.05	-	0.15	-	-
Rainfall	mm/day	350	335	325	-	-
Flow Accumulation		160000	125000	`95000	65000	35000
Inundated Roads	Distance to in meters	10	20	30	40	50
Land use	Type	Built up	Marshland	Agriculture	Open Space	Waterbodies

Table 6 – Criteria with suitability Level

Suitability Level 1 – Extreme Risk, 2 – High Risk, 3 – Moderate Risk, 4 – Safe, 5 – Very Safe

3.2.2.1 Elevation

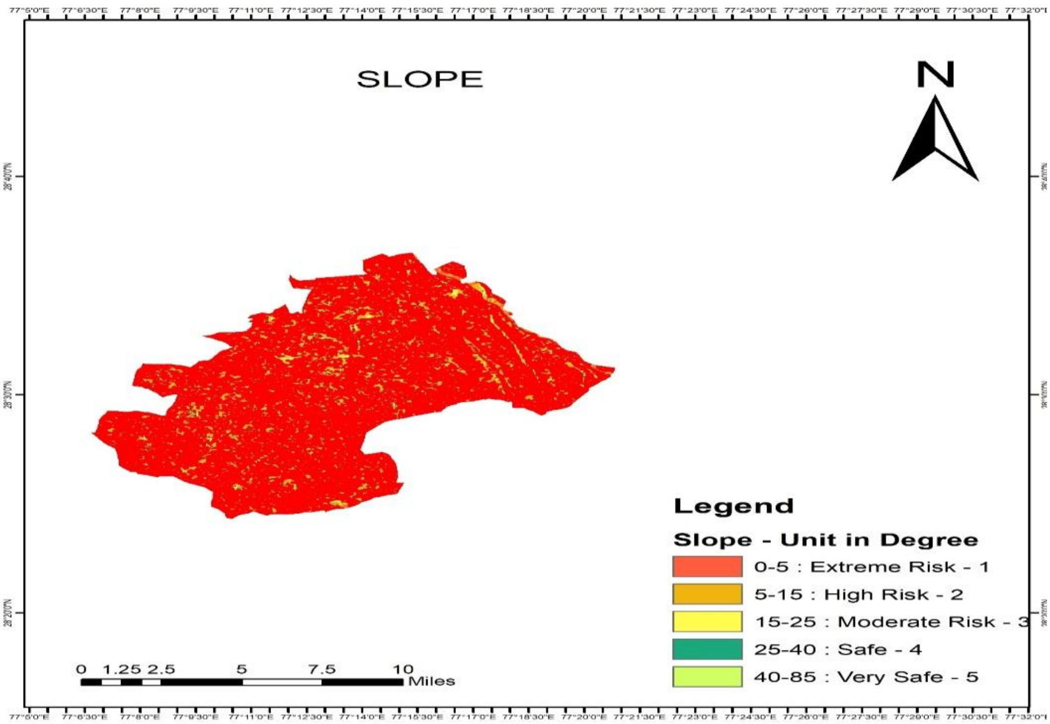
In this study, one of the environmental factors used to identify the inundated zones is elevation. A terrain's stability is greatly influenced by the elevation of the surrounding area.The surface run off is improved in steeper places where the elevation is high, preventing water accumulation. Low-elevation locations are vulnerable to floods because they provide very little surface runoff, and the flat terrain is particularly vulnerable to water logging. Areas with low elevation or flat terrain are more likely to experience flooding. The research location is close to the ocean and has a generally flat topography; there aren't many elevational undulations in this area. The research area's elevation varies from mean sea level (zero) to 100 metres. According to the study, localities with an elevation difference of less than 5 metres are thought to be extremely dangerous, whereas those with an elevation difference of more than 40 metres are thought to be quite safe (Aggarwal et al., 2009, pp. 145–158). The detailed classification of the elevation range for this criteria is shown in Table 6. The classification denotes the food risk in the study area with respect to the elevation.



Map 5 – Elevation Flood Risk Classification

3.2.2.2 Slope

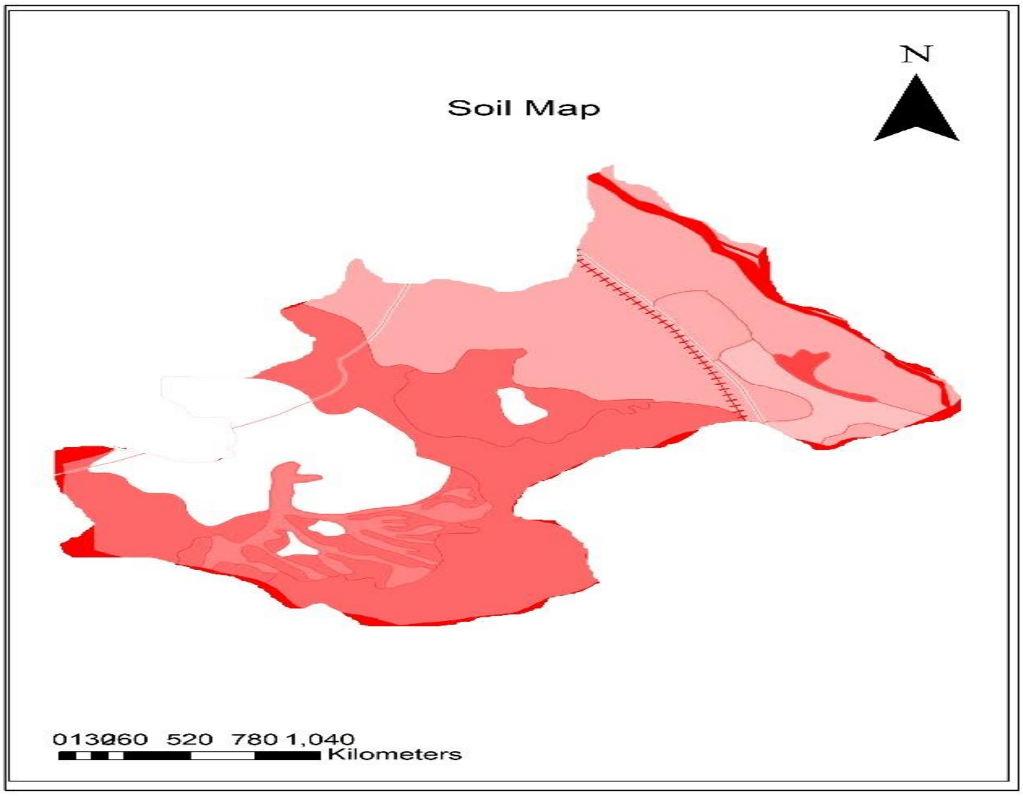
The direction and volume of surface runoff that reaches a drainage system are greatly influenced by slope, a different factor. With the help of the ArcToolbox's slope generating capabilities, slope is calculated from DEM raster data in the ArcMap software. Areas with depressions, low elevations, and minimal slopes always have a tendency to gather water. In contrast to nominal slopes, which tend to absorb water, steeper slopes can increase surface runoff. High gradient slopes are not as prone to flooding as low gradient slopes are (Ouma & Tateishi, 2014). In this study, the slopes with a high degree of inclination are categorised as extremely safe areas, whereas slopes with an inclination range of 5 degrees are categorised as places with a very high risk of flooding. The detailed classification of the slope range for this criteria is shown in Table 6.



Map 6 : Slope – Flood Risk classification

3.2.2.3 Soils

In this study, another environmental criterion used to identify the flood-inundated zone is soil. The soil texture, moisture content, and infiltration rate all indicate a soil's properties. The runoff capacity and subsequent flood consequences of an area are determined by the soil's potential for infiltration. While clayey soils are less porous and cause more runoff, sandy soil has a greater capacity to absorb water and as a result, contributes less to runoff. This demonstrates that areas with clayey soils are more likely to have a flood in the near future (Ouma & Tateishi, 2014). loamy soil, clayey and sandy soil, or similar features identify the study area. The Soil Survey of India department provided the study's soil data. According to NRCS-defined Hydrologic Soil Group standards, sandy soil has an infiltration capacity of 0.15 to 0.3 inches for every hour of rainfall (Wikipedia, 2021). Areas with sandy soils are designated as being of moderate risk and are given a weight of 3. Very little more than 0.05 inches of water can permeate the Marshland in an hour of rainfall. The other surface types are impervious surface. The locations with sandy soils are categorised as being at moderate risk and given a weight of 3. The Marshland can only absorb a little less than 0.05 inches of water for every hour of rainfall.



Map 7 : Soil-Flood risk Classification

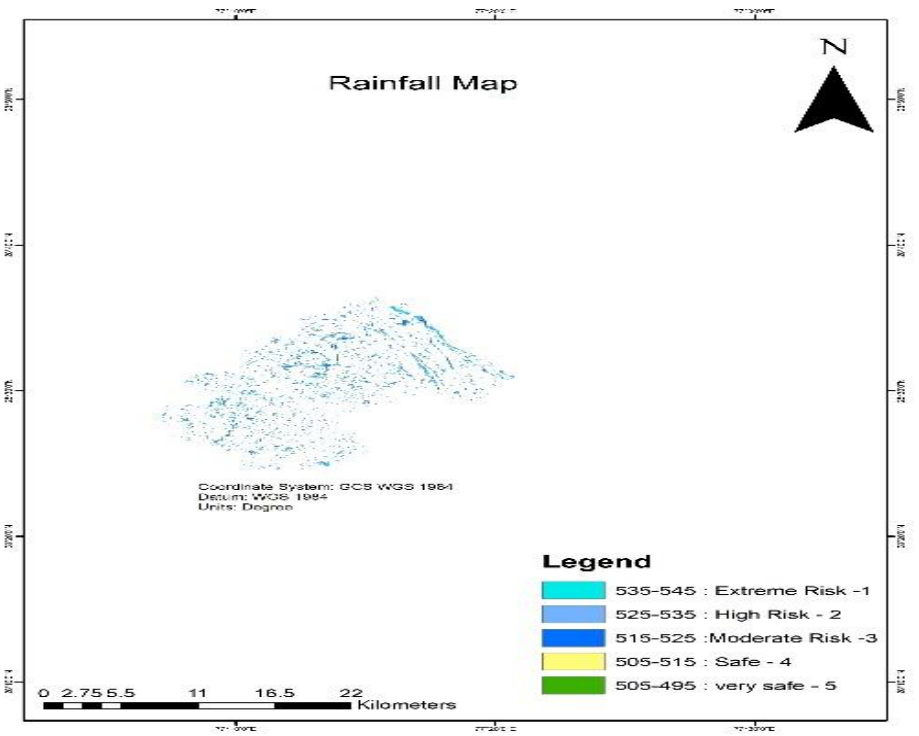
3.2.2.4 Rainfall

Rainfall or precipitation is the main phenomenon that causes a flood in every place, despite all the other components. Flooding won't happen if the natural drainage system is capable of removing the water during a cloud burst. However, in urbanised areas, the natural drainage systems are overused, which reduces their ability to drain the runoff from a cloud burst. A region is more likely to flood the more drainage there is. The amount of runoff is influenced by the amount of rainfall a location has received. Peak rainfall in the study area occurred in October and November. It is determined and extrapolated from the research area's greatest daily rainfall range. To build a continuous raster of rainfall data, the data is interpolated using inverse distance weighting (IDW). Based on its intensity, the rainfall raster data is divided into 3 categories. The area receiving rainfall between

315 and 325 mm/day is categorised as Moderate risk, the area receiving rainfall between 325 and 335 mm/day is categorised as High risk, and the remaining area receiving more than 335 mm/day is categorised as Extreme risk.

Table 7 : Avg Rainfall in 2018

Station Name	Average Daily Rainfall (mm/day) - 2018											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	D
Aya Nagar	19	23	75	80	83	532	543	550	563	510	534	5
South Delhi	34	38	60	65	75	389	400	442	447	789	803	8

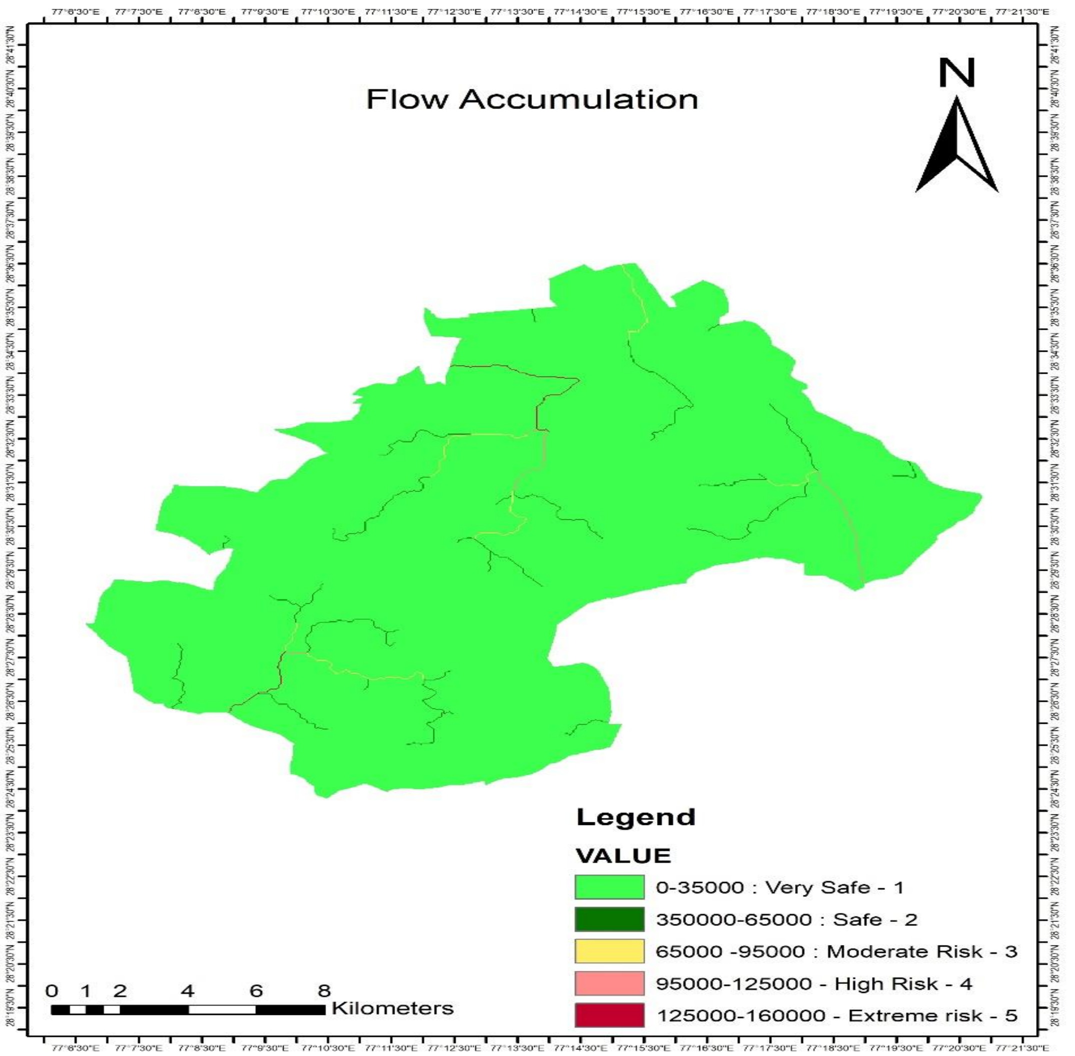


Map 8 : Rainfall – Flood Risk Classification

3.2.2.5 Flow Accumulation

Flow Accumulation is another factor that acts as the contributing environmental criteria to identify the flood risk zones. Flow Accumulation shows the likely path of streams or rivers in a region, suggesting that when it rains, water will accumulate in this stretch. The

DEM is used to generate the flow accumulation. The accuracy of the DEM used in this study is 30 m. The sink and fill tools in ArcGIS are used to fix the minor depression errors in the DEM. The sinks in the DEM are located using the Sink tool from ArcToolbox Hydrology. The areas where the sinks are indicated in the DEM are filled using the fill tool from the ArcToolbox Hydrology. Then, the flow direction Hydrology tool from the ArcToolbox is used to determine the flow direction, which denotes the direction that the water will flow from one cell to another. To identify the areas draining to points on the DEM, the Flow Accumulation Hydrology tool from the ArcToolbox is used. Adjei-Darko (2017).

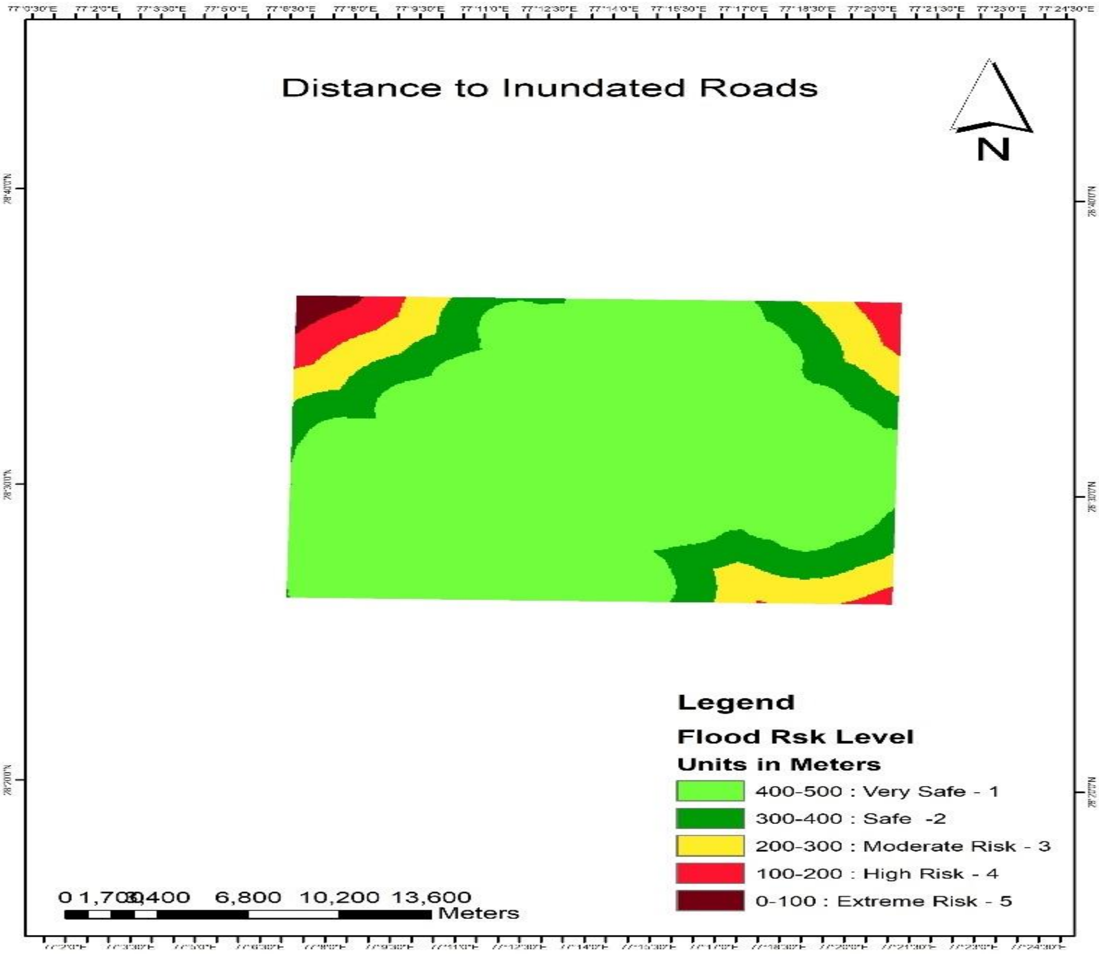


Map 9 – Flow Accumulation-Flood Risk Classification

The area with the lowest flow accumulation between 0 and 35000 is categorised as extremely safe, whereas the area with the highest flow accumulation value between 95000 and 125000 is categorised as high risk.

3.2.2.6 Distance to Inundated Road

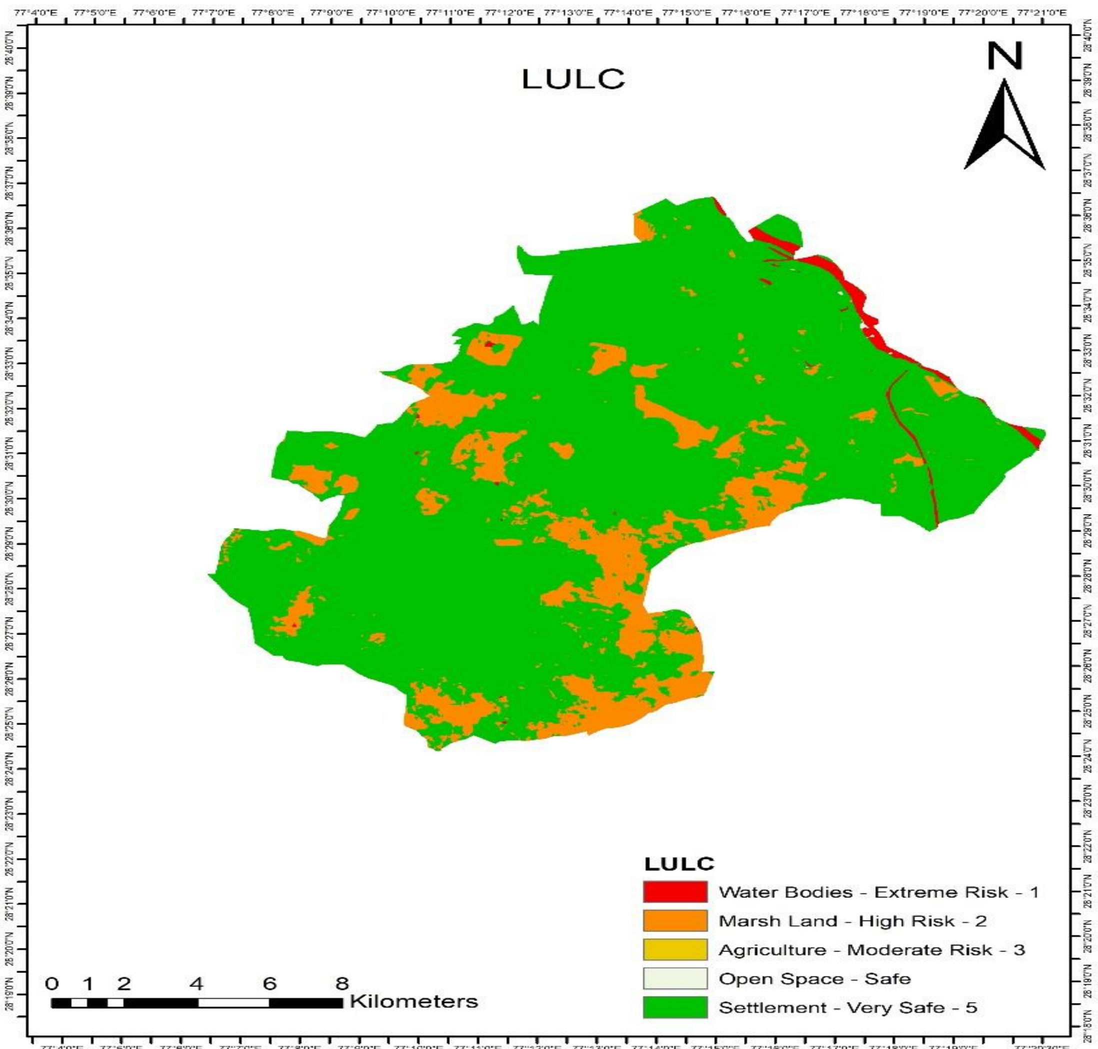
Roads are one of the important social factors to be considered in this study. Since all working class groups are represented in the study area, the roads there are often used, and any problems with them will put the general public through a significant deal of discomfort. The MCD delhi provided the historical information about flooded streets throughout the year's severe rains. The gathered information was mapped in Google Earth and then imported into the ArcGIS software. In order to pinpoint the locations in the flood-risk zones, multiple ring buffers were built around these submerged highways. In this study, areas that are 500 metres or more from inundated roads are considered to be very safe because they have a lower risk of becoming inundated in the event of heavy rain or a storm, and areas that are within 100 metres of inundated roads are considered to have an extremely high risk because they frequently become inundated in the event of rainfall or a storm. Buildings and utility infrastructure are at risk of flooding.



Map 10 – Distance to Inundated Roads

3.2.2.7 Land Use Land Cover

When calculating the flood risk zone for a particular area, the land use and cover of the area are crucial factors. In addition to showing how the land is used, the land use of a region also reveals its stability and surface infiltration rates. During a rainfall, water will be able to infiltrate and be stored by the type of land use—agriculture—and vegetation cover. A farmland will have permeable ground to allow for water absorption. The risk of floods is increased by the open, barren landscapes, which also contribute to runoff during a rainstorm. The urban built-up region is the safest land use since it has an impermeable surface and contributes to significant runoff. This is the location designated by the surface of impervious concrete. Buildings, highways, and slum areas all reduce the soil's ability to adsorb water and increase runoff (Ouma & Tateishi, 2014). In contrast, places with existing waterbodies are thought to be particularly dangerous because they are the types of land use where rainwater can collect quickly. . The flood risk classification is done accordingly.



Map 11 – LULC 2022- Flood Risk classification

Suitability	Value Scores
Extreme Risk	1
High Risk	2
Moderate Risk	3
Safe	4
Very Safe	5

Table 8 – Suitability Scores

The next step is to determine weights and execute the weighted overlay analysis using all the categorised maps.

3.2.3 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) of the Multi Criteria Decision Analysis (MCDA) as proposed by Thomas Saaty (Saaty, 2007) is used to derive the weightage for each criteria. This technique was used to derive a weighting factor from a pairwise comparison. When comparing paired elements, a 9-point scale based on Saaty's scale of relative importance was used to assign values to each element.

Table 9 : Saaty's Scale of Relative Importance

Definition	Relative Importance
Equal Importance	1
Moderate Importance	3
Strong Importance	5
Very Strong Importance	7
Extreme Importance	9
Intermediate Values	2, 4, 6, 8
Inverse Comparison	1/3, 1/5, 1/7, 1/9

	C1	C2	C3	C4	C5	C6	C7	Criteria Weights
C1	0.07	0.07	0.08	0.03	0.10	0.05	0.09	0.0705
C2	0.07	0.07	0.08	0.03	0.10	0.06	0.09	0.0718
C3	0.07	0.07	0.08	0.04	0.10	0.06	0.09	0.0720
C4	0.15	0.17	0.14	0.07	0.06	0.03	0.09	0.0988
C5	0.13	0.13	0.14	0.21	0.18	0.16	0.19	0.1630
C6	0.17	0.13	0.15	0.31	0.13	0.12	0.09	0.1557
C7	0.33	0.34	0.34	0.31	0.35	0.52	0.38	0.3683

Table 10 – Normalized Pairwise matrix

	C1	C2	C3	C4	C5	C6	C7
C1	1.00	1.00	1.00	0.50	0.56	0.44	0.22
C2	1.00	1.00	1.00	0.44	0.56	0.56	0.22
C3	1.00	1.00	1.00	0.56	0.56	0.50	0.22
C4	2.00	2.25	1.80	1.00	0.33	0.22	0.22
C5	1.80	1.80	1.80	3.00	1.00	1.40	0.50
C6	2.25	1.80	2.00	4.50	0.71	1.00	0.22
C7	4.50	4.50	4.50	4.50	2.00	4.50	1.00

Table 11 - Pairwise Comparision matrix

Where,

C1 – Elevation, C2 – Slope, C3 – Rainfall, C4 – Flow Accumulation, C5 – Soil,

C6 – Inundated Roads, C7 – Land use Land Cover

Table 12 : Consistency Calculation

	C1	C2	C3	C4	C5	C6	C7	Ratio
C1	0.0705	0.0717	0.0720	0.0494	0.0905	0.0692	0.0818	7.1675
C2	0.0705	0.0717	0.0720	0.0439	0.0905	0.0865	0.0817	7.2032
C3	0.0705	0.0718	0.0720	0.0547	0.0904	0.0777	0.0817	7.2178
C4	0.1410	0.1615	0.1295	0.0988	0.0543	0.0346	0.0817	7.0994
C5	0.1268	0.1292	0.1295	0.2965	0.1630	0.2189	0.1841	7.6523
C6	0.1585	0.1292	0.1439	0.4447	0.1162	0.1557	0.0818	7.9012
C7	0.3172	0.3230	0.3233	0.4446	0.3260	0.7006	0.3683	7.6129

$\lambda max = 7.42$

Consistency Index = 0.07

Consistency Ratio = 0.05

The formulas listed in section 3.2.2 of this Thesis are used to calculate the max, CI, and CR. According to Saaty's standard rule, the consistency ratio was calculated as 0.05, which is less than the value of 0.10, demonstrating that the weighted value for the criteria was determined consistently.

Where,

C1 – Elevation, C2 – Slope, C3 – Rainfall, C4 – Flow Accumulation, C5 – Soil, C6 – Inundated Roads, C7 – Land use Land Cover

3.2.3 Weighted Overlay Analysis

In the previous section, the AHP approach was used to determine the weights that should be given to each criterion. This section uses ArcGIS software to create a weighted overlay map and conducts a weighted overlay analysis.

The 'Weighted Overlay' tool is located in the Overlay section of the Spatial Analysis Tools in the Arc Toolbox, and it is used to perform weighted overlay analysis. Using a common measurement scale and weighting each raster according to its significance, the weighted overlay tool overlays multiple rasters (ESRI, 2008).

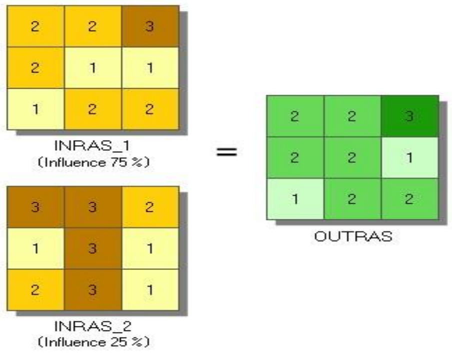
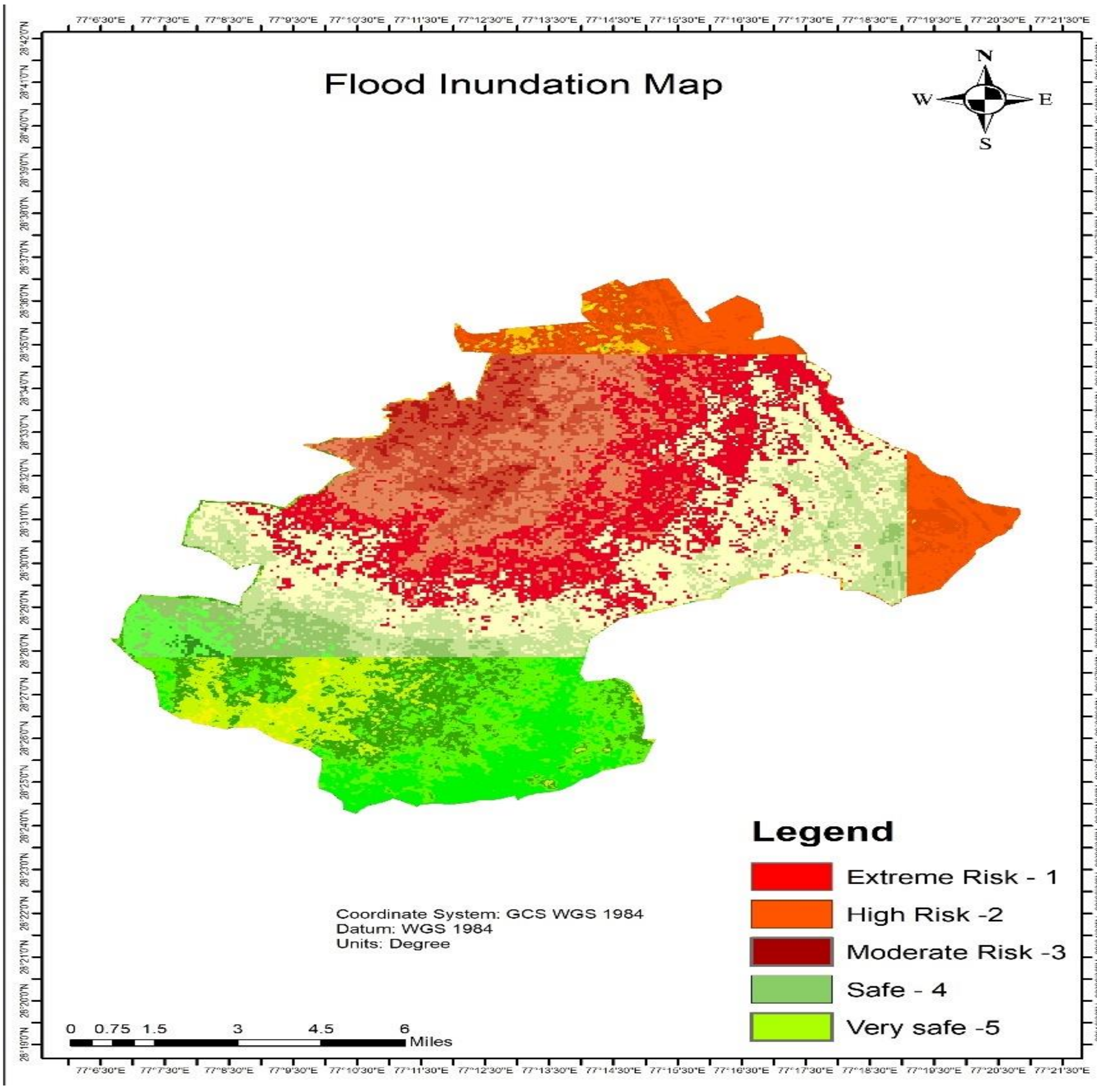


Figure 4 - Illustration of Weighted Overlay(ESRI2008)

The AHP method was used to determine the individual weights for each of the seven criteria in the current study.

Table 13 – Criteria weight

Criteria	Weights
Elevation	7 %
Slope	7%
Rainfall	7%
Flow Accumulation	10%
Soil	16%
Inundated Roads	16%
Land use	37 %



Map 12 : Flood inundation Map

The tools were run and the resulting map generated was called the Weighted Overlay Map. This map shows the flood risk zones in the study area. It can be seen from the above map that the area that are in the lower edge of the study area contributes to more high risk. Inbetween there are also moderate risk zones given as result by the GIS Weighted Overlay tool.

3.3 Results

The objective of this research was to create a method to use AHP-MCDA to identify flood risk zones in the study area, as was mentioned in the earlier chapter. The objective is to locate structures that are vulnerable to flooding, identify flood-prone areas within the study area, and create a map of that area's susceptibility to flooding.Using various methodologies, tools, and data, the study produced two results.

Result 1-

The structures at the flood prone areas were identified by using high resolution DEM. This is a nonscientific method of approach to identify the infrastructures at the flood prone areas. .The hydrology tools of Arc Tool box is used to develop a model to identify the probable inundation spots in the study area. The structures are overlaid on the Inundation spots. The buildings that are within and intersect these spots are queried using select by location to find out the building at the flood prone areas.

The field photos were taken in Delhi during the months of September and October when there was a lot of rain. Four locations were matched with the findings of this study out of 10 photographs taken during the period of heavy rain. With regard to the data collected in the field, this produced a 40% match. The buildings in the area were flooded with the rain water and the roads in the areas were also inundated. These structures found in the flood prone areas cannot be removed now, so they can be advised to raise their foundations to a certain height to avoid inundation and flooding in the future.

The obtained results shows that the structures that were built on the pond and lake beds and the structures that were built on the earlier agricultural and marshland are now very prone to flooding. And, the DDA have to be strict in approving the land for construction of building and thorough and routine inspection have to done in these areas frequently.

Result 2-

The study's next objective was to map the flood risk areas in the study area using a weighted overlay analysis method when combined with the Multi Criteria Decision Analysis, AHP methodology. Various socioeconomic and environmental criteria were used in the MCDA method. Seven criteria—including elevation, slope, rainfall, soil, flow accumulation, land use and land cover, and historically inundated roads—were taken into consideration for the study.

Table 14 – Flood Risk Area – MCDA

	Area (Sq.km)	**Percentage Covered**
Study Area	**364**	
Moderate Risk	98.28	27%
High Risk	10.92	3 %

The result shows that, of the total study area of 364 sq. km, 98.28 sq. km falls in the moderate risk zone, making up 3% of the total study area, and 10.92 sq. km falls in the high risk zone, making up 27% of the total study area.

According to news reports, the zones near the bottom of the study area tend to flood with 40 to 60 mm of rain per hour, therefore the results reveal that they urgently need a storm water drainage system. Additionally, it is discovered that this area lacks a natural watershed for the water to drain into. In areas where there is a high risk of flooding, it can be suggested to the SWD department that new drains be planned. The later-mentioned location is also where the structures at risk of flooding are located.

The study area experienced 27.1mm of rain per day during the monsoon in the year the year 2022. The absence of facilities for the water to drain put many households at risk of flooding. For the purpose of to reduce the risk of flooding, the populace asked the civic bodies to plan better facilities and infrastructure. The PWD planned to improve the SWD in these areas since this was a problem for all the areas in and around south and south-east Delhi. With the aim to implement the infrastructure more quickly and decrease the effects of flooding during the monsoon days, the corporation will find this study methodology to be very helpful in determining where the need for SWD is on an urgent basis. The Greater Kailash area's Archana T-point, the DND Flyover heading towards Maharani Bagh, and the Jaitpur areas are found to be at the greatest risk of flooding.

Anywhere, regardless of the land's natural topography, one could find low lying depressions and sinks. In normal weather conditions, it will be difficult to spot these areas; however, when extremely heavy rains strike, they become clear. In the event of a significant downpour, these low-lying areas flood, flooding not only the buildings but also the surrounding infrastructure, such as the roads, rails, and so forth. The solution to this problem is a well-designed storm water drain (SWD). Since the state has not yet conducted a study on flood vulnerability at the building level (April 2021), it is advised to use this methodology to identify flood victims at the final stage of the flood and then plan appropriate flood mitigation, preparedness, and rescue measures.

This chapter provides a thorough explanation of the procedure and the outcomes. The disaster management departments can carry out their flood preparedness and mitigation efforts in the proper locations in light of the aforementioned results. The Corporation's disaster management team can make extensive use of the results and methodology because the flood risk zone results were determined by taking into account all significant factors that contribute to or are related to flooding. The land use type, soil group, and actual precipitation values of the study area are also taken into account when conducting the flood prediction study.

CHAPTER 4

CONCLUSIONS

The issue of flooding during rainstorms has persisted for the past few years in Delhi, a city that is rapidly developing. Not only is this issue present here, but it is also prevalent in a number of other cities, states, and nations. The negative effects of flooding result in the loss of socioeconomic activities, material assets, cultural resources, and economic resources. Injurious natural disasters are being exacerbated by the changing global climate. Poor planning and the growth of economic infrastructure in areas that are vulnerable to food shortages have increased the risk to Delhi's sustainable development and to poverty.

This problem has reduced the momentum of a country’s growth (Rajib & R, 2009). It is too late to turn the encroached flood prone lands into their natural form, so we need to find a solution to make this place a better risk free zone for the people living in it.

A document on managing urban flood risk from the WMO/GWP has been released, and it suggests using GIS technology to assess the risk in flood-prone areas. When assessing risks, a number of factors must be taken into account. In addition, future development plans, the potential for urbanisation, and waterbodies on the verge of extinction all play a significant role in risk assessment (WMO, 2008). Past records of hazards, their intensity, loss, exposure, and vulnerability of the society need to be taken into consideration.

To research and determine the locations at risk, spatial visualisation and analysis are required. The GIS tools were used in this study to identify flood-prone areas in Delhi Zone, flood risk zones, and to forecast the flood in terms of rainfall events. The technology of GIS, along with Multi Criteria Decision Analysis and ArcGIS-based Hydrology tools, was used to arrive at these results.

4.1 Discussion

This study is conducted utilising data acquired from the Storm Water Drain Department, public interviews, and open source data, hence there are minimal limits in this study. The limitations of the two approaches employed in this investigation are discussed further below.

Common Limitations:

The study's common limitations is that it only used free source geographic datasets with varying resolutions and sizes.

Building at Flood Prone Areas:

This method uses a non-scientific approach to locating structures in flood-prone zones. This approach has its own drawbacks.

The scale of the toposheet utilised in this investigation differs from that of the Orthophoto. The toposheet is scaled at 1:50000, and the aerial picture is 30m high quality and derived from open survey data.

MCDA Approach:

This method identifies flood risk zones by combining GIS and an AHP-based Multi Criteria Decision Analysis-based methodology. This approach has its own drawbacks.

- The AHP calculations are done in consultation with only few experts. The advice from the major decision making team of the corporation were not taken.

- This study does not take into consideration evaporation, runoff capacity, or future land use.
- The soil data is derived from the Survey of India's district level map.

4.2 Future Work

The methodology will be used by the Disaster Management division to effectively site the buildings at risk. The results can identify not only the building but also all other infrastructure at risk of flooding, such as roads, rails, and subways. Only when flood preparation was inadequate did the worst effects of the flood occur. This study will assist planners in focusing on areas at risk of flooding in order to plan and upgrade infrastructure accordingly.

The future works recommended for each methodology are discussed below.

Buildings in Flood-Prone Areas:

This method could be improved further by,

- Comparing land use change at different scales.
- This study could take into account the building's elevation. Additional building height data can provide detailed and accurate risk information for buildings.

MCDA Approach:

This method could be further improved by,

- Carrying out the AHP calculations with the assistance of seniors and experts. The advice of the corporation's major decision-making team should be considered when developing the criteria and its pairwise comparison matrix.
- To improve the results, additional criteria such as evaporation, runoff capacity, and future land use should be considered.

- The soil data is derived from the district level map obtained from the Survey of India. To improve results field soil survey should be done and the infiltration capacity to be analysed from soil samples and applied to the study which will give more accurate results.
- The rainfall data obtained from the rain gauge station located within the study area will produce more accurate results.

In the end, this project work can aid in the effective management of flood preparedness, mitigation, and rescue measures for the benefit of society as a whole.

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