Master Thesis

submitted within the UNIGIS MSc. programme
at the Department of Geoinformatics - Z_GIS
University of Salzburg, Austria
under the provisions of UNIGIS India framework

Identification of Flood Risk Zones and Flood Prediction in Ward 200, Chennai Corporation, India

by

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A thesis submitted in partial fulfilment of the requirements of
the degree of
Master of Science (Geographical Information Science & Systems) – MSc (GISc)

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Chennai, 30.06.2021

Science Pledge

By my signature below, I certify that my project report is entirely the result of my own work. I have cited all sources of information and data I have used in my project report and indicated their origin.

Chennai, 30.06.2021

Place and Date | Signature

Acknowledgements

First of all, I express my sincere thanks to my Parents and my brother for their moral support, endless encouragement and care.

I would like to thank my Professor, Dr. Shahnawaz, Director (S & SE Asia), UNIGIS International, University of Salzburg | Interfaculty Department for Geoinformatics - Z_GIS for his valuable guidance, expert advice, support and suggestions in the Thesis work.

My heartfelt thanks to Mr. L.Nandakumar, Chief Engineer, Storm Water Drain Management Division, Greater Chennai Corporation, Chennai, India for giving me the permission to acquire data from their records and also access the staff's library at the Corporation Office.

My extended Thanks to Mr, B.Sivakumar, Superintending Engineer, Storm Water Drain Management Division, Greater Chennai Corporation, Chennai for spending his valuable time in explaining the present and planned Flood mitigation and Storm Water Drain activities of the Corporation.

Thanks to the IMD Staffs of IMD, Chennai for giving me the right data from their official records.

Thanks to the Librarians of the Anna Centenary Library for helping me pick the right books and journals as per my requirements.

I also convey my gratitude to my friends and colleagues who have supported me throughout the Thesis work.

I would like to thank everyone who have helped me indirectly for the successful completion of the Thesis work.

Last but not the least, I express my deepest gratitude to The God Almighty for giving me the strength to overcome the hardships.

Thank you!

Dhivya Selvarajan

Abstract

Flood is a very common natural disaster faced by countries worldwide. Urban Flood is a phenomenon that is caused due to uncontrolled development, rapid urbanization, overburdened drainage, alteration in the natural topography and migration of population into cities. These factors make urban flood a manmade disaster. Cities that fall in the coastal zones frequently become the victims of flooding. Chennai being a coastal city is often affected by floods due to storms, monsoon rainfall and cyclones. Countries like, Nepal, Philippines, Argentina and even India have used GIS technology to support in the Flood mitigation and Rescue measures. Chennai was hit by the Cyclone Nivar during the month of November, 2020. The southern parts of Chennai received as high as 310 mm of rainfall per day. Being the resident of Chennai at Ward 200, I faced the extreme effects of the rainfall in this region. Whenever rain starts pouring, the roads get inundated very easily. Due to the lack of Storm Water Drains, the sewerage and manholes start to over pour and mix with the rainwater. Water gets into the basement floors of the buildings contributing to social and economic loss to the community. This situation made me take up this subject and explore it further.

The aim of this study is to find the Flood risk zone and Flood Prediction in Ward 200, Chennai Corporation, India. This study used GIS techniques to find the structures at the flood prone areas, GIS based AHP Multi Criteria Decision Analysis approach to build the flood risk zones map and finally SCS-CN method with Time Area approach based on GIS Hydrology modelling tools were used to generate unit hydrographs for the watersheds in the study area and predict flood by estimating the discharge volume at the watershed with respect to unit time. A visual analysis was done between the land use land cover maps of the year 1954 and 2020. It was observed that the waterbodies were shrunk and were even lost due to rapid urbanisation. These natural land use features that turned to urban land use were considered to be flood prone areas, and the structures that fall on them were classified as flood prone structures. The result was further improved by deriving the inundation zones in the study area using the high resolution DEM data by applying the GIS based hydrology tools. The MCDA approach used environmental and socio economic criteria to study the flood risk zones. The environmental criteria used in the study are, Elevation, Slope, Rainfall, Soil, and flow accumulation. The Socio economic criteria considered are the present Land use land cover, and Historical Inundated roads data. Then the last method of flood prediction used SCS-CN method to derive the runoff at the watershed with respect to its land use and soil texture and infiltration properties, followed by the derivation of Isochrone map using Time Area Histogram approach. And finally Unit Hydrograph is derived by Mathematics computations and Hydrology tools in the ArcGIS software.

The results show that the structures built on the waterbodies, marshland and agricultural land are in the flood prone areas. The result was compared with the newspaper reports and field photographs of the floods of November, 2020. The results revealed that 40% of the flood prone buildings and roads structures identified by the current study were matched with the buildings and roads inundated during the Nivar Storm that hit Chennai on November 2020. The GIS based AHP MCDA result shows that out of the total study area of 7 sq.km, 0.2 sq.km area falls in the moderate risk zone which accounts for 3% of the total study area, and 1.9 Sq.km of area falls in the High risk zone which accounts for the 27% of the study area. There were two watersheds observed in the study area. It was inferred from the Hydrological modelling result that, if the study area experiences continuous rainfall of three to five hours then the watersheds tends to get flooded.

The worst effects of the flood are faced only when the flood preparedness was poorly done. This study will help the Disaster Management department to concentrate on the areas with the high risk of flooding to plan the preparedness and mitigation measures accordingly.

Key words: GIS, AHP, Flood Risk, Flood Prediction, SCS-CN, Time Area Histogram Weighted Overlay, Flood Prone, Unit Hydrograph.

Table of Contents

List of Tables

List of Figures

List of Maps

List of Abbreviations

AHP	Analytical Hierarchy Process
AMC	Antecedent Moisture Condition
C	Criteria
CI	Consistency index
CMA	Chennai Metropolitan Area
CMDA	Chennai Metropolitan Development Authority
cms	centimetres
CMWSSB	Chennai Metro Water Supply and Sewage Board
CN	Curve Number
CR	Consistency Ratio
CV	Consistency Vector
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
M^3	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

RI	Random Index
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 all the natural disasters happening around the world, Floods are the most common disaster faced by many countries. Flood is a situation in which enormous amount of water intrudes the dry land area (Wikipedia, 2021) Floods can happen due to different reasons, Phenomena like heavy Rainfall, storms, overflow of rivers and Dams, Climate Change and poor planning and development can contribute to the onset of flooding. The floods that are caused as a result of poor planning and development is termed as Urban Floods (FloodSite, 2008). The early civilisation are known to have settled along the river valleys and waterbodies, like the Euphrates and Tigris Valleys in Mesopotamia, the Nile valley in Egypt, the Indus Valley in India etc. The River plain tends to have high development potential due to its rich soils, good water supply and transportation means (Avinash, 2009, pp. 48-51) The growing human population not only developed settlements along the river and other waterbodies, but also gradually encroached them to build their homes and community as a whole. This uncontrolled and ill planned development by the humans gradually blocked the natural drainage system. According to (Sieker, 2008, pp. 303-304) the process of urbanization involves, Sealing the natural Landscape by buildings, other utilities and transportation networks. He mentions that Agricultural area also contribute to flood by its increased runoff on arable lands. Irrespective of urban and rural areas, human intervention into the natural drainage system in the name of development has led to numerous disasters, among which Flood is the major disaster faced by people currently worldwide.

It's not only the urbanization that leads to flooding, there are many other factors which also contribute to the disaster. The extreme impacts of flood are felt due to urbanization, deforestation, population growth, climate change and its consequence in sea level rise. It is also believed that the people vulnerable to flood will increase in the coming years (Avinash, 2009, pp. 48-51). Many urban areas face the situation of flash floods due to heavy rainfall for a shorter duration. The areas like cities are mostly prone to flooding as they are majorly built up by impervious surface like asphalt, concrete, bricks etc. In these areas where the majority of the surface is impervious often leads to run off of rainfall that falls on the ground. The run off increases tremendously when rainfall occurs, and when the existing drainage system cannot sustain the excess runoff from the rainfall, then flood occurs. It is highly recommended to use the right technology and technique for flood Management.

India's neighbouring country, Nepal had used GIS during the Earthquake on 2015. The government used the technology to find the people at risk during the emergency, which guided the emergency workers to reach the victims. The government understood the need of the technology and prepared a Post Disaster Need Assessment Report. In which it is mentioned that the urban recovery includes, Hazard Mapping, Participatory Planning, risk-sensitive urban planning, rapid urban expansion studies, and facilitated management are need to be done as a part of recovery (NPC, 2015, pp. 1-5).

Philippines is one of the top most countries vulnerable to Natural Disasters. The country frequently faces the risk of inundation due to cyclones and frequent typhoons. The government agencies looked out various apps and technologies to help them in various stages of any disaster. Finally they concluded to use GIS technology to solve their purpose. A GIS system was built and the topographical data were fed into the database. By feeding the spatial inputs like building locations, inundated areas and combining it with current weather conditions helped the departments to identify natural hazard susceptibility. This also helped the department to quantify the population that would be exposed to flooding and plan the rescue measures very soon before anything worst happens (Rosy, 2021).

The city of Buenos Aires, Argentina has developed a GIS based Flood Risk Management system to reduce the risk and impacts of floods. They concentrated on flood prevention, Mitigation and response. As part of the Prevention, the vulnerable inhabitants were mapped with respect to the historical flood events, the Inter Ministerial Flood Risk Management

Council ensured participation and coordination of all departments. The Mitigation measures involve accessing the current infrastructure and propose new infrastructures for flood mitigation. The existing Storm Water Drainage (SWD) system along the vulnerable areas were studied and new primary networks were proposed to be constructed. In the already existing SWD network secondary and tertiary networks were planned and proposed. This measure largely reduced the risk of the vulnerable inhabitants and also improved the traffic along these streets during rainy days (LatinAmerica & Caribbean, 2016)

Flood has impacted millions of people worldwide, and India is highly susceptible to floods. India is ranked as the 14th most vulnerable country in the world in terms of Natural Disaster. India's vast coastline measuring 7500 kilometres has exposure to the tropical cyclones arising in the Bay of Bengal and Arabian Sea (Aggarwal et al., 2009, pp. 145-158). According to National Disaster Management Authority, 40 million hectares of the total geographical area of India is flood prone (NDMA, unknown). The regular occurrence of flooding initiated various government departments to use relevant technologies throughout the stages of Prevention, Preparedness, Response and Recovery of any disaster. The officials and authorities opted to use GIS (Geographical Information System) technology to help in the later mentioned stages of any disaster.

GIS is a technology that has the capability to visualise all the Topographic features in terms of its location (Latitude and longitude) and as well as altitude. GIS has the power to visualise and analyse accurate spatial data, which provides greater insights towards disaster preparedness and response planning. GIS played a very important role in emergency response, planning and analysis during the cyclones Hud-Hud, Gaja, Amphan, and Nisarga that hit between the years 2019 to 2020 in India.

The Odisha State Disaster Management Authority had used GIS based Satellite Remote Sensing during the 1999 Floods. GIS helped the department in various stages of Flood. The officials used GIS to find best location to construct multipurpose food shelter, and locate weak spots to initiate the rescue operation. Further developments were done to the system to develop district and gram panchayat level vulnerability map for future preparedness (OSDMA, 2019, pp. 21-28).

Karnataka is a South Indian State which suffers from urban floods due to heavy rainfall in the Monsoon seasons (Wikipedia, 2021). This state attracts people from different part of the country due to its job offerings in the IT sector. As an impact of population growth many buildings started to rise and waterbodies were illegally encroached for development. The Karnataka State Natural Disaster Monitoring Centre (KSNDMC) has used the GIS technology in a smart way to tackle their urban floods. A GIS dashboard was developed by the department which is interlinked with the rain sensors, thus updating real time rainfall data into the system. This live information will be used by the KSNDMC to predict flooding incidents, find affected locations due to inundation, and instruct the rescue team to go to the flood hit location immediately (KSNDMC, unknown).

1.2 Research Problem and Motivation

Chennai is a city situated in the eastern coast of Tamilnadu, India. The geographical setting of Chennai makes it vulnerable to natural disasters like Floods and Cyclones. The monsoon rainfall is received from the North east monsoon winds from September to December. Apart from it, the city is frequently hit by cyclones formed in the Bay of Bengal (Wikipedia, 2021). Some of the recent and strong cyclone that hit Chennai are, Cyclone Nivar (Year 2020), Cyclone Amphan (Year 2020), Cyclone Gaja (Year 2018), Cyclone Fani (Year 2019) and Cyclone Vardah (Year 2015). “These extreme weather conditions result in heavy rains, way beyond the carrying capacity of the river systems and the drainage system, disrupting normalcy. Some of the cyclonic storms are accompanied by gale winds gushing even beyond 140 Kmph, wreaking havoc on the public infrastructure including power infrastructure and causing loss of lives and damages to housing and agricultural properties" (TNSDMA, 2017).

With the growth in economy and opportunities the settlements started to expand into towns and cities. Over population in the Chennai city forced the mediocre community to carry out their socioeconomic activities in areas exposed to natural hazards (Avinash, 2009, pp. 48-51) and build their houses on dried up lakes, flood risk zones, marshlands etc. The need for land and housing made way for real estate developers to plunder the lands further. In some places, the marshlands and lake beds were filled up with gravel and sand, to make strong foundations and high rise apartments and building were built and sold. This became a common practice. The natural drainage system was chocked and suffocated by these developments. Instead man started building artificial storm water drains to escape from the inundations caused by rainfall. But these community suffer from socio economic losses when a cloudburst occurs. Thus the aggressive encroachment of ponds and lakes by uncontrolled development and poorly planned drainage network has made the city prone to flooding. The Chennai Corporation authorities claim that the storm water drains of the city is designed only to sustain 70 mm of rain per day (Sivakumar, 2021). Most of the Buildings in Chennai are built on dried out lakes and marshlands. Due to this scenario, some low lying streets of Chennai gets inundated by receiving less than 100 mm of rainfall per day. This condition of flooded streets highly affects the daily livelihood of the people. Some local residents even increased the height of their buildings at their own cost. A study titled, "Future changes in precipitation extremes during northeast monsoon over south peninsular India "by Pune-based Indian Institute of Tropical Meteorology (IITM) and SRM Institute of Science and Technology (SRMIST), Chennai concluded that there could be a 5% increase in the average amount of rainfall during the northeast monsoon from 2020 to 2049. So it is necessary to carry out a study to identify the flood risk free area for people to reside.

The Greater Chennai Corporation (GCC) along with National Centre for Coastal Research (NCCR) did a study to list out the most vulnerable areas in Chennai after the 2018 monsoon. The data showed that Zone 15 tops the list with 19 vulnerable spots. Zone 15 is the southernmost and the last zone of the Chennai Corporation. It comprises of 9 wards. Among which the study will be carried out on Ward No.200 of Zone 15.

This ward comprises mostly residential buildings. People from different parts of the city, and even State started moving into this area, which attracted many real estate developers to invest in this area as it is said that 40% of the IT population lives in this region. Poor Slum residents from Besant Nagar, Santhome, Korrukkupet and Mylapore areas from the city were also rehabilitated to this area. The development of residential Buildings and illegal encroachments started to happen on the unsuitable areas like dried lake beds and marsh lands. The worst after effects were seen during Rainfall. The area faced severe inundation for several days even for minimal rainfall. People were unable to come out of their homes, and the helpers were unable to enter the houses. People were stuck in their houses for nearly a month. Essential amenities were supplied to them through bulldozers.

Rainfall: The land of Chennai is situated in the tropical monsoon zone. The climatic conditions of Chennai can be divided based on the hydro meteorological features of the land area which it covers.

- The Monsoon period from June to December every year
    - Southwest monsoon from June to September
    - Northeast monsoon period from October to November
- Non Monsoon period spanning between January to May every year
    - Winter from January to February
    - Summer from March to May every year.

The monsoons in Chennai are very aggressive in the past few years. The city faced flood disaster almost every November and December each year due to heavy rainfalls. The average rainfall received by Chennai in the previous year 2020 is received from IMD and shown below,

Table 1: Average Daily Rainfall at Major Rain Stations of Chennai – 2020

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Rainfall	32	37	64	68	73	530	568	650	584	798	962	959
Sholling anallur	19	23	75	80	83	632	643	690	663	610	775	789
Meenam bakkam	39	45	60	65	70	512	543	670	612	830	976	983
Nungam bakkam	34	38	60	65	75	489	500	642	547	897	1076	1034
Red Hills	35	40	60	61	64	485	587	598	512	854	1021	1031
Average Rainfall	32	37	64	68	73	530	568	650	584	798	962	959

Source: IMD, Chennai

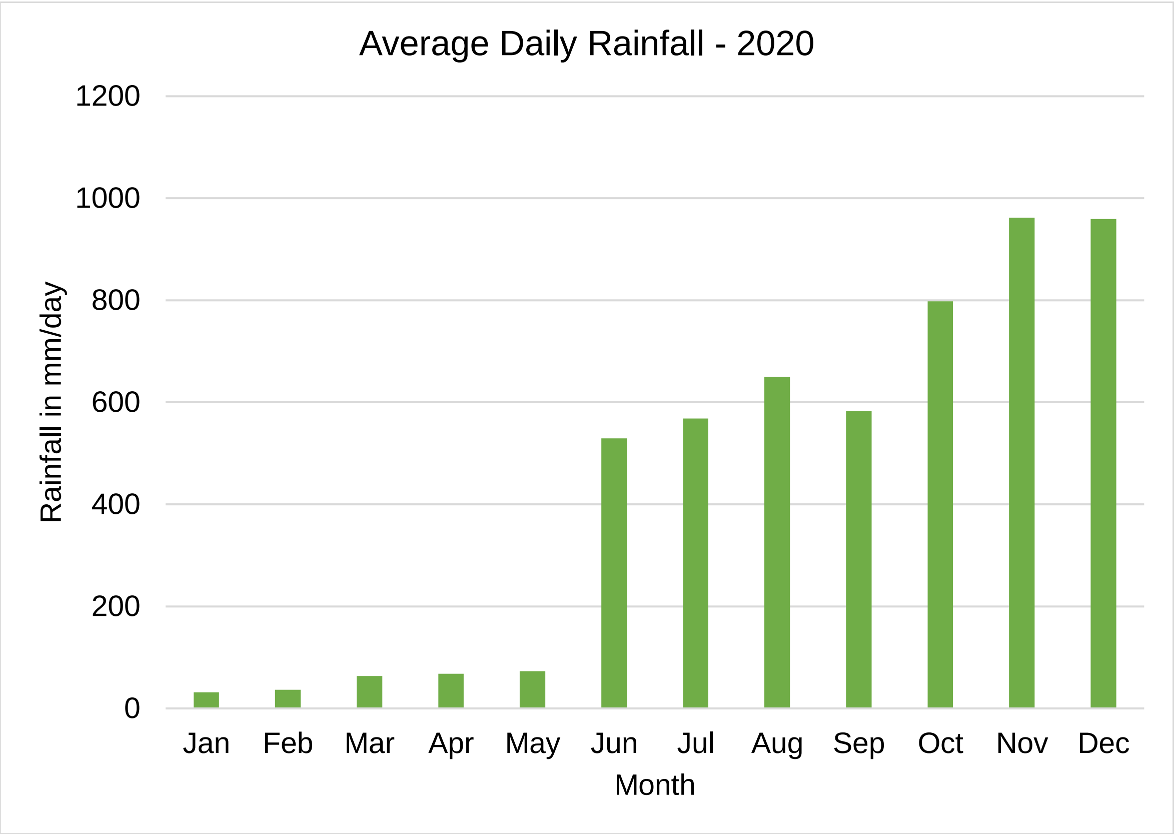


Figure 1: Average Daily Rainfall - 2020

The annual rainfall report since the year 1994 is shown below (National Water Mission, 2020),

- Maximum rainfall is 2772.45 mm in Cooum sub basin (1994-95).
- Minimum rainfall is 412.85 mm in Nagariar sub basin (2016-17)
- Annual average rainfall varies from 587.56 mm (2016-17) to 2162.17 (2015-16)

The study area receives its maximum rainfall in the months of November and December every year.

1.2.1 Flood Mitigation Practises in Chennai

I visited the Storm Water Drain Department of the Greater Chennai Corporation to understanding the Flood Mitigation practices that are currently followed. The SWD department is headed by Mr, L.Nandakumar, the Chief Engineer.

The Greater Chennai Corporation (GCC) has formulated a Disaster Management Plan, 2018 after facing the deadly 2015 floods. It is after this Catastrophe, the departments of GCC realized that they need better preparedness and improved disaster management plans to ensure safety. Experts and stakeholders from various domains framed the Disaster Management Plan, mentioning the importance of archival of relevant data like, the topography, rainfall pattern, position and extent of waterbodies, river and storm water drain system, fire and medical emergency facilities, telecommunication facilities, and coastal tidal pattern. These data shall be used to make better decisions in case of emergency (GCC, 2018, pp. 8-78). The GCC's Disaster Management Plan takes into account the Global and National Trends in Disaster Management and it incorporates the approaches suggested in the Sendai Framework for Disaster Risk Reduction 2015-2030 (Karthikeyan, 2018, p. 8).

As part of emergency management, Indian Meteorological Department (IMD) has set up automated warning systems, at Avadi, DGP Office, Egmore, Shollinganallur, and Madhavaram. The Flood rescue measures include, boats and choppers to rescue people.

Heavy duty pumps, excavators, fire service machines were used to pump the water out and clear the inundated areas. Material and Relief centres were formed around the inundated areas. The GCC opened about 176 relief centres to accommodate more than 1.2 lakhs of people.

Picture 1: A scene from The Chennai Floods, 2015

Picture 2: Relief Centers

Picture 3: Flood Rescue Measures and Flood Mitigation measures

Remote Sensing: A pilot project on Remote sensing based study was carried out using Radar Imaging Satellite (RISAT) Microwave Satellite Imagery to map Inundated areas during the 2015 Floods.

After the rescue and mitigation works a committee was formed to analyse the causes of the Flood. The following points were concluded as the major factors contributing to the urban flooding,

- The main cause was most of the waterbodies disappeared due to uncontrolled encroachment
- Sand bar formation at the mouth of the rivers, which slow down the discharge rate
- Clogging of drains due to dumping of Solid waste and debris
- Inadequate design capacity of SWD in Highways and major roads
- Lack of connectivity of existing storm water drainages with macro drainage system and also absence of Storm Water Drain in the extreme end wards of the Chennai Corporation

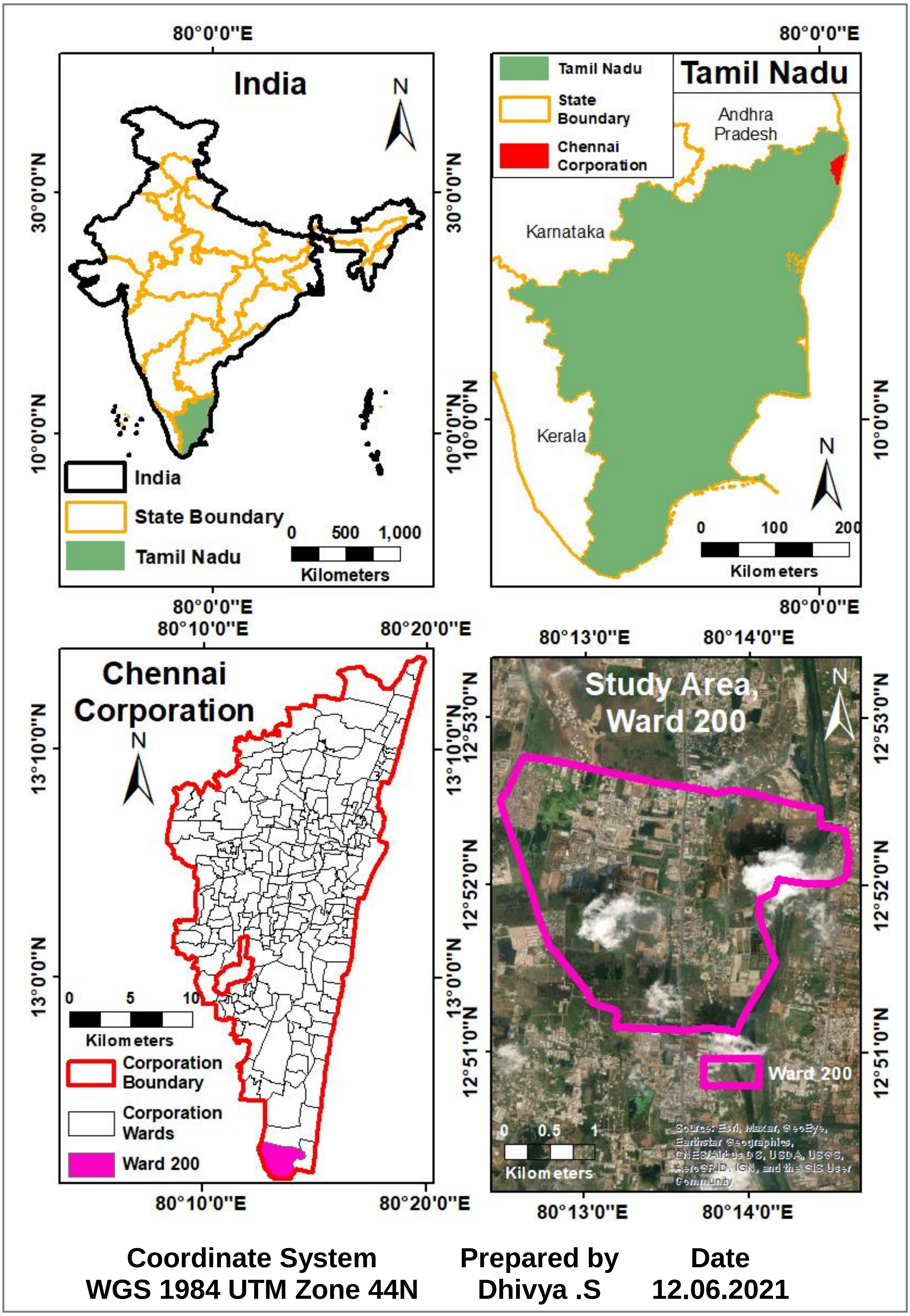
1.3 Study Area

The Corporation of Madras was first formed in the year 1688 under the royal charter issued by King James II of the East India Company. This is the second oldest corporation in the world. In the year 1765, Lord Clive introduced a policy to set up habitats for the East India Company's forces alone. These places were named Cantonments. Following this, The Cantonment Board St. Thomas Mount cum Pallavaram was established in Madras in the year 1774 covering an area of 12 sq.km. Under the provisions of the Cantonments Act 2006, the Cantonments come under the administrative control of Government of India in the Ministry of Defence, and it will not be a part of the Corporation boundary. The boundaries of the corporation was first extended in the year 1901 to an area of 68 sq.km. The second expansion happened in 1978 after the British Rule, where the corporation's area was extended to 174 sq.km. Madras was officially renamed to Chennai in the year 1996. In October 2011 the Chennai Corporation's boundary was extended to a very large area of 430 sq.km. The Chennai Corporation was then renamed as Greater Chennai Corporation (GCC) with 15 zones comprising of 200 wards.(Wikipedia, 2020).

Zone 15 is the southernmost and the last zone of the Chennai Corporation. It comprises of 9 wards. Among which the study will be carried out on Ward No.200 of Zone 15. This area is a suburb which was worst affected due to the Rainfall and Cyclones that hit Chennai. Ward 200 comprises of Shollinganallur, Thalambur and Navalur settlements covering an area of 7.4 sq.km with a total population of 35602 (Office of the Registrar General & Census Commissioner, 2011). It is approximately 2 km away from the eastern coast of Bay of Bengal and is situated between the latitude of 12°52' N and 12°51' N and between the longitude of 80°12' E and 80°14' E at an average altitude of 23 feet above Mean Sea Level (Wikipedia, 2021). This place was dotted with lakes, marshy lands and Agricultural Lands, BUT due to rapid boom in the IT industries, many high rise buildings and complexes emerged. Even as the IT corridor connects the ward with the city, major IT buildings are not located in the ward 200 (Lopez, 2016, p. 4).

The study area is crossed by the Buckingham canal, which is considered as the drain for rainfall runoff. This canal was originally a navigation canal stretched between Andhra Pradesh and Chennai, Tamil Nadu. This runs parallel to the coast of Bay of Bengal. This waterbody is now used to drain the rainfall run off water from the urban land. The outlet point is surveyed and mapped by GCC, which is obtained and used for the study.

The location of the Chennai Corporation zones along with the study area Ward 200 is illustrated in the map below,



Map 1. Location of the Chennai Corporation and Ward 200 in India and Tamil Nadu

1.4 Literature Review

GIS based approach has been used in number of studies in various stages of flood disaster management. Majority of the research papers, used GIS with a combination of AHP (Analytical Hierarchy Process) Multi Criteria Decision Algorithm approach to do the flood mitigation studies. Flood risk at Vietnam was conducted using a combination of GIS and AHP methods (Dang et al., 2011, pp. 169-194). There are many factors that contribute to a flood risk, the flood risk areas shall be identified using historical flood hazard impact data, Social factors and Infrastructure exposure vulnerability (Armenakis et al., 2017, p. 123). Many articles, journals and research papers were reviewed for my study. The important ones are explained below in this Literature Review section.

1.4.1 Causes of Flooding

Flooding is a very common natural disaster which the world is facing recently. The intensity and occurrence of flooding has increased predominantly in the last few years. Many literature papers quote the major reasons for flooding in urban areas are due to land use change i.e., urbanisation and climate change.

In the paper, "Causes and Impact of Urban Flooding in Dehradun" by (Bansal et al., 2015, pp. pp.12615-12627) the author explained that the city of Dehradun is often hit by urban floods. Due to rapid urbanisation in the city premises, the buildings were built in much closed proximity which led to the closing and blockage of the existing storm water drains. Due to encroachments, the streets were also become very narrow restricting the rainfall run off water to reach the outlet of storm water drains. Due to these manmade scenarios, the region gets flooded and inundated even for a low intensity rainfall. The author used historical evidences and field survey of residents along with various factors like, Topography, elevation, slope, rainfall, Runoff volume, river beds encroachment, failed embankments, urban storm water drains, roads width, river pollution, Vulnerable urban infrastructures, building vulnerability classification as per building material, classify building based on age, historical flooding water depths, and traffic jammed streets during flooding. All these factors were analysed to conclude the causes of flooding in an urban area. From the study the author concluded that, the Flood risk in general is higher in cities with a backdrop of high demographic growth, unplanned urbanization and impact of climate changes, which are general and most frequent causes of urban flooding.

1.4.2 Flood Risk management

The WMO/GWP has published a document on Urban Flood Risk Management, in which the GIS technology is proposed to do the Risk Assessment of the Flood Prone areas. Various parameters has to be considered while doing a risk assessment. The past records of hazard, its intensity, loss, exposure and vulnerability of the society needs to be considered, along with it, the future development plans, possibility of urbanization, waterbodies at the verge of extinction all play a major role in risk assessment (WMO, 2008).

In the paper, "Flood risk and context of land-uses: Chennai city case" (Gupta & Nair, 2010, pp. 365-372), the author has evaluated land use change pattern in Chennai in regards to loss of hydrological features, encroachment of waterbodies like rivers, streams, lakes and ponds, uncontrolled development of buildings using GIS techniques. This study was drawn from the technical report of a national level study accomplished in India covering 8 important cities – Bangalore, Bhopal, Chennai, Kolkata, Hyderabad and Mumbai, Bhopal and Surat by National Institute of Disaster Management. In this context the city infrastructure, existing drainage, geo environmental, hydrological and socio-economic profiles were analysed. It is concluded that, planning and regulatory controls to prevent development in old tank beds unless adequate flood defence measures are in place enforced by the local government of Chennai.

The paper, “Flood damage assessment of an urban area in Chennai, India, part I: methodology” (Suriya et al., 2012, pp. 149-167) aims to prepare a flood management strategy for efficient management of future flood disasters. The study area is suffering from uncontrolled growth in infrastructure due to (IT) corridor and industries development led to rapid encroachment of water bodies due to population explosion. The storm water is a real problem in these newly emerging areas. Due to this, the flood risk level increases every year. The author used Quick Bird imagery to generate map the features and did a field survey to prepare a Triangulated Irregular Network (TIN). The flood patches were generated using ArcGIS software. Then field questionnaire survey was executed to study the flood risk on the field. In the second part of the paper, “Flood damage assessment of an urban area in Chennai, India, part II: results and discussions” (Suriya et al., 2012, pp. 159-167) a stage damage curve was drawn based on the information collected. It was concluded that Optimal and sustainable mitigation measures can be achieved only when the sociological aspects are fully considered.

The book on, “Flood risk assessment and flood risk management” (Klijn Frans, 2009) is developed based on experiences and findings of flood site. It is mentioned clearly that a flood cannot be prevented but if we take necessary measures the after effects of a flood could be prevented or reduced. Some of the measures presented in this book are, flood defence measures, flood control measures and spatial planning, which aims on lowering the intensity of the flood impacts in the vulnerable zones. It is also mentioned that single measurement approach cannot solve the flood risk management purpose, instead a combination of all the measures like, Geospatial, Mechanical, Infrastructure, electrical etc. must be in synchronised to achieve the best flood risk management plan.

It is found from various literature reviews that, GIS methods and tools are widely used in many flood related studies, like flood risk mapping, flood prediction, Mitigation measures, and rescue operation and planning. GIS along with various models are also incorporated for better results in various studies. This thesis incorporated GIS tools along with other approach and model to derive better results of flood risk mapping and flood prediction.

1.4.3 AHP and GIS Approach

The paper on, “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) aims to estimate flood risks in growing urban areas. The author adopted GIS integrated with AHP techniques to estimate the results. The study was carried out in the Eldoret Municipality in Kenya. The Municipality has been prone to flooding since the last decade. The cause of flood in the municipality is due to unplanned urban development, encroachment of low lands, drainage clogging, precipitation, water logging, and natural process of soil erosion. The municipality’s area has predominantly increased from 12 Sq.km to 248 Sq.km between 1912 and 2013. This paper used the various criteria contributing to the urban floods to derive the flood risk zones results. The criteria used in this paper are, rainfall distribution, elevation and slope, drainage network and density, land-use/land-cover and soil type. The results produced were cross verified by historical flood reports. The results matched ~92% of the real time results during the flood, a maximum error of not more than 8% was observed in the highly vulnerable flood zones

In the research paper, “Evaluation of food risk parameters in the Day River Flood Diversion Area, Red River Delta, Vietnam” (Dang et al., 2011, pp. 169-194) has quantitatively evaluated the flood risk factors using GIS and Analytical Hierarchy Process (AHP) approach. The study was carried out in the Red River Delta, Vietnam which is about 169,000 sq.km. There has been several occasions of flooding in this delta due to flood diversions in the incident if broken dykes. In the year 1985 Hoa Binh reservoir was built in the upstream for flood control, after this the people overlooked the flood risks and encroached the floodway areas. This paper aims to enlighten the population regarding the flood risks due to the land use change effects and make them understand that Residential buildings and population factors contribute to the flood vulnerability from the economic, social, and environmental perspectives.

In the paper, "Remote Sensing and GIS Applications in Flood Management" (Aggarwal et al., 2009, pp. 145-158), the author has presented the importance of geospatial technology in the preparedness, monitoring and mitigation phases in the event of a Flood. This study was carried out in rural Orissa (Kendrapara) using a community-based approach together with geospatial analysis tools. It is mentioned in the study that GIS database prepared during the preparedness phase must contain agriculture, socio-economic, communication, population and infrastructural data. This will be the base data, which shall be used in the mitigation stage to plan the rescue operations. This data will be also integrated with the historical precipitation, storm data to generate the flood risk maps and flood vulnerable zones and streets.

The paper on, "Remote Sensing and Geographic Information Systems for Flood Risk Mapping and Near Real-time Flooding Extent Assessment in the Greater Accra Metropolitan Area" by (Adjei-Darko, 2017) aims to carry out a flood risk assessment and management study on the Greater Accra Metropolitan Area using remote sensing and Geographic information system with a combination of Multi Criteria Decision Analysis approach. The study is prone to flooding which resulted in many environmental and material losses. This study was done to identify the flood prone areas so that the vulnerable population could be relocated to a safe place before a flood occurs. Sentinel-1A SAR images were used as the raster base map to derive the criteria for the MCDA. The criteria used to derive the flood risk map are, elevation, slope, rainfall, drainage, land cover and soil geology. The result showed that over 50% of the study area is likely to experience high level of flooding. The author also mentions that the time of capture of the satellite imagery also affects the analysis results, as the imagery taken right after flood will show more real time risks while the imagery taken days after the flood will predict the risk depending on other criteria.

This paper, “Flood Susceptibility Assessment through GIS-Based Multi-Criteria Approach and Analytical Hierarchy Process (AHP) in a River Basin in Central Greece” (Lappas & Kallioras, 2019) aims to identify the flood prone areas in the within the Atalanti drainage basin in Central Greece using GIS bases AHP Multi criteria approach. The criteria used for this study were, Rainfall intensity, river basin’s slope, land use and land cover, Topography of the area, soil type, distance from the drainage network, Topographic Wetness Index (TWI) and Digital Elevation Model (DEM). The resultant flood risk map was used for Flood risk Management studies. The result also helped the authorities to construct the appropriate infrastructures in the risk zones.

The paper, “Flood vulnerable zones in the rural blocks of Thiruvallur district, South India (Periyasamy et al., 2018, p. 21) aims to map the flood vulnerable zones in the study area using GIS technology. The study was carried out using drainage, geology, geomorphology, land use, and land cover, tectonic map, DEM and slope derived from the Resourcesat-2 LISS IV - 2014 and Shuttle Radar Topographic Mission (SRTM) data. The data was classified and Weighted overlay analysis was performed in ArcGIS software to derive the flood vulnerable map.

The paper, “Mapping Storm Water Sewer System using GIS” (Subramanian et al., 2015, pp. 23-32), aims at developing a solution through GIS to arrive at the right location to build storm water drains. The study was carried out in Zone 109 of the Chennai Corporation. Field survey was carried out using GPS to map the existing storm water drainage network. The author has used open source satellite imagery to map the existing infrastructures and Land use features. The SWD data is integrated with this Land use data to arrive at the SWD classification Map. The flood prone areas were collected from the respective departments and the data is mapped in Google Earth platform. The SWD maps when overlaid with the flood prone map gave the areas where new SWD are necessary.

It is found that AHP based GIS approach is widely used in many study areas to generate the Flood Risk zone map. From the review of various literatures, it is decided to use AHP based Multi Criteria Decision Analysis method along with GIS tools to generate the Flood Risk zone map in the present study of the thesis.

1.4.4 Flood Prediction Studies

In this paper "GIS Framework for Spatiotemporal Mapping of Urban Flooding and Analyze Watershed Hydrological Response to Land Cover Change" (Abedin, 2014) the author aims to use GIS technology to model the spatio temporal variation of floods in the urban micro watershed. This paper points out that the major culprits of flooding in urban areas are the increased impervious surface and inadequate drainage infrastructure system which are the results of urbanisation. The author also terms the urban flood as a manmade disaster. Floods can bring in economic, structural, and environmental damages, and casualties too, due to this it has become very important to predict the flood before it comes for preparedness. For a precise flood modelling high resolution DEM is required. This study used DEM derived from LiDAR point cloud data. The modelling framework includes, delineating urban watershed, generation of runoff hydrograph, and time series mapping of inundation depths and flood extent. The developed model was tested in University of Nevada Las Vegas (UNLV) main campus, Blacklot parking lot and East Mall and validated using newspaper reports and photographic evidence of flooding. The results provided insights on the future planning of storm water drains in the region and prepare for mitigation measures before the flood occurs.

In the paper, "Flood Modelling with GIS-derived distributed Unit Hydrographs" (MUZIK, 1996, pp. 1401-1409), the author did a study on the Alberta watershed to predict the flood using Unit hydrograph. The unit hydrograph was derived for spatially distributed excess rainfall and computed from the time area diagram of a watershed. The GIS technology was used to derive the spatial data. The flow direction, flow accumulation and flow length parameters are derived from DEM using the Hydrology tool of the GIS technology. The paper concluded that this method of modelling could be used when there is very minimal data and the data on discharge is not there.

In the paper on, “Developing GIS-Based Unit Hydrographs for Flood Management in Makkah Metropolitan Area, Saudi Arabia” (Dawod & Koshak, 2011, pp. 160-165), the authors used unit hydrograph to compute the flood risk study in Makkah metropolitan area, southwest Saudi Arabia. The study area did not contain the discharge records of its drainage system, so the available metrological, geological, and land use datasets were used to prepare the model. The resulting hydrographs were used to identify the basin which is in risk zone and it was found that the third basin in Makkah city was the most hazardous catchment. This helped the officials of the disaster management department to plan before floods.

In the paper, “Sustainable Urban Drainage System Modeling for Managing Urban Surface Water Flood Risk” by (Ellis & Viavattene, 2014), the authors used an integrated approach of GIS and Hydrology modelling for management of urban surface water flooding. The Dem was used by the author along with hydrograph modelling methodology to derive the results related to flooding events. The results obtained din the study were, critical drainage areas, areas susceptible to flooding in case of extreme rainfall events, and visualization of the flooded areas and associated damages before, and after the implementation of flood control measures. The author concluded that the integration of GIS techniques with hydrologic models produces and effective way to model and control flooding in an urban watershed.

In the paper, “A Comparative Study of GIS Based Runoff Estimation using Distributed CN Method and Time-Area Method” (Sasidharan & Sithara, 2014), the authors explained the methodology of SCS-CN and Time Area to estimate the runoff at a watershed. The study was done to derive the runoff at the Vamanapuram River Basin for implementation of watershed development program. The paper demonstrated the usage of Initial abstraction of 0.2S and 0.3S and comparing the results. The Time Area method was combined with Muskingum Method to derive the Time Area. The paper concluded that the Time Area method and the SCS-CN method estimates the runoff more accurately.

The paper, "Rainfall–runoff estimation using SCS–CN and GIS approach in the Pappiredipatti watershed of the Vaniyar sub basin, South India" (Satheeshkumar et al., 2017, p. 24) aims to derive the suitable location for installing artificial recharge structures in the study area for watershed development and planning of water resources. This study adopted SCS–CN method in the Vaniyar sub basin considering the geomorphological factors, and, land use change to predict the runoff volume and the runoff rate at the catchment. The results were analysed and interpreted to propose the artificial recharge structures.

In the paper, "Estimation of Surface Runoff Using Remote Sensing and GIS Techniques for Cheyyar Sub Basin" (Gayathri C & Jayalakshmi S, 2018) the authors described the SCS-CN methodology to estimate the change in runoff characteristics in the watershed due to urbanisation and land use change. The study was carried out on the Cheyyar sub basin. The handbook of Hydrology by NRCS is used in this paper to estimate the HSG, land use class and the AMC parameters. The obtained result was compared with the actual runoff measures in the sub basin for validation. The authors conclude that the SCS-CN model gives more acceptable results compared to the runoff calculated by the other methods.

In the paper, "GIS Based SCS - CN Method For Estimating Runoff In Kundahpalam Watershed, Nilgiries District, Tamilnadu" (Viji et al., 2015), the authors used SCS-CN method to derive the runoff at the Kundapallam watershed. The paper defines the SCS-CN method as the physical based and spatially distributed hydrological model. The study derived the runoff of the watershed based on AMC I, AMC II and AMC II parameters. The results show that the average annual runoff depth estimated by SCS-CN method for the average annual rainfall of 173.5 mm is 72.5 mm. The results were then validated with the actual runoff at the watershed derived from the field which gave satisfactory results.

It is found that SCS-CN method, Time Area approach along with GIS tools are widely used in many papers to estimate the runoff and predict the flood in the study areas. This hydrological model is widely recommended because it incorporates, land use, soil texture and infiltration characteristics, along with actual rainfall data from the study area. From the review of various literatures, it is decided to use SCS-CN method, Time Area Histogram method along with GIS tools to estimate the runoff and carryout the Flood Prediction in the present study of the thesis

1.5 Aim and Objective of the study

The aim of the study is to identify the Flood risk zones and Flood Prediction at Ward 200 of the Chennai Corporation. The aim of the study is achieved by carrying out the following objectives,

- Identify the flood prone areas and find the flood prone Structures using the LULC of 1954, LULC of 2020 and DEM data
- Decide the Criteria to be used in AHP calculations to find the flood risk zones
- Flood risk zone mapping using AHP in a GIS environment
- Delineate urban watershed with respect to the pour points
- Estimate Runoff at watershed with respect to rainfall, Land use type and Soil group using SCS-CN method
- Compute Time Area Histogram to prepare Isochrone Map
- Generate Unit Hydrograph for Flood Prediction

1.6 Structure of the Project Report

The Thesis Report is organised into four Chapters.

- Introduction: This chapter gives a brief explanation on the study and its background. This chapter is divided into six sub sections Background, Research Problem and Motivation, Study Area, Literature Review, Aim and Objective of the study, and Structure of the Project Report.

- Methodology: This chapter explains the methodology used in this study. This chapter is divided into five sub sections, Data Used, Interpretation of Flood Prone Areas and Structures, Multi Criteria Decision Analysis, Unit Hydrograph Modelling and Software used.

- Process and Result: This is the chapter which illustrates the process followed in the project and the results obtained. This chapter is divided into four sub sections, Flood Prone Areas and Structures, Flood Risk Mapping using MCDA, Flood Prediction using Hydrograph and Results.

- Conclusions: This chapter concludes the project report by explaining the Discussions, and Future works of the study.

- References: All the references are listed in this section

This chapter gives a very detailed introduction of the Thesis work. The need to take up the study, detailed explanation of the study area, aims of the project are explained in this chapter along with the methodologies reviewed across various literature works will be practically implemented in the study area in the subsequent chapters to arrive at the result for this Thesis work.

Chapter 2: Methodology

The aim of this thesis is to generate a flood risk zone map and flood prediction for the study area using GIS and supporting techniques and technology. The objectives of the project include the interpretation of flood prone areas, Find flood risk zone and execute flood prediction study. These objectives were achieved using GIS, MCDA, mathematical calculations and hydrological modelling techniques. This chapter explains in detail about the methodology adapted in this study. The chapter is divided into the following sections,

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

Geographical Information System (GIS) technology along with the required data shall be used to find out the flood prone areas and the Structures at flood prone areas. The data will also be used to study the existing drain system and predict flood using mathematical calculations and Unit Hydrograph. This study and the resultant maps can help Chennai Metropolitan Development Authority (CMDA), the planning and development department of Chennai to make informed decisions on where not to build or where development should be accompanied with special landscape architecture (ESRI, 2021). The results shall be used by the disaster management department to plan the rescue activity and recovery measures.

2.1 Data Used

This project used a profusion of raster and vector data for the study. Some data were received as documents and AutoCAD DWG format files from official records of the Greater Chennai Corporation, which were converted to shapefile formats using ArcGIS, Google

Earth and World Imagery Base map of ESRI. Other data were collected from freely available official data sites like Bhuvan (an Indian web utility portal), USGS Earth Explorer and State Govt. websites. The processing and analysis of the data were done in ArcGIS 10.2 software. The data collected for this project are mentioned in Table 2

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)
Tamil Nadu District Boundary	Vector - Polygon	Open source data from Data Meet (http://projects.datameet.org/maps/districts/)
Chennai Ward map	Vector - Polygon	Open source data from Data Meet (http://projects.datameet.org/Municipal_Spatial_Data/)
Ward 200 Study Area Boundary	Vector - Polygon	Derived from the ward map of Chennai. Area of the Study area is 7.45 sq.km
Raster Data		
Data	**Format**	**Source**
Toposheet	Raster	Toposheet No 66D1 is obtained from Anna University Library for the surveyed year 1954 at 1:50000 scale Toposheet No 66D1 is obtained from Survey of India. 1: 50000 Scale for the surveyed year 1970 (https://soinakshe.uk.gov.in/Login.aspx)
Aerial Imagery	Raster Data with 2cm resolution	Received from a Private consultant who is surveying for the Chennai Metro Water Supply and Sewage Board (CMWSSB). Receive the data, strictly to be used only for the MS Thesis purpose.
High Resolution DEM	Raster TIFF with 5 cm accuracy	Received from a Private consultant who is surveying for the Chennai Metro Water Supply and Sewage Board (CMWSSB).

Soil Data	Raster	Digitized from Soil Survey of India Maps of Kanchipuram District.
Vector Data		
Data	**Format**	**Source**
Water Bodies	Vector Polygon	Open source data from Map Cruzin (https://mapcruzin.com/free-india-country-city-place-gis-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.
Flood Relief Camps	Vector Points	Digitized from Google Maps (https://www.google.com/maps/d/u/0/edit?mid=1xT-nmpJ678sF4tiyy0KEvy5Iyg8&ll=15.090756380921277%2C78.10247868437524&z=7)
SWD (Storm Water Drain)	Vector Line	The data shall be digitized as points and lines from the High resolution Aerial Imagery The existing SWD network was procured from the SWD department, Chennai Corporation.
Historical Flood Inundation data	Vector Line	December 2019 - Open source data from GitHub database (https://github.com/osm-in/flood-map/blob/gh-pages/data/chennai-flooded-streets-Dec2.geojson) September 2015 – Data from UNITAR (United Nations Institute for Training and Research) (https://unitar.org/unosat/node/44/2312)
Other Data		
Data	**Format**	**Source**
Existing Flood management Procedures in Chennai Corporation	PDF Document	Received from Mr, B.Sivakumar, Superintending Engineer, Storm Water Drain Management Division, Greater Chennai Corporation Office, Chennai

Inundated Streets Data	Excel File	Received from SWD Department of GCC.
Rainfall Data	PDF	Maximum rainfall per day data of Sathyabama and Shollinganallur station Average monthly rainfall of all stations of Chennai for the year 2020. The data was procured from IMD, Chennai Hourly rainfall of Chennai that occurred on November 25 2020. The data was procured from World Weather Online (https://www.worldweatheronline.com/chennai-weather-history/tamil-nadu/in.aspx)
Field Data		
Data	**Format**	**Source**
Inundated areas	Photographs	Site Photographs from November 2020 during Nivar Cyclone

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 Interpretation of Flood Prone Areas and Structures

This is a non-scientific method to identify the flood prone area and the flood prone structures in the area. The land use land cover of the study area is digitized out from the 1954 toposheet. This is will be termed as old land use in this study. The new land use land cover data is digitized out from the Orthophoto. This shall be termed as new land use land cover.

The current building layer is overlaid on the old toposheet to identify the buildings that fall on the flood prone areas.

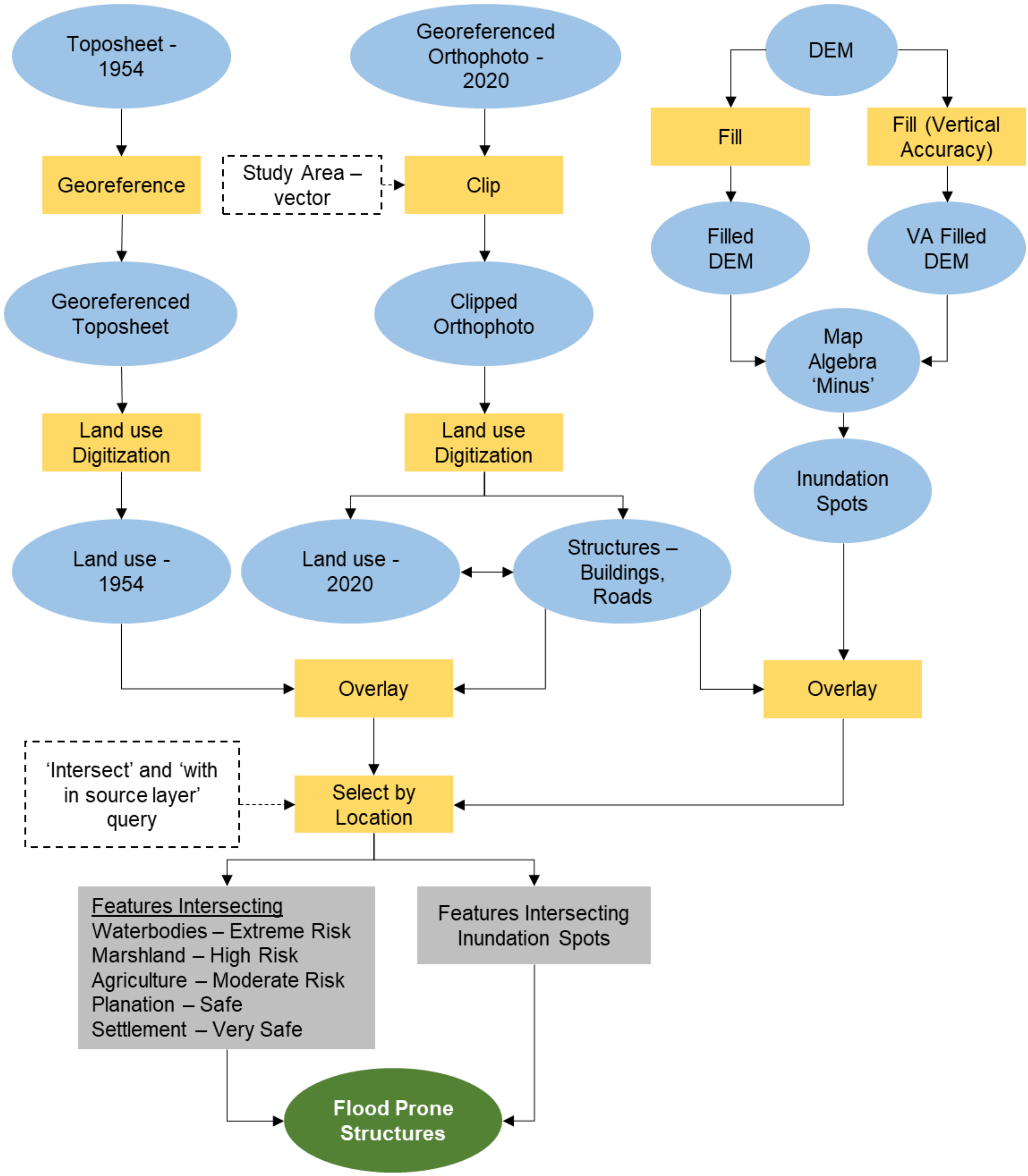


Figure 2: Methodology of Identifying Flood Prone Areas and Flood Prone Structures

2.3 Multi Criteria Decision Analysis

This study adopted GIS based AHP approach to find the Flood Risk zones in Ward 200. Geographical Information System abbreviated as GIS is a conceptual technology that lets us map geographical/spatial data and analyse the data using different tools to arrive at a spatial solution. GIS tools were used in natural disaster management studies to locate risk and Risk zones, spatially visualises features and gives nearly accurate results. Many similar papers from the journals with good impact factors were studied and the most appropriate approach, GIS – AHP Multi Criteria Decision Analysis (MCDA) was selected. In my study I integrated GIS with AHP technique considering a combination of various criteria to find the flood Risk zones in the study area.

The analytic hierarchy process (AHP) is a structured technique for organizing and analysing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s (Wikipedia, 2020). AHP (Analytical Hierarchy Process) has been proposed as a systematic approach to set priorities and to determine the weight of each criteria. The AHP (Analytical Hierarchy Process) is used to form a pair wise comparison matrix of the criteria. The criteria are ranked as per Saaty's fundamental scale (Saaty, 2000). The criteria are combined and given the right weightage to generate the Flood Prone Buildings map. The weightage of each criteria is arrived by normalising the pairwise comparison matrix. The weights are then assigned to the criteria to perform the weighted overlay analysis in the ESRI's ArcGIS 10.7 Software. The Buildings that fall in these zones are identified to be prone to flooding.

The criteria for this study were selected based on environmental and socio economic factors. Then each criteria were reclassified to a scale of 1 to 5 with respect to the decided parameters. Pairwise comparison matrix was developed as per the AHP methodology. Normalised Pairwise Matrix was prepared and the weighted criteria were derived as per literature review and expert opinion. The consistency ratio as checked, which should be less than 0.10. Once the consistent value was reached the weighted criteria was applied. The steps for the AHP calculation are mentioned below,

- Pairwise Comparison Matrix: The matrix is arrived by establishing relative importance for the criteria by rating the criteria in a matrix at a scale of 1 to 9.

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	Experience and judgement strongly favour one activity over another
4	Very Strong Importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
5	Extreme Importance	The evidence favouring one activity over another is of the highest possible order of affirmation

Source: (Saaty, 2007)

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

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \times \begin{bmatrix} W_{11} \\ W_{22} \\ W_{33} \end{bmatrix} = \begin{bmatrix} C_{v11} & C_{v12} & C_{v13} \\ C_{v21} & C_{v22} & C_{v23} \\ C_{v31} & C_{v32} & C_{v33} \end{bmatrix} \quad \text{eq. 2.1}$$

Where,

C = Criteria

W = Weight

C_v = Consistency vector

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

$$R = \sum_{i}^{j} (C_v \div W) \quad \text{eq. 2.2}$$

$$\lambda_{max} = \left(\sum_{i}^{j} R\right) \div n \qquad \text{eq. 2.3}$$

$$CI = (\lambda_{max} - n) \div (n - 1) \qquad \text{eq. 2.4}$$

$$CR = CI \div RI \qquad \text{eq. 2.5}$$

Where,

R = Ratio

n = No of criteria

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	14
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	1.58

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

2.3.1 Criteria Used

This project proposes to use GIS techniques with a combination of AHP Multi Criteria Decision Approach to find the flood Risk zones in the study area. The criteria considered in this study to find the inundation risk zones are, elevation, slope, soil data, rainfall data, flow accumulation, Inundated roads, and land use. These criteria were selected based on environmental and socio economic criteria. The criteria under the environment factors are elevation, slope, soil data, rainfall data, flow accumulation. The socio economic factor considered in this study are the Inundated roads and land use. It is due to the rapid urbanisation and increased rates of land the destitute population started developing their community in and around the 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 Risk maps will be classified to five classes, 1 – Extreme Risk, 2 – High Risk, 3 – Moderate risk, 4 – Safe, 5 – Very Safe.

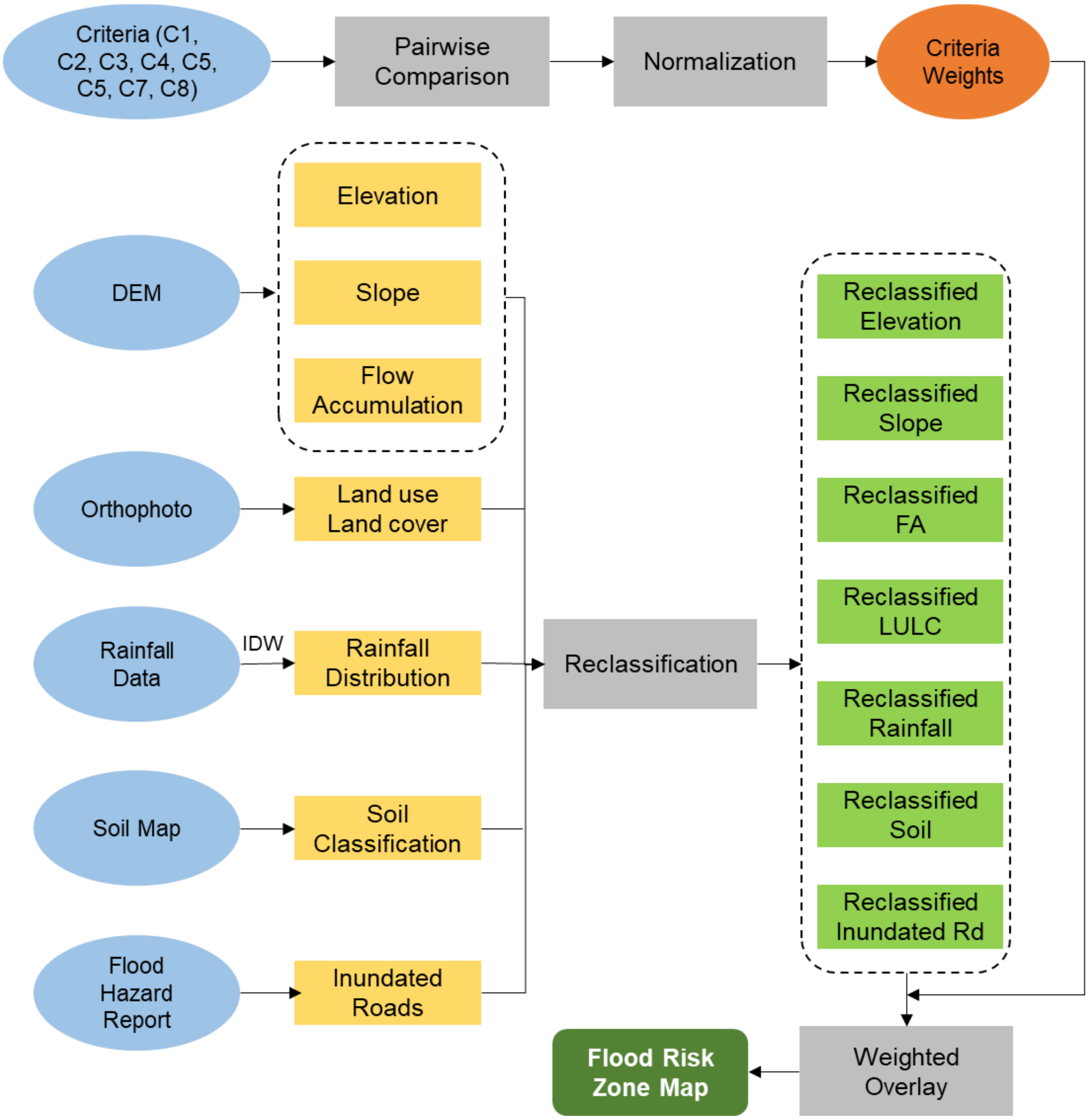


Figure 3: Methodology of MCDA

2.4 Unit Hydrograph Modelling

The flood prediction study is performed on the study area by generating unit hydrograph using the SCS-CN and Time Area Histogram method. Hydrographs are line graphs which depicts the volume of water a drainage will discharge to its outlet, in a defined time interval during the event of a rainfall.

2.4.1 Watershed Delineation

The watershed is delineated using the hydrology tools flow direction and Watershed tool under the Spatial Analyst Tools in the toolbox. It is pointed in many literature that filled DEM must be used to delineate the watershed, thus removing all the sink errors in the DEM being used. The generated True DEM is given as the input surface raster for the flow direction tool, the default flow direction type 'D8' is accepted. This method assigns flow direction to the steepest downslope neighbour. The derived Flow Direction raster ys used to generate the Flow Accumulation raster of the study area. The Flow Accumulation result depicts the value of a cell is the number of upstream cells that contribute their flows to the cell. The raw pour point is picked from the Flow Accumulation. Snap pour point tool is used to snap the raw pour point to the exact point of maximum flow accumulation, thus acquiring the final pour point. The watershed is now derived from the Watershed tool under the Hydrology tool of the Spatial Analyst Tools in the toolbox.

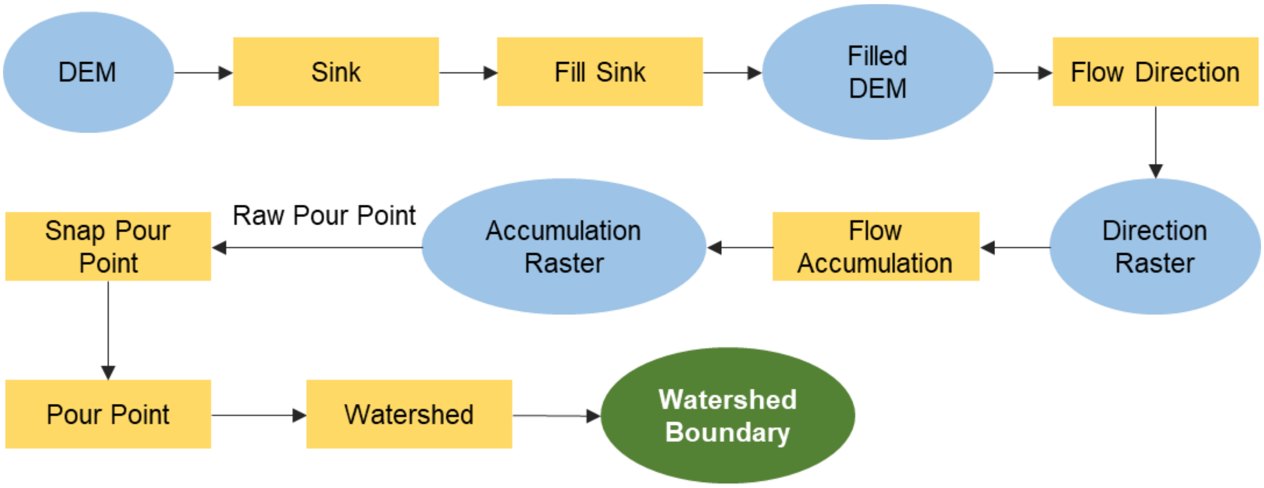


Figure 4: Methodology of Watershed Delineation

2.4.2 SCS Curve Number Method

This study used SCS-CN based GIS method to find the amount of run off from a rainfall event in a particular watershed area. This method was developed by the USDA Natural Resources Conservation Service, which was formerly called the Soil Conservation Service or SCS (Wikipedia, 2021). This methodology can be termed as SCS-CN method or NRCS CN method. The SCS-CN method calculates the runoff of a watershed area by considering the soil texture and infiltration capacity, Antecedent Moisture Condition (AMC) of the watershed and the land use type of the area. The USDA has classified the different types of soil into four groups based on its infiltration capacity and soil texture, which is termed as Hydrologic Soil Group (HSG).

Table 6: Hydrologic Soil Group (USDA, 2009)

Hydrologic soil (HSG)	Soil textures	Runoff potential	Water transmission	Final infiltration
Group A	Deep, well drained sands and gravels	Low	High rate	> 7.5
Group B	Moderately deep, well drained with Moderate	Moderate	Moderate rate	3.8–7.5
Group C	Clay loams, shallow sandy loam, soils with moderate to fine textures	Moderate	Moderate rate	1.3–3.8
Group C	Clay soils that swell significantly when wet	High	Low rate	< 1.3

The AMC calculation is done to find the infiltration capacity of the soil during an event of a rainfall. If the soil is dry, it has the capacity to infiltrate more water during the event of a rainfall, whereas when the soil is wet, it will have very less capacity to infiltrate the rain water and will contribute to more runoff. The AMC is divided into dry, average and wet classes based on the five day antecedent rainfall event. The classification of the AMC based on the antecedent five day rainfall event is shown below.

Table 7: Antecedent Moisture Condition (SCS, 1972)

AMC Group	Soil characteristics	Five day antecedent rainfall in mm	
		Dormant season	Growing season
I	Wet condition	Less than 13	Less than 36
II	Average condition	13–28	36–53
III	Heavy rainfalls	Over 28	Over 53

The major advantage of this method is that it considers the land use type of the area for which the study is being done. Land use type has a major contribution towards the runoff for a particular rainfall event. The SCS method has a well-defined land use category and its corresponding curve number with respect to its soil group. Few major land use categorisation with respect to the soil group are shown below for reference.

Table 8: Curve Number of Land use based on HSG (SCS, 1972)

Land use Type	Curve number for HSG			
	A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.)	49	69	79	84
Commercial and business	89	92	94	95
pervious areas only, no vegetation	77	86	91	94
Row Crops	67	78	85	89
Open space	49	69	79	84
Water	0	0	0	0

The runoff in a watershed is estimated using mathematical computations incorporating the above mentioned HSG, AMC, and land use parameters. The methodology with the steps carried out in this thesis study is explained in Figure 5.

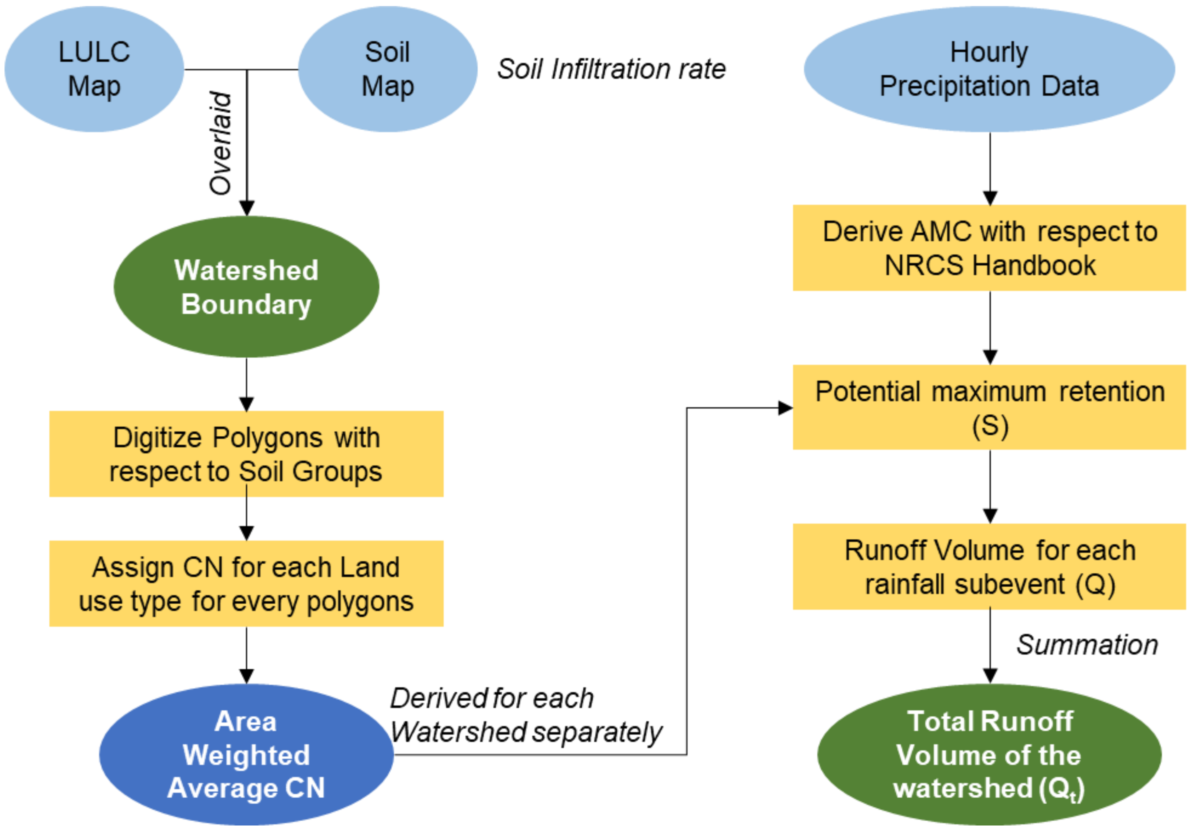


Figure 5: Methodology of SCS-CN

The formula for the estimation of the runoff is based on the water balance equation and two fundamental hypothesis. As per the first hypothesis, the ratio of the actual amount of direct runoff to the maximum potential runoff is equal to the ratio of the amount of actual infiltration to the amount of the potential maximum retention.

$$\frac{Q}{P - I_a} = \frac{F}{S} \qquad \text{eq. 2.6}$$

$$P = I_a + F + Q \qquad \text{eq. 2.7}$$

The second hypothesis says that the amount of initial abstraction is equal to fraction (λ) of the potential maximum retention.

$$I_a = \lambda S \qquad \text{eq. 2.8}$$

Where,

Q = Runoff Volume (mm)

P = Precipitation (mm)

I_a = Initial abstraction (mm)

F = cumulative infiltration excluding I_a (mm)

S = potential maximum retention or infiltration (mm)

λ = A fraction which is derived with respect to the topographic condition of every region.

For Indian terrain the fraction is considered to be 0.3 (Satheeshkumar et al., 2017, p. 24)

$$I_a = 0.3S \qquad \text{eq. 2.9}$$

Combining the equation 2.1 and 2.2 the runoff Q can be formulated as,

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \qquad \text{eq. 2.10}$$

Substituting I_a = 0.3S, the equation in its standard form is

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)} \qquad \text{eq. 2.11}$$

Where Q = 0 for P ≤ 0.3S. S is mapped on to CN as follows:

$$S = \frac{25400}{CN} - 254 \qquad \text{eq. 2.12}$$

CN = curve number, which depends on land use, hydrologic soil group, and AMC

The above mentioned runoff equation is used to derive the runoff for each sub event of rainfall occurring at the watershed. The summation of the runoff for all the rainfall subevents will give the total runoff of the watershed.

$$Q_t = \sum_{n=1}^{N} Q \qquad \text{eq. 2.13}$$

Where,

Q_t = Total Runoff Volume (mm)

N = cardinality of sequence for each rainfall sub event

2.4.3 Time Area Histogram

The time area histogram computes the area of discharge in a watershed in a specified time. The histogram is derived based on several hydrological equations and GIS Hydrology tools. The computation is done based on DEM and Slope and without considering the land use categorisation. The runoff derived from the SCS-CN method is computed with the time area result to derive the unit hydrograph.

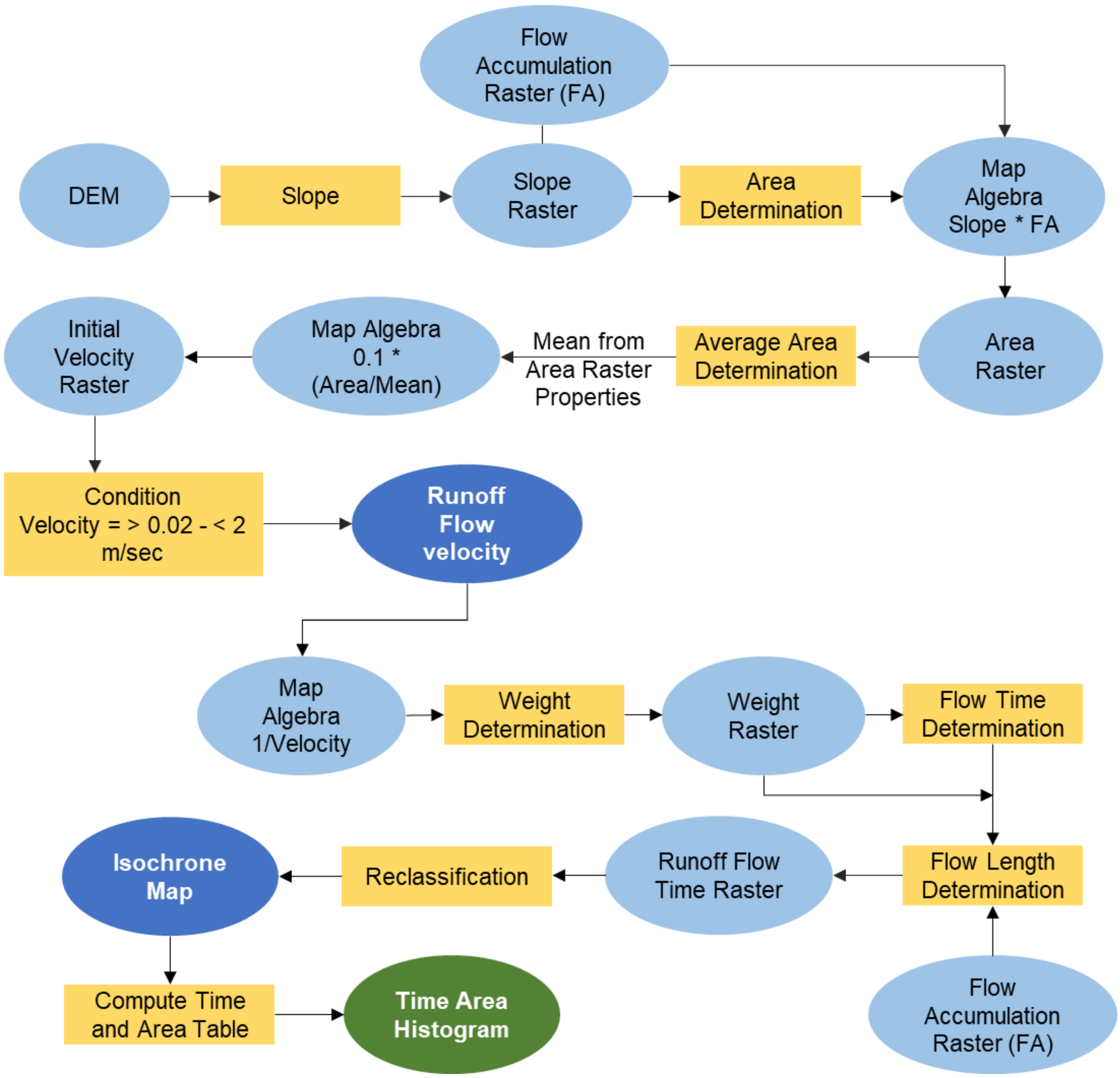


Figure 6: Methodology of Time Area Histogram derivation

The Area of the watershed contributing to the runoff is derived using the following formula,

$$A_r = \sqrt{S_l} \times \sqrt{FA} \qquad \text{eq. 2.14}$$

Where,

A_r = Runoff Flow Area (sq.m)

S_l = Slope (degrees)

FA = Flow Accumulation

Once the Area raster is derived, the velocity in which the water will flow to the outlet or the pour point is derived using the following formula,

$$V_r = V_a \times (S_l \times A_r) \div (S_l \times A_r)_a \qquad \text{eq. 2.15}$$

Where,

V_r =Runoff Flow Velocity (m/s)

V_a = Average Velocity (In this study the average velocity is considered to be 0.1 m.s)

S_l x A_r = Slope Area Term (which is the multiplication of Slope and runoff Area)

$(S_l \times A_r)_a$ = Average Slope Area Term

Computation of the above formula using the Map Algebra GIS tool will yield the Runoff Velocity raster. The runoff time is then computed using the Flow Length tool from the ArcGIS software. The flow length tool require a weight and flow direction to be given. The flow direction is derived from the flow direction tool from the Arctoolbox under the Hydrology tools of the Spatial Analyst tools. The flow direction is derived based on the DEM data of the watershed. The weight is actually a travel time for each cell to cross the distance of the cell (Abedin, 2014), which is considered to be the inverse of velocity. Thus the formula goes by,

$$W = 1 \div V_r \qquad \text{eq. 2.16}$$

$$T_r = L_r \div V_r \qquad \text{eq. 2.17}$$

$$T_r = L_r \times W \qquad \text{eq. 2.18}$$

Where,

W = Weight

T_r =Runoff Flow Time

L_r = Runoff Flow Length

The derived Time Area field determines the time required for the area of the watershed to get drained. The travel time is divided into specified intervals and reclassified to derive the Isochrone map. Isochrone map represents the area of the watershed that takes the same time to drain the excess rainfall to the outlet. The graph derived by plotting the areas of the isochrones with respect to its corresponding time values will generate the Time Area Histogram.

2.4.4 Unit Hydrograph

Unit hydrographs represent the volume of runoff at the outlet in unit time. The results of the SCS-CN method and Time Area Histogram is used to derive the Unit Hydrograph of the watersheds.

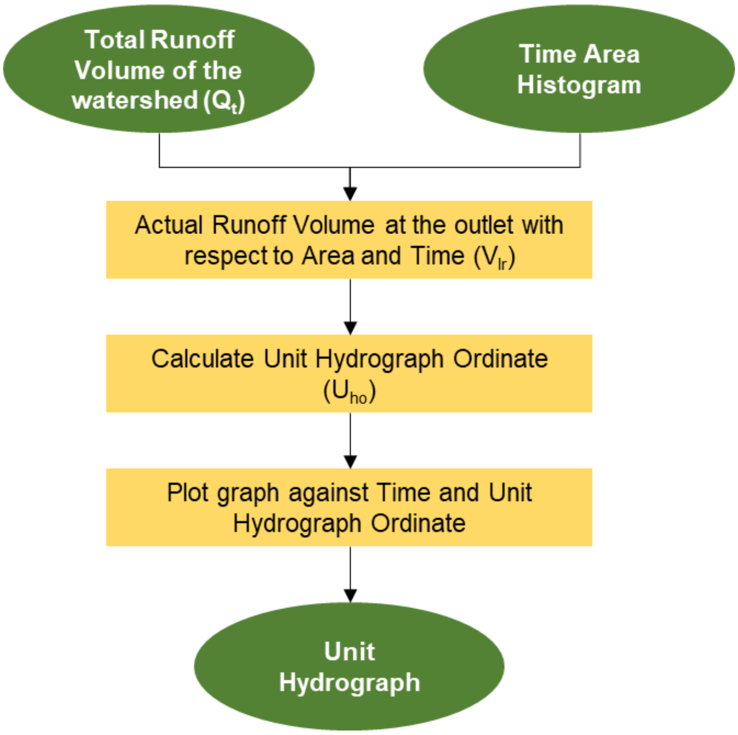


Figure 7: Methodology of Unit Hydrograph derivation

The areas obtained from the time area histogram method is multiplied by the Runoff value obtained from the SCS-CN method to derive the runoff Volume at the outlet of the watershed.

$$V_{lr} = A_r \times (Q_t \times 0.001) \qquad \text{eq. 2.19}$$

Where,

Vlr = Actual Runoff Volume (m^3)

Ar = Runoff Area (sq.m)

(Qt x 0.001)= Total Runoff (m)

The derived volume is divided with the time interval in which the isochrones are divided, to derive the Unit Hydrograph Ordinate. The unit hydrograph ordinate specifies the volume of discharge at the outlet per second for an hour of rainfall.

$$U_{ho} = V_{lr} \div \Delta t \qquad \text{eq. 2.20}$$

Where,

Uho = Unit Hydrograph Ordinate (m^3/s)

Δt = Isochrone Time Interval (seconds)

Plotting the graph against time and the unit hydrograph ordinate will yield the Unit Hydrograph. This graph shows the Volume of discharge at the outlet per second against time.

2.4.4.1 Actual Runoff Calculations with respect to LULC and Soil Infiltration

The actual runoff area, runoff time, and runoff velocity are calculated in the watershed with respect to DEM, slope, flow accumulation, precipitation, LULC and soil infiltration data. The methodology and the formulas used to derive the maps are described below.

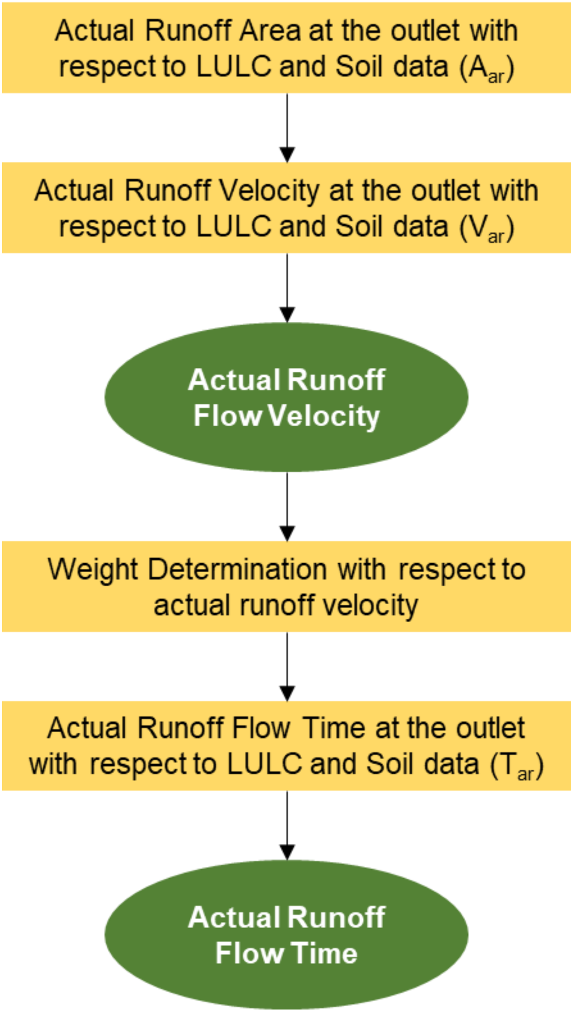


Figure 8: Methodology to derive Actual Runoff Velocity and Time

The actual runoff area in the watershed is derived using the following formula,

$$A = U_{ho} \div Q_t \quad \text{eq. 2.21}$$

$$A_{ar} = A \times S \times FA \quad \text{eq. 2.22}$$

Where,

A = Area of watershed contributing to flow (sq.m)

A_{ar} = Actual Runoff Area (sq.m)

The actual runoff velocity in the watershed is calculated using the following formula,

$$V_{ar} = 0.1 \times (A_{ar} \div (A_{ar})_a) \quad \text{eq. 2.23}$$

Where,

V_{ar} = Actual Runoff Velocity (m/s)

A_{ar} = Actual Runoff Area (sq.m)

$(A_{ar})_a$ = Average Actual Runoff Area (sq.m)

The actual runoff flow time in the watershed is calculated using the actual runoff velocity using the equation 2.26. The formula uses flow length, which is derived using the flow length tool from the ArcToolbox hydrology tools. The flow length tool requires flow direction of the watershed as the input. The flow direction is derived for the watershed with the Flow direction tool from the ArcToolbox hydrology tools using the DEM as input.Thus the formula goes by,

$$W_a = 1 \div V_{ar} \quad \text{eq. 2.24}$$

$$T_{ar} = L_{ar} \div V_{ar} \quad \text{eq. 2.25}$$

$$T_{ar} = L_{ar} \times W_a \quad \text{eq. 2.26}$$

Where,
W_a = Weight

T_{ar} =Runoff Flow Time

L_{ar} = Runoff Flow Length

2.5 Software used

The GIS software used for this study was ArcGIS Desktop 10.2. ArcGIS is a geographic information system for working with maps and geographic information maintained by the Environmental Systems Research Institute (ESRI) (Wikipedia, 2020). Microsoft Excel from the Microsoft Office suite of software was used as spreadsheets to perform AHP calculations. Google Earth Pro was used to abstract spatial data that were not available from any sources. End Note is a software which is used to cite the references in the Project Report.

This chapter has explained in detail about the various methodologies and the data used in this study to achieve each objectives. The methodologies discussed in this chapter are, GIS based visual interpretation, GIS based AHP Multi Criteria Decision Analysis, Mathematical Calculations and Hydrological Modelling using the GIS software. The methodologies explained in this chapter are implemented in the study area using the collected data to achieve the aim and objectives of the thesis.

Chapter 3: Processes and Results

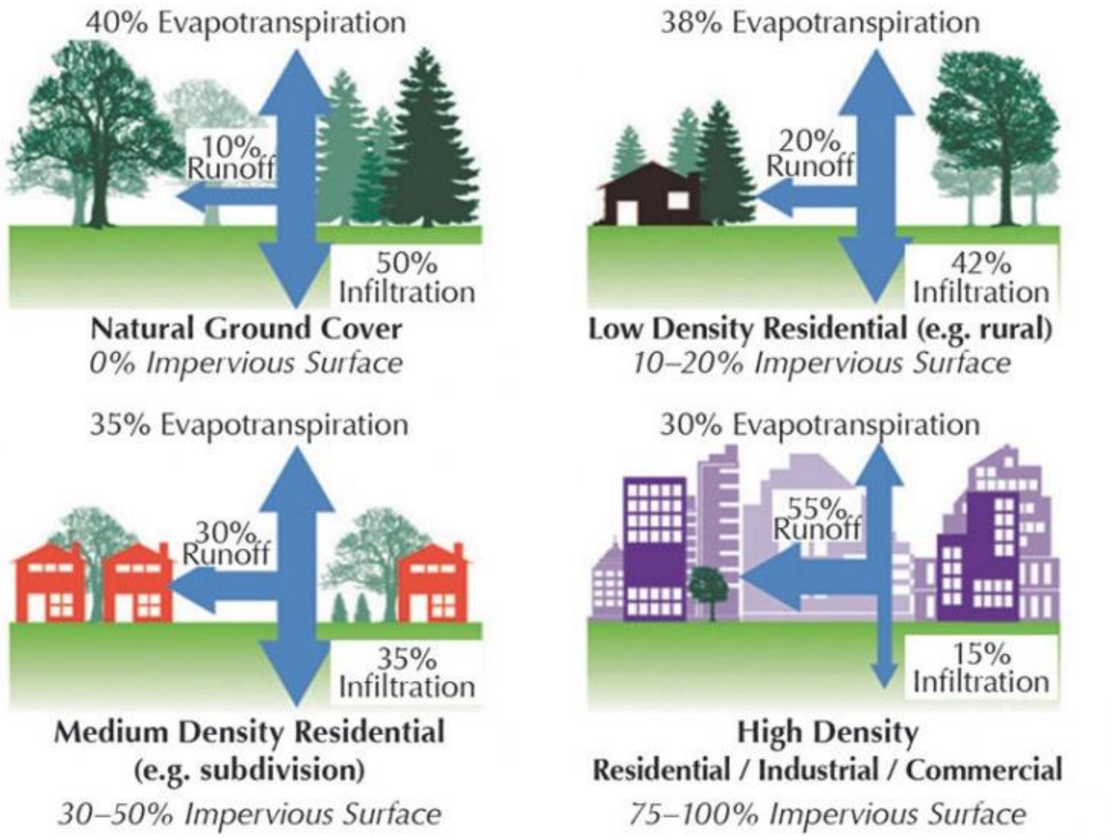
This chapter explains the processes carried out in the study area with respect to the methodologies and the data presented in Chapter 2. The detailed stages of the process involved and the results obtain for every objective of the study are presented in this chapter. This chapter is divided into the following sections,

- Flood prone Areas and Structures
    - LULC Change based result
    - DEM based result
- Flood Risk Mapping using MCDA
- Flood Prediction using Hydrology Modelling

3.1 Flood prone Areas and Structures

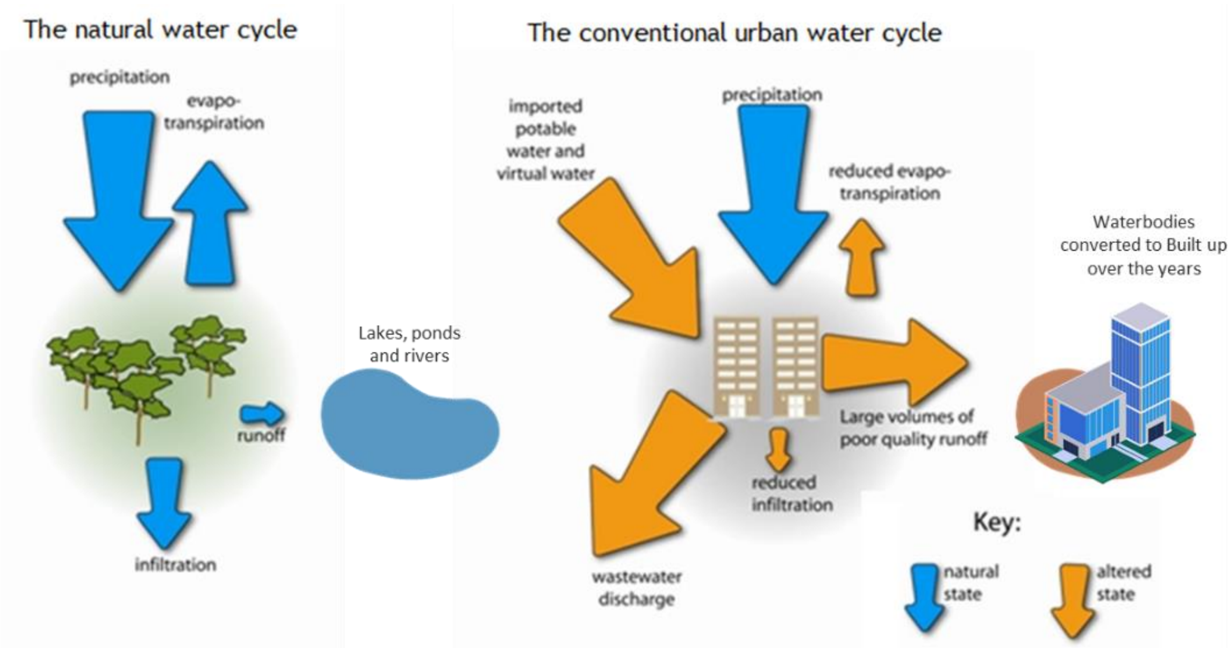
3.1.1 Identifying Flood prone Structures using LULC

The land use and land cover of a region plays a very vital role in accessing the area's natural disaster effects. Land use of an area comprises of residential, commercial, transport utilities like roads, rails, and Industrial areas which shall be completely considered as Built up area. Built up area is a land use type which signifies the urban growth the region has gone through. The developed areas are usually made up of concrete, bricks, asphalt, gravel and packed earthen materials. These materials does not allow water to percolate thus eliminating rainwater infiltration and natural ground water recharge (CITY OF PACIFIC GROVE, 2019). During the occurrence of a heavy rainfall, the surface infiltration and runoff capacity depends on the amount of urban growth or the occurrence of impervious surface in the area. It can be simply said that, increased urbanization contributes to less infiltration and more run off leading to flooding in urban areas. The picture below gives a good explanation on the effects of imperviousness on runoff and infiltration.



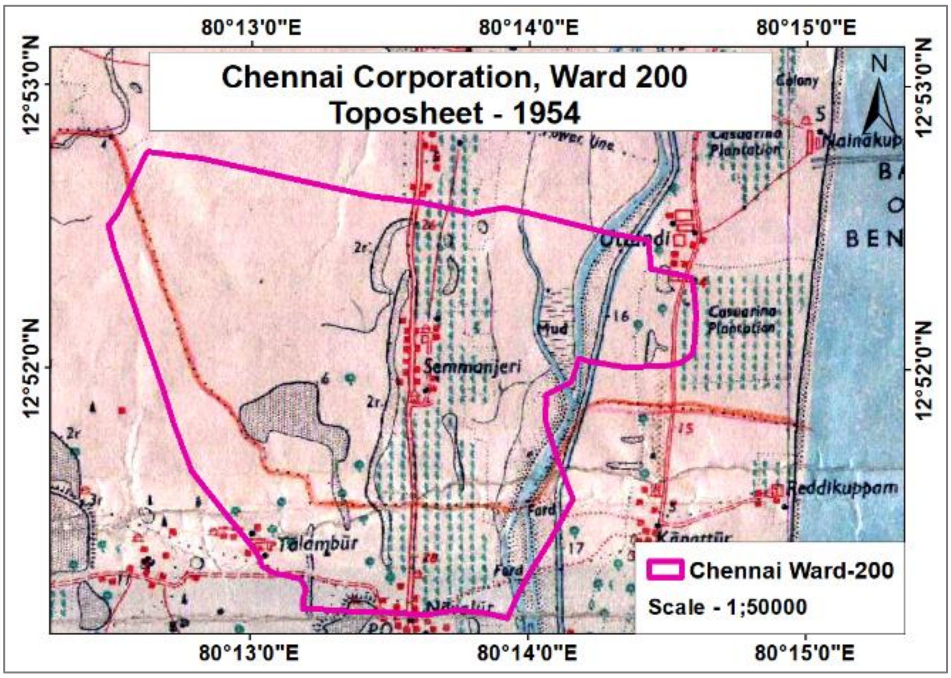
Picture 4: Infiltration effects on impervious surface (John Hopkins University, 2020)

The eventual process of urbanization steers the path to build more and more buildings. Chennai is one of the well known victim of urbanization. Many ponds and lakes has fallen prey to uncontrolled urbanization. The practice of closing the ponds and elevating buildings on it has become very common in Chennai. The consequences were felt only when the corporation faced hue rainfalls. The study area was also dotted with various lakes and ponds, but eventually they were all vanished due to urban developments, population and many other factors. People did not realise the consequence of encroachments and started building in the unsuitable areas. The building which were built on these waterbodies and low lying areas are today's flood prone areas. The picture below represents the impact of urbanization by eliminating the natural resources like ponds, lakes and forest.

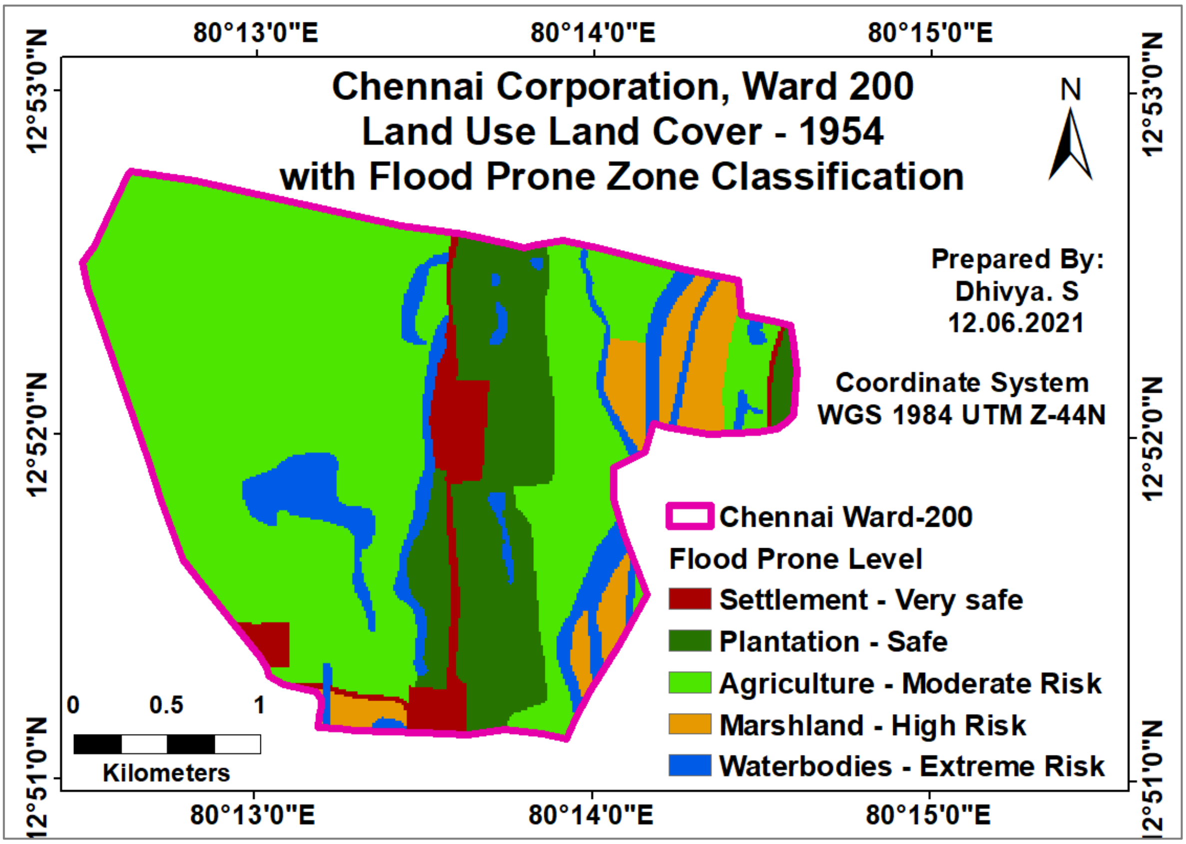


Picture 5: Pictorial representation of the effects of Urbanisation during precipitation (Seen & Spuhler, 2020)

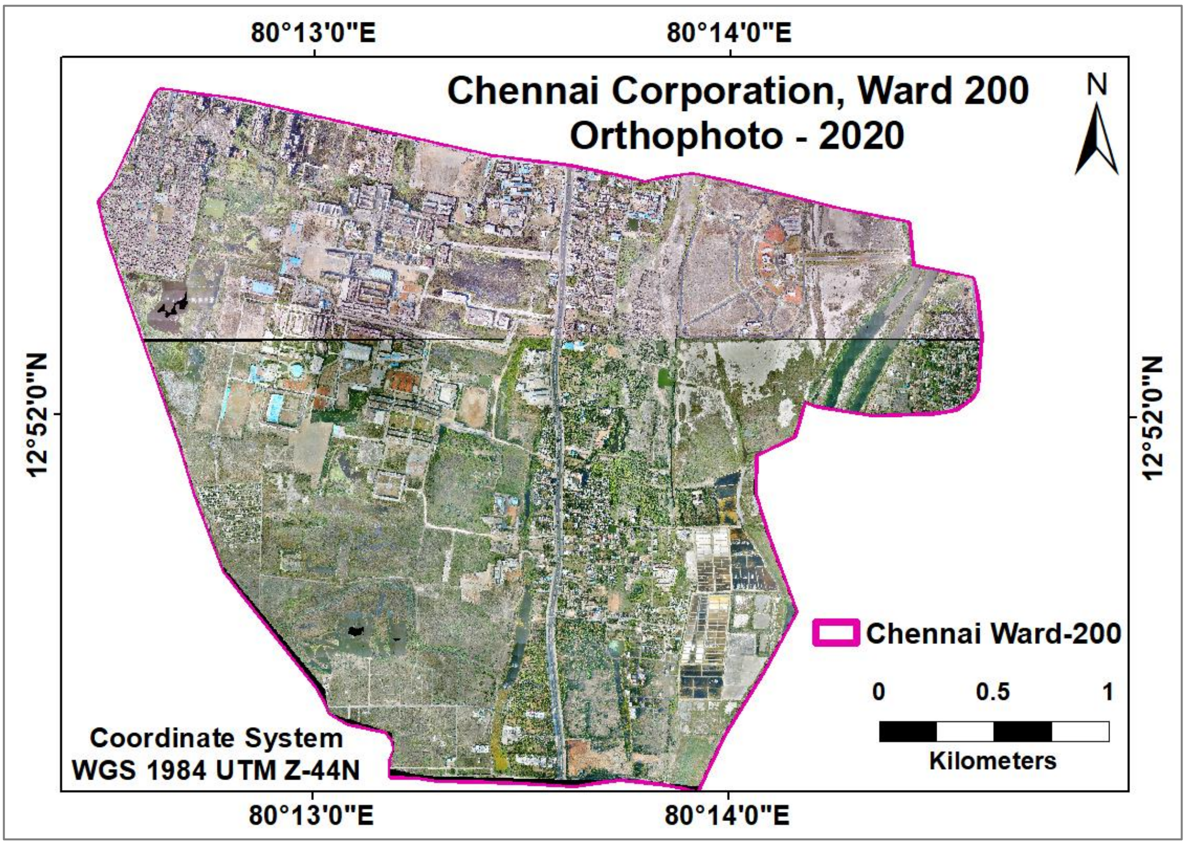
The land use of the study area is digitized out from the 1954 toposheet. This is will be termed as old land use in this study. The new land use data is digitized out from the Orthophoto. This shall be termed as new land use. The current building layer is overlaid on the old toposheet to identify the buildings that fall on the flood prone areas.



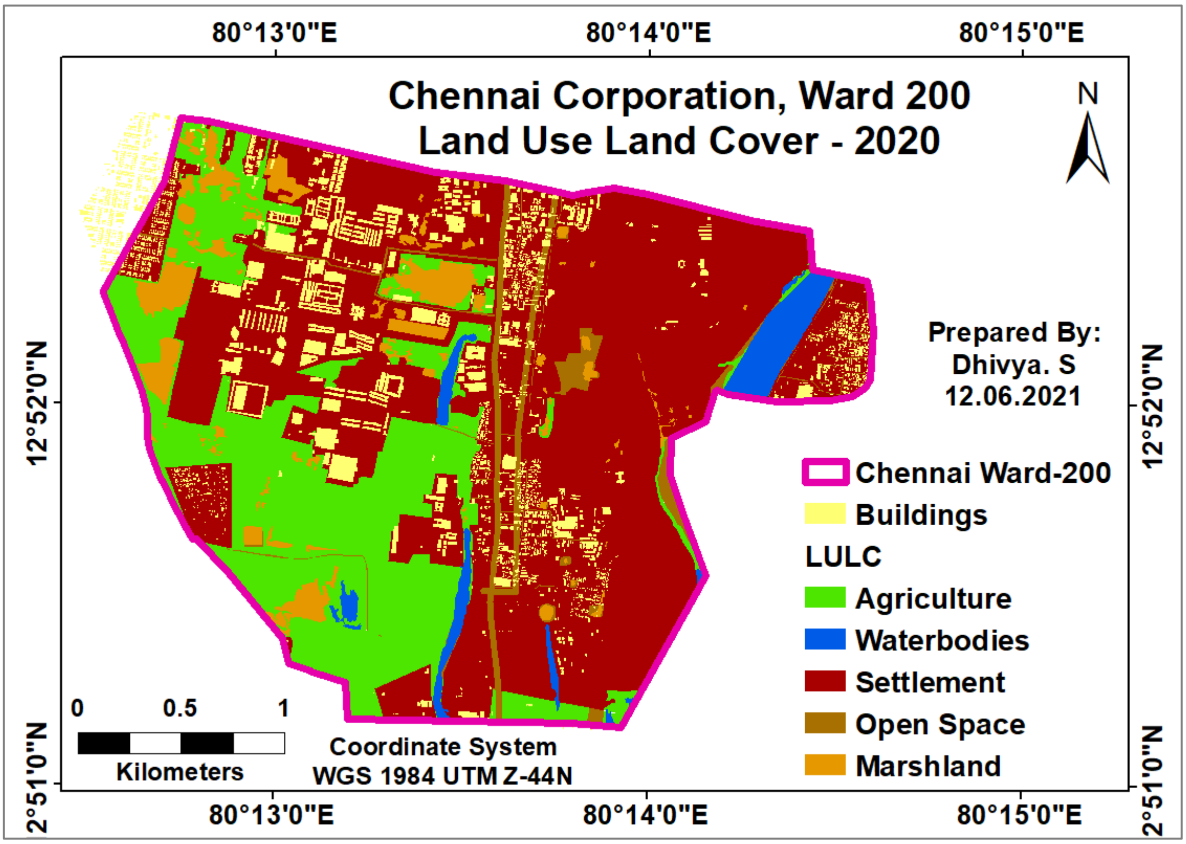
Map 2: Toposheet 1954



Map 3: LULC 1954

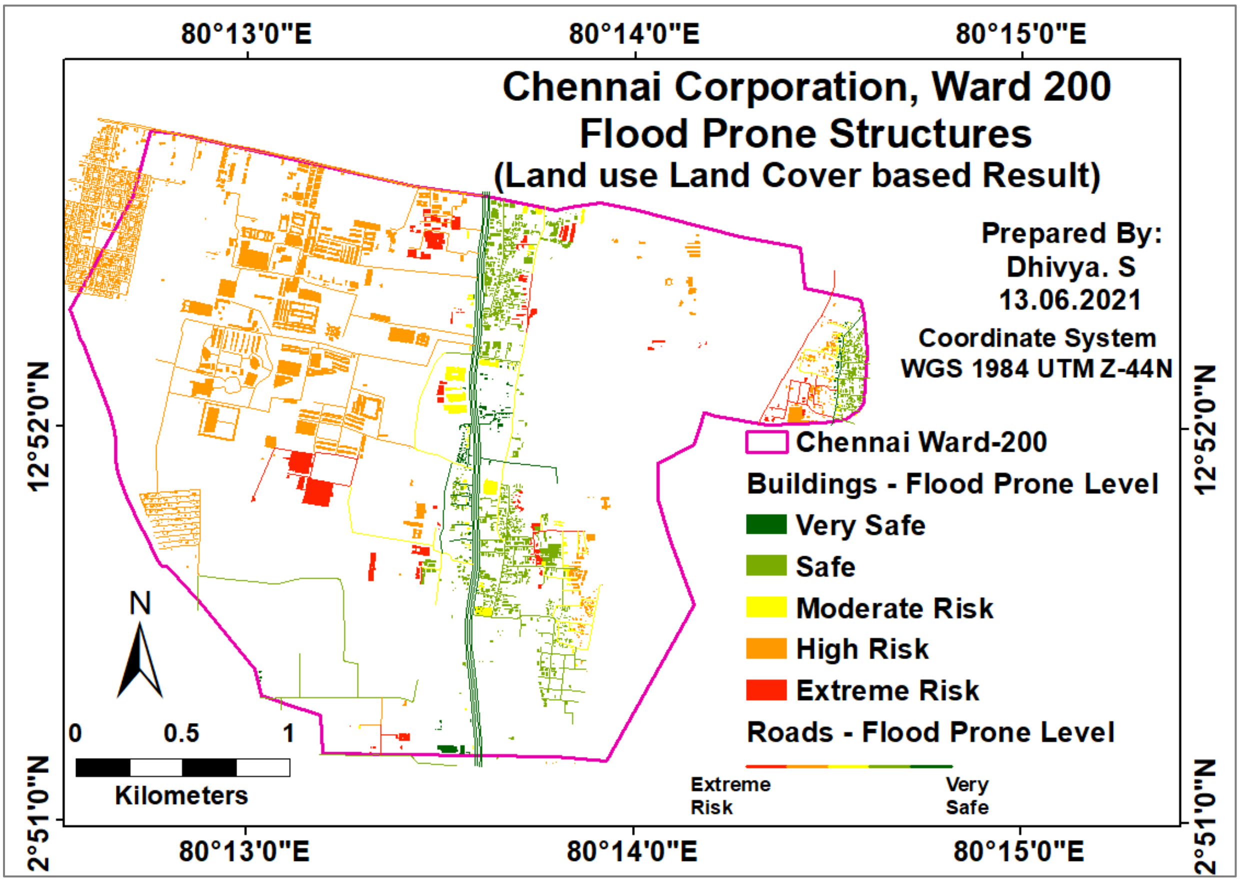


Map 4: Orthophoto 2020



Map 5: LULC 2020

From the above maps it can be seen that waterbodies have been deteriorated and disappearing eventually over the period of years. The study area has been the prey to urbanisation and commercialisation for many years. Even the government buildings and infrastructures were built on some waterbodies in this area. The waterbodies are closed with soil when it dries up and converted to Poramboke land which belongs to the government. The South Asia Consortium of Interdisciplinary Water Studies has mentioned that, Government has encroached the waterbodies in the area to build the infrastructures like, roads, bridges, railway stations, housing board buildings, industrial estate (SIPCOT), etc., which resulted in the disappearance of 15 waterbodies (Vishwanath, 2019). Other than government buildings, the encroachment also happened in the study area by developing Information technology office buildings and uncontrolled development of Apartments and housing units. These areas contribute to more runoff as all are turned into impervious surface areas.



Map 6: Flood Prone Structures – LULC based result

3.1.2 Identifying Flood prone Structures using DEM

Digital Elevation Model (DEM) is a raster dataset which contains the elevation details of a terrain in its pixels. DEM are usually used for hydrological analysis in GIS. In this study DEM is used to find the zones which will have the probability to get inundated during a cloudburst.

The high resolution DEM was procured from a Private consultant who is surveying for the Chennai Metro Water Supply and Sewage Board (CMWSSB). The DEM used for this study is extracted using Aerial Imagery. The DEM has an accuracy of 3 meters. Initial sinks was filled using the Fill Tool in ArcMap software. The watershed was then delineated from the DEM, followed by Flow direction. The probable inundation spots were derived from the DEM. The Buildings that fall in these zone were identified to be prone to flooding (Periyasamy et al., 2018, p. 21). Model Builder in ArcGIS was used to derive the inundation areas using DEM. The model builder used for this stage is obtained from the ESRI training lesson, “Find areas at risk of flooding in a cloudburst” (ESRI, 2021), then the model is updated as per the study purpose.

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. Here the Vertical accuracy is 0.3 meters. 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.

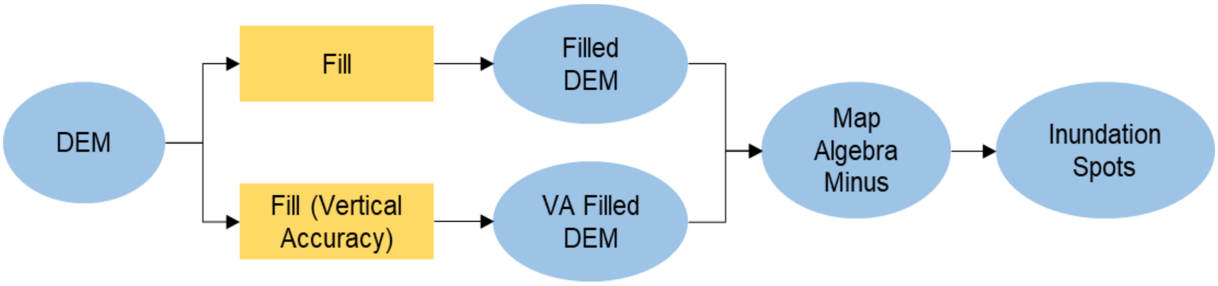
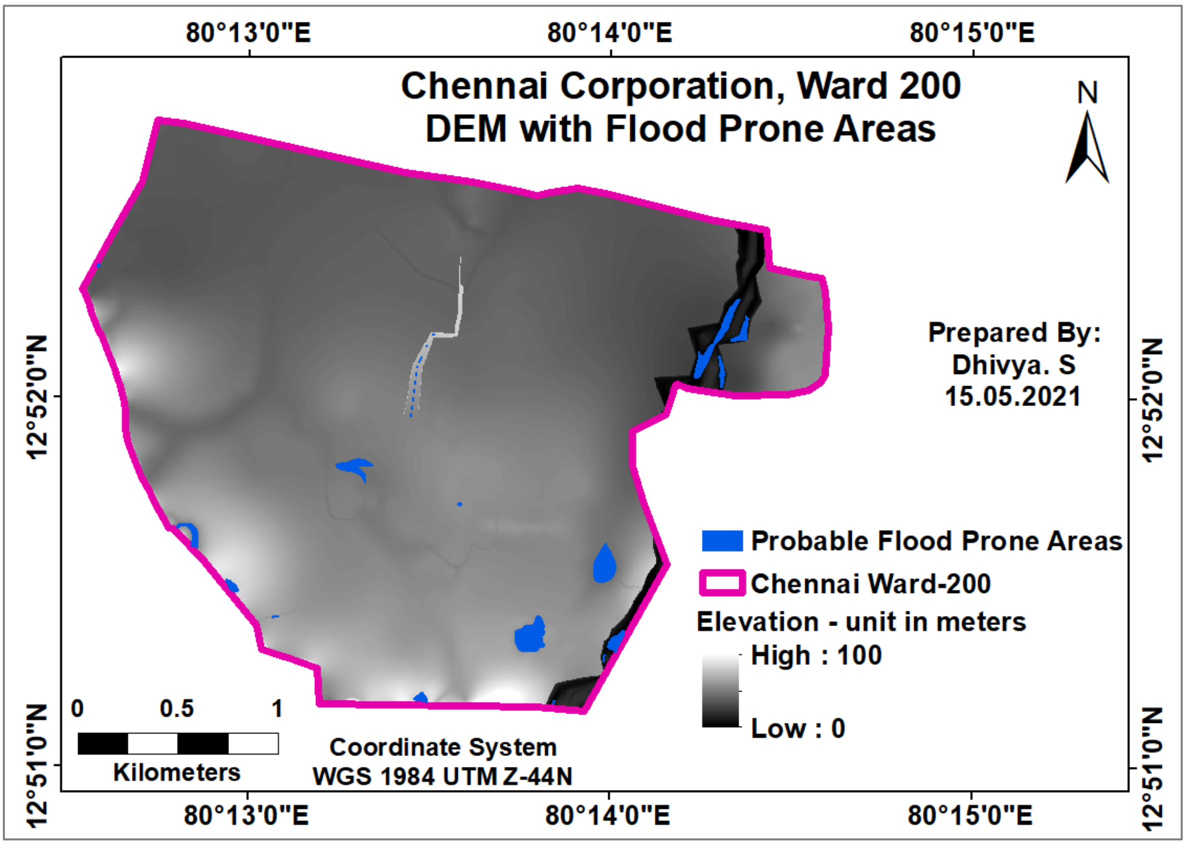
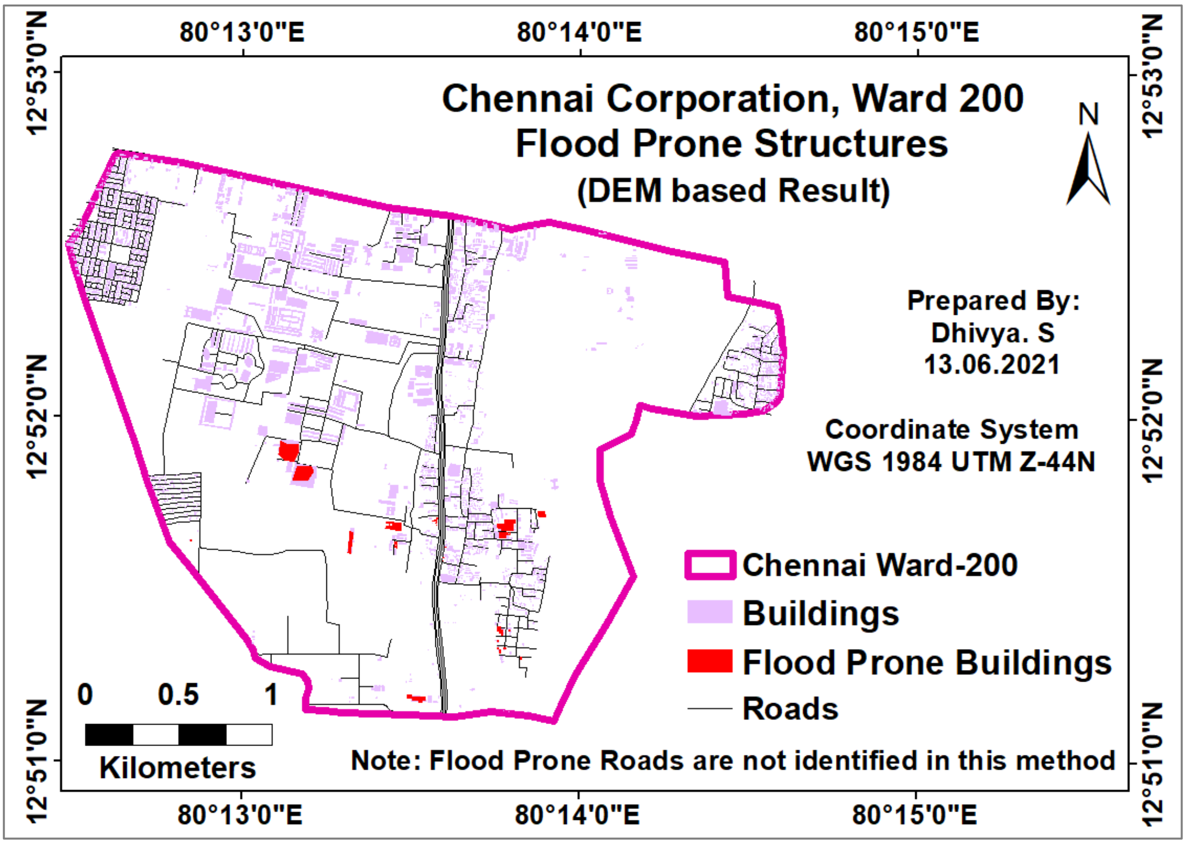


Figure 9: Steps to find Flood Prone Areas using DEM



Map 7: 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 16Map 7. 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.



Map 8: Flood Prone Structures – DEM based Result

3.1.3 Field Verification

Field Verification could not be carried out due to COVID-19 spread in the study area, and the areas to be field verification is restricted access due to increase in Corona cases in the locality. However I was able to connect with few residents in the area virtually and obtain field photographs taken during the Nivar Cyclone that hit Chennai in the month of November 2020.

A low pressure was formed in the Bay of Bengal in November 22nd 2020, then it got intensified into a depression in the early hours of November 23 2020. The intensified depression made a landfall in the coastal regions of Chennai, Puducherry and Marakkanam as Cyclone Nivar in the early hours of November 2020 (Wikipedia, 2021). The southernmost ward of Chennai Ward 200 felt the after effects of the storm very intensively. The area faced severe inundation for several days after the cloudburst. People were unable to come out of their homes, and the helpers were unable to enter the houses. People were stuck in their houses for nearly a month. Essential amenities were supplied to them through bulldozers. Some of the field photographs taken during the crisis in ward 200 is shown below.

Picture 6: Field Photograph 1 during Nivar Storm, Nov 2020 at Semmancheri

Picture 7: Field Photograph 2 during Nivar Storm, Nov 2020 at Semmancheri

Picture 8: Field Photograph 3 during Nivar Storm, Nov 2020 at Majestic Residency

Picture 9: Field Photograph 4 during Nivar Storm, Nov 2020 at Gandhinagar Society

3.2 Flood Risk Mapping using MCDA

3.2.1 Criteria Evaluation and Reclassification

As mentioned in section 2.2.1, there are 8 important criteria chosen for this study to find the inundation risk zones. These criteria are classified as per the distance range and several other properties considering the knowledge gained from papers, from the high Impact factor journals, and the criteria for development from the Second Master Plan for Chennai Metropolitan Area, 2026 (CMDA, 2013, pp. 14-87). The criteria used in this study are illustrated below in the flow chart. This study used environmental and socio economic criteria which are closely related to the flood risks before, during and after the event of a flood.

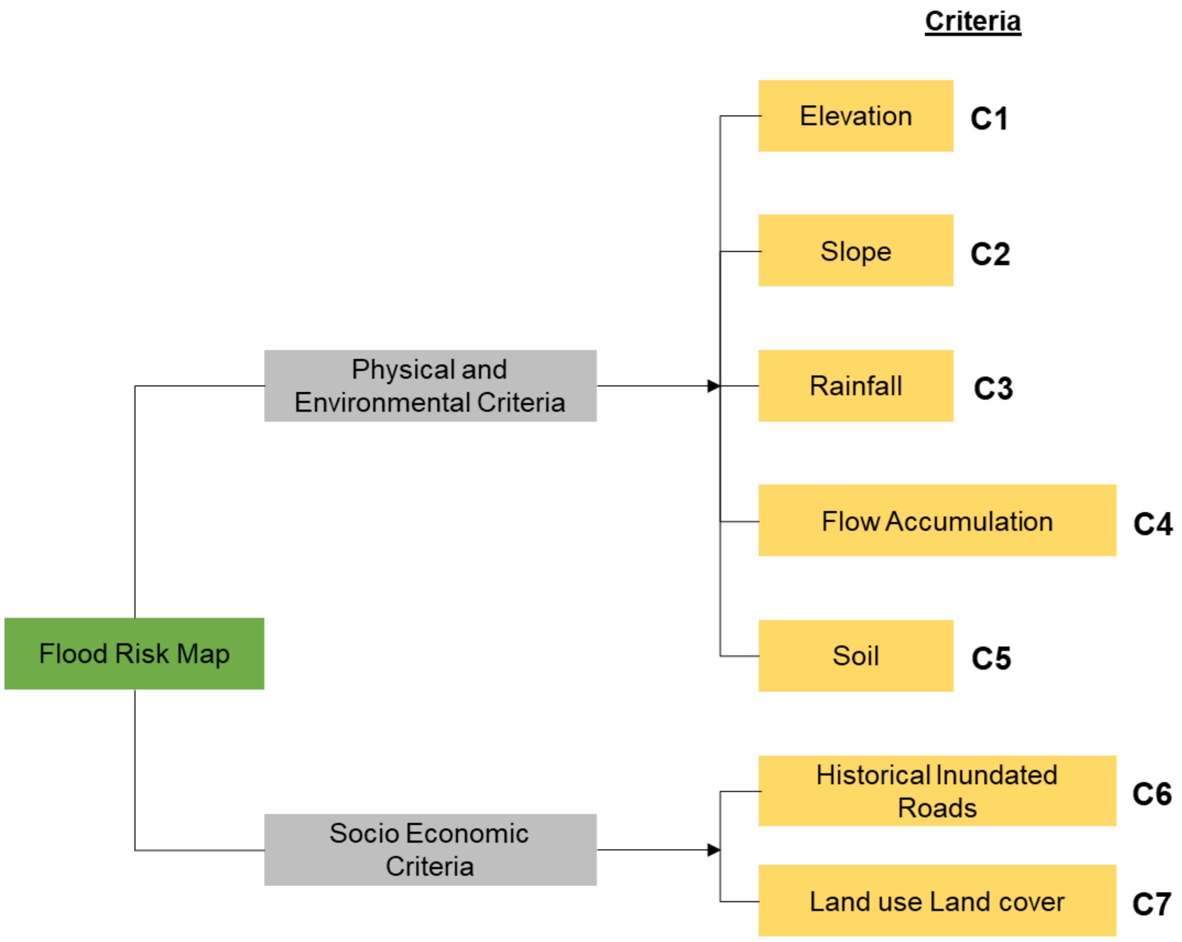


Figure 10: Criteria for MCDA

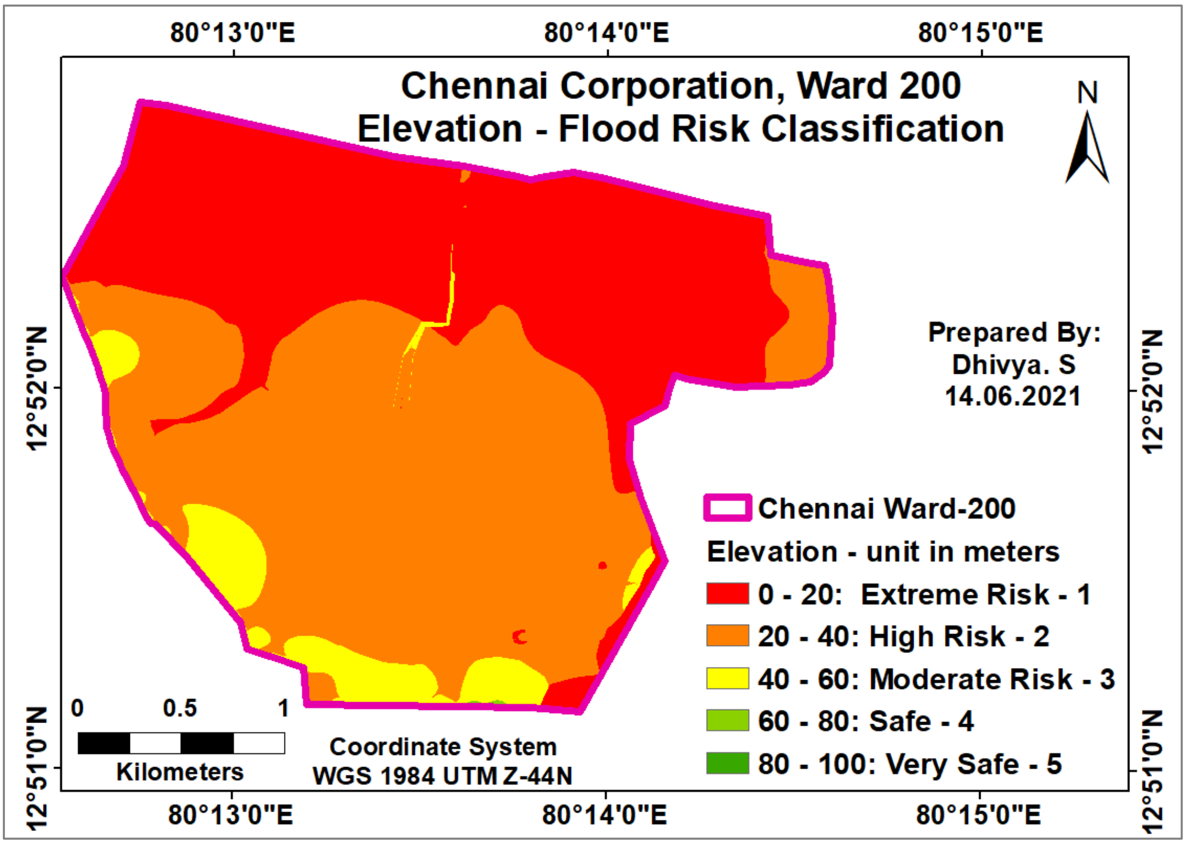
Table 9: Criteria with Suitability Level

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

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

3.2.1.1 Elevation

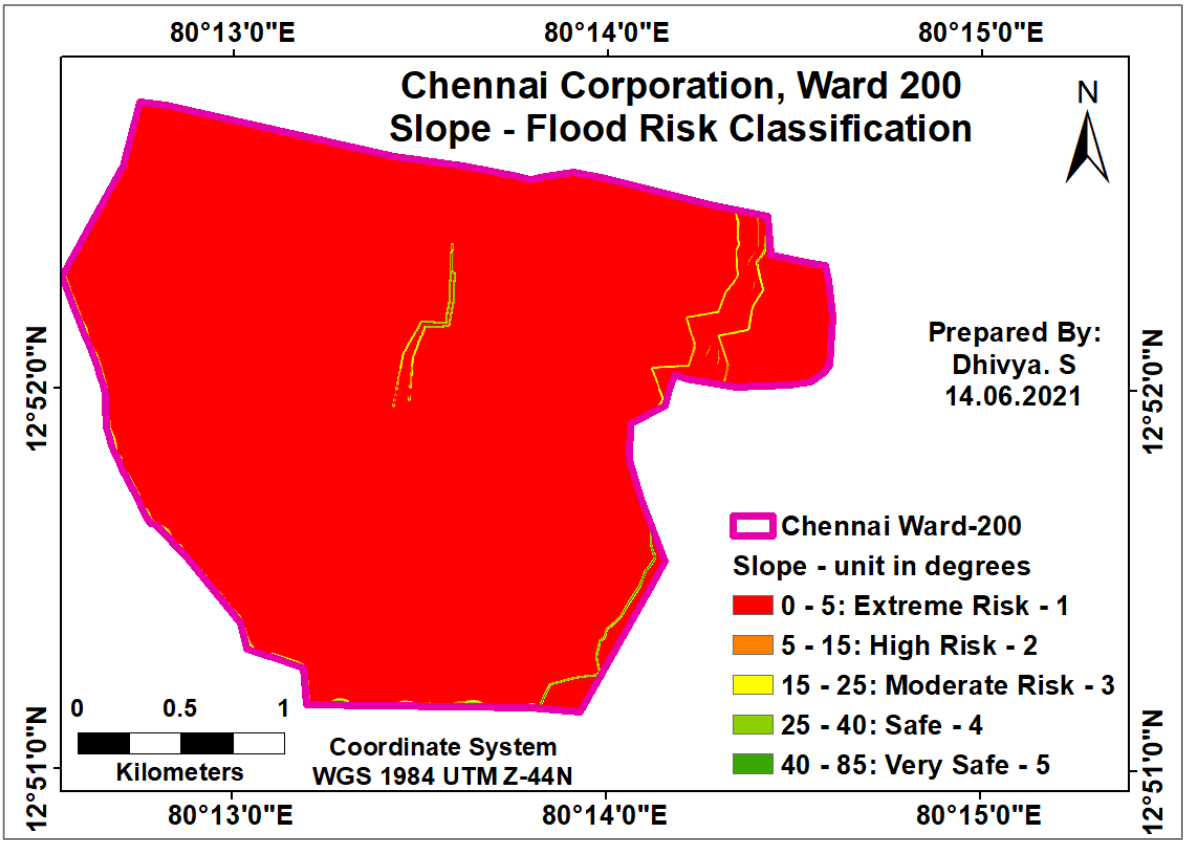
Elevation is one of the environmental criteria considered in this study to find the inundated zones. The elevation of an area plays a vital role in determining the stability of a terrain. The steeper areas where the elevation is high improves surface run off, so the water doesn't get accumulated. The areas where the elevation is low are susceptible to flooding as they contribute to very less surface runoff and the flat terrain also becomes prone to water loggings. The flat terrain or low elevated areas are liable to be flooded easily. The study area is near to the coastal zone and this area do not have much elevation undulations in its terrain, the study area is mostly flat. The elevation in the study area ranges from 0 or Mean sea level to 100 meters. In the study the areas with elevation range less than 5 meters are considered to be at extreme risk, and the area with elevation range above 40 meters are considered to be very safe regions (Aggarwal et al., 2009, pp. 145-158). The detailed classification of the elevation range for this criteria is shown in Table 9. The classification denotes the food risk in the study area with respect to the elevation.



Map 9: Elevation - Flood Risk Classification

3.2.1.2 Slope

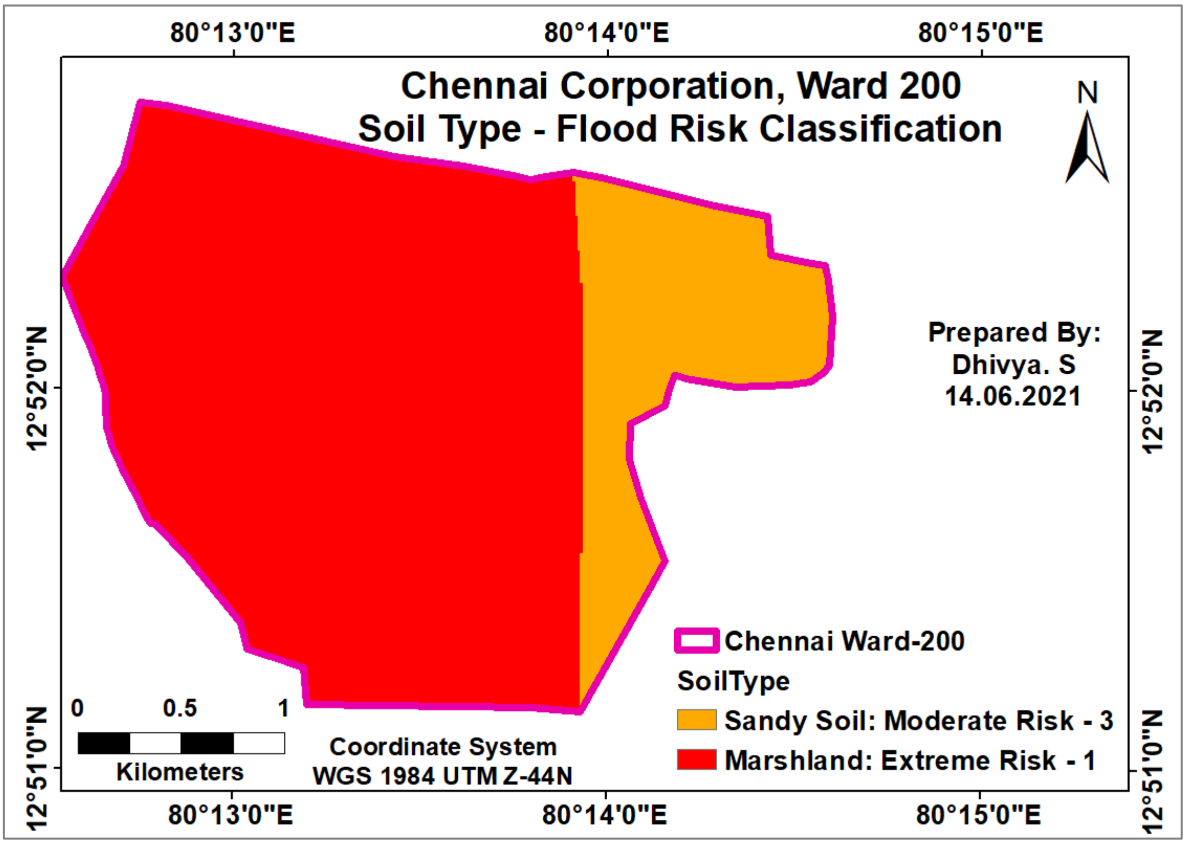
Slope is another criteria which has much influence on the direction and the amount of surface runoff reaching a drainage system. Slope is derived using the DEM raster data in the Arcmap software using the Slope generation tools in the ArcToolbox. Water always tend to accumulate in the area where there is depression, low elevation and nominal slopes. The steeper slopes has the capacity to improve surface runoff while nominal slopes has the tendency to accumulate water. Low gradient slopes are highly vulnerable to flood occurrences while the high gradient slopes are not (Ouma & Tateishi, 2014, pp. 1515-1545). In this study the slope with the high degree of inclination is classified as very safe area and the slope with an inclination range of 5 degrees are classified as the regions with extreme risk of flooding. The detailed classification of the slope range for this criteria is shown in Table 9.



Map 10: Slope - Flood Risk Classification

3.2.1.3 Soils

Soil is another environmental criteria considered in this study to find the flood inundated zone. The characteristics of a soil is marked by its soil texture, moisture content and infiltration capacity. The infiltration capacity of soil determines the runoff capacity thus determining the flood impacts of an area. Sandy soil has the capacity to absorb more water and thus it contributes to less run off whereas clayey soils are less porous and contribute to more runoff. This shows that the area with clayey soils are more likable to be flooded soon (Ouma & Tateishi, 2014, pp. 1515-1545). The study area is marked by marshland or clayey soil and sandy soil. The soil data of the study is obtained from Soil Survey of India department. The infiltration capacity of sandy soil is between 0.15 to 0.3 inches for an hour of rainfall as per NRCS defined Hydrologic Soil Group standards (Wikipedia, 2021). The areas marked with sandy soils are classified under moderate risk category and given a weight of 3. The Marshland has the capacity to infiltrate very less than 0.05 inches of water for an hour of rainfall. The other surface types are impervious surface. The areas with the marshland are classified as extreme risk zones and given a weight of 1.



Map 11: Soil Type - Flood Risk Classification

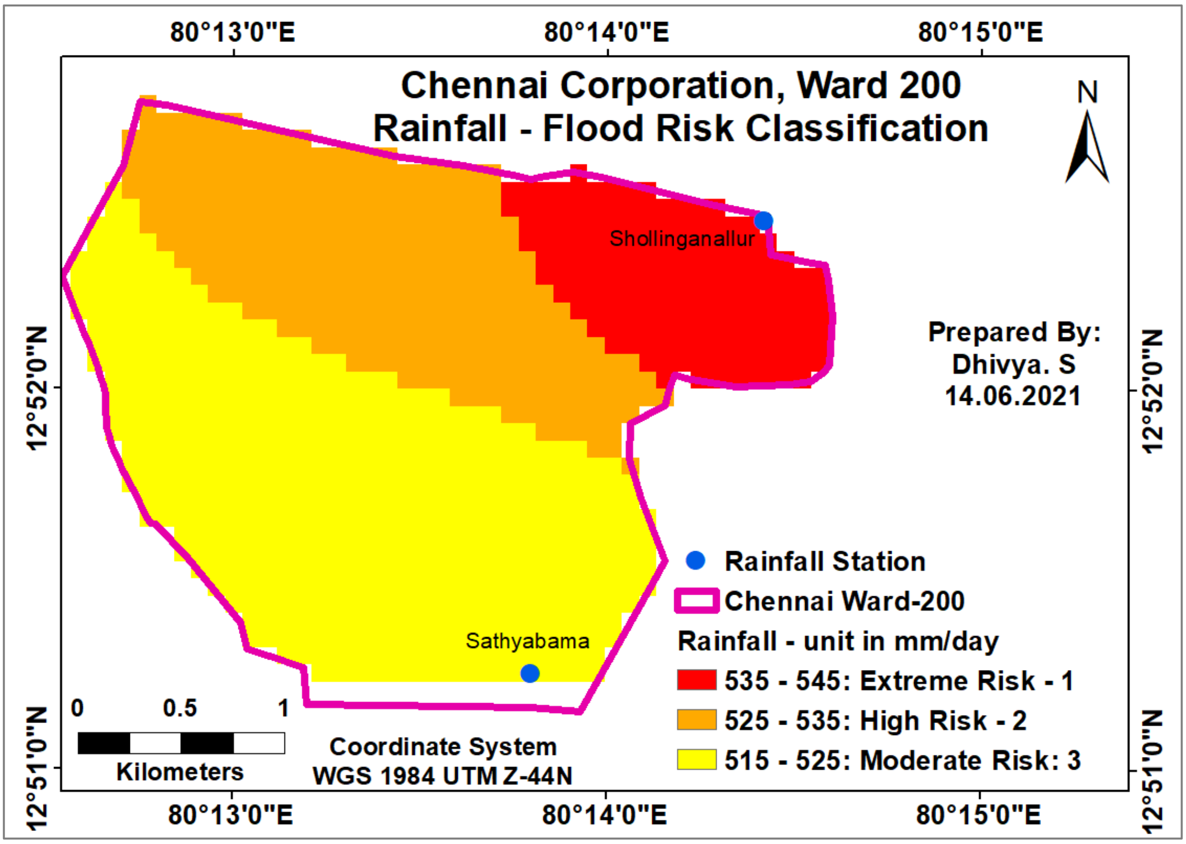
3.2.1.4 Rainfall

Among all the other factors, Rainfall/precipitation is the major phenomena stimulating a flood in any area. When the natural drainage system has the capacity to drain the water during a cloud burst then flooding will not occur. But in urbanised areas, the natural drainages are exploited thus weaken its capacity to drain the rainfall run off during a cloud burst. More the runoff, more the risk of flood in an area. The runoff quantity depends on the amount of rainfall a region has experienced. The study area experienced peak rainfall in the months of November and December. The highest rainfall range experience by the study area in a single day is identified and interpolated. The data is interpolated using Inverse

Distance Weighting (IDW) to create a continuous raster rainfall data. The rainfall raster data is reclassified into 3 classes based on its intensity. The area receiving rainfall range between 315 to 325 mm/day is classified as Moderate risk, the area with rainfall range between 325 to 335 mm/day is classified as High risk and the rest of the area receiving more than 335 mm/day is classified as Extreme risk.

Table 10: Average Daily Rainfall, Ward 200

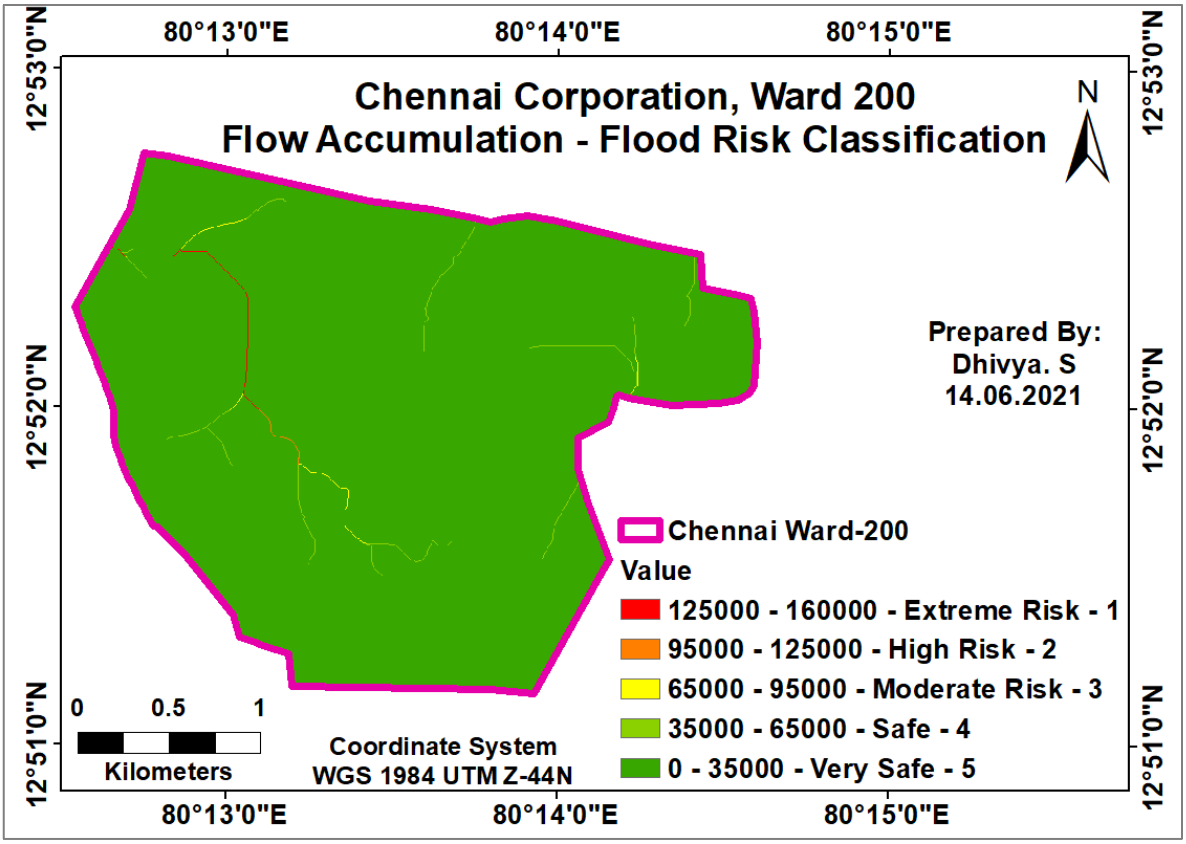
Station Name	Average Daily Rainfall (mm/day) - 2015											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Satyabama	19	23	75	80	83	532	543	550	563	510	534	540
Shollinganallur	34	38	60	65	75	389	400	442	447	789	803	876



Map 12: Rainfall - Flood Risk Classification

3.2.1.5 Flow Accumulation

Flow Accumulation is another factor that acts as the contributing environmental criteria to identify the flood risk zones. Flow Accumulation shows the probable course of streams or rivers in an area, which implies that the water will get accumulated in this stretch when there will be a rainfall. The flow accumulation is derived from the DEM. The DEM used in this study is of an accuracy of 5cm. The small depression errors in the DEM are rectified using the sink and fill tools in ArcGIS. The Sink tool from the ArcToolbox Hydrology is used to locate the sinks in the DEM. The fill tool from the ArcToolbox Hydrology is used to fill the places where the sinks are identified in the DEM. Then flow direction Hydrology tool from the ArcToolbox is used to derive the flow direction, which implies the direction that the water will flow from one cell to another. The Flow Accumulation Hydrology tool from the ArcToolbox is run to determine the areas draining to points on the DEM (Adjei-Darko, 2017)

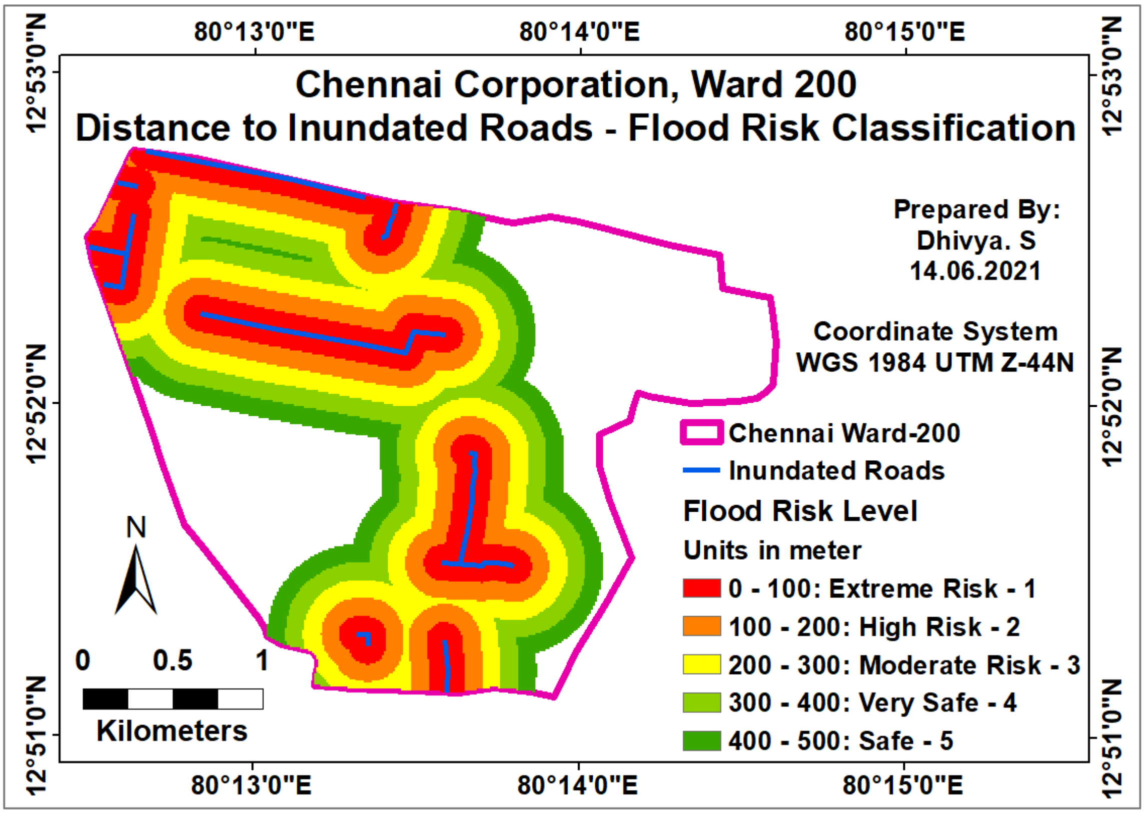


Map 13: Flow Accumulation - Flood Risk Classification

In the flow accumulation classification the area with the lowest flow accumulation between 0 – 35000 is classified as very safe area, and the highest flow accumulation value in between 95000 – 125000 is classified as High risk area.

3.2.1.6 Distance to Historical Inundated Streets

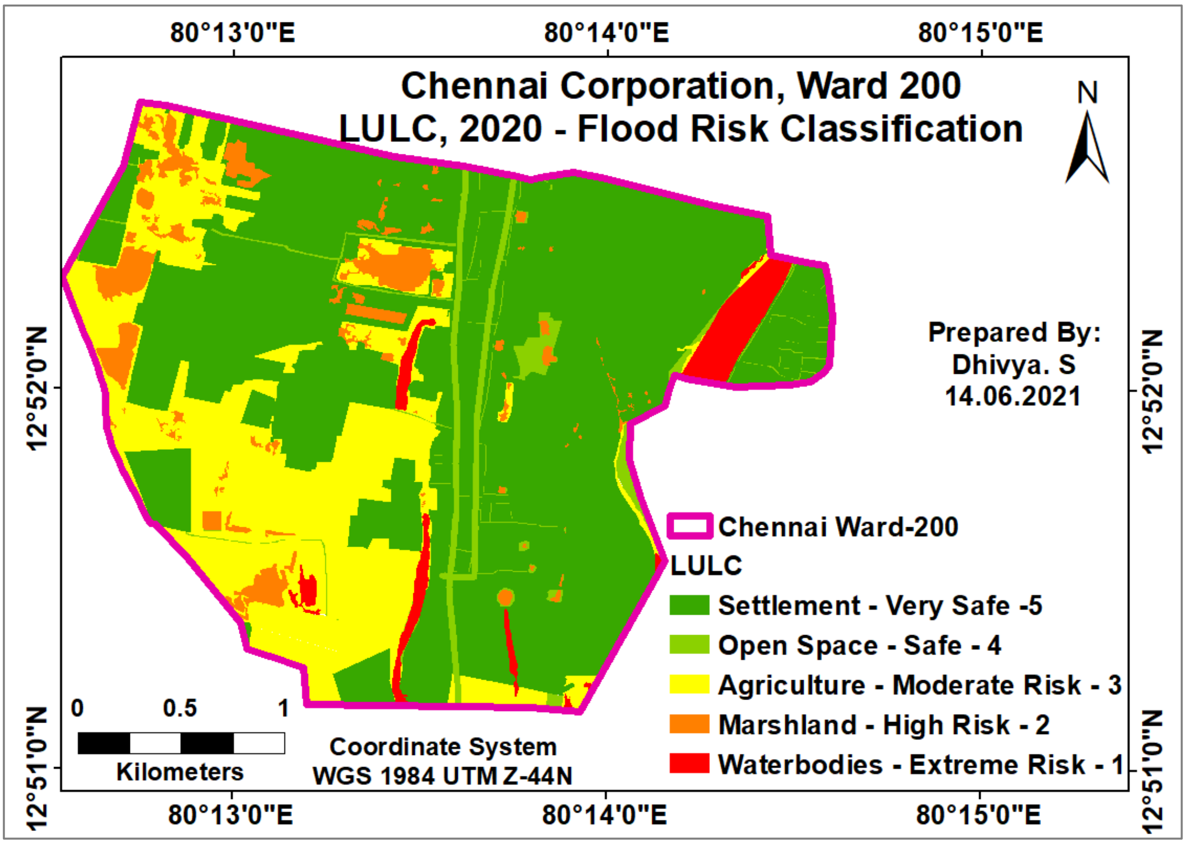
Roads are one of the important social factors to be considered in this study. Since the study area accommodates all sectors of working class people, the roads in the study area are used very often and any problem in the roads will create great inconvenience to the public. The historical data of inundated streets during the cyclone and rainfall in the year 2015 and 2017 were collected from the disaster management department of the Chennai Corporation. The collected data were mapped in Google Earth and imported into ArcGIS software. Multiring buffers were created around this inundated roads to identify the areas at the flood Risk zones. In this study, areas that are at a distance of 500 meters away from the inundated roads are considered very safe as they possess a lesser risk of getting inundated during the event of a heavy rainfall or a storm, and the area that are within a distance of 100 meters are considered as the area with Extreme Risk, as these areas tend to get inundated quickly during an even of a rainfall or storm. The structures like building and utilities are under the risk of inundation.



Map 14: Distance to Inundated Roads – Flood Risk Classification

3.2.1.7 Land Use Land Cover

The land use land cover of an area plays a very important role in determining the flood risk zone of an area. The land use cover of an area not only displays the use of land in an area but also its characteristics of surface infiltration and stability. The Land use type of Agriculture and vegetation cover will have the capacity to infiltrate and store water during a rainfall. The surface of an agricultural area will be porous to absorb the water. The open and barren lands also contribute to runoff during a rain thus contributing to the risk of flooding. The safe area in a land use is the urban built up area as it has impervious surface and contribute to high run off. This is the area marked with impervious concrete surface. Land-use like buildings, roads, slum areas, decreases penetration capacity of the soil and increases the water runoff (Ouma & Tateishi, 2014, pp. 1515-1545), Whereas the areas of existing waterbody is considered to be extreme risk as this is the land use type where the rain water gets accumulated easily. The flood risk classification is don accordingly.



Map 15: Land use Land Cover - Flood Risk Classification

Table 11: Suitability Scores

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

With all the classified maps the next step is to identify weights and run the weighted overlay analysis.

3.2.2 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. Through this method a weightage factor from a pairwise comparison was derived. Paired elements were compared, and each element was assigned a value from a 9-point scale derived from Saaty's scale of relative importance.

Table 12: 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

Table 13: Pairwise Comparison 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

Where,

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

Table 14: Normalised Pairwise Matrix

	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 15: Consistency Calculation

	C1	C2	C3	C4	C5	C6	C7	Ratio
C1	0.0705	0.0718	0.0720	0.0494	0.0905	0.0692	0.0818	7.1676
C2	0.0705	0.0718	0.0720	0.0439	0.0905	0.0865	0.0818	7.2030
C3	0.0705	0.0718	0.0720	0.0549	0.0905	0.0779	0.0818	7.2179
C4	0.1410	0.1615	0.1295	0.0988	0.0543	0.0346	0.0818	7.0997
C5	0.1269	0.1292	0.1295	0.2965	0.1630	0.2180	0.1841	7.6524
C6	0.1586	0.1292	0.1439	0.4447	0.1164	0.1557	0.0818	7.9014
C7	0.3172	0.3230	0.3238	0.4447	0.3260	0.7007	0.3683	7.6128

$\lambda_{max} = 7.41$

Consistency Index = 0.07

Consistency Ratio = 0.05

The λ_{max}, CI and CR are calculated as per the formulas mentioned in the section 2.2 of this Project Report. As per the standard rule of Saaty's the Consistency Ratio arrived is 0.05 which is less than the value 0.10, which proves that the weightage value arrived for the criteria was consistent. The weightage of each criteria is mentioned in Where,

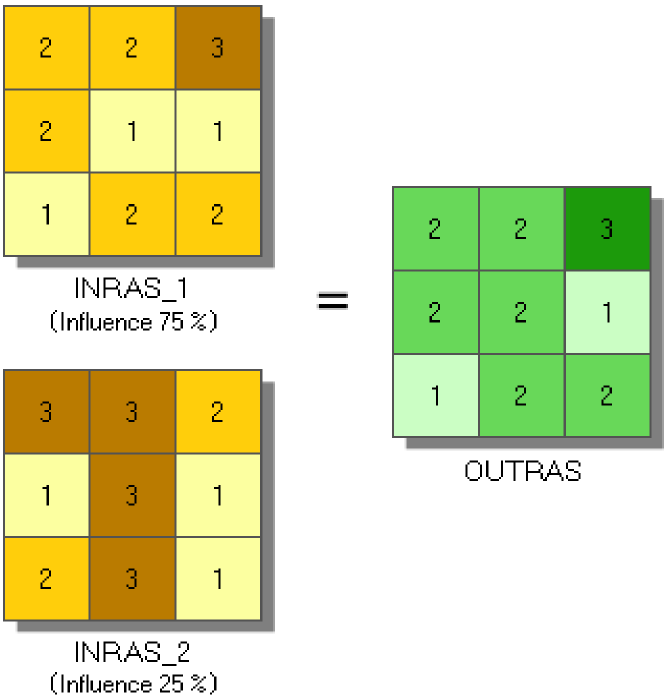
C1 – Elevation, C2 – Slope, C3 – Rainfall, C4 – Flow Accumulation, C5 – Soil, C6 – Inundated Roads, C7 – Land use Land Cover

Table 14 in the Criteria Weights column. The next step is to derive a Weighted Overlay map by performing a weighted overlay analysis.

3.2.3 Weighted Overlay Analysis

The weight to be assigned for each criteria were derived in the previous section using AHP approach. In this section, weighted overlay analysis is performed using the ArcGIS software to generate the Weighted Overlay map.

Weighted overlay analysis is done using the 'Weighted Overlay' tool from the Overlay section of the Spatial Analysis Tools from the Arc Toolbox. The weighted overlay tool overlays several raster using a common measurement scale and weights each according to its importance (ESRI, 2008). An illustration of the weighted overlay analysis is given in Picture 10 (ESRI, 2008)

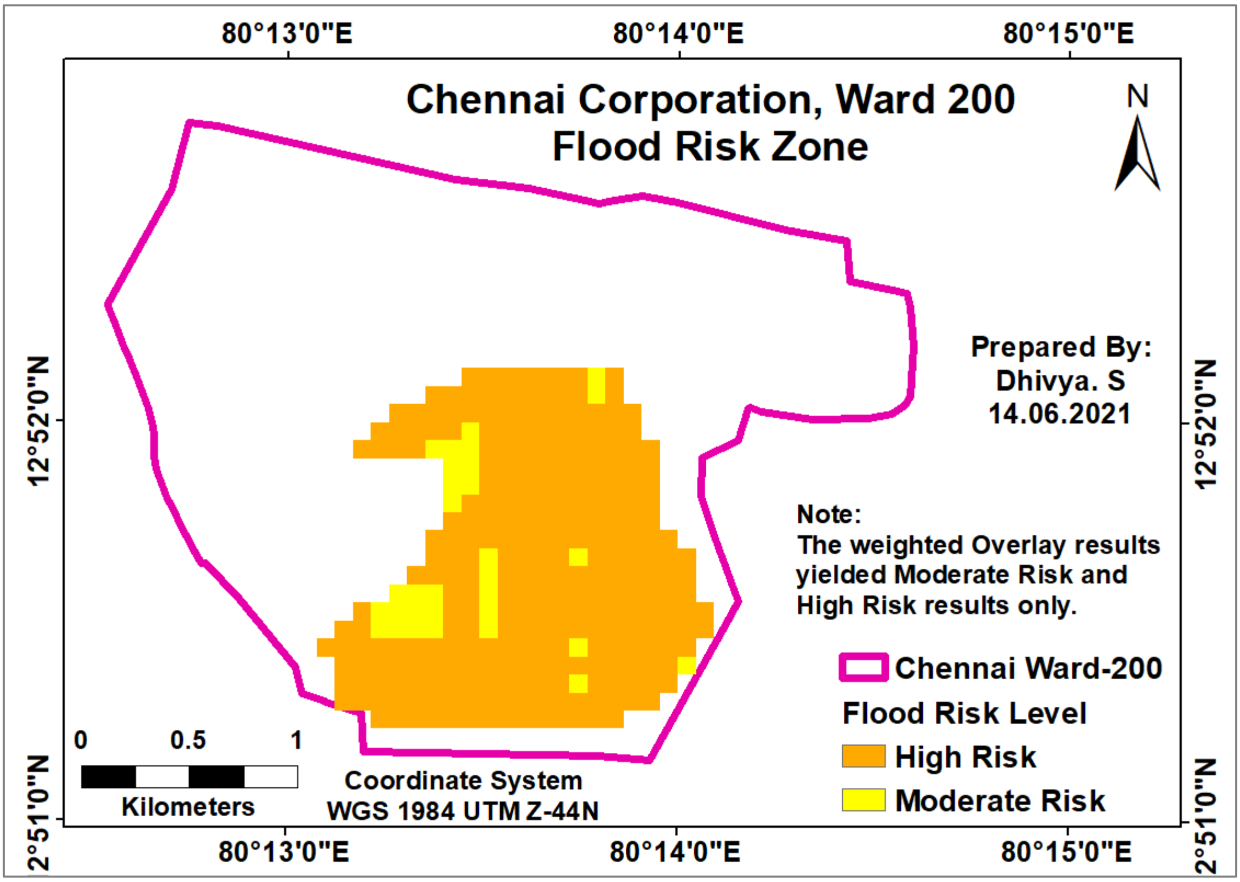


Picture 10: Illustration of Weighted Overlay

In the present study, 7 criteria were given individual weights as derived from the AHP method.

Table 16: Criteria Weights

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



Map 16: Flood Risk Zone

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. In-between there are also moderate risk zones given as result by the GIS Weighted Overlay tool.

3.3 Flood Prediction Using Hydrology Modelling

Hydrographs are line graphs which depicts the amount of water a drainage will discharge during the event of rainfall. In this section of the study, unit hydrographs are built with respect to the available DEM data. The estimation of flood prediction is done with respect to the watershed in the area. The Buckingham canal being the only drainage system in the area, the outlet point of this canal where the rainwater drains is considered to develop the watershed. The outlet point or the pour point is obtained from the official records Storm water drain department of the Greater Chennai Corporation. The watershed is delineated with respect to this pour point.

This section of the study has four broad steps,

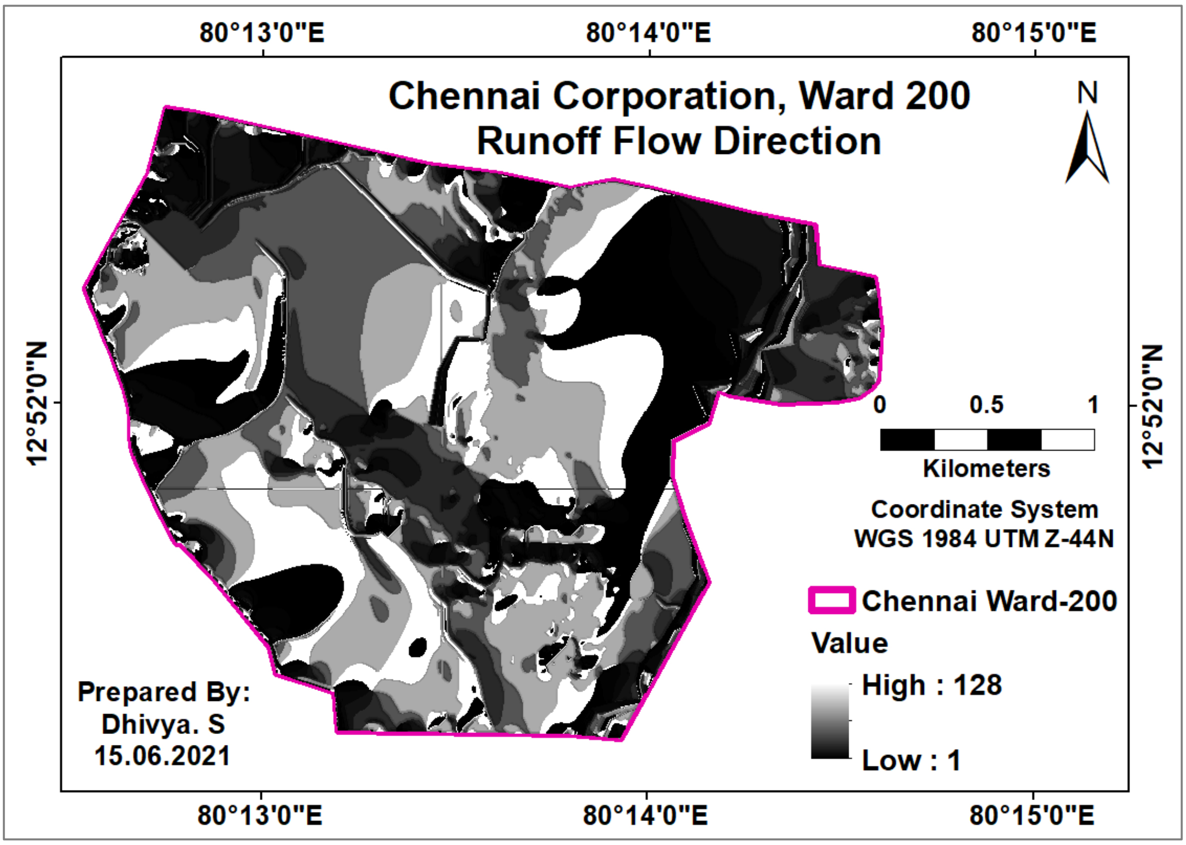
- Watershed Delineation
- Runoff flow Velocity determination
- Isochrone Map generation
- Unit Hydrograph generation

3.3.1 Watershed Delineation

The watershed map of the study area is derived from the true DEM prepared in the earlier section of the study. Watershed is an upslope area that contributes to flow of water (ESRI, no date). The watershed is delineated using the hydrology tools flow direction and Watershed tool under the Spatial Analyst Tools in the toolbox. Following the methodology defined in section 2.4.1 the watershed of the study area is delineated.

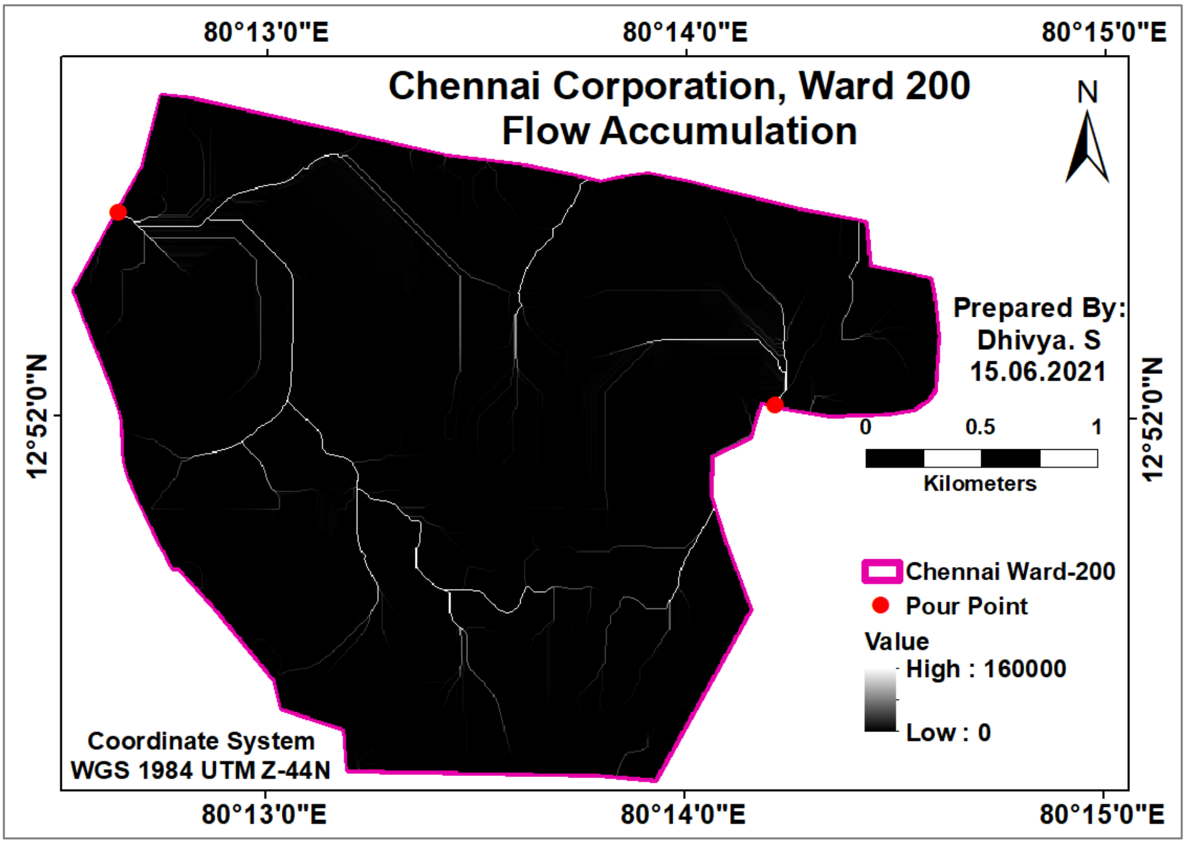
Fill Sink: The DEM used in this stage is the filled DEM. Sinks are usually data errors in a DEM raster dataset, which will generate possible errors in the results. The fill tool is used to remove these sinks from the DEM data.

Flow Direction: Now the DEM is ready to be used. The next step is to derive the flow direction raster data. Flow direction is Hydrology tool in GIS which will calculate the direction of stream flow in each cell. The flow direction data is the initially derived raster dataset for any hydrological modelling and calculations. The GIS Flow direction hydrology tool uses eight-direction flow direction coding, which follows the hypothesis that a steam flows from the centre cell to its eight neighbouring cells and it is considered flows to eight different directions, and the eight neighbouring cells will be assigned a number. In the Flow direction tool, the "Force edge cells to flow outward" is checked which depicts that the cells on the edge of DEM will be treated as flowing outward across the elevation surface (Supergeo, 2016). The derived data shows the direction the runoff water is more likely to flow. In the map below, the darker colours indicates a more southerly flow direction and lighter colours indicating a more northerly flow direction.



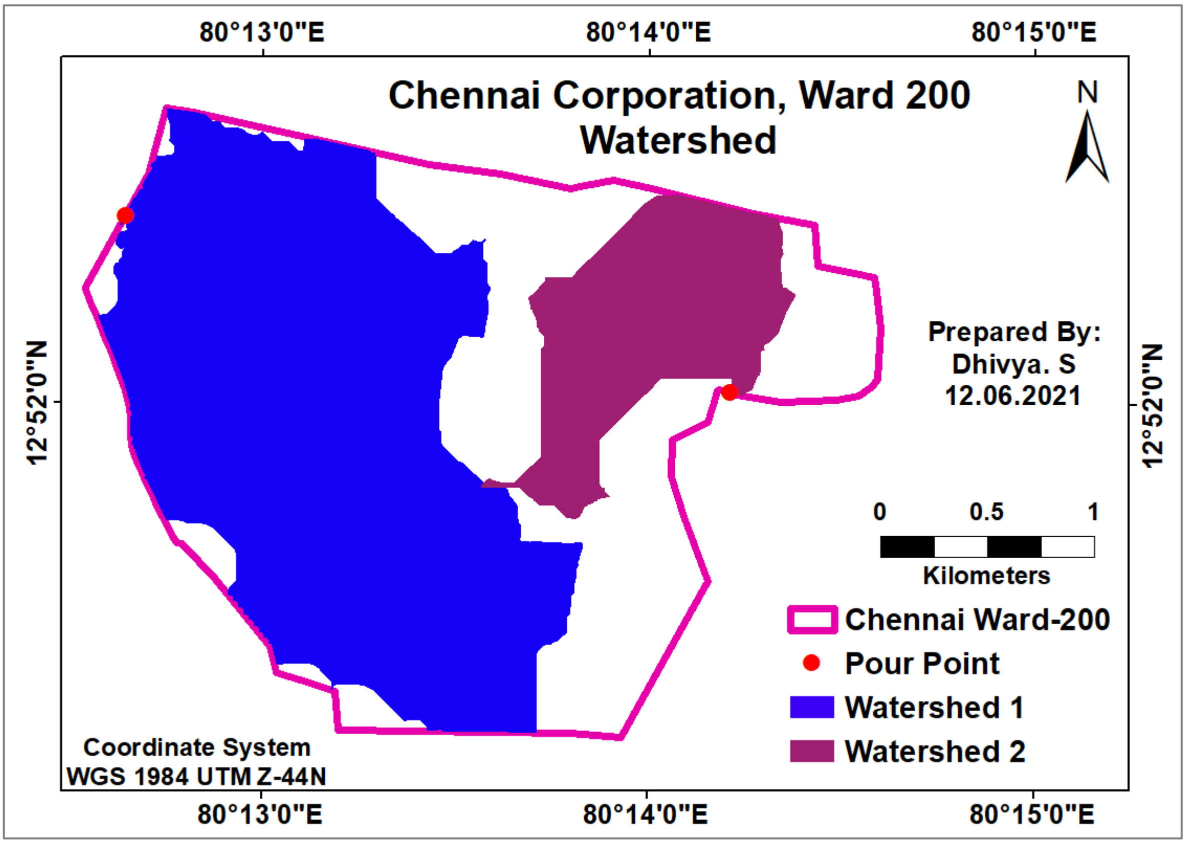
Map 17: Runoff Flow Direction

Flow Accumulation: This raster data set is generated to snap the pour point to the point at which the flow accumulation is maximum, which is thereby assumed to be the outlet location of the watershed. Flow Accumulation is the next important hydrology data used for any Hydrology based modelling and calculations. The flow accumulation data is derived by giving the Flow direction as the input in the GIS tool. Flow Accumulation Hydrology tool from the Arctoolbox is used to create the flow accumulation layer which depicts the portions where the runoff water is more likely to accumulate. The value of flow accumulation depicts the number of cells that flow into that cell. The cells with a high flow accumulation are areas of concentrated flow and may be used to identify stream channels and pour points for watershed delineation (ESRI, 2021). From the derived flow accumulation data, pour points are identified to generate the watershed of the study area.



Map 18: Flow Accumulation

Watershed Delineation: A watershed is an area which has the characteristics to cumulate the runoff water and drain it through a pour point. Pour point is the location at which the runoff water from the watershed gets drained into the drain. This pour point is used to derive the watershed and also the flood prediction's hydrograph will also be based on this point. In the study area pour points are assigned at various locations with reference to the flow accumulation data. Snap pour point tool is used to generate the exact or meaningful pour points in the study area with respect to the flow accumulation value. The tool generated two pour points in the study area, one towards the extreme left and the other towards the extreme right. This generated snap pour raster is given as input to the watershed GIS hydrology tool to derive the watersheds. The tool derived two major watersheds in the study area. The further hydrological modelling is done with respect to these watersheds.



Map 19: Watershed

3.3.2 Rainfall to Runoff Estimation

The actual runoff in the watershed is calculated as per the SCS-CN method using the formulas explained in the Section 2.4.2 of this thesis. As per the methodology the land use map and the soil map are overlaid on the watershed to derive the unique land use and Hydrologic soil group polygons and thereby derive the CN for each land use type. The derived CN values are summed up using the equation 3.2 to determine the area-weighted average CN of the entire watershed. The CN computation of the two watersheds present in the study area are derived below.

$$CN_a = (A \times CN) \div A_t \qquad \text{eq. 3.1}$$

$$CN_{Awa} = \sum_{1}^{n} \big((CN_a \times A_t) \div A_t\big) \qquad \text{eq. 3.2}$$

Where,

CN_a = Average Curve Number

A = Area (sq.km)

A_t = Total Area

CN_{Awa} = area-weighted average Curve Number

Table 17: Area-weighted average Curve Number Computation for Watershed 1

Watershed 1					
HSG	LULC Type	A	CN	% of Land use	CN_a
D	Commercial and business	1.8374	95	47%	44.5924
D	pervious areas only, no vegetation	0.3522	94	9%	8.4581
D	Row Crops	1.5761	89	40%	35.8338
D	Open space	0.0919	84	2%	1.9715
D	Water	0.0569	0	1%	0.0000
		A_t = 4			**CN_a = 91**

The watershed 1 has only one soil group D and five land use types. Applying the derived values in equation 3.2 the area-weighted average CN of the watershed 1 is 91. From the above computation the following is derived.

Table 18: CN and AMC values of Watershed 1

Total Area of Watershed 1	4 sq.km
Area-weighted average Curve Number	91
AMC	III

Table 19: Area-weighted average Curve Number Computation for Watershed 2

Watershed 2					
HSG	LULC Type	A	CN	% of Land use	CN_a
D	Commercial and business	0.3849	95	88%	83.6689
D	pervious areas only, no vegetation	0.0094	94	2%	2.0132
D	Row Crops	0.0048	89	1%	0.9677
D	Open space	0.0380	84	9%	7.3068
		A_t = 0.44			**CN_a = 94**
HSG	LULC Type	A	CN	% of Land use	CN_a
B	Commercial and business	0.5558	95	91%	86.7313
B	pervious areas only, no vegetation	0.0007	94	0%	0.1112
B	Row Crops	0.0037	89	1%	0.5473
B	Open space	0.0072	84	1%	0.9934
B	Water	0.0413	0	7%	0
		A_t = 0.61			**CN_a = 88**

The watershed 2 has soil group D and soil group B with four land use falling in soil group D and five land use types falling on soil group B. Applying the derived values in equation 3.2 the area-weighted average CN of the watershed 2 is 91. From the above computation the following is derived.

Table 20: CN and AMC values of Watershed 2

Total Area of Watershed 2	1.04 sq.km
Area-weighted average Curve Number	91
AMC	III

Table 21: Runoff Computation

Hourly Rainfall at Chennai on November 25 2020						
Time	Precipitation (mm)	CN as per AMC II	Converting AMC II to AMC III	S (mm)	0.3S	Q (mm)
1 am	16.8	91	97	7.8557	2.3567	9.3551
3 am	4	91	97	7.8557	2.3567	0.2843
6 am	6.3	91	97	7.8557	2.3567	1.3179
9 am	7.3	91	97	7.8557	2.3567	1.9092

12 pm	8.9	91	97	7.8557	2.3567	2.9735
3 pm	6.7	91	97	7.8557	2.3567	1.5464
6 pm	7.5	91	97	7.8557	2.3567	2.0350
9 pm	4.7	91	97	7.8557	2.3567	0.5384

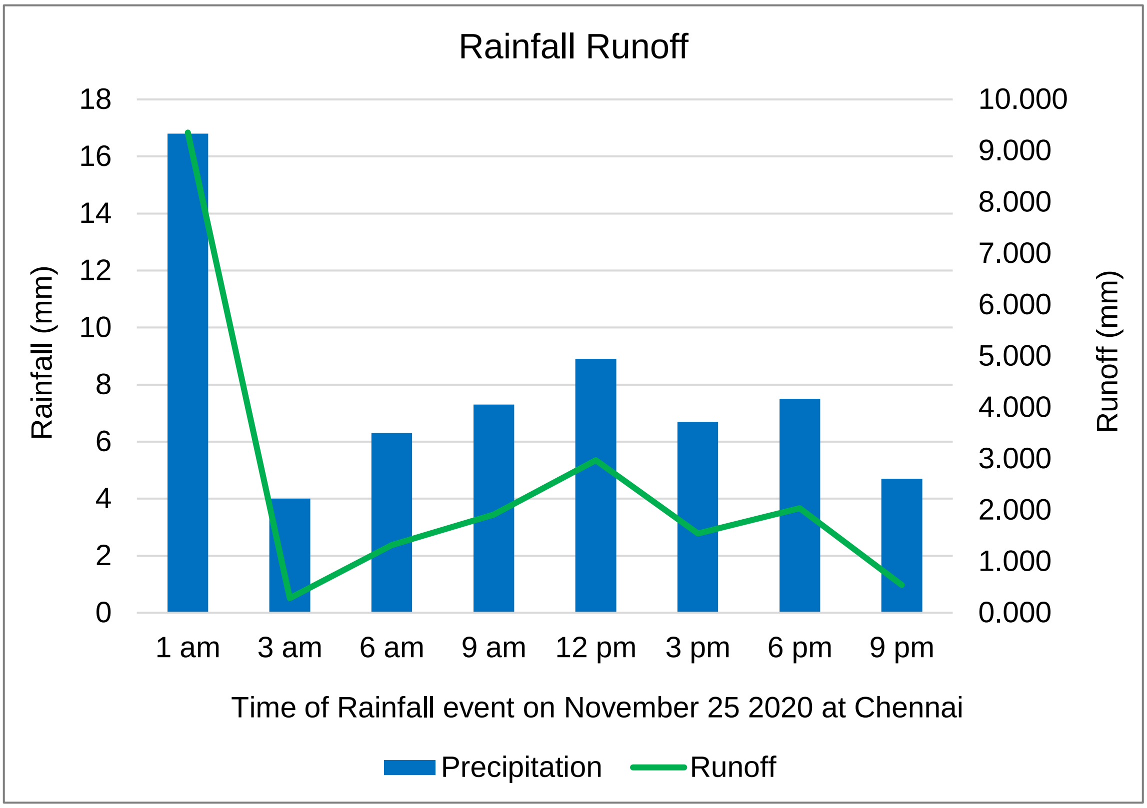


Figure 11: Rainfall Runoff graph

The table 20 depicts the runoff calculation performed for the hourly rainfall data of Chennai on November 25 2020. The derived AMC value falls in the AMC III category. The CN constant of AMC III is obtained from the NRCS handbook of Hydrology Engineering (NRCS, 2004, p. 12). The potential maximum retention ‘S’ and the Runoff Volume is computes as per the equation 2.11 and equation 2.12. As both the watersheds fall on AMC III and has the same area-weighted average Curve Number, the rainfall runoff calculation is considered common for both the watersheds. Substituting the values from Table 20 into equation 2.13 the total runoff volume can be derived.

$$Q_t = 20 \text{ mm}$$

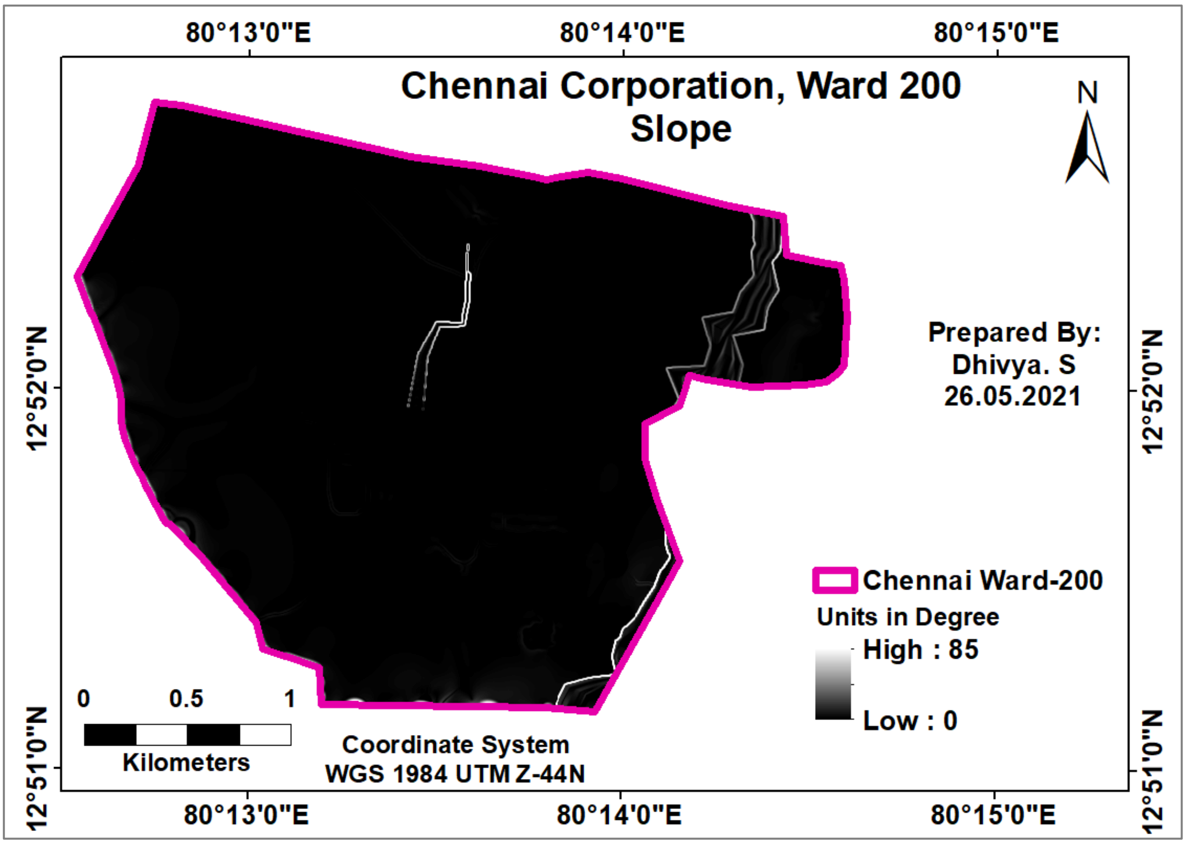
3.3.3 Runoff Velocity and Time considering DEM

The next step of the study after generating the watershed is to determine how fast the water will flow into the drain in the study area and also how much time it will take to drain into the outlet. Based on which the flood occurrence can be predicted. The mathematical equations mentioned in section 2.4.2 are used to derive the velocity field considering few assumptions. The velocity raster generated will be spatially variant, but time and discharge invariant (Learn ArcGIS, 2020), which means the following criteria are considered during the generation of the velocity raster,

- The criteria of slope and flow accumulation is considered, which shall be referred as spatial variant.
- The other factors which affect the velocity field is the time, which is not considered in this study due to lack of data. So the velocity field generated will be irrespective of the time factor.

Evaluating the velocity field with respect to the spatial criteria of slope and flow accumulation gives nearly accurate results. The method adopted to derive the velocity is referred from (MAIDMENT et al., 1996, pp. 831-844). In this method each cell in the raster is given a velocity field. This velocity field is calculated based on the slope and the flow accumulation in that particular cell.

The flow accumulation raster derived during the watershed delineation will be used in this stage. The slope raster data have to be created. The slope option under the Hydrology tool of the ArcToolbox is used to generate the slope data. The slope is derived by determining the change in elevation between cells, to the original DEM without filled sinks is used as the input. The output measurement selected is ‘Percent rise’ which calculates the slope as percentage of vertical elevation over horizontal elevation. The other parameters are maintained as it is and the slope tool is run.



Map 20: Slope

Slope Area Term Determination

The slope raster and the flow accumulation raster derived from the previous step is used to derive the Slope Area term for calculating the velocity. The raster calculator tool from the Arctoolbox will be used to determine the Slope Area term. The Slope Area data depicts the area of the watershed which will contribute to the accumulation in the watershed of the study area. This data is further used to determine the runoff velocity of the watersheds.

The computation is done as per equation 2.14. The resulting raster layer is masked to the watershed extent of the study area. There exists two watershed in the study area, so two Slope Area raster are derived by computing the values and raster with the respective equation. This is done to identify the average Slope Area term for the calculation of runoff velocity.

Velocity Calculation

The velocity calculation is done as per the formula mentioned in equation 2.15. Now we have the slope area term and the average slope area term is determined from the slope area term raster properties.

Property	Value
Vertical Coordinate Syste...	
⊟ **Statistics**	
⊟ Band_1	
Build Parameters	
Min	0
Max	271.8419494628906
Mean	3.123752259641585
Std dev.	6.971969492372495
Classes	0

Picture 11: Slope Area Properties of Watershed 1

Property	Value
Vertical Coordinate Syste...	
⊟ **Statistics**	
⊟ Band_1	
Build Parameters	
Min	0
Max	467.9262390136719
Mean	3.48789106841746
Std dev.	8.511464508423819
Classes	0

Picture 12: Slope Area Properties of Watershed 2

The average slope area term is the mean value of the Slope area term,

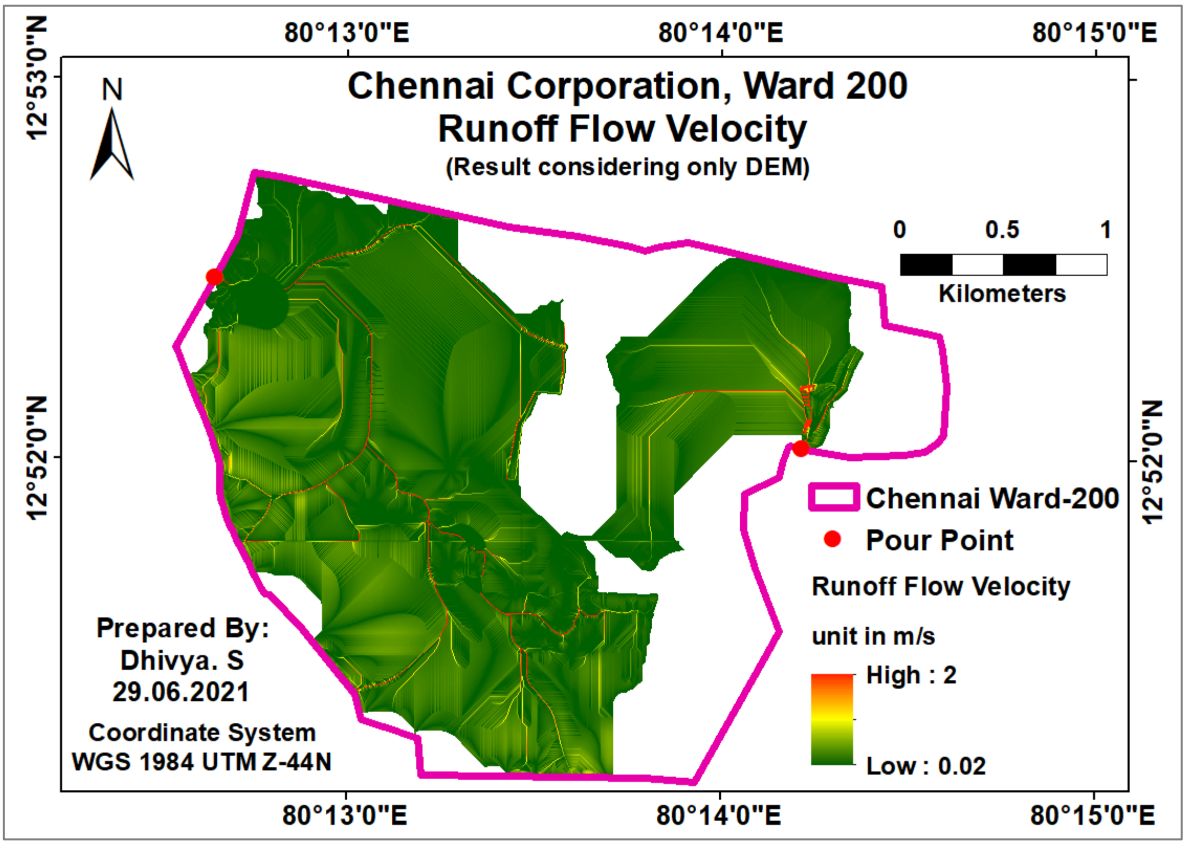
For Watershed 1: $(S_l \times A_r)_a = 3.123752259641585$

For Watershed 2: $(S_l \times A_r)_a = 3.48789106841746$

Now we know the average velocity, slope area term and average slope area term, the velocity can be calculated as per the equation 2.15, For Watershed 1: $Vs = 0.1 * (S_l \times A_r)_a / 3.123752259641585$

For Watershed 2: $Vs = 0.1 * (S_l \times A_r)_a / 3.48789106841746$

Map algebra is used to calculate the velocity with the raster datasets. This calculation generates the Velocity raster data which depicts the velocity in which the runoff drains into the pour point from the watershed. This gave a velocity value stretch between 0 to 9 meters per second. The lower velocity and higher velocity are an unrealistic figures, as 9 meters per second run off is a very unrealistic figure, which is not possible even during a major flood. To obtain the realistic figures, the velocity values are limited between 0.02 meters per second to 2 meters per second. The Con function from the ArcToolbox is used to limit these values. The resulting raster data depicts the velocity in which water flows in its course towards the pour point. In the below map it can be read that the velocity of water to flow through the outlet ranges between 0.02 meters per second to 2 meters per second for the watershed 1 and watershed 2.



Map 21: Runoff Flow Velocity

In the above map, the darker colour represents slower velocity and the lighter colour represents higher velocity. With this result we know how fast the runoff water will flow and drain into the pour point. The next step is to generate the isochrones map.

3.3.3.1 Runoff Flow Time using DEM

Isochrones are the contour lines that passes through the locations of equal travel time towards the watershed. The next step is to determine the time that the runoff water takes to reach the outlet. In this study, the isochrones are developed for a time interval of one hour in the watershed. This means that the derived isochrones map will depict the hourly runoff at the watershed area towards its outlet or the pour point. By deriving this data we will get the information on the quantity of the water or the excess rainfall flowing into the outlet and the time required for the excess rainfall to drain from the watershed. With this information unit hydrograph can be generated to do the flood prediction in the watersheds.

The weighted grid is prepared to use as an input to the flow length tool. The weight is derived from the velocity field data. The weight here represents the rate at which the water flows through a surface. Water tends to flow slowly in a very compactly built urban area, whereas water flows freely in an open surface area. This criteria of weight is derived using the equation 2.16

With the velocity raster data the weight is determined. Map algebra tool from the ArcToolbox is used to carry out the raster calculation of one divided by velocity. The weight is used as one of the parameter in the flow length tool to calculate the flow time of the watershed 1 and watershed 2.

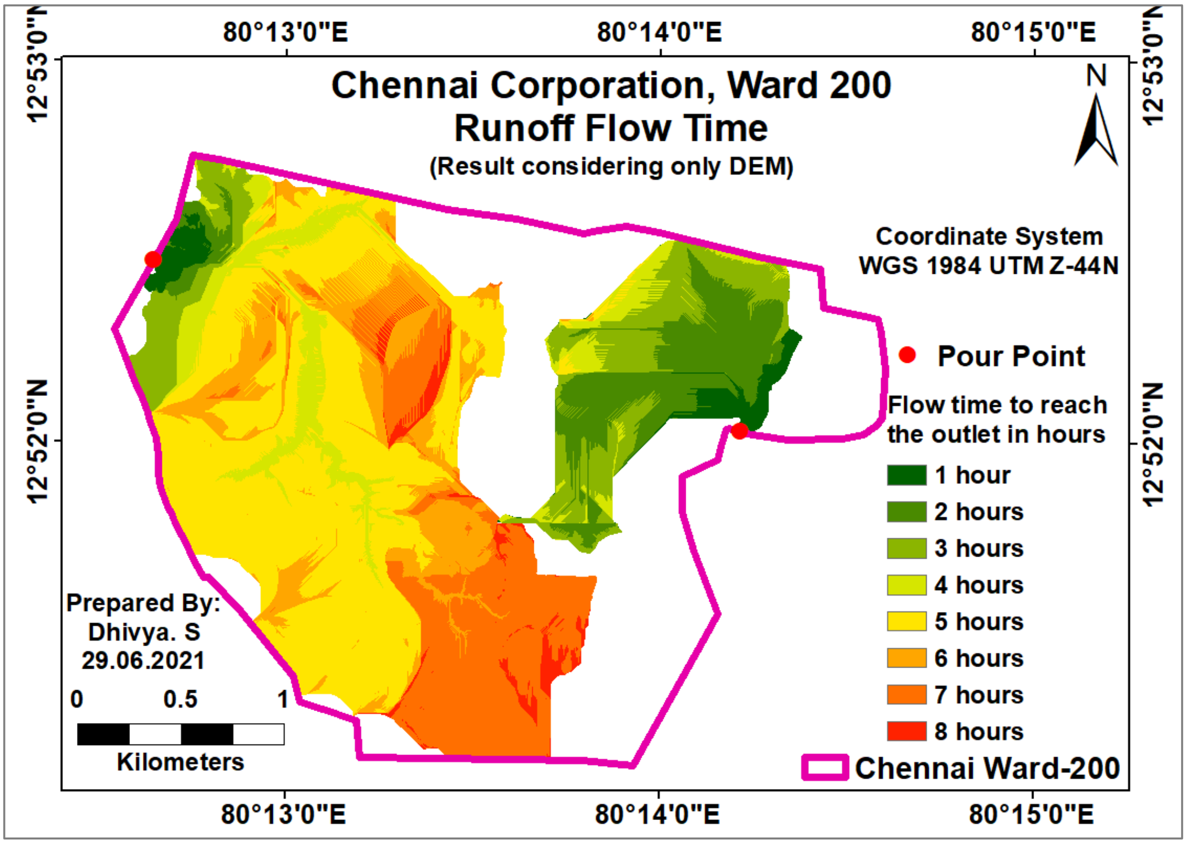
Flow length tool from the Hydrology tool from the ArcToolbox is used to determine the flow time data. The tool has an option to use weight data to determine the flow time. The tool is run and the data is generate which depicts the run off flow time raster data.

The resulting raster will depict the time of flow in seconds. The time it takes for the water to flow to the outlet ranges from 0 to approximately 30000 seconds, i.e., it requires 100 minutes or 8 hours to flow into the outlet during an extreme rainfall and inundation scenario.

There are several unique values in the generated flow time raster map which are difficult to interpret. So the Run off flow time isochrones map is generated by reclassifying the flow time data into seven unique flow time values.

Table 22: Runoff Flow Time Classification

Flow Time Values (seconds)	Reclassified value (hours)
0 – 3600	1
3600 – 7200	2
7200 – 10800	3
10800 – 14400	4
14400 – 18000	5
18000 – 21600	6
21600 – 25200	7
25200 – 28800	8



Map 22: Isochrone Map

The above map depicts the time in hours it takes for the water to pour into the outlet of the watershed. In the above map, the light blue in watershed 1 and magenta colour in watershed 2 represents that the water takes one hour to drain into the outlet, similarly the map can be read with respect to its respective colour coding.

In the isochrones raster the area field is calculated by multiplying the cell values of the raster data into the number of cells. The raster data being generated from the DEM, the cell size of the DEM is considered to calculate the area field. The cell size of the DEM is 5cm.

Area is calculated by multiplying the cell count by the square of the DEM cell size,

$$Isochrone\ Area = \ Cell\ Count\ \times 5 \times 5 \qquad \text{eq. 3.3}$$

The table generated from the isochrone map is used to generate the Time Area Histogram. The time area values and the respective histograms of both the watersheds are depicted below.

Table 23: Time Area Values of Watershed 1

Watershed 1	
Time (hours)	Area (sq.m) (A)
1	59575
2	53050
3	179125
4	287275
5	1781500
6	610775
7	839775
8	103900

Table 24: Time Area Values of Watershed 2

Watershed 2	
Time (hours)	Area (sq.m) (A)
1	84125
2	444750
3	382850
4	117000
5	17450
6	1075

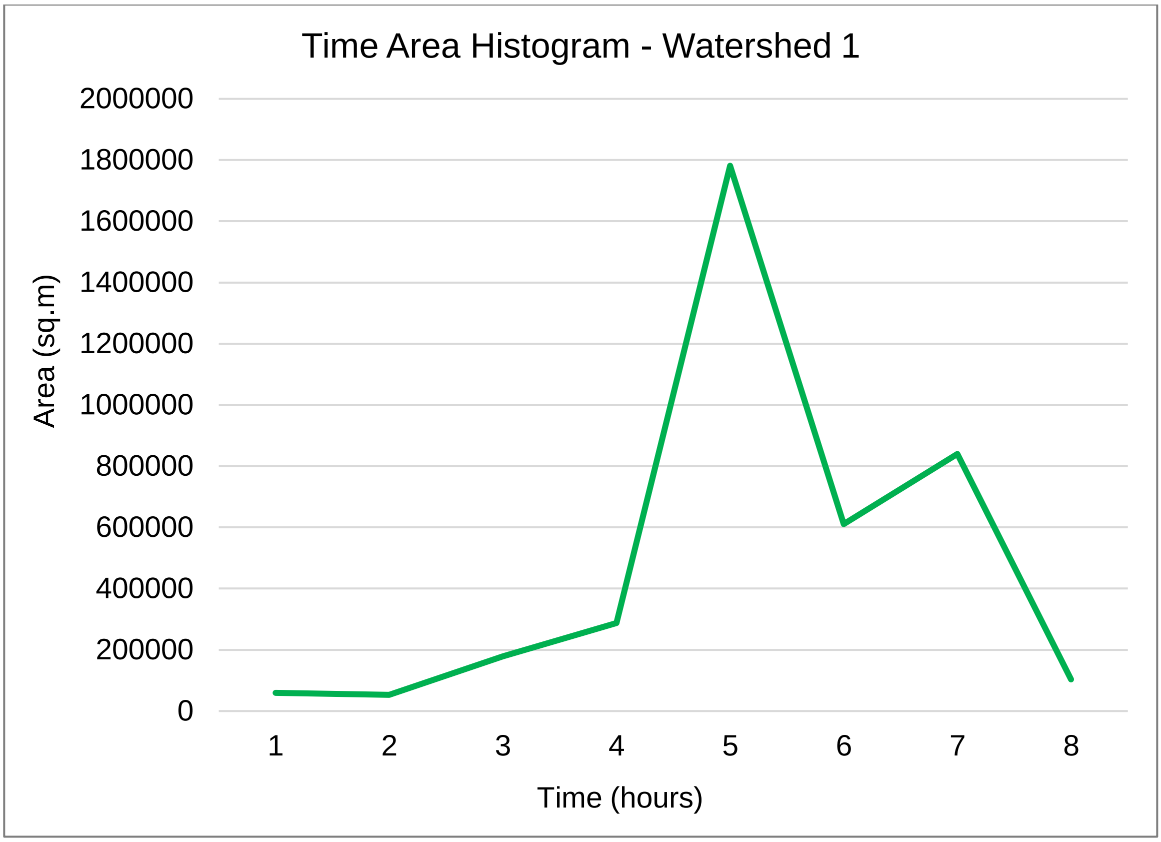


Figure 12: Time Area Histogram of Watershed 1

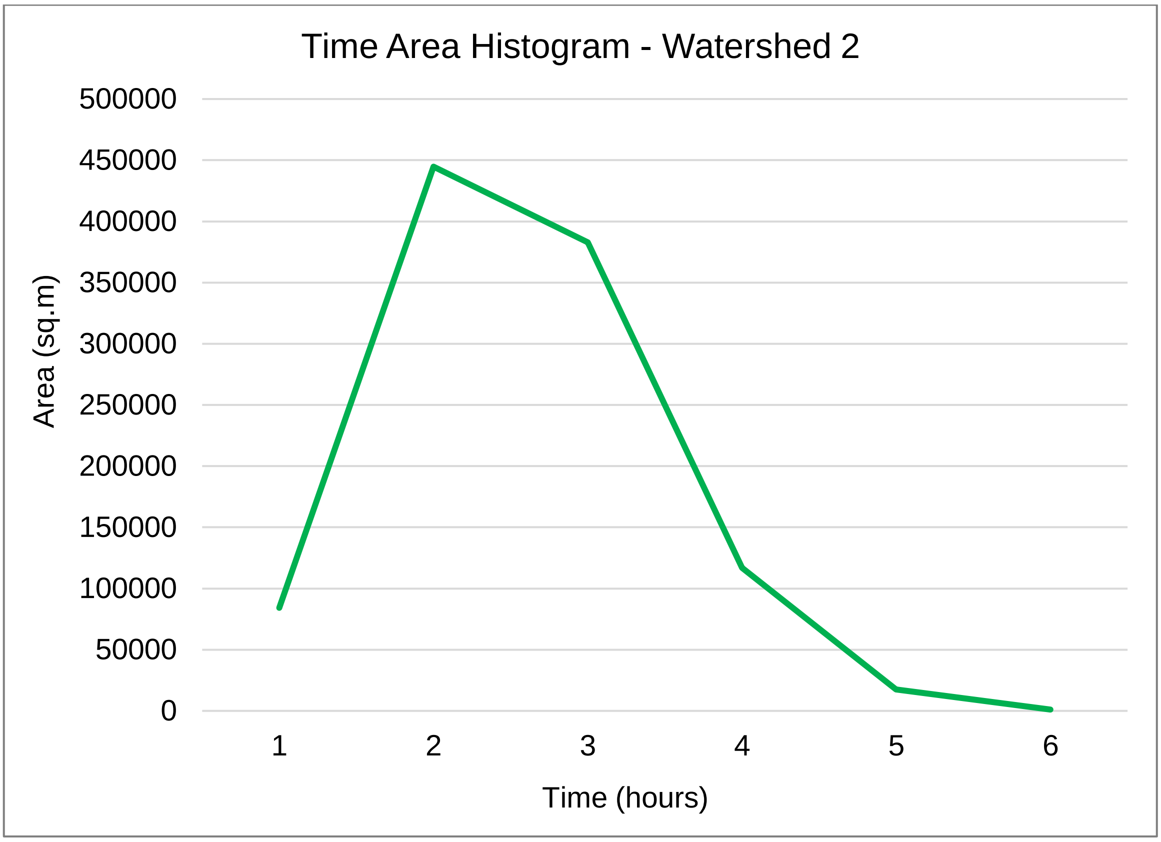


Figure 13: Time Area Histogram of Watershed 2

The above graphs depicts the area in the watershed contributing to runoff with respect to the time. The above graph is called Time Area Histogram and is derived using Time Area Method considering DEM only as an influencing factor. It can be read from the graph in figure 12 that watershed 1 contributes to around 1800000 square meters of peak runoff area in 5 hours of continuous rainfall. And it can be read from the graph in figure 13 that watershed 2 contributes to around 450000 square meters of peak runoff area in 2.5 hours of continuous rainfall.

3.3.4 Unit Hydrograph

The Unit Hydrograph depicts the discharge volume at the outlet in unit time. It is obtained with respect to the values obtained from the Time Area method and the watershed's Runoff capacity derived from the SCS-CN method. The values are computed in the equation 2.19 and equation 2.20.

The Unit hydrograph ordinate field is calculated to generate the unit hydrograph. This will calculate the volume of water reaching the outlet each second. This value is derived using the equation 2.20. The table used to generate the unit hydrograph is shown below,

Table 25: Unit Hydrograph Ordinate Calculation – Watershed 1

Time (hours)	Time (Seconds)	A_r (sq.m)	V_{lr} = A*0.02 (m^3)	U_{ho} (m^3/s)
1	3600	59575	1191.5	0.33
2	7200	53050	1061	0.29
3	10800	179125	3582.5	1.00
4	14400	287275	5745.5	1.60
5	18000	1781500	35630	9.90
6	21600	610775	12215.5	3.39
7	25200	839775	16795.5	4.67
8	28800	103900	2078	0.58

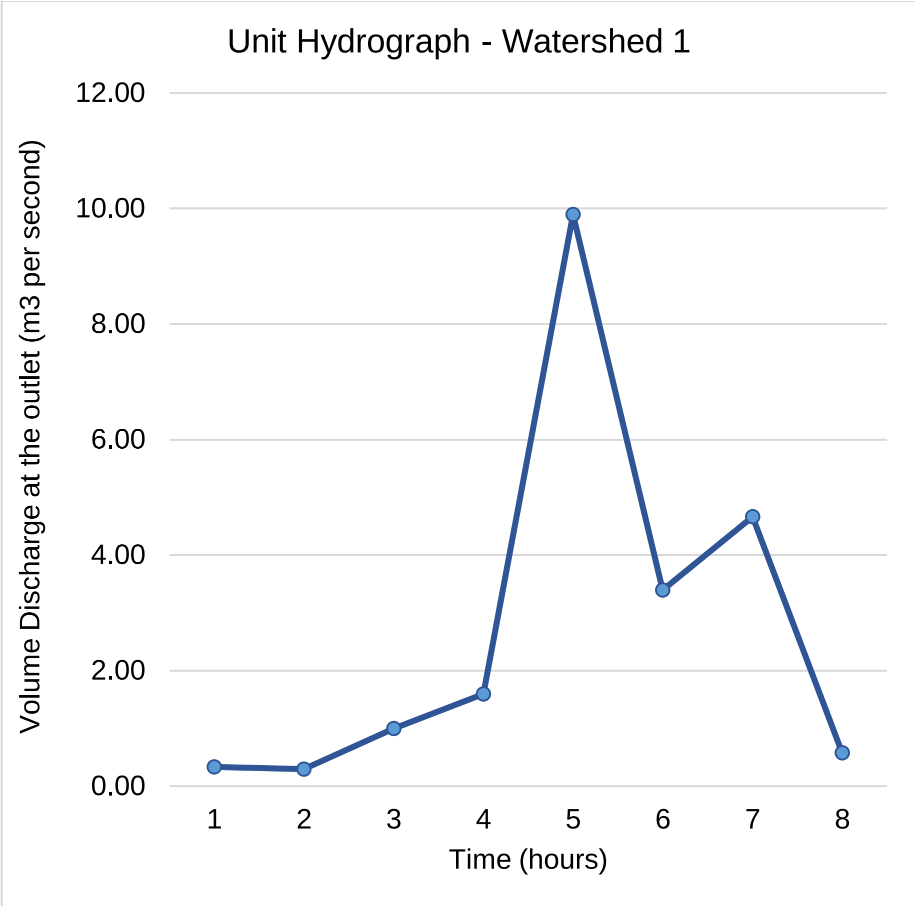


Figure 14: Unit Hydrograph – Watershed 1

The graph depicts the discharge at outlet per unit of excess rainfall with respect to the time. It is found from the graph that maximum volume of discharge of water to the outlet is approximately approx.10 cubic meters per second. The watershed will reach its peak runoff volume point when it experiences rainfall for five to six hours.

Table 26: Unit Hydrograph Calculation – Watershed 2

Time (hours)	Time (Seconds)	A_r (sq.m)	V_{lr} = A*0.02 (m^3)	U_{ho} (m^3/s)
1	3600	84125	1682.5	0.47
2	7200	444750	8895	2.47
3	10800	382850	7657	2.13
4	14400	117000	2340	0.65
5	18000	17450	349	0.10
6	21600	1075	21.5	0.01

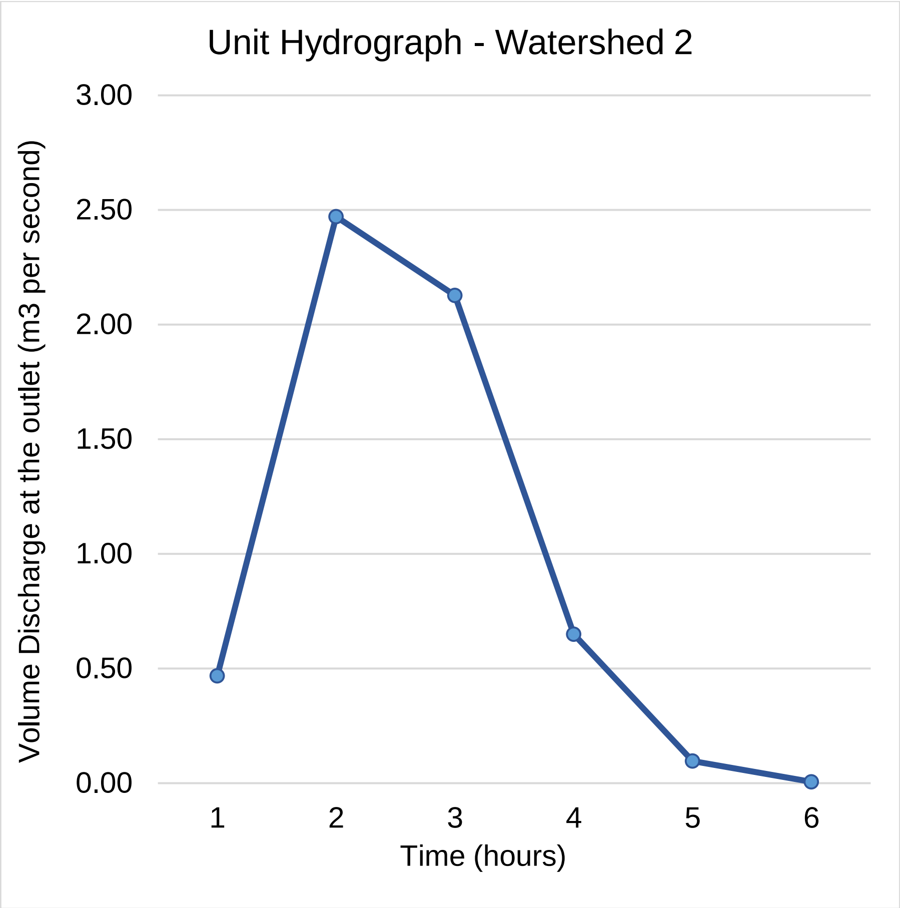


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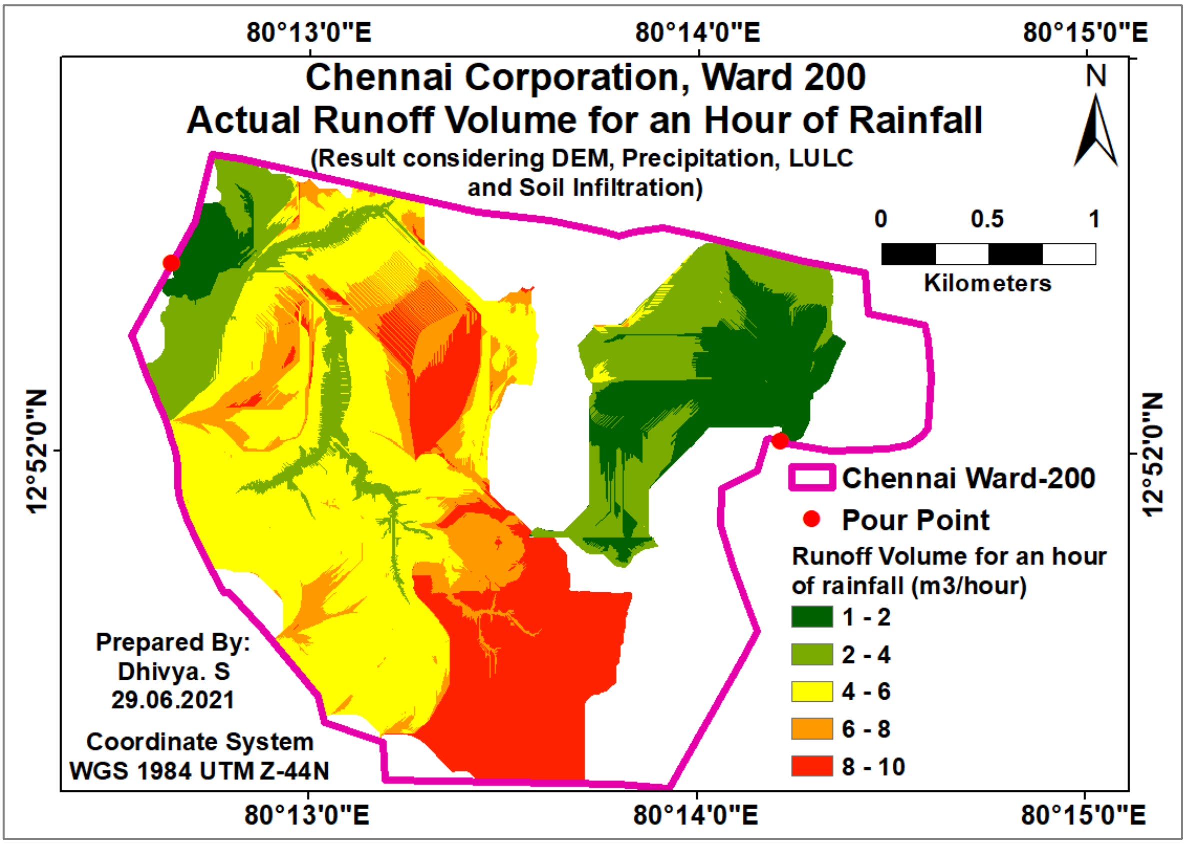
Figure 15: Unit Hydrograph – Watershed 2

The graph depicts the discharge at outlet per unit of excess rainfall with respect to the time. It is found from the graph that maximum discharge of water to the outlet is approximately approx.2.5 cubic meters per second. The time to attain this peak discharge volume is 2 hours after the event of rainfall in the watershed.

3.3.5 Actual Runoff Volume

The runoff volume is reclassified and mapped in ArcGIS to depict the actual runoff volume characteristic of the watershed for an hour of rainfall. This derived runoff volume is resulted by considering the precipitation in the watershed, Land use and land cover hindrances, Soil infiltration and Slope of the watershed area using the formula defined in the Methodology chapter section 2.4.4.1.



Map 23: Actual Runoff Volume for an hour of Rainfall

From the above map, it can be depicted that the green portion is where the runoff volume is less, because the portion is very near to the outlet so the water gets discharged quickly. The map predicts that when there is an hour of excess rainfall in the watershed, then the areas depicted with the dark green colour has the peak capacity to discharge only 1 to 2 cubic meters of water per hour. The area of the watershed away from the pour point has larger volume of runoff because it tends to reach the outlet slowly. In the above map the areas displayed in bright red colour conveys that for an hour of excess rainfall in the watershed the runoff volume is 8 to 10 cubic meters per hour. The peak discharge volume of the watershed in 10 cubic meters per hour of rainfall.

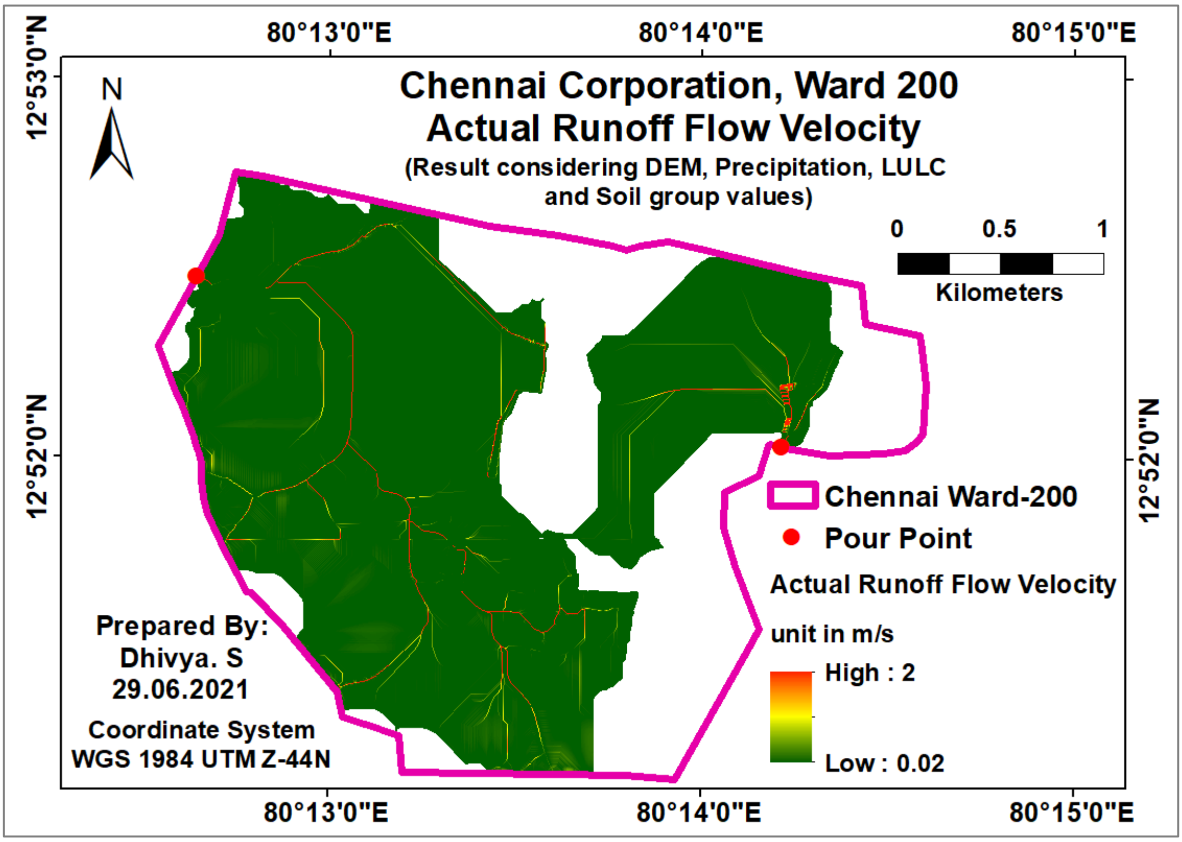
The disaster relief and planning department or the planners and decision makers can refer this information of runoff volume to predict flood in the study area and plan their development and rescue measures accordingly.

3.3.6 Actual runoff Velocity and Time considering DEM, LULC and Soil Infiltration

In the previous step the runoff volume for an hour of rainfall in the watershed is calculated. This ordinate is derived considering the hourly Precipitation of the study area, land use land cover type and soil infiltration rate. Using the unit runoff volume, the actual runoff velocity and actual runoff time of the watershed is calculated using the equation 2.23 and 2.26.

The area of the contributing run off is calculated by dividing the unit runoff volume with Actual runoff of the watershed as per equation 2.21. The resulting area factor is used to derive the actual runoff area in the watershed as per equation 2.22. The derived raster is the Actual Runoff Area raster.

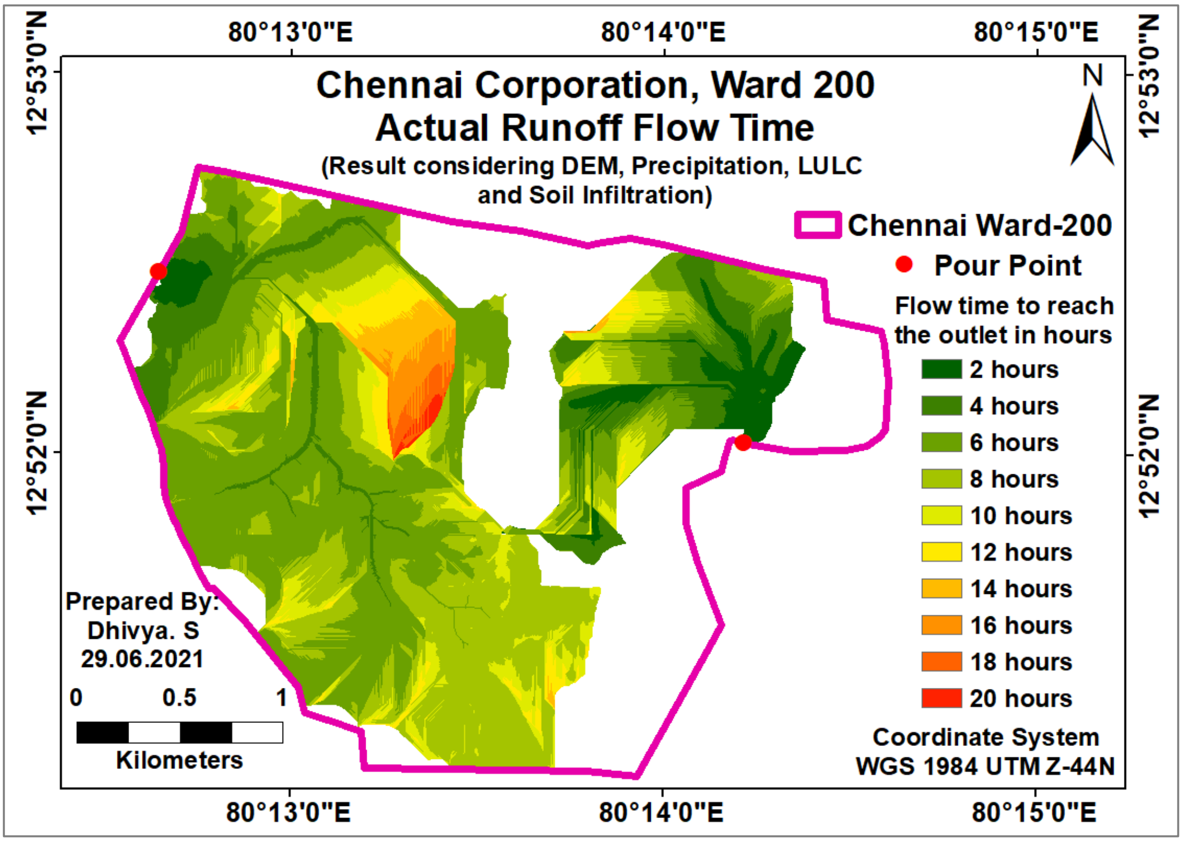
The Actual runoff Area and the Average Actual runoff i.e., the mean value of the raster is substituted in the equation 2.23 to derive the actual runoff velocity in meters per second.



Map 24: Actual Runoff Flow Velocity

The above map depicts that the velocity of flow is high at the locations represented in red colour legend and the velocity is low in the areas depicted in green colour legend. Since the study has mostly flat terrain, the influence of slope is much less, so most of the watershed has the runoff velocity in the lower range.

The derived velocity raster is computed using 2.24 to derive the weight. The weight will be input to the Flow length tool in the Arctoolbox, spatial analyst hydrology tool. Flow direction derived from the DEM will also be one of the input to the flow length tool. The tool is run to derive the actual runoff flow time of the watershed.



Map 25: Actual Runoff Flow Time

The above map depicts that the runoff time is maximum at the portion represented in red colour legend. So when excess rainfall occurs, this area tends to get inundated for many days, so the action has to be taken

3.4 Results

As mentioned in the earlier chapter, the aim of the study was to develop a methodology to find the flood risk zones and Flood Prediction in the study area. The objective is to identify the flood prone areas in the study area and find the structures that are prone to flooding, and use hydrological modelling approach to predict the urban flooding in the study area watersheds. The study yielded three results using the different methodologies, tools and data.

Result 1: The structures at the flood prone areas were identified by comparing the land use change in the study area over a period of 56 years between 1954 and 2020. The study yielded the results of the structures which are in the flood prone areas. This is a non-scientific method of approach to identify the infrastructures at the flood prone areas. Since the scale of data being compared is not the same the results might not be accurate. The results are further improved by using high resolution DEM. 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 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. The field photographs taken during the Nivar Cyclone that hit Chennai on November 2020 is used to cross verify the results. Out of 11 photographs that were obtained during the flood, 4 locations were matched with the result obtained in this study. This yielded 40% match with respect to the field obtained data. 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.

And, the CMDA 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 next aim of the study was to map the flood risk zones in the study area using weighted overlay analysis method combined with Multi Criteria Decision Analysis, AHP methodology. The MCDA method used various environmental and socio economic criteria. A total of 7 criteria were used in the study which includes, elevation, slope, rainfall, soil, flow accumulation, Land use and land cover, and historical Inundated roads.

Table 27: Flood Risk Area - MCDA Result

	Area (Sq.km)	Percentage Covered
Study Area	**7.1**	
Moderate Risk	0.2	3%
High Risk	1.9	27 %

The result shows that out of the total study area of 7 sq.km, 0.2 sq.km area falls in the moderate risk zone which account for 3% of the total study area, and 1.9 Sq.km of area falls in the High risk zone which accounts for the 27% of the study area.

Semmancheri, Gandhi Nagar society, Majestic Residence society, Jeppiar Institute and Thalambur Locations are the areas where new Storm Water Drain network are required on urgent basis

The results show that the zones in the bottom of the study area is in the urgent requirement of Storm Water Drain as they tend to inundate with 40 to 60 mm of rainfall per hour itself as per news reports. It is also found that there is no natural watershed to drain the water in this region. It can be proposed to the SWD department that new drains shall be planned in the regions where the risk of inundation is high. The buildings with the risk of inundation also falls in the same region as mentioned later.

In the year 2020, the study area experienced 59 mm of rainfall per day during the monsoon. Many residents suffered the risk of inundation due to the lack of facilities for the water to drain. The people requested the civic bodies to plan better facilities and infrastructure to avoid the risk of inundation. This being the problem for all the regions in and around ward 200, the Greater Chennai Corporation (GCC) planned to improve the SWD in these regions. The Greater Chennai Corporation (GCC), through the Integrated Storm Water Drain (ISWD) project of the Kovalam Basin, has planned to prevent flooding and save rainwater which would go waste into the sea. This study methodology shall be very helpful for the corporation to decide where the need of SWD is on urgent basis, so that the infrastructure can be implemented faster thus reducing the impacts of flooding during the monsoon days. It is found that the Semmancheri, Gandhi Nagar society, Majestic Residence society, Jeppiar Institute and Thalambur areas are under the greater risk of inundation.

Low lying, depressions and sinks could be found anywhere irrespective of the natural terrain of the land. These areas will be hard to identify during normal climatic conditions, they become apparent when hit by extreme rains. When a heavy rainfall is witnessed, these low lying areas get flooded affecting not only the buildings but also the infrastructures like road, sub way, rails etc. A well-structured Storm Water Drain (SWD) is necessary to overcome this issue. Buildings level flood vulnerability study has not been done in the state till date (April, 2021), so it is advised to carry out this methodology to find the end level victims of flood and thus plan the flood preparedness and mitigation and rescue measures accordingly.

Result 3: The next analysis was done to predict the flood in the study area using Unit Hydrograph. This method analysis the volume of water that can drain into the outlet of the study thus determining the peak watershed capacity. When there is a rainfall which exceeds this time to attain the peak flow to the drain, then there is a risk of flooding. First, the watersheds were delineated with respect to the pour points with respect to the flow accumulation data derived from the DEM. There were two watersheds observed in the study area, the watershed1 of the area measured up to 4 square kilometre and the watershed 2 of the study area measured up to 1.04 square kilometre. Then with respect to the watershed the other parameters like the flow accumulation, flow direction, flow length, flow velocity and flow area are calculated. The estimate was done with respect to time in hours. It is observed from the result that the maximum discharge of water at the outlet is approximately 10 cubic meters per second in watershed 1 and the maximum discharge of water at the outlet is approximately 2.5 cubic meters per second in watershed 2. It can be inferred from the result that, if the study area experiences continuous rainfall of five to six hours or more then the watershed 1 tends to get flooded and if the study area experiences continuous rainfall for 2 hours or more the watershed 2 tends to get flooded. The result depicted in Map 25 shows the Actual Runoff Time of the watershed calculated with respect to Land use land cover, soil infiltration, DEM and precipitation. The area which are classified as red colour depicts that more time is needed for the water to flow through the outlet in the event of a heavy rainfall. So this area must be considered as priority for Inundation rescue measures.

The processed and the results are explained in this chapter in detail. With respect to the above results the departments of disaster management can perform their mitigation and flood preparedness activities on the right places. As the flood risk zone results are obtained by considering all the important parameters contributing or related to flood, the results and methodology can be widely used by Disaster management team of the Corporation. The flood prediction study is also done considering the land use type, soil group and also real precipitation values of the study area, so these results are highly recommended to be used by the flood preparedness team for planning the rescue measures before the flood occurs. With the effective utilisation of GIS, SCN-CN and Time Area methods good results are obtained. These results help in good decision making. The Chennai Metropolitan Development Authority is the department giving permissions for Building constructions and development. Thus with these results the CMDA can evaluate the areas prone to flooding and deny the permissions of urbanisation wherever necessary.

Chapter 4: Conclusions

Chennai Corporation is a rapidly growing place where the problem of Inundation during rainfall is persistent for the past few years. This problem is not only faced here, but also in several other cities, states and countries. The socio economic activities, material assets, cultural and economic resources are lost due to the adverse effects of flood. The world's climate is also changing increasingly contributing to adverse natural disasters. Development of economic infrastructures in the food prone area, along with poor planning has increased the magnitude of hazard which has invariably increased risk to the sustainable development and poverty in Chennai. 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.

The WMO/GWP has published a document on Urban Flood Risk Management, in which the GIS technology is proposed to do the Risk Assessment of the Flood Prone areas. Various parameters has to be considered while doing a risk assessment. The past records of hazard, its intensity, loss, exposure and vulnerability of the society needs to be considered, along with it, the future development plans, possibility of urbanization, waterbodies at the verge of extinction all play a major role in risk assessment (WMO, 2008). Spatial visualisation and analysis is needed to study and identify the locations at risk. This study used the GIS tools to find the flood prone location in the Ward 200 of Chennai Corporation, Flood risk zones and also predicted the flood in terms of rainfall event. These results were arrived using the technology of GIS combined with Multi Criteria Decision Analysis and ArcGIS based Hydrology tools. The flood prediction results were derived with a combination of GIS hydrology tools with hydrology calculations in SCS-CN method and Time Area Histogram method.

4.1 Discussion

This study is performed using the data collected from the Storm Water Drain department of the GCC office, Public interview and available data from the open source platform so there exists few constraints in this study. The common limitations and the limitations of the three methods used in this study are explained below.

Common Limitation: The common limitations in this study is that it used only open source spatial datasets with different resolution and scales.

Buildings at Flood Prone Areas: This method uses a non-scientific approach to find out the buildings at flood prone areas. This method has its own limitation,

- The toposheet used in this study is of different scale compared to the Orthophoto. The toposheet is of scale 1:50000 and the Orthophoto is a high resolution aerial imagery collected from Drone Survey. The buildings derived from Orthophoto when overlaid on the Toposheet data will have positional accuracy errors.
- The elevation of building is also not considered in this study. Additional building height information can give detailed and accurate risk of buildings.

MCDA Approach: This method uses the combination of GIS and AHP based Multi Criteria Decision Analysis- approach to find out the flood risk zones. This method has its own limitation,

- 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 consider the factors of evaporation, run off capacity, and future land use
- 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.

Flood Prediction using Unit Hydrograph: This method used GIS based Hydrology modelling tools to derive a unit hydrographs, which predicts the runoff capacity at the outlet.

- Very high resolution DEM can give more accurate results
- The Strom water drain is not considered in this study to derive the unit hydrograph as it is a very negligible length, and also it doesn't drain into a proper drainage system.
- The clogging factors in the drain is not considered in this study
- Considering the drainage depth will generate better results using this methodology

Since this is a large scale project, further site investigation, advice from experts and decision makers are necessary to arrive at the right result. This study results can be used by the authorities to narrow down flood preparedness and mitigation and rescue measures accordingly.

The results can be used by Chennai Metropolitan Development Authority (CMDA) to give approval for new building constructions. The officials need not go to the field to check out the site. The approvals can be given easily just by inspecting this results. This shall further reduce many wrong approvals for building to be built at flood risk zones. In areas that are already developed, these maps In areas that are already developed, maps can be used to prioritize areas for better climate-proofing (ESRI, 2021). The flood prediction results can be effectively utilised by the Flood preparedness team of the Chennai Corporation department to well prepare for flood mitigation and rescue measures in the study area well before the flood occurs.

4.2 Future works

The Disaster Management division shall use the methodology to effectively site the buildings at risk. Not only the building but all other infrastructure like roads, rails, sub way etc. at the risk of inundation can also be identified with the results. The worst effects of the flood were faced only when the flood preparedness was poorly done. This study will help the planners to concentrate on the areas with the risk of flooding to plan and upgrade the infrastructures accordingly.

The recommended future works for each methodology is discussed below,

Buildings at Flood Prone Areas: This method could be further improved by,

- Using to the scale data to compare land use change.
- The elevation of building could be considered in this study. Additional building height information can give detailed and accurate risk of buildings.

MCDA Approach: This method could be further improved by,

- Carrying out the AHP calculations in consultation with seniors and experts. The advice from the major decision making team of the corporation should be taken in account while preparing the criteria and its pairwise comparison matrix.
- More criteria like the factors of evaporation, run off capacity, and future land use should be considered to improve the results
- 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 present within the study area will yield better results

Flood Prediction using Unit Hydrograph: This method of GIS based Hydrology modelling using unit hydrographs ca be further improved by.

- Using very high resolution of DEM probably the DEM derived using the LiDAR technology
- Field survey shall be done to find out the outlets and thus derive the watersheds of the area.
- Once the storm water drain system is constructed, the same shall be considered to improve the results
- Clogging of the natural and manmade drains are one important factor to be considered. That too in urbanised areas, this is a very common and predominant problem. The clogging factor shall be used in the methodology to improve the results.
- The unit hydrograph model can be further improved by considering the drainage depth in the study area. Considering this parameters will give precise results on the time and the unit discharge point which will convey at what point of time the flood will turn into average, moderate and high risk stages.

In the end, this project work can be further developed by the Storm Water Drain Department of the Chennai Corporation to effectively manage flood preparedness, mitigation and rescue measures for the benefit of the society at large.

References

Abedin, Sayed Joinal Hossain. (2014). GIS Framework for Spatiotemporal Mapping of Urban Flooding and Analyze Watershed Hydrological Response to Land Cover Change. Available online at. https://digitalscholarship.unlv.edu/cgi/viewcontent.cgi?article=3238&context=thesesdissertations. Accessed on 21-05-2021

Adjei-Darko, Priscilla. (2017). Remote Sensing and Geographic Information Systems for Flood Risk Mapping and Near Real-time Flooding Extent Assessment in the Greater Accra Metropolitan Area. Available online at. https://www.diva-portal.org/smash/get/diva2:1087549/FULLTEXT01.pdf. Accessed on 21-04-2021

Aggarwal, Shiv., Thakur, Praveen., & Dadhwal, Vinay. (2009). Remote sensing and GIS Applications in Flood Management. *Journal of Hydrological Research and Development, Theme Flood Management, 24*, 145-158. Available online at. https://www.researchgate.net/publication/230660751_Remote_sensing_and_GIS_Applications_in_Flood_Management. Accessed on 02-04-2021

Armenakis, Costas., Du, Erin Xinheng., Natesan, Sowmya, et al. (2017). Flood Risk Assessment in Urban Areas Based on Spatial Analytics and Social Factors. *7*(4), 123. Available online at. https://www.mdpi.com/2076-3263/7/4/123. Accessed on 10-02-2021

Avinash, Tyagi. (2009). *Flood Risk Management*. Geneva, Switzerland: World Meteorological Organization. Available online at. https://slideplayer.com/slide/4453340/, Accessed on 15-03-2021

Bansal, Neha., Mukherjee, Mahua., & Gairola, Ajay. (2015). CAUSES AND IMPACT OF URBAN FLOODING IN DEHRADUN. *International Journal of Current Research, 7*, pp.12615-12627. Available online at. https://www.journalcra.com/article/causes-and-impact-urban-flooding-dehradun#:~:text=The%20urban%20floods%20in%20the,etc%20causing%20severe%20economic%20damage. Accessed on 17-03-2021

CITY OF PACIFIC GROVE. (2019). Replacement of Impervious Surfaces with Pervious Surfaces Design Guidelines. Available online at. https://www.cityofpacificgrove.org/living/community-development/planning/stormwater/lid-techniques/design-guidelines/replacement-impervious-surfaces-pervious-surfaces-design-guidelines#:~:text=Impervious%20Surface%3A%20a%20surface%20that,allows%20water%20to%20percolate%20through. Accessed on 12-02-2021

CMDA. (2013). Second Master Plan for Chennai Metropolitan Area, 2026. Chennai Metropolitan Development Authority, Government of Tamil Nadu, Chennai, Available online at. http://www.cmdachennai.gov.in/smp_main.html. Accessed on 15-02-2021

Dang, Nguyen Mai., Babel, Mukand S.., & Luong, Huynh T. (2011). Evaluation of food risk parameters in the Day River Flood Diversion Area, Red River Delta, Vietnam. *Natural Hazards, 56*(1), 169-194. doi:10.1007/s11069-010-9558-x. Accessed on 10-02-2021

Dawod, G.., & Koshak, N. (2011). Developing GIS-Based Unit Hydrographs for Flood Management in Makkah Metropolitan Area, Saudi Arabia. *3*, 160-165. Available online at. https://www.scirp.org/journal/paperinformation.aspx?paperid=4667. Accessed on 24-05-2021

Ellis, Bryan., & Viavattene, Christophe. (2014). Sustainable Urban Drainage System Modeling for Managing Urban Surface Water Flood Risk. *CLEAN - Soil, 42*. doi:10.1002/clen.201300225. Accessed on 12-02-2021

ESRI. (2008). ArcGIS Desktop Help, Environmental Systems Research Institute. Available online at. http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=weighted_overlay. Accessed on 24 May 2020

ESRI. (2016). ArcGIS for Desktop, Reclass by ranges of values, Environmental Systems Research Institute. Available online at. https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/reclass-by-ranges-of-values.htm. Accessed on 20 May 2020

ESRI. (2021). Find areas at risk of flooding in a cloudburst. Available online at. https://learn.arcgis.com/en/projects/find-areas-at-risk-of-flooding-in-a-cloudburst/. Accessed on 15-02-2021

ESRI. (2021). How Flow Accumulation works. Available online at. https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-flow-accumulation-works.htm. Accessed on 21-06-2021

ESRI. (no date). How Watershed works. Available online at. https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-watershed-works.htm. Accessed on 29-03-2021

FloodSite. (2008). Flooding in urban areas (urban flooding). Available online at. http://www.floodsite.net/juniorfloodsite/html/en/student/thingstoknow/hydrology/urbanfloods.html. Accessed on 21-03-3021

Gayathri C., & Jayalakshmi S. (2018). Estimation of Surface Runoff Using Remote Sensing and GIS Techniques for Cheyyar Sub Basin. *International Journal of Engineering Research & Technology (IJERT), 6*(7). Available online at. https://www.ijert.org/estimation-of-surface-runoff-using-remote-sensing-and-gis-techniques-for-cheyyar-sub-basin. Accessed on 20-06-2021

GCC. (2018). City Disaster Management Plan. Corporation, Greater Chennai, Chennai, Accessed on 15-03-2021

Gupta, Anil K., & Nair, Sreeja S (2010). Flood risk and context of land-uses: Chennai city case. *Journal of Geography and Regional Planning, 3(12)*, 365-372. Available online at. https://www.researchgate.net/publication/228477342_Flood_risk_and_context_of_land-uses_Chennai_city_case. Accessed on 23-01-2021

Karthikeyan, D. (2018). I.A.S, Commisioner. Corporation, Greater Chennai, Chennai, Accessed on 15-03-2021

Klijn Frans. (2009). *Flood risk assessment and flood risk management*. Available online at. http://www.floodsite.net/html/partner_area/project_docs/T29_09_01_Guidance_Screen_Version_D29_1_v2_0_P02.pdf, Accessed on 30-03-2021

KSNDMC. (unknown). Web GIS. Karnataka State Natural Disaster Monitoring Centre, Govt. of Karnataka, Available online at. https://www.ksndmc.org/KsndmcDashBoard/KSNDMCMap.aspx. Accessed on 13-03-2021

Lappas, I., & Kallioras, A. (2019). Flood Susceptibility Assessment through GIS-Based Multi-Criteria Approach and Analytical Hierarchy Process (AHP) in a River Basin in Central Greece. *International Research Journal of Engineering and Technology (IRJET), 6*(3). Available online at. https://www.irjet.net/archives/V6/i3/IRJET-V6I3137.pdf. Accessed on 24-01-2021

LatinAmerica., & Caribbean. (2016, Nov 11, 2016). Flood Risk Management in the City of Buenos Aires. Available online at. https://www.youtube.com/watch?v=5rpQ2TdGPs4&t=4s. Accessed on 18-03-2021

Lopez, Aloysius Xavier. (2016). No stormwater drains - Ward 200. *The Hindu,* p. 4. Available online at. https://www.thehindu.com/news/cities/chennai/No-stormwater-drains-Ward-200/article14470804.ece, Accessed on 10-02-2021

MUZIK, I. (1996). FLOOD MODELLING WITH GIS-DERIVED DISTRIBUTED UNIT HYDROGRAPHS. *10*(10), 1401-1409. doi:https://doi.org/10.1002/(SICI)1099-1085(199610)10:10<1401::AID-HYP469>3.0.CO;2-3. Accessed on 27-05-2021

National Water Mission. (2020). Chennai Report. Available online at. http://nwm.gov.in/sites/default/files/Chennai_Report.pdf. Accessed on 21-05-2021

NDMA. (unknown). Floods. National Disaster Management Authority, Government of India, Available online at. https://ndma.gov.in/Natural-Hazards/Floods. Accessed on 12-03-2021

NPC. (2015). Nepal Earthquake 2015,

Post Disaster Needs Assessment. Commission, National Planning, Kathmandu, nepal: Government of Nepal, Available online at. https://www.worldbank.org/content/dam/Worldbank/document/SAR/nepal/PDNA%20Volume%20A%20Final.pdf. Accessed on 16-03-2021

NRCS. (2004). Estimation of Direct Runoff from Storm Rainfall. In *National Engineering Handbook* (pp. 12): Natural Resources Conservation Service, United States Department of Agriculture, Accessed on 16-06-2021

Office of the Registrar General & Census Commissioner, India. (2011). Ministry of Home Affairs, Government of India. Affairs, Ministry of Home, Available online at. https://www.census2011.co.in/data/town/803360-sholinganallur-tamil-nadu.html. Accessed on 09-02-2021

OSDMA. (2019). State Disaster Management Plan. Odisha State Disaster Management Authority, Government of Odisha, Available online at. https://www.osdma.org/state-dm-plan/#gsc.tab=0. Accessed on 02-04-2021

Ouma, Y.., & Tateishi, R. . (2014). Urban Flood Vulnerability and Risk Mapping Using Integrated Multi-Parametric AHP and GIS: Methodological Overview and Case Study Assessment. *6*, 1515-1545. Accessed on 13-02-2021

Periyasamy, Punitha., Yagoub, Mohamed Mohamed., & Sudalaimuthu, Mahalingam. (2018). Flood vulnerable zones in the rural blocks of Thiruvallur district, South India. *Geoenvironmental Disasters, 5*(1), 21. doi:10.1186/s40677-018-0113-5. Accessed on 12-02-2021

Rosy, Mina. (2021). Philippines looks to improve disaster preparedness with geospatial tech. *Mongabay*. Available online at. https://news.mongabay.com/2021/03/philippines-looks-to-improve-disaster-preparedness-with-geospatial-tech/. Accessed on 31-03-2021

Saaty, Thomas L. (2007). *Fundamentals of Decision Making and Priority Theory* (Vol. 6). Available online at. https://books.google.co.in/books?hl=en&lr=&id=wct10TlbbIUC&oi=fnd&pg=PT1&ots=_C7uQXWLxc&sig=yFA5vQxulj2DxJd6SZJYrR2Hu0o&redir_esc=y#v=onepage&q&f=false. Accessed on 05 April 2020

Sasidharan., & Sithara. (2014). *A Comparative Study of GIS Based Runoff Estimation using Distributed CN Method and Time-Area Method*. Calicut. Available online at. https://www.researchgate.net/publication/344897782_A_Comparative_Study_of_GIS_Based_Runoff_Estimation_using_Distributed_CN_Method_and_Time-Area_Method, Accessed on 20-06-2021

Satheeshkumar, S.., Venkateswaran, S.., & Kannan, R. (2017). Rainfall–runoff estimation using SCS–CN and GIS approach in the Pappiredipatti watershed of the Vaniyar sub basin, South India. *Modeling Earth Systems and Environment, 3*(1), 24. doi:10.1007/s40808-017-0301-4. Accessed on 17-06-2021

SCS. (1972). *Soil Conservation Service, National engineering Handbook*. Washington: Hydrology, Department of Agricullture. Accessed on 11-06-2021

Sieker, F. (2008). Investigations of the Effects of On-Site Stormwater Management Measures in Urban and Agricultural Areas. In *Flood Issues in Contemporary Water Management* (pp. 303-304). Netherlands: Kluwer Academic Publishers, Accessed on 12-03-2021
Sivakumar, B. (2021) *Superintending Engineer, Storm Water Drain Management Division/Interviewer: Dhivya, Selvarajan*. Interviewed on 15-03-2021
Subramanian, T.., Cheyapalan, Tharini., Selvaraj, Tanushree, et al. (2015). Mapping Storm Water Sewer System using GIS. *Civil Engineering and Environmental Systems, 1*, 23-32. Available online at. https://www.researchgate.net/publication/271329025_Mapping_Storm_Water_Sewer_System_and_using_GIS. Accessed on 12-03-2021
Supergeo. (2016). Flow Direction. Available online at. https://www.supergeotek.com/SpatialAnalyst_ENG_HTML/flow_direction.htm. Accessed on 23-06-2021
Suriya, S.., Mudgal, B. V.., & Nelliyat, Prakash. (2012). Flood damage assessment of an urban area in Chennai, India, part I: methodology. *Natural Hazards, 62*(2), 149-167. doi:10.1007/s11069-011-9985-3. Accessed on 15-03-2021
Suriya, S.., Mudgal, B. V.., & Nelliyat, Prakash. (2012). Flood damage assessment of an urban area in Chennai, India, part II: results and discussions. *Natural Hazards, 62*, 159-167. Available online at. https://www.researchgate.net/publication/278209262_Flood_damage_assessment_of_an_urban_area_in_Chennai_India_part_II_results_and_discussions. Accessed on 03-04-2021
TNSDMA. (2017). Risk Mapping, Tamil Nadu State Disaster Management Authority. Available online at. https://tnsdma.tn.gov.in/pages/view/Risk-Mapping. Accessed on 09-02-2021
USDA. (2009). National Engineering Handbook Hydrology United States Department of Agriculture, Natural Resource Conservation Service (NSDA), Available online at. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1043063. Accessed on 17-06-2021
Velma, I., Grover., Guha, B K, et al. (2000). *Solid Waste Management,* . Rotterdam, Brookfield: A A Balkema, Rotterdam. Accessed on 10 October 2020
Viji, R., Rajesh, P., Prasanna, et al. (2015). Gis Based SCS - CN Method For Estimating Runoff In Kundahpalam Watershed, Nilgries District, Tamilnadu. *Earth Science Research Journal, 19*. Available online at. http://dx.doi.org/10.15446/esrj.v19n1.44714. Accessed on 20-06-2021
Vishwanath, Madhumitha. (2019). Chennai's OMR lost 40 water bodies to rampant urban jungle. *The Indian Express,*. Available online at. https://www.newindianexpress.com/cities/chennai/2019/mar/14/chennais-omr-lost-40-water-bodies-to-rampant-urban-jungle-1950767.html, Accessed on 15-05-2021
Wikipedia. (2020). Analytic hierarchy process. Available online at. https://en.wikipedia.org/wiki/Analytic_hierarchy_process. Accessed on 18 May 2020
Wikipedia. (2020). ArcGIS,. Available online at. https://en.wikipedia.org/wiki/ArcGIS. Accessed on 25 April 2020
Wikipedia. (2020). Greater Chennai Corporation,. Available online at. https://en.wikipedia.org/wiki/Greater_Chennai_Corporation. Accessed on 24 March 2020
Wikipedia. (2021). Available online at. https://en.wikipedia.org/wiki/Runoff_curve_number. Accessed on 12-06-2021
Wikipedia. (2021). 2019 Karnataka floods. Available online at. https://en.wikipedia.org/wiki/2019_Karnataka_floods. Accessed on 13-03-2021
Wikipedia. (2021). Cyclone Nivar. Available online at. https://en.wikipedia.org/wiki/Cyclone_Nivar. Accessed on 10-04-2021

Wikipedia. (2021). Flood. Available online at. https://simple.wikipedia.org/wiki/Flood. Accessed on 20-03-2021

Wikipedia. (2021). Geography of Chennai. Available online at. https://en.wikipedia.org/wiki/Geography_of_Chennai#:~:text=The%20city%20gets%20most%20of,%2DSeptember%20to%20mid%2DDecember.&text=Highest%20annual%20rainfall%20recorded%20is,the%20rest%20of%20the%20year. Accessed on 24-01-2021

Wikipedia. (2021). Runoff curve number. Available online at. https://en.wikipedia.org/wiki/Runoff_curve_number. Accessed on 17-06-2021

WMO. (2008). Urban Flood Risk Management. World Meteorological Organisation, Global Water Partnership, Available online at. http://repo.floodalliance.net/jspui/bitstream/44111/933/1/Urban%20Flood%20Risk%20ManagementA%20Tool%20for%20Integrated%20Flood%20Management.pdf. Accessed on 15-03-2021