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Urbanization and its Impacts on Floods Using GIS —A Case Study

by

Talha Ahmed

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I want to dedicate this work to people who have meant and continue to mean so much to me, first and foremost my family, who helped me throughout my education. I will be forever grateful to my fiance, for her patience, and her faith, because she always understood. Last but not least, this is likewise a tribute to my best teachers who guided us to go up against the troubles of presence with ingenuity and boldness, and who made us what we are today.

CERTIFICATE OF APPROVAL

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Abstract

Urban areas or metropolitan are portrayed by the very high density of population. Due to result of economic activities in urban areas, they are more exposed to flooding during periods of extreme precipitation. Some critical elements, such as urban expansion and climate change, are driving changes in cities with exposure to the incidence and impacts of pluvial floods. Urban communities are recurrently developed by huge spaces by which water cannot enter impermeable surfaces, such as man-made permanent surfaces and structures, which do not cause the phenomena of infiltration and percolation. Urban sprawl can result in increased run-off volumes, flood stage and flood extents during heavy rainy seasons. Moreover, the frequency and intensity of extreme precipitation events is expected to be affected by climate change, as experienced in many regions of the world.

Natural processes and human activities can contribute to enhance flood risk. The flood risks require a thorough examination of all aspects affecting to severe an event in order to accurately estimate their impacts and other risk factors associated with them. For risk evaluation and its impact due to urbanization, an integrated hydrological modelling (simulation of surface models) approach is used on the study area in Islamabad, (Pakistan) focusing a natural waterbody called Gumrah khas which has been adopted in this research. The vulnerability of the physical elements at risk in the research region is analyzed using GIS. The research has been broadly divided into two phases, first is related to urbanization, its change over the time and its effect using supervised classification of land covers. Second phase is regarding flood risk due to the impacts of urbanization. The first phase includes the supervised classification of land use containing the images from 1980 to 2020 using ARC-GIS. The second phase involves DEM, with selected return period, which is to be used for hydrodynamic model for flood event inundation using HEC-HMS, SOBEK1-D/2-D and ARC-GIS. The selected return periods are 50,75 and 100 years which are used in flood modelling. Mannings friction coefficient was used for model calibration within the channel/ water stream to obtain data for water depth, water velocity and impulse maps over a period of time.

The findings of this study provided useful information on high-risk places and at-risk properties. The level of risk assessment was determined by incorporating land use and flood characteristics information. The study's final outputs have the potential to be useful to analyze the impacts of urbanization on flood risk on large scale. A detailed research program is needed to investigate other factors affecting the flood risk. Moreover, awareness among people and with involvement of strategic planners and decision makers, the adverse effects of urban sprawl on flood risk can be minimized with involvement of local administrative bodies

Keywords GIS, Urbanization, Urban floods, Flood risk, Hydrodynamic model.

Contents

List of Figures

List of Tables

Abbreviations

ACOE	Army Corps of Engineers
ANUDEM	Australian National University Digital Elevation Model
ASCAT	Australian National University Digital Elevation Model
ASCAT	Automated Steel Cleanliness Analysis Tool
ASTER	Advanced Spaceborne Thermal Emission and Reflection
CH2M	Cornell, Howland, Hayes Merryfield
DD	Dynamic Downscaling
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EA	Environmental Agency
ESRI	Environmental Systems Research Institute
ETM	Enhanced Thematic Mapper
FRI	Flood Risk Index
GCM	Global Climate Model
GLC	Global Land Cover
GRACE	Gravity Recovery and Climate Experiment
HMS	Hydrological Modeling System
ICT	Islamabad Capital Territory
ISIS	Integrated Set of Information Systems
LCC	Land Cover Classification
LCUC	Land Use Land Cover
MSS	Multispectral Scanner System
OLI	Operational Land Image
RCM	Regional Climate Model

RCP	Representative Concentration Path
RFS	Rapid Flood Simulation
RS	Remote Sensing
SAR	Synthetic Aperture Radar
SD	Satcom Direct
SEA	Statistical energy analysis
SRTM	Shuttle Radar Topography Mission
TIFF	Tagged Image File Format
TIN	Triangulated Irregular Network
TM	Thematic Mapper

Chapter 1

Introduction

1.1 Background

Urbanization all across the world due to migration and growing population towards developed areas is lashing the use of land change in the form of urban sprawl. By 2050, around 70% of the worlds population is expected to settle in bult-up areas [1]. Urban migration is not something new that is gaining attention just now. It has been around from many centuries due to the growth in population, infrastructural facilities and living standards available in urban areas. In a developing country like Pakistan, the rate of urbanization is very fast. In this situation, land use changes and land cover are investigated as vital components in monitoring the current policies, managing environmental changes and natural resources.

Urbanization results in loss of natural vegetated and agricultural lands into constructed built-up environments resulting increase in impervious areas leading to more vulnerability to floods in areas adjacent to water bodies. This can also be due to increase in densification of population around areas which are more vulnerable to floods such as river beds and flood plains. According to [2], the hydrological parameters (like increase in runoff, decreased infiltration, increase in frequency with increase in flood height) and urbanization have a direct relation with each other. Land Cover Classifications (LCC) plays an important role in social science and physical research on topics such as soil mapping and urbanization. LCC change has also become an essential constituent in the current strategies for managing and monitoring of environmental changes and natural resources, particularly for those areas, such as suburbs which have more facilities in surroundings [3, 4]. Land cover change is one of the major parameters in developing countries that is affected by rapid increase in population and economic growth. Understanding and identifying these essential changes are critical for the assessment of their drastic effects and impacts on main cities. In addition, it would help in decision making and make it easier to identify priorities for policy makers and for making appropriate and informed decisions.

Flooding among natural hazards, is one of the most common natural hazardous events. Numerous events of floods have caused casualties and great economic losses all across the world. Moreover, the development of urbanization intensifies the regional threat caused by flooding. There is a dire need for the assessment of flood prone areas for better management of watershed and to reduce the probable losses due to floods. Urban floods have noticeable socioeconomic impacts and can hinder to urban services (e.g., electricity supply, sewerage, communication services and transportation) and damages to infrastructure of urban areas. [5–8]. There is a great point of concern in many regions all across the world that with the increase in population, the risk of flood will increase, especially in those urbanized areas [9–11] like Islamabad and Rawalpindi where there are large assets and a high number of populations. Climate change and urbanization are some of the key factors among other that contribute to the increase in flood risks. The most influential one is suburbanization which challenges the current and future flood risks [7, 12, 13].

The study of climate change in the twenty-first century is of great importance. The information of climate change, either at the global scale or at the regional scale is a great point of concern in the studies of climate because it provides a base to analyze the impact and its formulation which have impact on socio-economic development. Global Climate Models (GCMs) are one of the influential tools for predicting the future trends of climate as well as hydrological parameters. As found in previous studies [14, 15] the computational effort in GCMs is easier because of wide resolution when reproducing the climate models, whereas RCMs provides greatly improved simulations with high resolution which needs more computational efforts for simulation, making it difficult in comparison with GCMs. However, numerous RCMs simulations have been carried out in regional models [9, 16–18].

In general, the flood risk assessment is commonly carried out by two main methods. The first one is the simulation of flood inundation, velocity and water depth based on hydrodynamic mechanisms through 1-D (one-dimensional), or by 2-D (two-dimensional) hydraulic models. The flood risk information can be obtained more abundantly by the simulation of hydraulic model methods, their complication and high demand of data quality makes it inappropriate to use and apply in few ungauged watersheds on a large scale. The second method is the flood risk assessment by the index-based method. The index-based method takes into account and integrates different factors to obtain an overall assessment. An integrated Flood Risk Index (FRI) considers the ecological and hydrological elements to assess the vulnerability in watershed for flood hazards. The most illustrative index-based evaluation method is multi-criteria analysis. It is more adaptable and widely used because of its simple implementation and interpretation of results. Moreover, the high efficiency in watershed studies with the capability in handling spare data makes it a more liable option.

1.2 Research Motivation and Problem Statement

All across the world, due to large number of flood events led to thousands of deaths along with tremendous ecological and economical losses. Pakistan is likely to suffer from the hazardous events of flood because of urban sprawl. Measuring urban sprawl in terms of its spatial forms should help policymakers prioritize policies and laws. In order to deal with this dominant form to assess the impact of floods due to urbanization. In each sequential year, the impact of floods is increasing but there is no mechanism available to reduce its impact and use the water effectively. This research work will help to identify the impact of urban sprawl and inner-cities affects for flood risk and its vulnerability.

Thus, the problem statement of this thesis is as follow:

"Flood risk assessment is one of the biggest challenges in developing as well as developed countries. Among the numerous factors contributing to increase in flood risks, urbanization is a major factor which intensifies the impact of floods. Thus, there is a need to analyze the impact of urbanization by comparing the conventional and modified methods adopted to predict the floods".

1.3 Research Questions and Significance

1.3.1 Research Questions

The focus of the current study was in order to gain a better grasp on knowledge of flood hazards and influence of urbanization in Islamabad. Based on the specific aim and overall goal of research following research questions are formulated.

- How Global Information Systems (GIS) is useful in the current study?
- What are the state-of-the-art techniques for flood modeling?
- Why there is a need to study urban sprawl in Islamabad?
- Why the specific area of Islamabad is considered for flood risk assessment?

1.3.2 Research Significance

The overall aim of investigation at this stage is to investigate the possible consequences of flood hazard by the use of modern tools and techniques in the assessment of risk. Some of the research significances are listed below as a precondition for addressing the objectives, which is especially important in an urban flood modelling context:

- One of its kind, till date no research work is done to study the impact of urbanization in terms of flood risk in Islamabad/ Rawalpindi region

- Comparing the modern tools which are are the state-of-the-art techniques for flood modeling to find the most efficient one.
- Will be able to understand and predict the trend of urbanization for developing countries specially.
- Will assist policymakers and local governments in developing a new prevention plan, which is required for the execution of disaster-prevention measures for planning purposes.

1.4 Scope of Work and Study Limitations

The influence of urban sprawl and climate change on flood risk are considered in this study for the specified three focal points. By comparing the influence of climate change and conventional and modified methods for predicting floods. The following limitations are considered.

- Only three focal points are considered in study area.
- Actual/recorded rainfall data taken from 2010 to 2020 will be used.
- LandSAT imagery is considered from 1980 onwards with 30m resolution for land use consideration.
- Climate change is considered only in terms of precipitation.
- This study focuses changes upto 2020 only.

1.5 Brief Methodology

The methodology adopted for this thesis will be initiated from the data collection including the recorded rainfall and preparing Digital Elevation Model (DEM) considering the land use, elevation and the slope of terrain. The area change in terms of urbanization will be observed using the Arc-GIS tool and LandSAT images.

Digital Elevation Model will help to examine the land use, elevation and slope of the area with the recorded rainfall, thus generating runoff of the catchment in that particular studied area. The flows generated with particular characteristic like DEM, recorded rainfall and the development of urban-sprawl can be used as critical input for flood simulation. Thereafter, the simulated models will be able to discuss in accordance with the climate change features. Thus, leading to predict the impact of urbanization on flood characteristics of particular area.

The methodology of the research work mainly consists of three phases, Moreover the breakdown structure of the methodology is shown in Figure 3.3 in Chapter 3.

- Phase-I consists of data collection and literature review.
- Phase-II consists of simulation and modeling.
- Phase-III includes the comparison and flood risk for different return period.

1.6 Thesis Layout

This study contains mainly six chapters introduction, literature review, methodology of the research, results and analysis, discussion and conclusion with future recommendations. The details of chapters are given below:

Chapter 1: Brief introduction of the study containing the project motivation, problem statement, overall goal and specific aim of design project, scope of work and study limitations with the methodology opted for the research work.

Chapter 2: Primarily focuses on the literature review about the collection of data/ base data including DEM for land use, elevation, and slope. The state-of-the-art techniques and packages that are available to measure the urban-sprawl and change in area use in-terms of urbanization are also presented. Similarly, the models either one-dimensional or two-dimensional available to predict and analyze the climate change effects in-terms of precipitation are considered to support the flood simulation for comparison of flood risk against different return periods by using GIS.

Chapter 3: Describes the methodology adopted for research work for the area under study consideration. Preparation of the models including the datasets available by DEM, recorded rainfall, Landsat images and climate change models to ensure the flood simulation for the result and analysis to be discussed for impact of urbanization on flood risk assessment.

Chapter 4: Explains the results and analysis obtained from the adopted methodology keeping the scope of work in mind, further discussions will be carried out in the next chapter.

Chapter 5: This chapter includes the discussions based on impact of urbanization, climate change and flood simulation of the particular studied area.

Chapter 6: The chapter 6 includes the conclusion of all the chapters with further recommendation to study on other parameters for future. Furthermore, guidelines are also provided for local administrative bodies to reduce the impact of urbanization.

Chapter 2

Literature Review

2.1 Background

Floods are one of the expensive occurring natural hazards and are potentially increasing with disrupting the economic activities each year. Urban floods have been considered as a huge menace that has posed a serious threat in a number of cities throughout the world. As a major concern, it is becoming recognized as posing a considerable risk to many cities throughout the world. Flooding impacts are extensive, affecting people and many economic sectors at the same time. Regarding the risk of flood and flood risk assessment, flood modeling approach enables to understand the assessment and predict the flood conditions and their impacts. Moreover, the impact of urban sprawl intensifies the vulnerability of floods in urban plains. Particularly, urbanized floods and their effective modelling with the choice of appropriate method is challenging. In addition, climate change in the present era have its own importance with great influence for predicting the floods in future.

2.2 Techniques Available for Data Retrieval

The use of Geographic Information System (GIS) in accordance with remote sensing (RS) technology has become an important tool for risk assessment by using flood mapping techniques [19, 20]. The GIS provides a number of tools for determining flood-affected areas and forecasting flood-prone areas due to high water levels. Even if floods are unavoidable, the damage they cause can be mitigated by implementing an integrated flood control strategy.

In the last few years, the accumulation of data from a variety of sources, as well as computational and technological breakthroughs has helped us to improve our understanding of natural hazards. With these improvements, a range of simulation packages are now available in each discipline, for example ESRI ArcGIS Pro, ESRI Story Maps, QGIS and ARC-Map are some of the available GIS techniques. However, HEC-RAS, HEC-HMS, ISIS etc. are some tools available for hydrological modeling. All of these packages have multiple usage as per the need of user. This has opened up new possibilities for assessing flood risk using some influential parameters. Because of the reduced computing cost and widely available requisite data, the approach is well suited for applications on large scale, data-scarce areas, opening up new vistas for flood risk assessment at national, continental, and global dimensions. Even the most detailed hydraulic models use simplifications to simulate the flooding process due to the complexity of natural inundation process.

2.2.1 Digital Elevation Model

The digital depiction of the land surface elevation with respect to any reference datum is known as a digital elevation model (DEM). DEMs are used to determine topographical parameters like elevation, slope, and aspect at any given position. DEMs can also be used to identify terrain features such as drainage basins and channel networks. DEMs are frequently utilised in hydrologic and geologic assessments, hazard monitoring, natural resource exploration, and agricultural management, among other applications. Groundwater modelling, calculation of the number of proposed reservoirs, estimating landslide probability, and flood prone area mapping are only a few of the hydrologic applications of the DEM.

Digital terrain model (DTM) and digital surface model (DSM) are two other related terminologies that are commonly used in the literature studies of DEM.

As demonstrated in Figure 2.1 by R.P. Gupta [21], the term DEM is applied in replacement of DTM of the Earth topography strictly, i.e., DSM, on the other hand, includes objects found on the ground such as buildings and trees. Because the focus is exclusively on the ground landscape, the words DTM and DEM are synonymous.

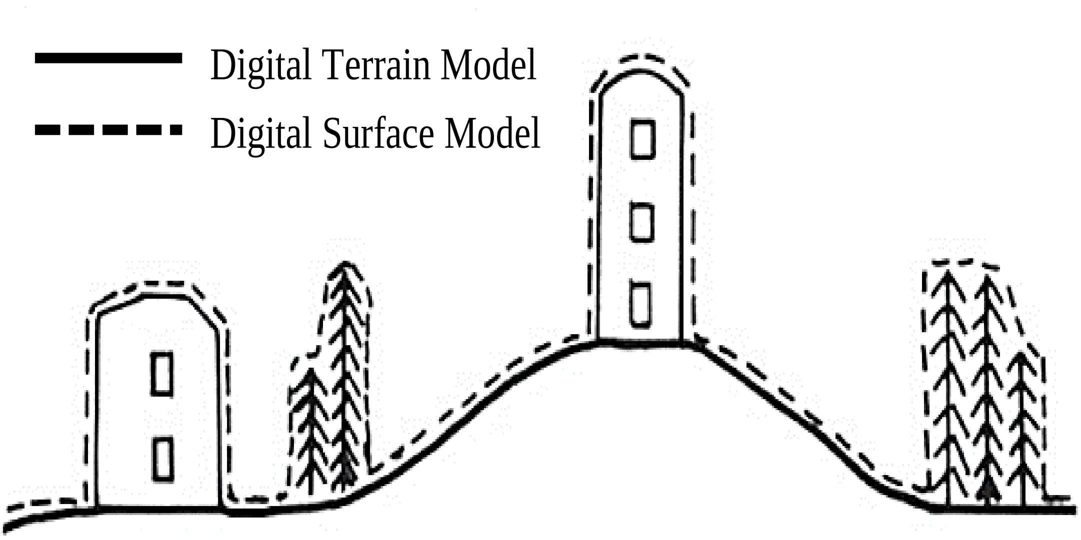


FIGURE 2.1: Digital Surface Model and Digital Terrain Model

Different forms of data structures, such as the line model, grid models and triangulated irregular network (TIN) model, have been utilised by different researchers to create DEM [22, 23]. The focus here is on square grid networks that function with remote sensing data (raster GIS). Over the recent decade, rapid advances in the technology of remote sensing have enabled more monitoring and data gathering for more precise activities of flood modeling [24]. With the widespread use of 2-D flood models with high quality, DEM resolutions become more important for practical use. Particularly in urban hydrology a variety of DEM resolutions in flood modelling, from 3 meters to 1 kilo-meters are available as shown in Table 2.1. [25–28] They discovered that increasing the DEM's grid size enhanced flood areas and flood depths. Figure 2.2 by Kim and Kim. [29] shows geographic factors such as values, land use, soil texture, and soil depth. shows geographic factors such as values, land use, soil texture, and soil depth.

However, when it comes to floods caused by surface water, researches reveal the opposite behaviour. Ozdemir et al. [28] discovered that increasing the DEM resolution from 1 m to 10 cm doubles the maximum flood depth. This resolution range, on the other hand, was designed to detect the effects of micro-urban surface dynamics like minor bumps in the road, and it cannot be used to a larger area where surface dynamics are dominated by larger structures and buildings.

Table 2.1: Available DEM and their resolutions

Sr. No.	Source	Spatial Resolution	Provider
1	Global Multi-resolution Terrain Elevation Data	30 arc-second (1 km) 7.5 arc-second (225 m) 15 arc-second (450 m)	USGS Earth Explorer
2	ASTER Global Elevation Data	1 arc-second (30 m)	USGS Earth Explorer
3	Shuttle Radar Topography Mission	3 arc-second (90 m) 1 arc-second for U.S. 1 arc-second global	USGS Earth Explorer Earth Explorer Reverb / Echo
4	National Elevation Dataset	1/9 arc-second (3 m) 1/3 arc-second (10 m) 1 arc-second (30 m) 2-arc-second (60 m) only Alaska	The National Map Viewer

Terrain data (point X, Y, Z coordinates) is necessary for DEM generation, and it can be obtained in a variety of ways and from a variety of sources:

- Aerial LIDAR
- UAV-borne digital camera
- Ground surveys
- Conventional aerial photographic photogrammetry
- Digital photogrammetry utilizing remote sensing image data
- Digitization of topographic contour maps
- Satellite SAR

Since 2015, NASA's Shuttle Radar Topography Mission (SRTM) has supplied a free 30m resolution DEM to the entire world. Furthermore, numerous countries maintain their own DEM databases with SRTM 30 meters data with higher resolution. DTMs and DSMs with a resolution of 1m are, for example, available for free from the Environment Agency (EA) in England (Environment Agency, 2018). When comparing model performance to satellite-derived inundation maps, it is well established that both DEM accuracy and model grid size have an impact on the derivation of spatial indices such water inundation extent [30, 31].

Recent advancements in the efficiency of geographic information system (GIS) technology applicable with remote sensing (RS) and have accompanied in a uprising in field of hydrology, notably in flood management, that can meet all of the needs for flood prediction, preparedness, prevention, and damage assessment [32]. Despite the prediction tools and the availability of flood forecasting, the accuracy of flood prediction maps remains a major concern. A high level of flood prediction mapping with relatively high accuracy should be attained in flood modelling, and innovative and efficient models should be investigated to improve accuracy.

2.2.2 Meteorological Models

The amount of rainfall and precipitation is a key input for hydrological models. As a fundamental meteorological variable; in particular, the estimation of spatially dispersed rainfall is required for distributed hydrological models. The distribution of Rainfall on an area may usually be approximated from a variety of sources, including rain gauge records and satellite observations etc.

Estimating the spatial distribution of rainfall has been the subject of several studies [33–37]. The rain-gauge record can be used to estimate spatially distributed rainfall over a defined region using various spatial interpolation algorithms [36, 37]. Although rain-gauge records are considered relatively precise and reliable at the location where a rain-gauge station is located, the density of the rain-gauge network is often insufficient to adequately capture the spatial distribution of rainfall.

Hence, as a result, satellite observations, which can offer area-based rainfall estimates, are seen as a feasible replacement or supplement for rain gauge data [33–35].

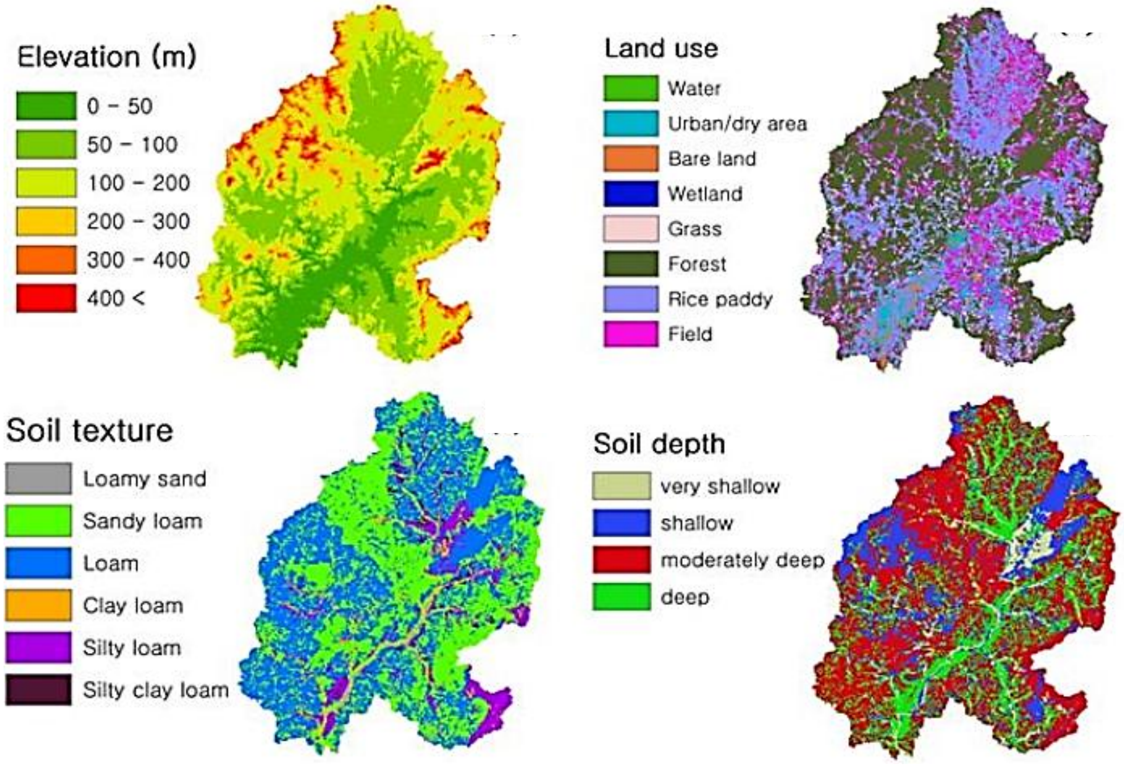


FIGURE 2.2: Digital Elevation Models with Geographical Features by Kim and Kim. [29]

2.2.3 Satellite Imageries

In the present era, the growing availability of free satellite data in the modern period has enabled the low-cost study of numerous natural and human-made phenomena, boosting research in a variety of sectors [38]. The European Union [39] provides worldwide coverage, high-frequency pass, and high spatial resolution synthetic aperture radar (SAR) and multispectral data. LandSAT, which has been providing data since 1972 [40], is another example of a free remote sensing service.

Every year, floods cause significant economic losses and human casualties [41]. As a result, accurate modelling and flood mapping are required for the assessment of flood hazard [42], estimation of damages [43], and long-term town planning to effectively manage flood risk [44]. In this situation, Remote sensing by satellite is a low-cost method that can be used to map floods profitably. [45**?** –47]. To extract flooded areas, the derived indexes and multispectral satellite data, SAR images, or the data in combined form might be used [48–52]. Other sorts of satellite data can help with flood mapping as well. For example, DEMs obtained from satellite data, such as the ASTER and Shuttle Radar Topography Mission SRTM have been used to assess flood-prone areas or improve a SAR/multispectral data-based map [53–55]. Flood indicators were also derived using the GRACE satellite data for water storage [56] and soil moisture data from ASCAT [57]. Each of the remote sensing technology for flood mapping has benefits and limitations [58] that must be considered individually.

Table 2.2: Remote Sensing Technology and Sensors Used for Analysis

Field of Application	**Specific Domain**	**Example of Satellite**	**Algorithm, Model or GIS**	**Reference**
Water Resource and Management	Glaciers	LandSat, SPOT, ASTER etc.	LandSat, TIN 3D, ASTER GDEM etc.	
	Soil moisture	SMOS, AMSR-E, SSM/I etc.	GRP, SMP, FO, GIS spatial	[72, 74]
	Ground water	GRACE	GPS, GIS etc.	
	Reservoirs, Lakes, wetlands and rivers	LandSat, ICESat, MODIS, SPOT, GRACE etc.	UAV, HTM for video image classification, GIS visualization	
Design Storm and Rainfall Measurements	Precipitation and Evapotranspiration	TRMM, MODIS, LandSat, NEXRAD, SRTM, ICESat, ENVISAT etc.	RCM, LSM, GSSHA, GPM IMERG etc.	[75]
Flood Forecasting and Rainfall-Runoff	River, Lake Discharge or Reservoir	TRMM, MODIS, LandSat, NEXRAD, SRTM, ICESat, ENVISAT etc.	MOGA, GSSHA, GPM IMERG, GIS Visualization etc.	[76]
Flood Maps and Water Bodies	Flooding and Droughts	LandSat, UAV, AMSR-E, MODIS, SMOS, ENVSAT etc	ASAR, ENVISAT, AUWEM, TMPA , ARX regressor, GIS spatial analysis	[77]

Data from multispectral satellites and the indices produced from them [59–61], SAR pictures [62–67], or a mix of these data [68] can be used to extract flooded areas. Other sorts of satellite data can help with flood mapping as well. For example, DEMs obtained from satellite data, such as the ASCAT and Shuttle Radar Topography Mission, have been used to estimate flood-prone areas or improve a SAR/multispectral data-based map [69–71]. Flood indicators were also derived using water storage data from the GRACE satellite [72] and soil moisture data from ASCAT [73].

Each and every remote sensing technology for flood mapping has benefits and limitations [74] that must be considered individually. In conclusion, remote sensing techniques have become more essential in the hydrologic sector. Table 2.2 summarizes the use of remote sensing technology and sensors used in GIS applications and hydrological model best practices and technologies. Water resources mapping, satellite rainfall data, storm hyetography analysis, runoff and urban flooding modelling, water body and flooding inundation mapping, and risk management are just a few of the uses.

In addition, free GIS plugins also make it possible to download and process unrestricted multispectral satellite images [78]. The accessibility of the resources is beneficial for managing the effects of natural disasters.

2.3 Urbanization in terms of Land-Use and Land Cover

The pace of urbanization is always accelerated by rapid economic development due to increase in population [79] as a result of which climate change has become a major concern [80]. Cutting down trees and removing vegetation in forest land to make way for residences, industries, building road networks, and modern infrastructures are all part of urbanization. The migration of people from rural to urban areas has resulted in these changes [81]. Figure 2.3 depicts the urbanization trend in Pakistan from 2005 to 2020. The mechanisms described above have the ability to raise the percentage of impervious surface coverage in a such area. Changes in land use and land cover (LULC) as a result of urbanization have a big impact on local climate, hydrogeology, floodplain dynamics, and environmental sustainability [82]. The speed with which these shifts have occurred over the world in recent years has been worrisome.

According to research undertaken by the World Bank in 2007, developing countries will have the most megacities in the world by 2020. Human activity's effects, such as land use/cover change, reservoir operations, and direct water extraction, are more complicated due to their diverse modes and multi spatial/temporal scales, which vary depending on the scientific and technological level [83]. The river network and Land use/cover change caused by widespread urbanization, in particular, merit more research effort than management approaches.

Urbanization transforms area of unpaved rural vicinity, natural wetlands and agricultural plains and into paved, impermeable metropolitan areas [84]. Due to increase in land of impervious surface in urbanized regions which has a substantial impact on urban hydrology, causing peak flow to occur earlier, more rainfall-induced runoff, and a rapid increase in peak discharge [85].

Historical records and flood modelling results are two typical data sources for assessing the impact of urbanization on flood risk. Early studies used historical field observations from river gauges and rainfall gauging stations to link urbanization to the extent and frequency of urban flooding. Advanced nonstationary flood-frequency models have recently been utilized to demonstrate that urbanization has a statistically significant impact on the increasing magnitude and frequency of floods [86].

The impact of numerous elements on rainfall-runoff processes in urban environments has been studied using hydrological models [87] and among others, looked into the interaction between rainfall intensity, surface vegetation and the consequent surface runoff. The impact of urbanization on flood hydrology was explored by Leopold (1968) [88], who established that several hydrologic factors like volume; peak flow and other information associated to the occurrence of life-threatening the basin's meteorological conditions are influenced by urbanization. Turner et al. [89] demonstrated the importance of land use change in flood-resilient urban planning and extreme event studies.

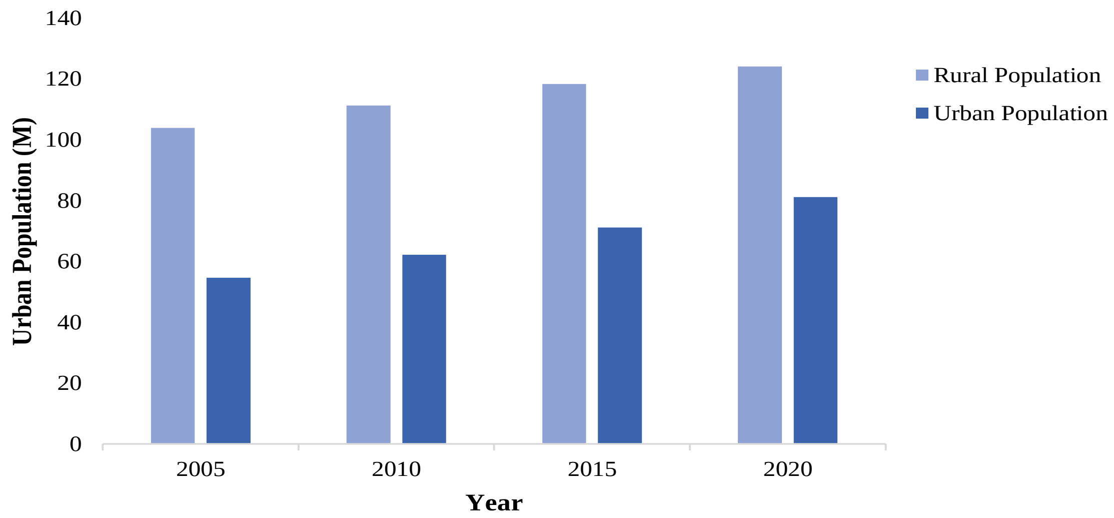


FIGURE 2.3: Urbanization Trend in Pakistan

The city's main hub or densely populated areas contain little water and produces minimal heat of latent energy, its surface heat is primarily dissipated as sensible heat. Additionally, increased energy use leads in massive volumes of heat being released (e.g., air conditioning and transportation). As a result, the temperature of the urban surface is much higher than the temperature of the natural surface [90].

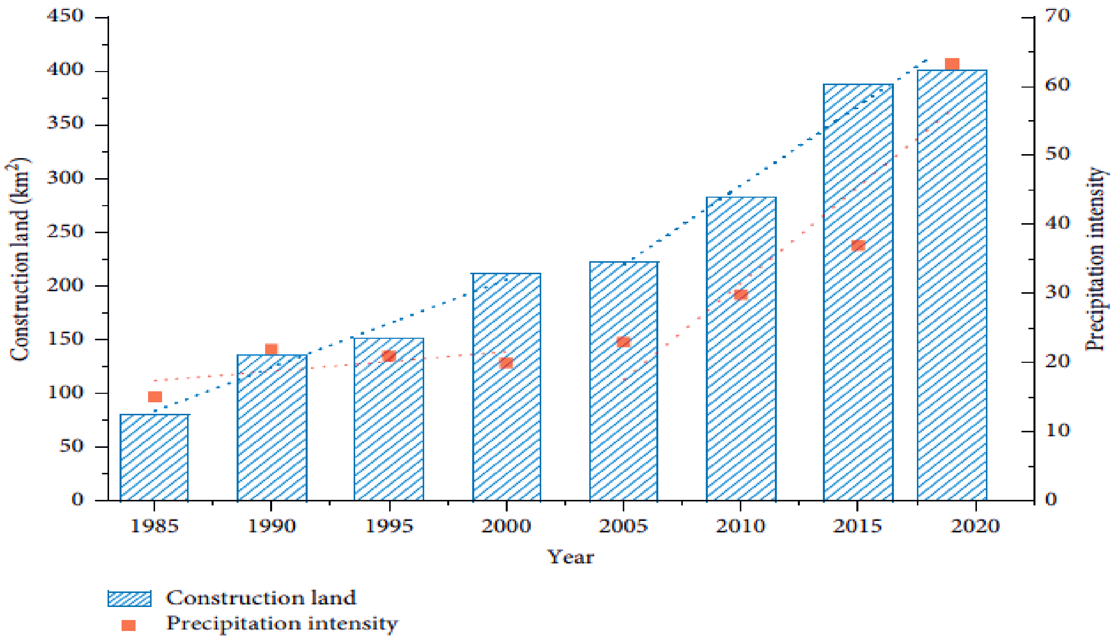


FIGURE 2.4: Effect of Urbanization and Construction on Precipitation Events

The influence of construction on the intensity of precipitation is shown in Figure

2.4 from 1985 to 2020 on the case study on China by Wei Wu et al., 2021 [91], make precipitation more likely in urban locations. It is vital to forecast the impact of urbanization in advance and grasp the laws of hydrology and climate affected by urbanization in time for the safety and better growth of a city. Many studies of the effects of urbanization on regional climate have relied on qualitative analysis based on observational data.

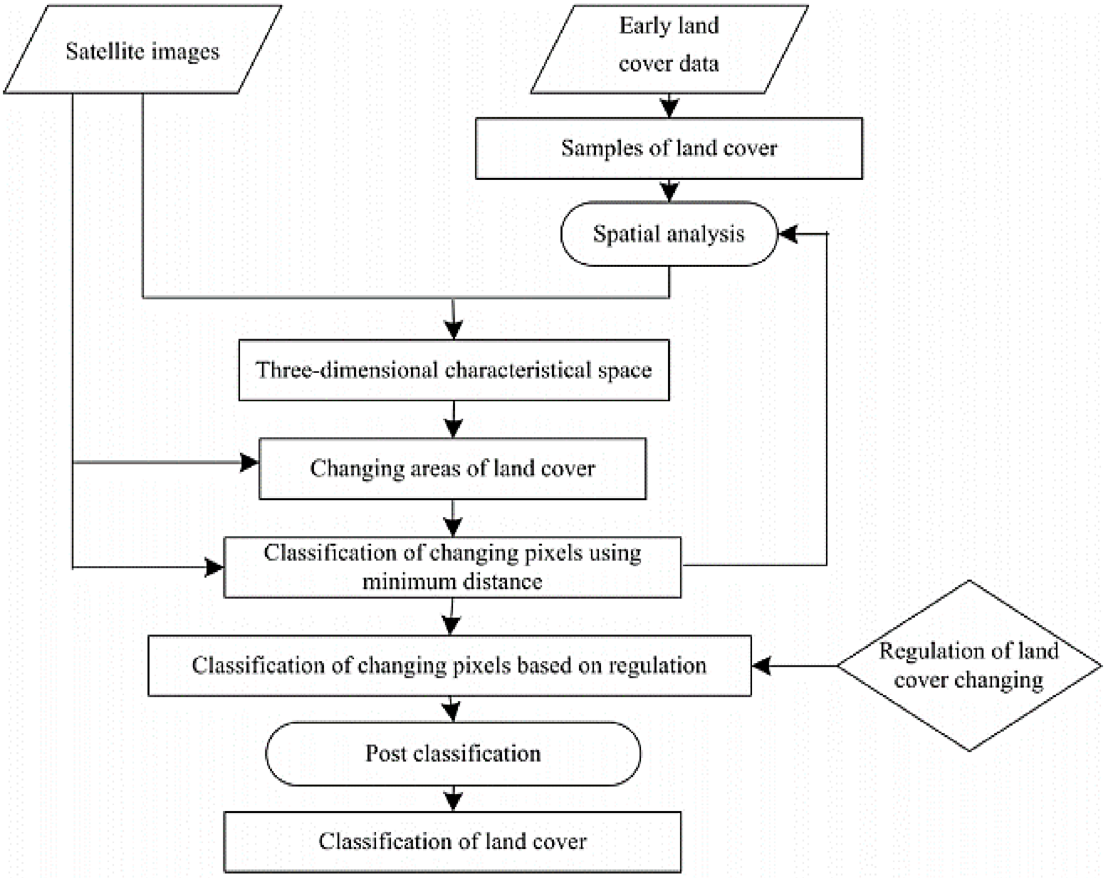


FIGURE 2.5: Phases for Supervised Classification of Land Use

To increase classification accuracy, many images were taken at different times for change detection. Many strategies for detecting and evaluating pixel-by-pixel differences between images of the same area taken at different times have been suggested with the majority of them yielding credible change detection results. Despite advances in our understanding of the causes of land use change in recent decades, reliably identifying the land cover types of changed pixels based on a comparison of two photographs without validation data is a significant challenge. It's because the two photos in question are typically from different seasons, which could pose problems with change detection. To address issues with change detection, [92], introduced a new technique for land categorization of photos lacking ground data which was carried out by [93] for supervised classification of land use as shown figure 2.5.

Thus, urbanization has significantly affected the land use and landcover contributing towards more vulnerable flood events. This needs the special consideration to understand in-depth understanding of the influence and its relative importance on regional hydrological processes to mitigate the increasing flood risks.

2.4 Impacts of Climate Change and its Vulnerability for Floods

Climate change affects all regions of the world, causing widespread anxiety that can be transferred to natural ecosystems, ultimately affecting the economic systems of the highlands. The world's climate looks to be shifting at an unprecedented rate. Climate change may be irreversible, and further extremes are possible (IPCC 2007). The climatic system has undergone repeated and often drastic adjustments during the last 100,000 years, according to historical data. Climate change has had an impact on natural systems across the globe, with global mean temperatures rising by up to 4 degrees Celsius [94].

Climate related impacts are droughts, floods, and cyclones which have a variety of consequences, including ecosystem disruption, damage to towns and infrastructure, morbidity and mortality, and disruption of food production and water supply. Land degradation caused by humans and an over-reliance on natural resources such as agriculture and water to meet basic necessities and food needs of an ever-increasing population have detrimental consequences for the climate [95].

Pakistan is one of the countries that has been hit the worst by climatic change. Temperature swings, rainfall variations, and the occurrence of dangerous events are all examples of climatic events [96]. Among the several environmental threats to which people are exposed, floods and droughts are the leading cause of economic and social risks for individuals, contributing to a rise in mortality. Because of their limited adaptive capacity and assets, rural residents in underdeveloped nations are particularly vulnerable to floods [96].

Global climate models (GCMs) may anticipate on the city level at high-resolution, climate projections for precipitation extremes, regional climate models (RCMs) and/or empirical-statistical approaches can then be used to downscale the data.. Rather than single model forecasts, multi-model ensembles are used to resolve the significant uncertainty associated with projections of future extreme precipitation frequency and intensity [97].

Furthermore, while future climate forecasts at global scales have been derived from a large number of simulations using GCMs. GCMs' coarse resolution (usually 100300 km) made their use in climate change effect assessments at local sizes impractical [98]. Downscaling of the regional climate, which can be done statically or dynamically, provides a way to derive coarse GCM outputs provide information at the local and regional scales [98]. While statistical downscaling (SD) does not necessitate a lot of computational power, it does rely on the availability of extended time-series of reliable and high-quality observed data [99]. Because SEA has limited access to observed data with adequate long temporal coverage and excellent quality, SD may be less viable in this region. Dynamically downscaling (DD), on the other hand, can be difficult and time-consuming to accomplish because to the massive computer resources necessary to have several GCMs.

The effects on precipitation by urbanization can be used for analyzing the impacts by two methods: data analysis methods and the methods of numerical simulations [100]. The data analysis method looks at multiple precipitation characteristics in the city and surrounding suburban or rural areas at different locations and uses the difference as a major indicator to analyze the influence of urbanization on precipitation. Sensitivity analysis can be performed using the numerical simulation method by adjusting model parameters to examine the effects of various factors on the urbanization process. Numerical simulation findings, on the other hand, are frequently inaccurate. The underlying surface qualities and regional precipitation can both be altered by urbanization, which can lead to major urban waterlogging problems. As a result, it is critical to understand the impact of urbanization on precipitation. Urban areas are more prone to experience thunderstorms than suburban areas [101]. The impact of urbanization on precipitation is primarily caused by the underlying surface changes, urban heat island effect, and aerosol emissions.

Thus, by merging the regional climate models (RCMs) in global climate models (GCMs), which cover a smaller area at a higher resolution, better-resolution climate change data can be acquired (50 km or finer). These have been proven to be accurate spatial and temporal details on how climate change may occur locally, and they are commonly employed. However, because to uncertainty in the modelling of processes in RCMs and GCMs, at the local level, such climate estimates are not usually accurate., resulting in a wide range of projected changes.

Furthermore, because to limited resources and due to restriction of the available data resources, simulations for all available GCM-RCM combinations are not practicable and it requires more computational efforts.

2.5 Flood Risk Assessment Modelling Techniques

Pluvial flooding is a type of flooding that happens in urban areas when the volume of runoff exceeds the receiving water body's conveyance capacity. Pluvial flooding has been a serious concern in recent years, posing a significant risk to many cities [102]. The conventional approach to mitigate moderate floods has essentially involved to adjust the flood attributes but the issues and its solutions are the same like old things. The demand for further efficient and effective flood management is quite obvious with the ever-growing technological expertise and higher living standards [103]. Flood inundation modelling has made major contributions in response to this hardship. Flood modelling gives information on the distribution and extent of flooding as well as its dynamics. Flood inundation modelling has also been touted as a useful tool for planning, designing, and analyzing storm sewers in cities [104]. It can help examine the network of stormwater sewers performance during severe storms, as well as test and evaluate the success of operational and structural solutions. Commercial and open-source simulation tools have also been used to realize their applications [105]. The existing hydrodynamic models are ascribed to a variety of underlying methodologies for modelling flood inundation. Some of the different forms are rapid flood simulation (RFS), one-dimensional sewer (1D-S), one-dimensional overland (1D), two-dimensional overland (2D), linking sewer overland (1D1D and 1D2D, and so on. In the context of urban flood management, high-resolution Digital Elevation Models (DEM) allow for a precise examination of overland flow. The selection and consideration of various methods for a specific flood modelling application needs to be taken in account.

Table 2.3: 3-D Modelling Approach and its Output Characteristics

Modelling Approach	**Overland flow illustration**	**Innudation Characteristics**				**Spatial data required**
		Overflow location	**Innudation depth**	**Innudation extent**	**Flow volocity**	
3-D	Yes, by using 1D-2D coupled	Yes	Yes	Yes, Similar to 2-D surface models	Yes, Three directional measure	The spatial resoultion of at least 10m including more higher quality of datasets and vertical accuracy.

The inundation extent and inundation depth of the modelling approaches differ from model to model. RFS models represents the extent only in final state while, 1-D surface and 1-D sewer presents only in surface networks and with virtual storage, respectively. Similarly, 2-D surface modelling enables to show inundation extent for 1D-2D coupled and 3-D modelling methods. The flow velocities cannot be measured by RFS and 1-D sewer but 2-D and 3-D models due to the constraint of modelling approach. The most important parameter affecting the runtime and accuracy of the analysis is spatial data requirement. DEM is an essential input parameter which is used in all of the modelling approaches. The relative accuracy and strength of the approaches also depends upon DEM. RFS use DEM irrespective of its scale and implementation magnitude. The 1D-2D coupled approach uses the DEM, surface network and topographic data with sewer surface network provided by individual 1-D and 2-D surface modelling approaches. Table2.3 shows the addition of 3-D modelling approach in comparison with the approaches discussed by [106].

Deltares/ Delft Hydraulics launched SOBEK software which is used commercially. Each of the package either 1-D or 2-D is specially designed for the rural, urban and river flows capable of overland flow. SOBEK 2-D is capable to evaluating the behaviour of flooding and drying with spatially varying surface roughness and wind friction. It also describes the breach growth by using empirical growth breach equations [107]. Both packages of SOBEK 1-D or 2-D work on the Saint-Venant equations using the rectangular grid by applying the finite difference scheme. Halcrow now known as CH2M Hill created a model in 2009 named ISIS-FREE which was based on the coupled 1-D and 2-D technique. The technique is limited to the use of 250 nodes in 1-D modelling and 2500 node cells in 2-D modelling techniques. The comparison of accessibility and modelling techniques are shown in Table 3 after the detailed review by [108].

In 1995, Army Corps of Engineers (ACOE) developed a package by model name HEC-RAS used the 1-D Hydraulic model. The access of HEC-RAS is limited to ACOE users. However, the source is accessible and open for other users. HEC-RAS works on the finite difference solution with the involvement of one-dimensional energy equation to solve friction contraction.

The main assumption involved in the package is the consideration of steady flow. However, the software can solve full 1-D unsteady flows with shallow water equation. Similarly, before HEC-RAS, ACOE launched HEC-HMS which was a hydrological modelling tool primarily designed for precipitation run-off process for the purpose of drainage basins.

DHI Water and Environment released many models like MIKE-11, MIKE 21, MIKE-Flood and MIKE-Urban etc. All of the versions have their own application and advantages. The MIKE-11 and MIKE-21 used 1-D hydraulic model and 2-D hydraulic model respectively. Both the packages are developed to simulate the water level, sediment transport load, flood plains, reservoirs and other water bodies. The packages can be applied on lakes, coastal areas and bays in two-dimension.

TABLE 2.4: Comparison of Accessibility and Modelling Technique used by Tools

Sr. No.	**Model Name**	**1-D Technique**	**2-D Technique**	**Coupled 1-D/ 2-D Technique**	**Open Source**	**Commerically Adopted**
1	HEC-RAS	√	√			√
2	HEC-HMS	√				√
3	ISIS-FREE		√		√	
4	MIKE FLOOD			√		√
5	TUFLOW	√	√			√
6	SOBEK	√	√	√	√	√

The MIKE-Flood used the coupled 1-D and 2-D coupled technique by providing the visualisation tool using the simulation engine. The tool was developed to strengthen the functionalities of MIKE-11 and MIKE-21, the package provides the satisfactory simulation of flood inundation in rivers and urban areas. The model is not well adopted in terms of application because each model requires calibration for validating the results.

Urbanization in flood plain areas increases the risk of flooding by increasing peak discharge and volume, as well as shortening the time to peak [109]. In flood-prone locations, increased human settlements, industrial growth, and infrastructural development have reduced agricultural land use, causing storm water drainage congestion during the monsoon season. Flooding will become a bigger problem in the future if this trend continues [110].

2.6 Summary

Urbanization is most common activity which is from many decades. The process of urbanization can never be stopped by limiting the lifestyle of people. The urban sprawl also influences the climate and hydrological processes. Therefore, that climate change has adverse effect in terms of precipitation and anomaly produced runoff due to change in landcover. Various studies are conducted to examine the impact of urbanization contributing to floods and flood risk mitigation. There is a direct relationship between the hydrological parameters and urbanization. Therefore, understanding and Identifying changes in land use and change in urbanization are critical for the assessment of floods in main populated area(s) or cities. Due to advancement in technology, change in landcover and land use can be determined using GIS and other modern tools. The information of climate change either at global scale or regional scale is of great concern in climate studies which provides a basis to analyze the impact. Similarly, different packages and softwares are developed to predict and notice the change in climate change behavior. GCMs and RCMs are available to measure climate change. The influence of rainfall and its frequency are more vulnerable to flood activities. In general, there are two main approaches that are commonly utilized for flood risk assessment. Flood simulation and risk assessment can be studied by a combination of 1-D and 2-D modeling techniques. To accurately simulate detailed urban flood propagation, the combination of the 1-D and 2-D hydrodynamic model is necessary.

Chapter 3

Methodology

3.1 Background

The impact of urbanization and rapid change in climatic conditions can lead to disastrous conditions in urban areas particularly in developing countries like Pakistan, it is, therefore, necessary to establish a hydrological model to simulate flood levels for the identification of possible flooded area. As a mean of evaluating this approach, the Hydrological Modeling System (HEC-HMS) is designed to simulate the rainfall-runoff process of watershed system. Some of the parameters can be estimated through observation and measurements of stream and basin characteristics. Similarly, the urban sprawl contributes to increase the runoff volume after precipitation event which need to analyzed either by 1-D/ 2-D modelling of stream or channel.

The overall work is divided into four phases; First phase includes the proposal writing, and data collection. In second phase, the impacts of urbanization in terms of land use and change in land cover are determined from 1980 to 2020. Third phase includes the hydrological modeling using rainfall-runoff data and spatial database of parameters including stream cross sections, direction of runoff and banks for flood risk for a particular year, while the fourth phase consists of comparison between the flood risks using flood risk assessment modelling obtained from hydrological models.

3.2 Study Area

The Islamic Republic of Pakistan's capital city, Islamabad Capital Territory (ICT), is located on the Potohar plateau as shown in Figure 3.1. The city expands over an area of 906 km^2 and includes uneven plains and mountains with elevations topping 1,175 meters above the level of the sea. According to the 2017 national population census, ICT has a population of almost two million people, making it Pakistan's ninth largest metropolis area. The four distinct seasons in this humid and subtropical region are autumn, spring, summer, and winter. Zones I, II, and V are for planned urban growth, whereas Zones III and IV are managed as National Parks and rural suburbs, respectively. All the zones are maintained and developed by the Capital Development Authority.

The tertiary sandstone, limestone, and alluvial deposits make to the geology of the study region. The area has a humid subtropical climate. May, June, and July are the hottest months, with average temperatures ranging from 36 to 43 degrees Celsius, with maximum reaching 48 degrees celsius. December and January are the coldest months, with mean low temperatures ranging from -1°C to -3°C. Simly watershed begins near Bhara Kahu, about 40 kilometers north-east of Islamabad (at latitude 33°43°N and longitude 73°19°E). It holds the Murree springs/Patriata mountain aquifer's perennial water flow as well as a considerable quantity of Soan River flood runoff.

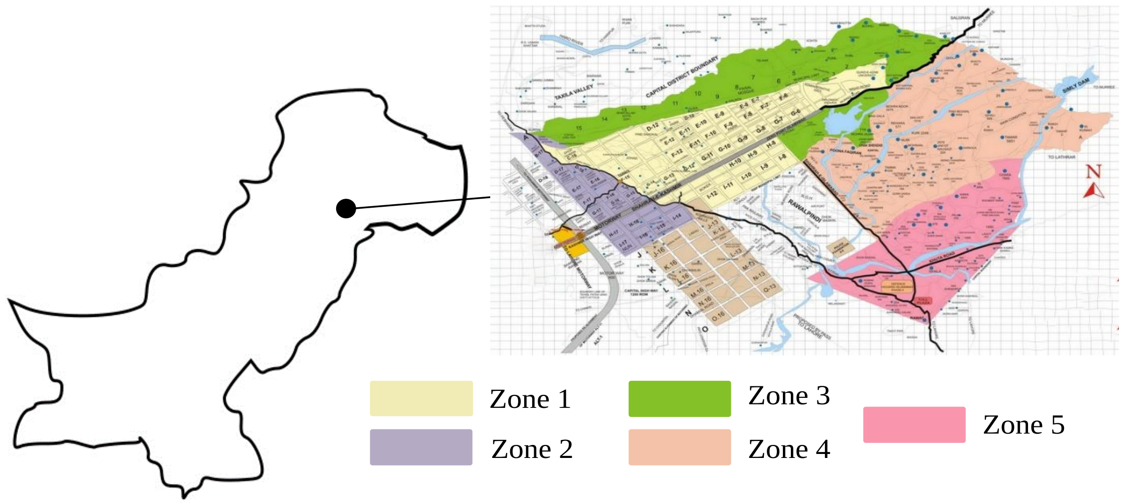


FIGURE 3.1: Overview of the Islamabad Capital Territory

Simly Dam is widely acknowledged as Islamabad's largest drinking water reservoir. Beautifully planted decorative trees, a resort, and picnic areas draw people to the area surrounding the Dam, which has aesthetic value.

FIGURE 3.2: Focal points of the study

Figure 3.1 depicts a map of the research area for analyzing the impact of urbanization. Furthermore, the area is especially prone to flooding due to the area's regular severe rains and mountainous geography. Furthermore, the area is especially prone to flooding due to the area's regular severe rains and hilly topography. The study area is around Gumrah Kas which is shown in Figure 3.2. The marked nullah starts from Murree Hills and join Korang nullah near Ghouri Town. The focal points taken in this study are 1, 2 and 3 as marked in Figure 3.2 which are Simly Dam Road bridge and Burma Bridge and near Gouri Town, respectively.

The longitude and latitude of the focal points are 33.71°N, 73.23°E; 33.69°N,73.19°E and 33.65°N,73.13°E, respectively. As shown in Figure 3.2, the study area is having 2 bridges connecting the main valleys and people living along the stream. The area is subjected to flash floods. Several factors contribute towards the flash flooding. Duration and intensity of rainfall in catchment area are among these key factors. Even though, intensity is the rate of rainfall how long the rain lasts. The intensity of the rain is mainly dependent on soil conditions, ground cover and topography of the area. Flash floods occurs within hours or in few minutes of the rainfall depending upon the said characteristics.

Gumrah Khas is a natural stream of rainwater originating from area of "Jandala" and ending near "Ghouri Town" where it joins Korang River on its path, it passes from wild areas as well as through populated areas. As its name speaks Gumrah means "deceiving" and Khas stands for "nullah or natural drain" Its history is that it deceives in terms of occurrence of floods. While interviewing a few people in Chak Shahzad, it is reported that people experienced damages because of floods due to a rain event occurring on upstream.

The design return period of bridges usually varies from 10 to 100 years depending upon the importance of the structure [111]. Various factors are taken for the choice of return period such as size of drainage area, importance of structure, risk of failure and the design life of bridges. In urban drainage, the shortest return period is 5 to 10 years [112]. Structures such as levees, which span huge distances and have correspondingly large drainage areas, are examples of regional flood protection measures. In this situation, the return durations could range from 50 to 100 years. So, the return period of 50, 75 and 100 years are taken for the determination of flood characteristics.

3.3 Data Collection

The research is related to both urbanization and flood characteristics; therefore, the current study is categorized in two types of data sets, the Landsat images (land use, landcover and topography) of different intervals and Hydrological modeling (rainfall, stream flow, direction, climate etc.). Figure 3.3 shows the brief methodology of the research.

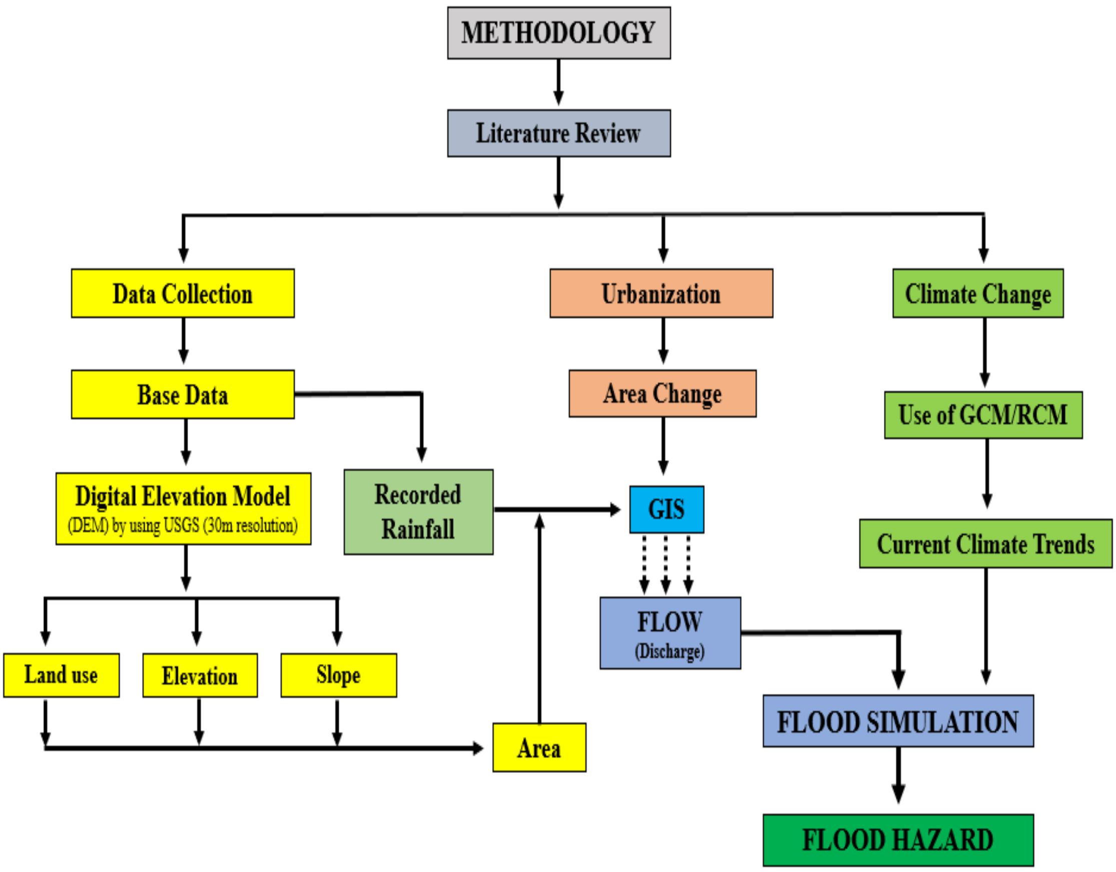


FIGURE 3.3: Overall Methodology of the Research

The overall methodology of the study is divided following phases. The first phase of the study was to go through identification of the required data and the gaps in the available datasets. A thorough search of the available database was conducted to determine what was already accessible and what was needed for the research. The data preparation for modelling and analysis was the focus of the second stage. The data preparation for modelling and analysis was the focus of the second stage. Data from the field was used for modelling, and field measurements were used to calibrate and validate the model. The flood modelling revealed the length, depth, and duration of the various return periods, as well as possibilities for them. The revealed parameters helped in the evaluation of risk assessment of the studied area.

3.3.1 Landsat Images Related to Urbanization

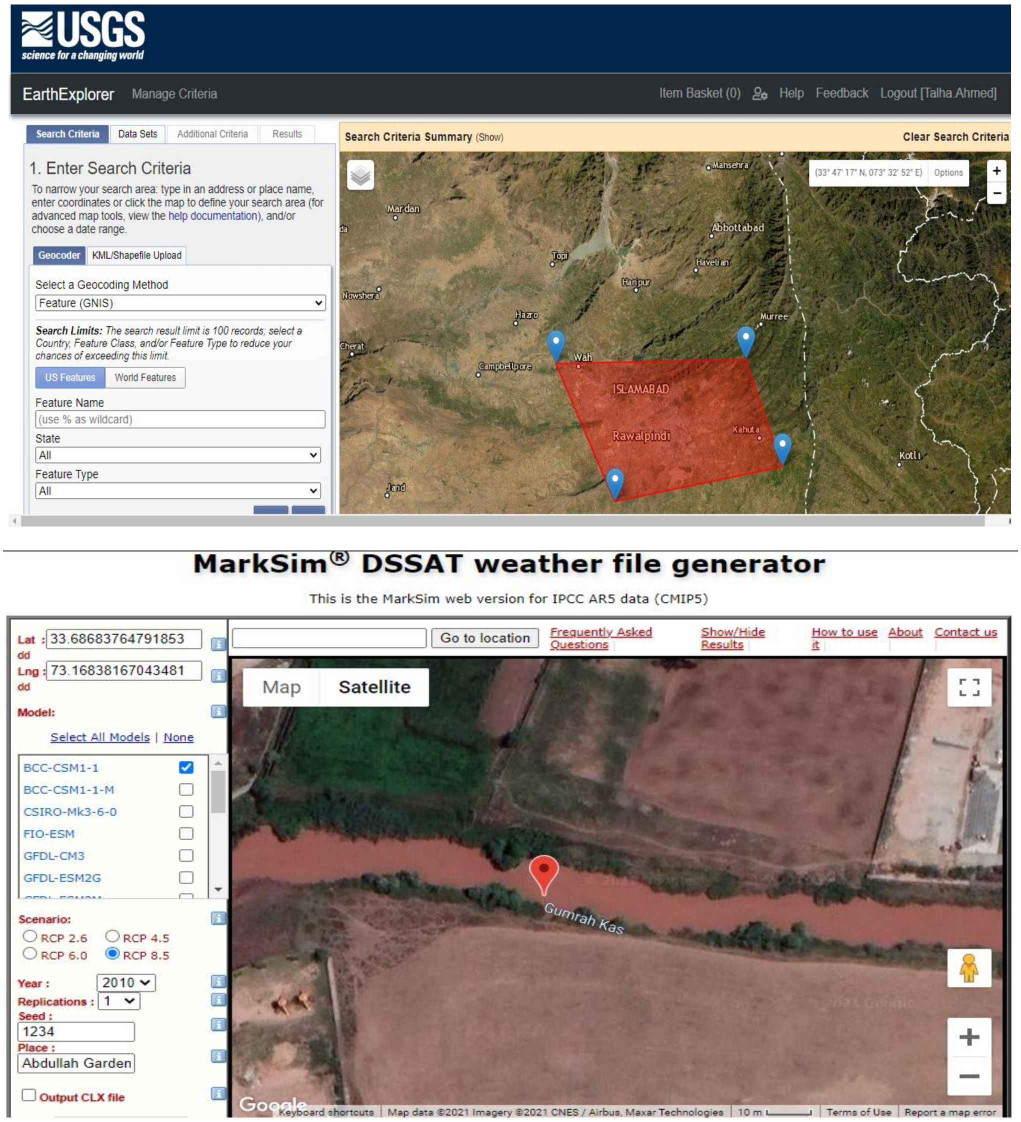
The images related to measure the land use, land cover and quantification the impacts of urbanization are taken by NASA platform using their USGS Earth Explorer module after getting the credentials to work as researcher. The interface of Earth Explorer can be used by the link https://earthexplorer.usgs.gov/ as shown in Figure 3.4 (a). The images are taken from 1980 to 2020 (1980, 2000, 2010, 2015 and 2020) as discussed in Chapter 1. The intervals after the year 2000 were reduced to measure the urban sprawl more precisely due to rapid increase in the real estate sector and construction in Islamabad.

3.3.2 Hydrological Modeling

The images related to hydrological modeling to accumulate flow is taken from the meteorological department and also using the earth data module of NASA using the link http://gismap.ciat.cgiar.org/MarkSimGCM and as shown in Figure 3.4 (b). The data is available both in Tiff and ASCII format. For the purpose of this study the data was downloaded in Tiff format.

3.4 Land Change Measure

Maps of land cover and land use provide crucial data for a variety of earth system investigations. For decades, land cover mapping on large-scale utilizing remote sensing data has been extensively researched. Land cover modules and features with resolutions of 300 meters to one kilometer or greater were created using coarse-resolution satellite data in the early days of global land cover mapping. Global land cover (GLC) module based on Enhanced Thematic Mapper+ (ETM+)



(a)

(b)

FIGURE 3.4: (a) User interface of USGS Earth Explorer, (b) Interface of Mark-Sim

and Landsat Thematic Mapper (TM) and data are utilized in the photos, which are captured at 30-m resolution.

Moreover, L1T Landsat TM/ETM+/OLI images from the USGS are acquired between 1980 and 2020, i.e., all available images with $<$70% cloud. The data used in the study is shown in Table 3.2.

The most common technique for quantitative analysis of remote sensing picture data is supervised classification. The concept of segmenting the spectral domain into sections that can be connected with the ground cover classes of relevance to a certain application lies at the heart of it. The principle behind supervised

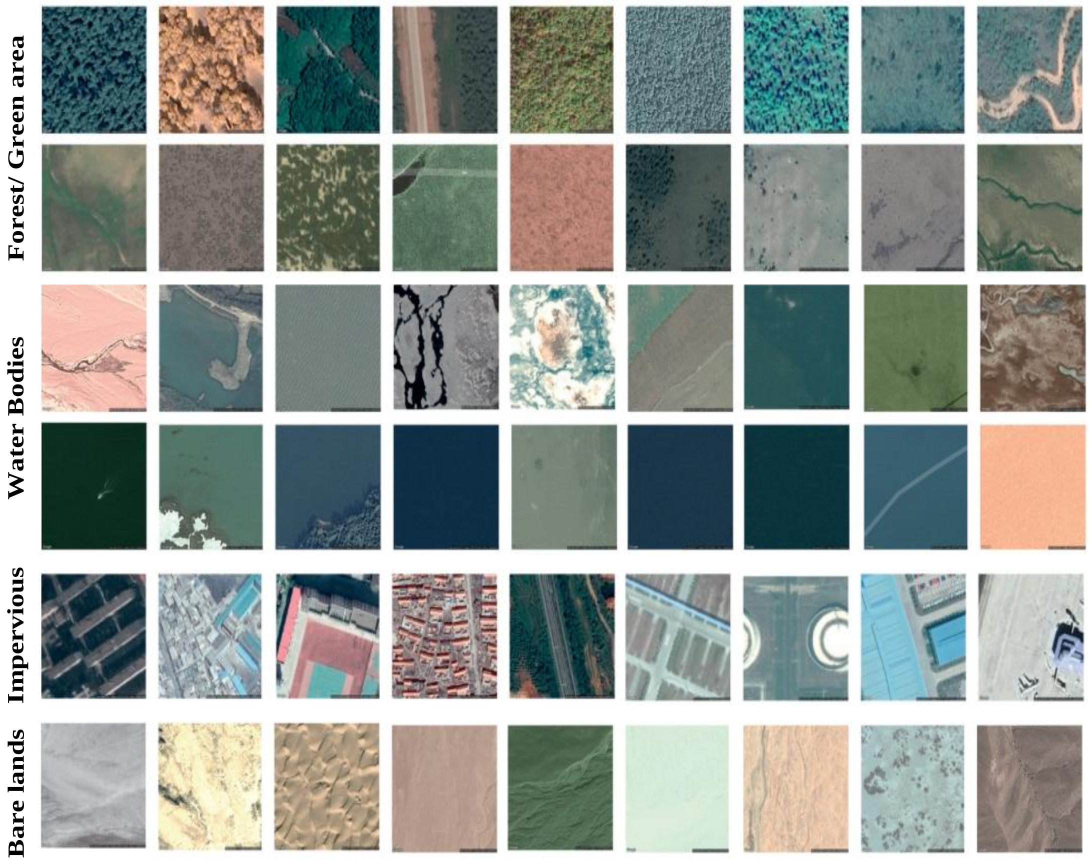


FIGURE 3.5: Samples images considered for land cover classifications [113]

classification is that a user can select sample pixels in an image that represent distinct classes, and then tell image processing software to utilize these training sites as references when classifying the rest of the pixels in the picture. The user's knowledge is used to select training places (also known as testing sets or input classes).

Furthermore, each pixel, in a Landsat image contains some information. The methodology to check the landcover and land use is computed in the same way as adopted Weijia Li et al [113]. The normalized difference of landcover from multispectral Landsat imagery are obtained as shown in Figure 3.6 by spectral reflectance of covers. All the images are obtained by using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

The Landsat image of the maximum landcovers is obtained with datasets in 30-m resolution in the same area but from various dates, and each single pixel is used as a sample image as shown in Figure 3.5, Section 3.4. Each pixel at each specified

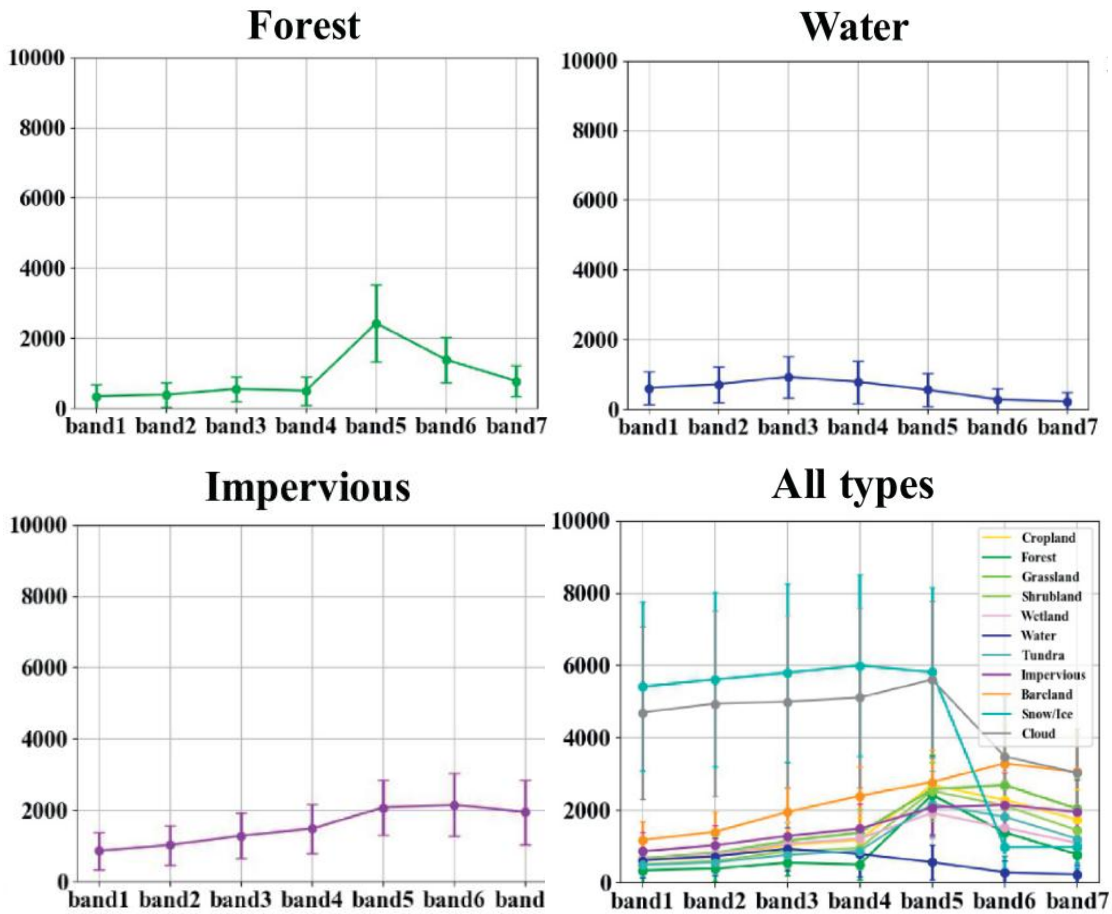


FIGURE 3.6: Spectral Reflectance Curve for Different Types of Landcovers

location is used for feature extraction, which is covered in detail in Section 4.2. All the images obtained are taken with cloud cover <70%.

Figure 3.6 depicts the Landsat spectral reflectance curves for all training samples of each land cover type. While, Table 3.1 presents the different band compositions used for the measure, which may be used as other representation which will lead to false color image.

In Table 3.1, the composite band combinations for different landcover images are shown from natural color image to false color image and color infrared image. Each of the bands have its own significance with the importance of data preference to be used the point to ponder is that, we may change the band combination as per our need to obtain the false color image for sampling as discussed above.

Based on the foregoing considerations, Weijia et al [113], introduced a unique land cover mapping approach that combines high-quality Google Earth photographs

TABLE 3.1: Composite Band Combinations for Landsat Images

Sr. No.	**Composite Name**	**Bands**
1	Natural Color	4 3 2
2	False Color	7 6 4
3	Color Infrared	5 4 3
4	Agriculture	6 5 2
5	Forest	5 6 2
6	Water/ Streams/ Rivers	5 6 4
7	Natural with Atmospheric Removal	7 5 3
8	Shortwave Infrared	7 5 4
9	Vegetation Analysis	6 5 4

with medium-resolution data to improve 30-m resolution land cover mapping found to have deep learning (e.g., Digital Elevation Model and LandSAT). As illustrated in Figure 3.5, the method involves land cover categorization based on sample datasets and land cover mapping based on large-scale remote sensing images. In the current analysis, 250+ samples are taken into account for each land cover category.

3.5 Flood Modelling

3.5.1 Digital Elevation Model

The topographic details were obtained in the form of a Digital Elevation Model (DEM) from NASAs Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument from the link https://search.earthdata.nasa.gov/ after registration as researcher. The files downloaded are divided into sub figures. In order to further manipulate this DEM these all images of the studied area are combined using the mosaic command. Figure 3.8 shows the steps for DEM which is used as crucial input for flow characteristics.

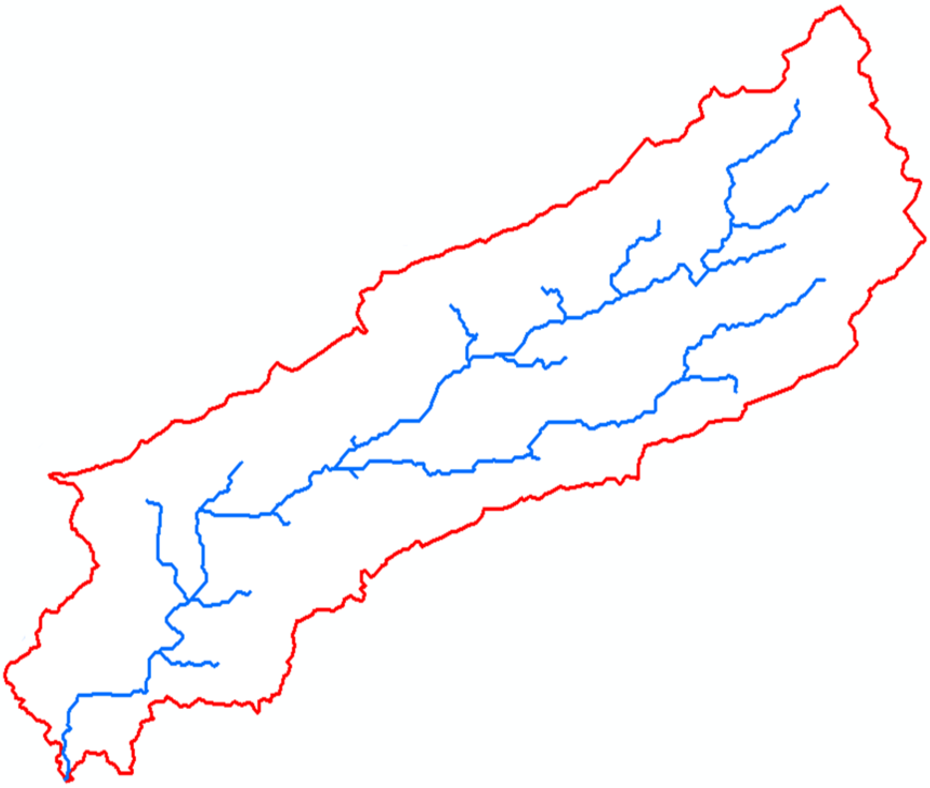


FIGURE 3.7: Delineation of the catchment

The flow direction grid and stream segmentation grid are required as inputs, and the catchment grid delineation function divides the entire area under consideration into a number of catchments based on the stream segments that drain into that area. The figure showing delineation is shown in Figure 3.7.

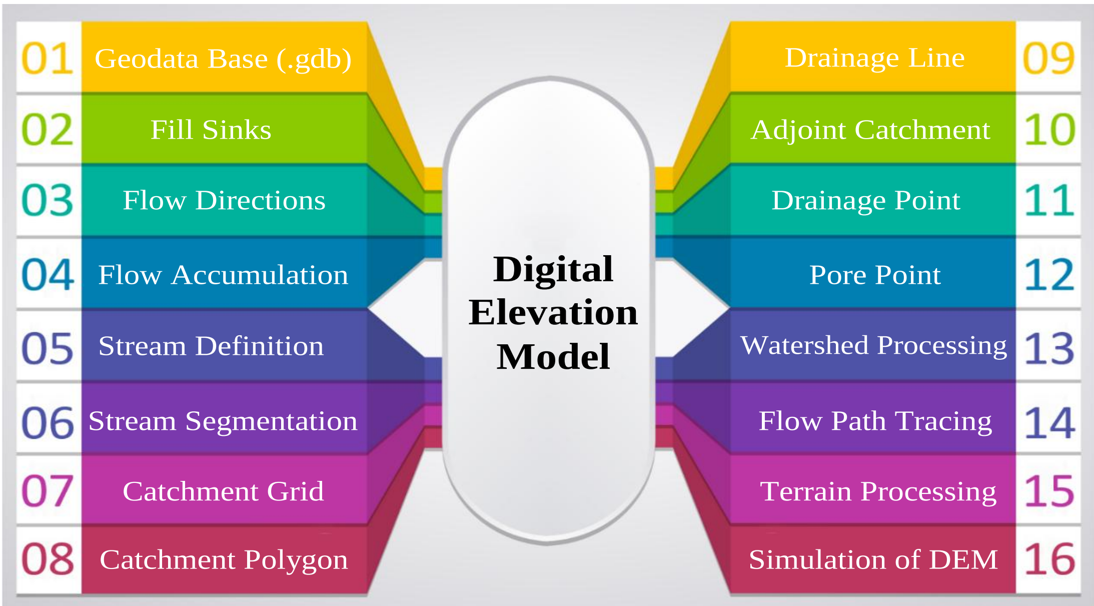


FIGURE 3.8: Terrain Processing for Digital Elevation Model

3.5.1.1 SOBEK Modeling

For modeling of flood risk hazard SOBEK 1D-2D was selected as discussed in Chapter 2 Section 2.5, Table 2.3, which allows both the one-dimensional and two-dimensional channel flow with simulation of overland flows. SOBEK's 1D-2D model was schematized to produce flood inundation-appropriate outputs. The initial values of the event are employed in the settings that determine the output of the flood inundation. The NETTER (Network editor in SOBEK) is used to schematize the model with preference of vector layers as reference. The processing needs for the 1D and 2D modules are different. Several cross-sections along the river are used as input with 2 bridges in the area to estimate the bathymetry of the river. Mannings Coefficient for surface roughness is used to analyze the data for appropriate values and optimum results. Figure 3.9 depicts the schematization phase of software. The results obtained are in the form of flood characteristics map having information about the flow characteristics of the stream by using the continuity equation and the momentum equation in one-dimensional analysis.

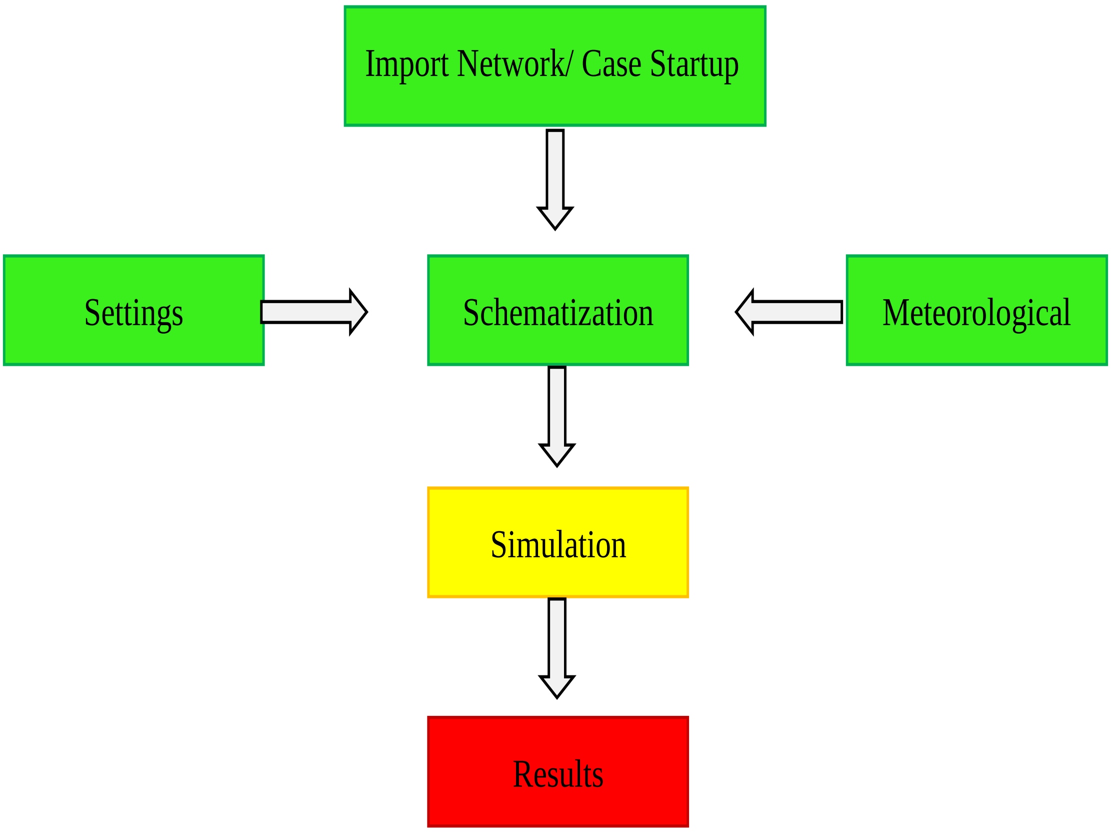


FIGURE 3.9: SOBEK 1-D/2-D Schematization Phase

While, in two-dimensional analysis SOBEK solves the momentum equation in both x and y directions in addition to the continuity equation. The output of flood characteristics includes; maximum flow velocity, maximum water depth and the maximum impulse map.

- The maximum velocity maps are essential for identifying the degree of damage that can be caused. It's worth noting that a huge amount of water accompanied by a low flow velocity produces far less harm than a higher velocity accompanied by a smaller amount of water.
- The maximum water depth is obtained in meters which identifies the potential areas which are at high risk with more water depth influencing in the area.
- The maximum impulse is obtained in area/time (m^2/sec). Therefore, it includes both the flood water depth and the water flow velocity are important aspects to consider.

Table 3.2: The required data used in research

Sr. No.	**Type of Data**	**Source**	**Description**
1	Topographical	https://earthexplorer.usgs.gov/	DEM Source SRTM, (ASTER Files)
2	Land Cover Maps	https://search.earthdata.nasa.gov/search	DEM Source (ASTER, TIFF)
3	Aerial Photos	Google Earth Pro	Archive and validated
4	Meteorological Data	Pakistan Meteorological Department	Meteorological Department
		https://www.worldweatheronline.com/	—
		http://gismap.ciat.cgiar.org/	MarkSim

3.6 Summary

Urbanization or urban sprawl is natural process which can have adverse effects. The change in land use can be measured by the use of satellite images. The satellites images are obtained from different years to measure change in use of landcover. Each image has its own significance using the band composition with respect to its reflectance curve. The adverse effect changes in landcover/ land use can be measure in terms of the level of flood risk. The flood risk assessment can be done by the use of different tools. Different tools have their own limitations and significance. The 1-D and 2-D dimensional analysis techniques are applied to calculate the maximum flow depth, maximum flow velocity and impulse maps using the reference vector layer for the accurate prediction of flood risk.

Chapter 4

Results and Analysis

4.1 Background

In the previous chapter the selected area and methodology were discussed in detail. Keeping the importance of problem statement and specific aim, the two influenced parameters urbanization and flood risk. The previous chapter discussed the methodology to incorporate both the factors by use of modern tools. The chapter under sight discusses the results and analysis that are obtained after the modeling of land cover classifications and flood risk by using Arc-GIS and SOBEK 1D/2D. The calibration of the hydrological model is done in these studies while the validation which is the next step has not been done in this project.

4.2 Change in Land use and Land Covers Impacts of Urban Development

In Pakistan, as in other poor countries, most urban growth is unplanned, with few planning measures in place. In the future, Pakistan will have more people living in cities than in rural areas. Prime agricultural land is being encroached upon as a result of rising population and rapid development. Enhanced Thematic Mapper Plus (ETM+), Thematic Mapper (TM), Landsat Multispectral Scanner

System (MSS) and Operational Land Image (OLI) sensor pictures with 30 m spatial resolution and cloud free images are utilized for land cover mapping. The OLI, ETM+ and TM sensors all have a spatial resolution of 30 meters, whereas the MSS has a resolution of 57 meters.

The image classification technique involves manually categorizing every pixel in a picture into land cover classes. The method of classification with the greatest likelihood was employed to map land cover from Landsat photos in this investigation. The maximum likelihood classification method is a supervised classification technique that uses both the variance and co-variance of each unknown pixel's spectral response to assign it to a certain category. It is based on a multivariate normal probability density function of categories.

To determine the quality of information produced from the data, classification accuracy of land cover maps from 1980, 2000, 2010, 2015, and 2020 was assessed.

To examine the land cover products derived from satellites which have a high degree of accuracy, a sample strategy was used. Ground truth data and satellite visual interpretation were used to assess accuracy using more than 250+ reference samples for each class. Table 5.1 summarizes the estimated land cover area for each image. While, the land cover maps of the Islamabad are shown in Figure 4.1.

The increase in urbanization or urban sprawl in ICT is observed from 45.07 Km^2 to 272.7 Km^2 in the years from 1980 to 2020. The decrease in the class of waterbodies is also observed in last four decades. Initially, in 1980 the area of the water bodies was around 17.06 Km^2 which are reduced up to 7.73 Km^2 in 2020. In case of urbanization an increase of 83.47% is observed while a decrease of 45.35% is observed for waterbodies present in the area. Over the previous four decades, there has been a general drop in the area of forest/green body classes. The decrease in area of the forests was from 448 Km^2 to 338 Km^2, which is about 24.37%. However, in case of bare lands it has shown fluctuation and was not significant during the studies period. The area of the bare lands was 298.3 Km^2 in 1980, while in 2020 it is was about 189.9 Km^2. The details of the change in land classes are presented in Table 5.1.

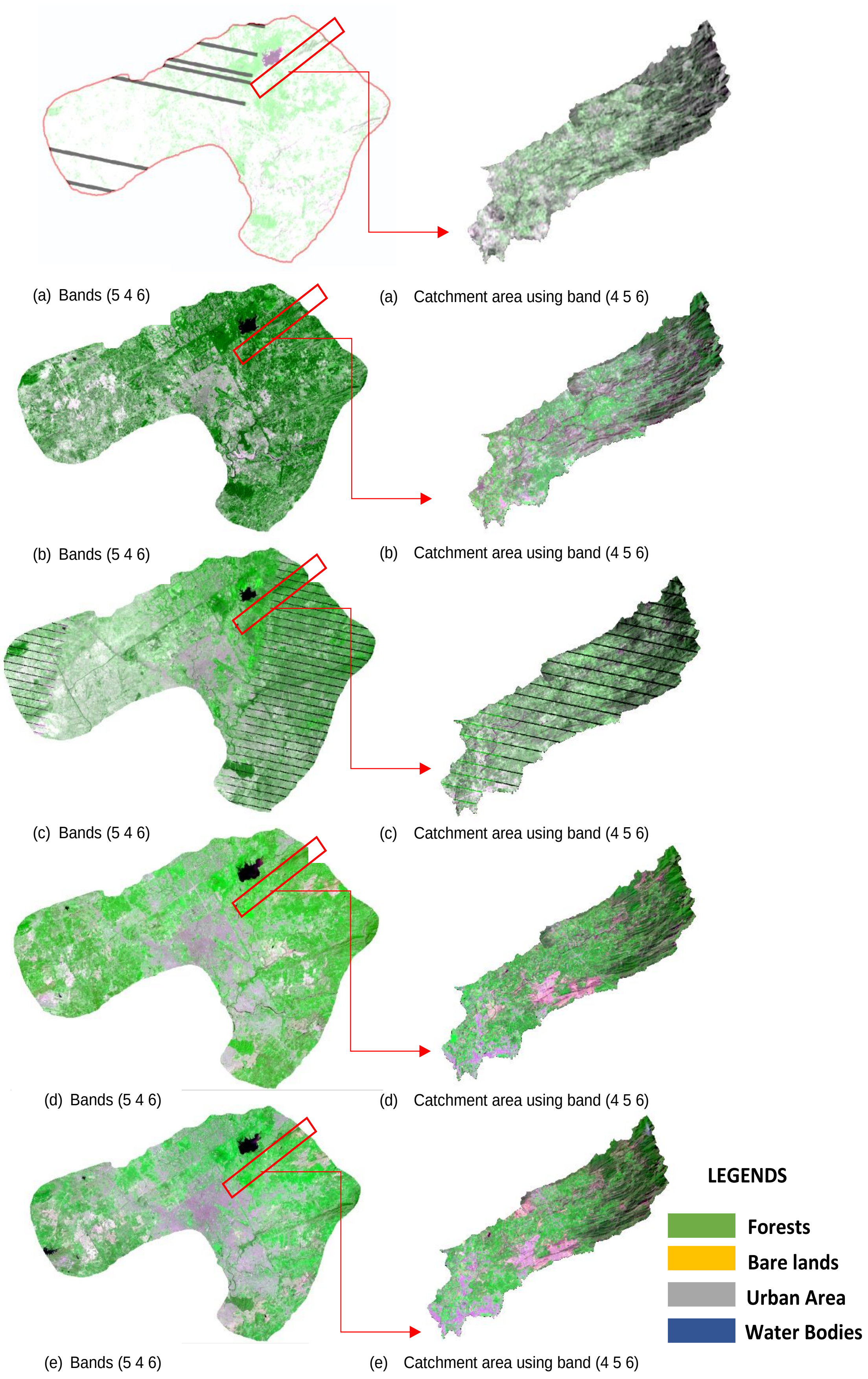


FIGURE 4.1: Land cover classes for 1980, 2000, 2010, 2015 and 2020

However, due to unexpected migration and population growth have resulted in urban expansion and the conversion of impermeable and concrete cover results from the conversion of green cover and fertile agricultural land, indicating a clear departure from the original ICT master plan. In addition, unchecked population growth in ICT as a result of rapid urbanization has degraded the living environment and increased the negative environmental effects on flora, and fauna.as well as human health.

4.3 Climatic Factors and Their Effects

Flood events are triggered by number of the factors affecting the flood situations. For accurate estimation of the floods, climatic considerations are essential. Climate characteristics are one of the most critical natural triggering elements for a flood event. Certain atmospheric phenomena are deemed to see the typical pattern of those observable facts based on observations by the Pakistan Meteorological Department, if there have been any major variations in their normal trend in the last few decades. Despite certain differences in data during important events, the provided data can provide a basic notion and trend about meteorological conditions in the study area. The unpredictability of climatic conditions in the area, particularly rainfall and temperature, has a significant impact on land form behavior.

Chapter 3 describes the research field has a dataset of precipitation from 1983 to 2020 with interval of two years as shown in Figure 4.2. It was examined in order to determine the temperature trend over the previous few decades. River floods occur in a variety of ways depending on the location. They can be caused by heavy rain that exceeds the soil's infiltration capacity, or by rain falling on saturated ground; in this instance, the quantity of flooding caused by a given amount of rain is determined by the extent of saturation. Variations in flood features are greatly impacted by changes in the frequency of severe rainfall when floods are predominantly caused by intense rainfall and antecedent conditions are irrelevant. Changes in flood characteristics are impacted not just by changes in

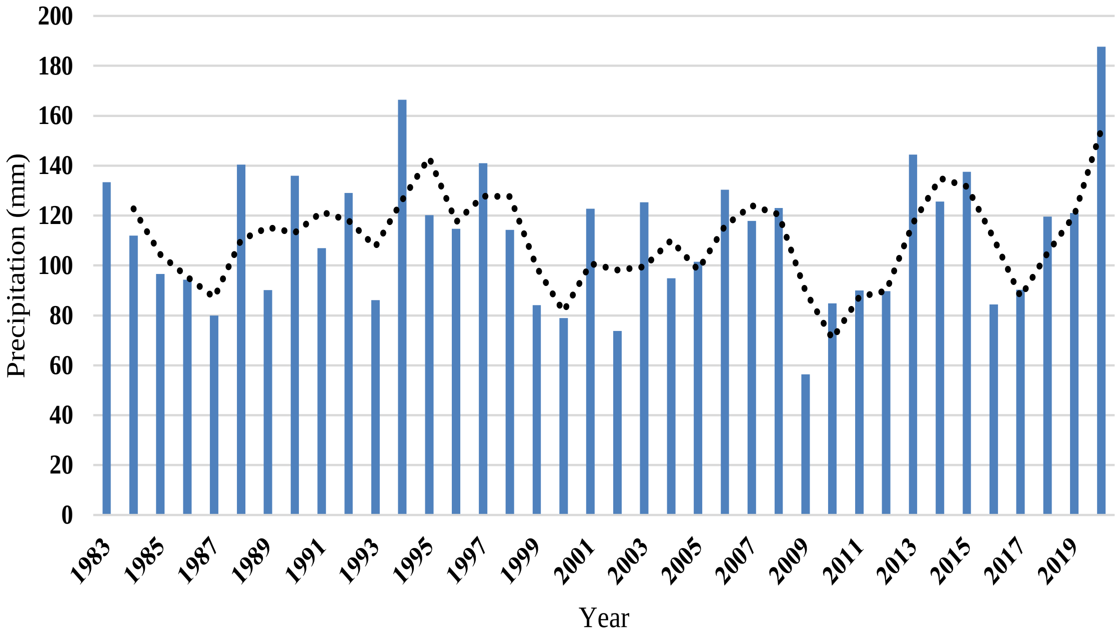


FIGURE 4.2: Maximum events of rainfall observed from 1983-2020

heavy rainfall, but also by changes in the occurrence of saturated conditions over time, which is influenced by both accumulated rainfall and evaporation.

Global climate models (GCMs) are our primary tool for forecasting how the global climate system will behave over the coming millennia. They can only provide information on climate change at broad regional scales due to their coarse resolution (typically 150300 km). Data on climate change can be gathered at a higher resolution by nesting regional climate models (RCMs) in global climate models (GCMs), which cover a smaller area at a higher resolution (50 km or finer). These have been proven to be accurate spatial and temporal details on how climate change may occur locally, and they are commonly employed. However, future climate projections at the local scale are not always credible due to uncertainty in the modelling of processes in GCMs and RCMs, which often results in a range of projected changes for which the likelihood cannot be determined [114].

Natural climatic variability also restricts our capacity to quantify projected changes obtained based on a small sample of baseline and concern climates, and it can be large enough to entirely mask a signal. GCMs have a drawback: their geographical and temporal resolution falls short of that required for hydrologic investigations. The resolution of GCMs is 200-700 km, which is too coarse for practical use.

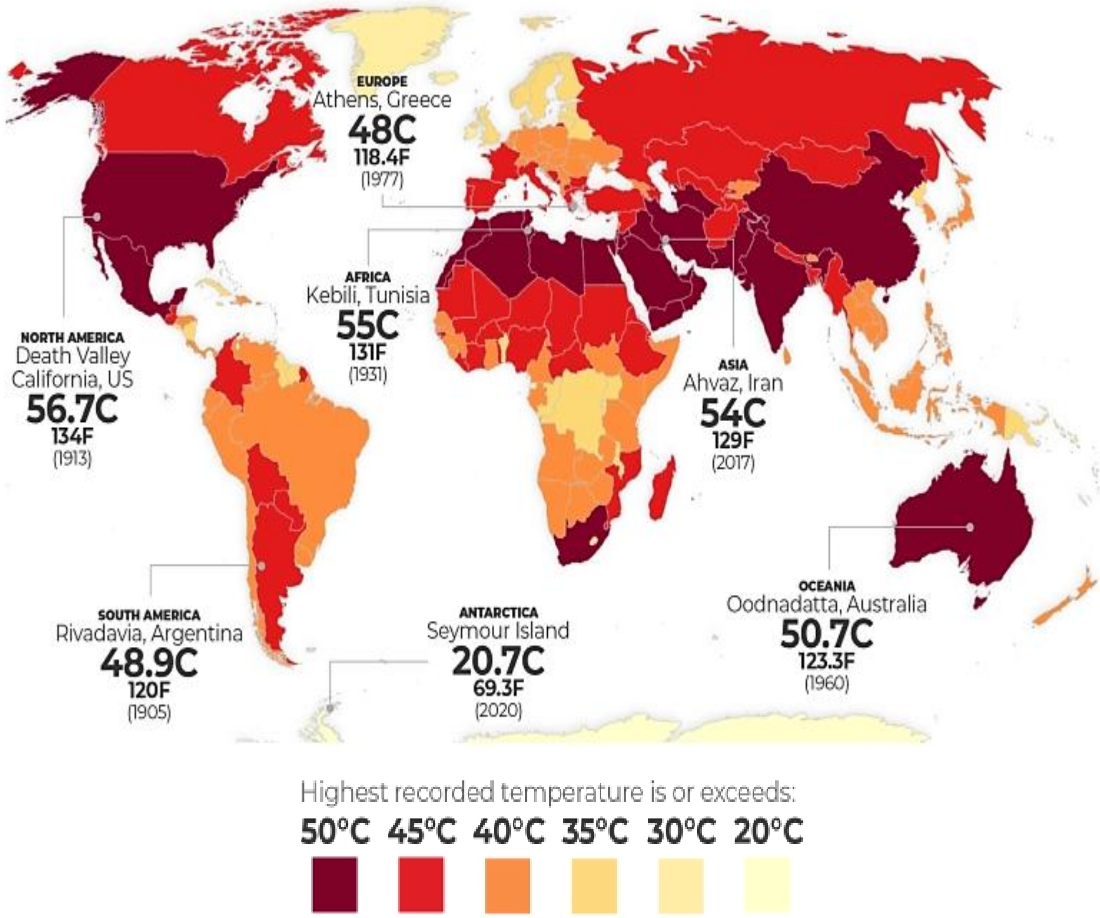


Figure 4.3: Hottest Temperatures Recorded in Different Countries

However, numerous approaches for downscaling GCM output to examine surface variables at the river basin scale have been established. As a result, to estimate the impacts of climate change on stream flow across a specific region, a combination of hydrological models and climate simulations from GCMs is often used for practical implementation.

The abbreviation RCP stands for "Representative Concentration Pathway." To anticipate how our climate will evolve in the future, we must first predict how humans will act. The RCPs make an attempt to forecast future trends. They predict how human activities will affect greenhouse gas concentrations in the atmosphere in the future. Future RCP concentrations range from very high (RCP8.5) to very low (RCP0.5) (RCP2.6). The numerical values assigned to the RCPs (2.6, 4.5, 6.0, and 8.5) correspond to concentrations in the year 2100..

As we are in a region which is under strong influence of climate change and we are

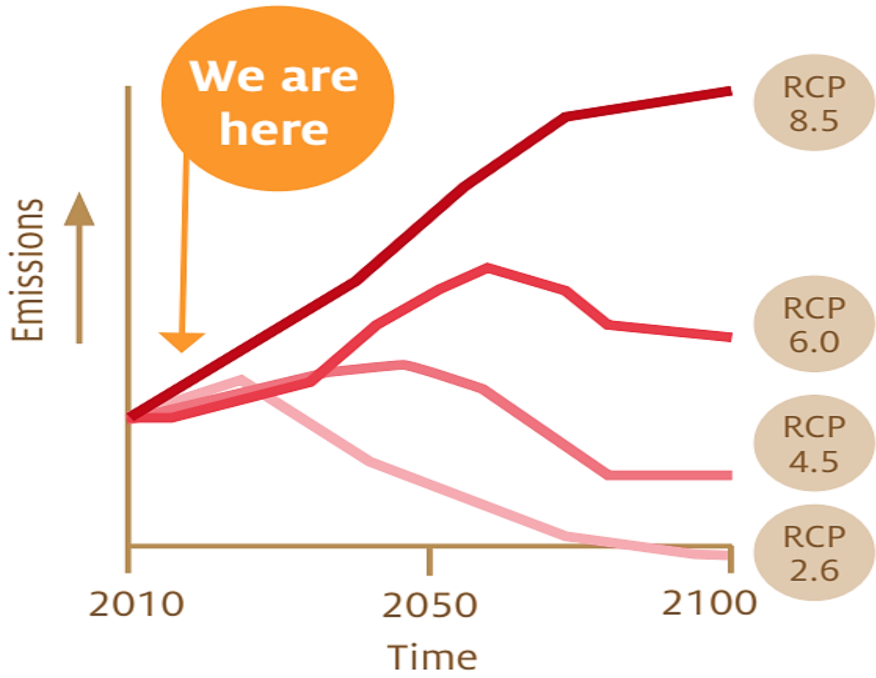


FIGURE 4.4: Climate change trend by use of RCPs for future

following the trend of RCP 8.5 as shown in Figure 4.3 and Figure 4.4. Therefore, as a result, streamflow is expected to decrease substantially. These results suggest that climate change will have a strong influence on the hydrological regime of the two sub catchments analyzed, which have important implications for the planning and management of water resources. Moreover, according to the dataset and following trends, the intensity of precipitation and temperature is projected to increase over the region of study under both RCP 4.5 and RCP 8.5 emission scenarios in the coming decades.

4.4 Calibration and Validation of the Model

For optimization of the model, there must be a clear difference or arrangement between the computed data and the observed data. In testing of calibration, the values of simulated outputs were compared to the observed outputs. The values for calibration of the model were selected for one day i.e., the 27th of March 2021. Mannings roughness coefficient n is a key factor for details of discharge values. Physical observations were compared with literature available in Chapter 4 of

Open Channel Flow, 2nd Edition by M. Hanif [115]. These values were compared with the observed water heights.

The area of the study is passing through the suburbs area as well as developed area which have sometimes regular cross-section and somewhere it is irregular in shape. The length of the stream is about 25.24 km (15.69 mi) with different cross-sections having 2 bridges on its flood plain. The major channel substrate was cobbles, pebbles, and sand, with moderate to low riparian vegetation. Within the canal, there were a few huge stones, but they were uncommon. The friction values were changed based on these considerations, as shown in Figure 4.5.

When compared to previous test runs, Manning's 'n' values with a vertical and horizontal friction of 0.02/0.019 yielded the most accurate results. In the boundary conditions (as shown in Figure 4.8), the model significantly overestimated as well as underestimated the values, while in the peak discharge areas, the best simulation's range of difference is 0.01 to 0.03 m. This could be because the comparison is only done for one single location of the focal points, it could be better if more observations are taken at different points.

4.5 Inundation of Flood Extent

Limited data availability is posing problems for water resource management in many river basins across the world.A major challenge with hydrological model validation is that spatial data is rarely accessible for calibration and validation. As a result, models are primarily calibrated and validated using discharge data, which severely limits their documented performance.

The flood hazard modeling using SOBEK 1D-2D model was selected as discussed in Chapter 2 which allows for one-dimensional channel flow and two-dimensional overland flow simulations to be computed. The characteristics of the input model is shown in Figure 4.5 which are used as boundary conditions. Boundary conditions basically validates the rule of nature by showing the relation between the water mass of study area with universe. In order to achieve this, equation of continuity is

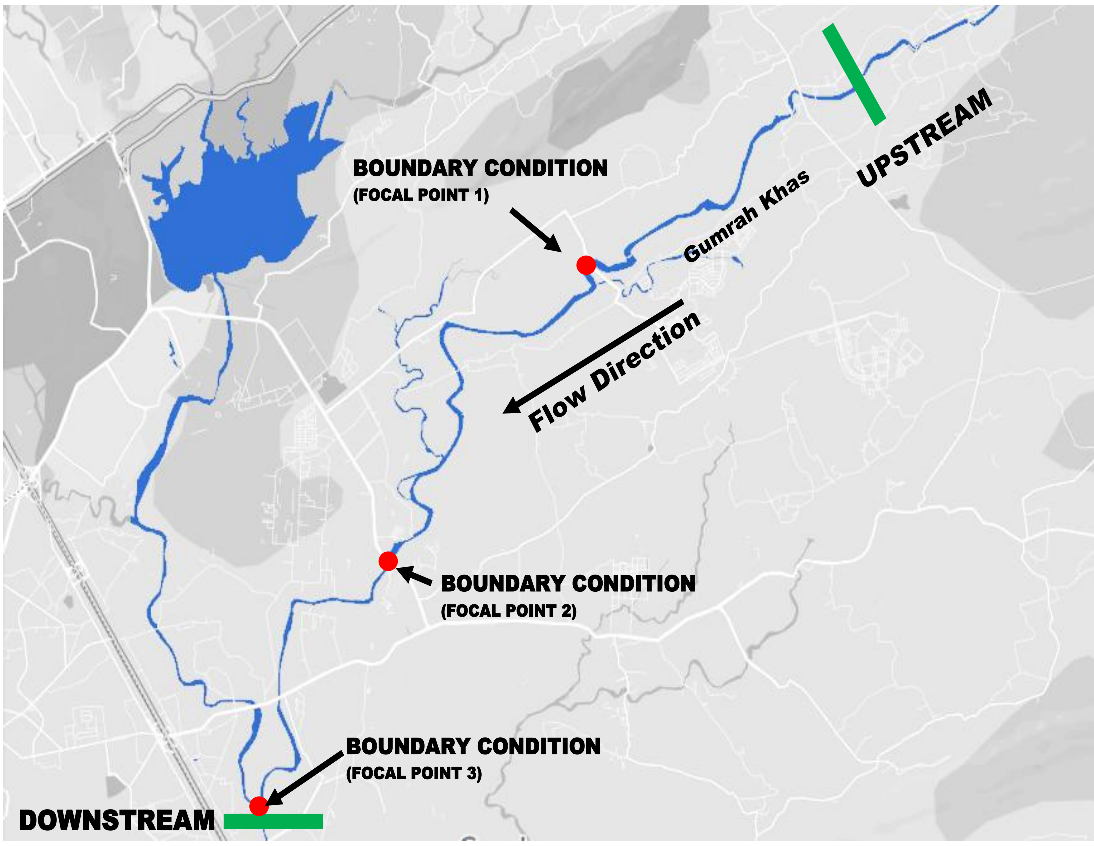


FIGURE 4.5: Input characteristic used for schematization phase

used. However, the discharge data is used as input for three different focal points to validate the boundary conditions. The discharge data, is shown in Figure 4.6 is obtained using the methodology described in Section 3.5.

The Gumrah Khas stream can be categorized as pluvial stream, which has the surface runoff water and flash flood bater both during the extreme events. According to the discharge statistics in Figure 4.6, the discharge maxima of each focal point differ from one another. The first reason for Focal Point 3 is the merging of Rawal Dam spillways, which collects spillway flow near Ghouri Town, resulting in increased discharge at point 3. Furthermore, the many streams that feed into the main stream (Gumrah Khas) are natural storm sewers that contribute to the main stream seasonally.

This leads to rapid erosion and the deposition of debris and sediments in the flood plain downstream. It can be noticed that due to climatic conditions, Islamabad is subjected to heavy monsoon rains starting from the end of June and prevails

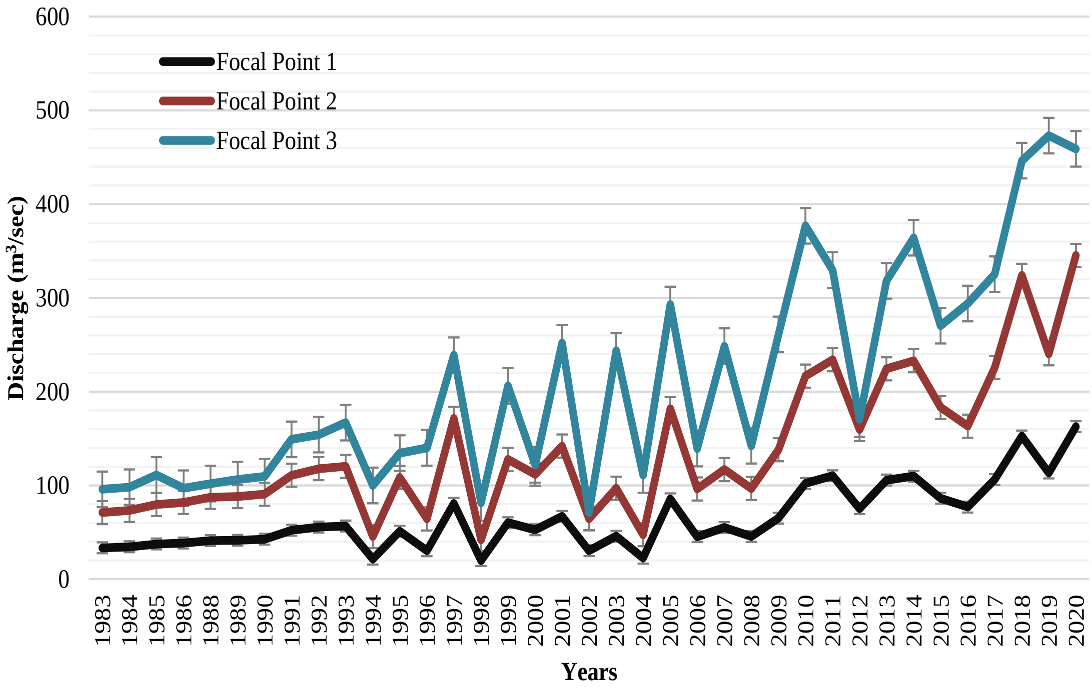


FIGURE 4.6: Hydrograph for focal points from 1980-2020

till the end of September. This shows the seasonal variability of the pluvial floods in the area. The hydrograph of Gumrah Khas under extreme precipitation events from 1980-2020 is shown in Figure 4.6 for each of the focal point.

The hydrograph (Figure 4.6) demonstrates the behavior of the hydrological regime of Gumrah Khas. The graph shows three different discharges against each of the focal point chosen from several years, against the maximum intensity of the rain fall. This depicts the impact of rainfall fluctuation on the river's hydrological regime, particularly during the monsoon season. As a result, it may be inferred that climate conditions play a significant role in triggering occurrences that may result in disasters. Water depth, water velocity, and impulse were the flood characteristics obtained from the model results. All of the maps were generated for various return durations of 50, 75, and 100 years. They were generated as parameter maps, and these maps will be visualized. These maps were subsequently evaluated in order to generate hazard maps, as shown in Figure 4.7-4.9.

During extreme precipitation, pluvial flooding can occur when there is an excess of surface water on the surface or when water flows in preferential flow pathways along roadways or between buildings. When the sewer system is surcharged then excess surface water can pond on the surface or flow in water streams and bodies along streets or between buildings. Depending on the local terrain, when the sewer system is overburdened or when soil infiltration and storage capacity are surpassed. When it comes to simulating overland flooding, there are numerous modelling concepts to choose from., including 1-D simulations based on local depression information or simple hydrodynamic drainage system models, as well as more advanced 2-D and 1-D/2-D coupled surface and subsurface flow representations during precipitation The advantages and disadvantages of these methods were extensively explored in Chapter 2, and the method of choosing is largely determined by the study's goal: for example, 1-D solutions are quick, but they provide poor approximation of complex (non-unidirectional) flows. The coupled overland flow model in SOBEK 1-D-2-D is used in this study to calculate water-level changes, maximum flood depth and surface flows, and in response to a range of precipitation extremes. One of the most noticeable outcomes of modern urban expansion is the conversion of pervious surfaces to impervious surfaces, which is a key predictor of a city's hydrological response during high precipitation. Because run-off is the percentage of precipitation that does not permeate, topography (slope), soil structure (compact vs granular) and soil texture, and are all critical factors in determining run-off volumes.

4.6 Summary

The study area was selected for change detection because of being subjected to urbanization. Evaluation in change of land covers and water bodies are of great importance for flood risk. Due to advancement in technology and availability of modern tools these changes and future trends can be predicted. It is clear from the graphic presentation in the above chapter that Islamabad is subjected to urban sprawl from last few decades. Due to changes in land covers over four decades, there has been a large decline in water bodies and green space, as well as a significant increase in settlements. The computation supervised land cover classifications it is necessary to comprehend the rate of land change in relation to the population growth. Based on the experimental study, it cannot be denied

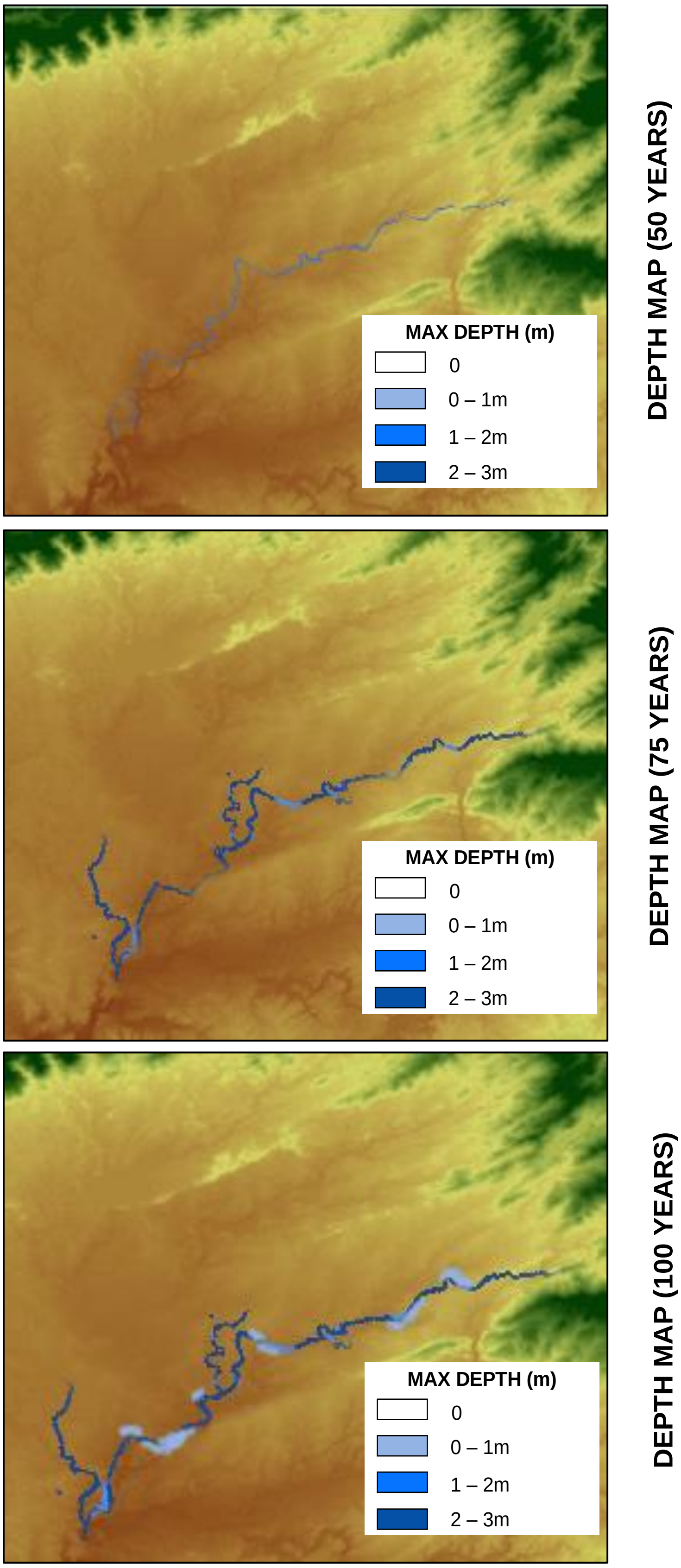


FIGURE 4.7: Maximum water depth map for 50, 75 and 100 return period

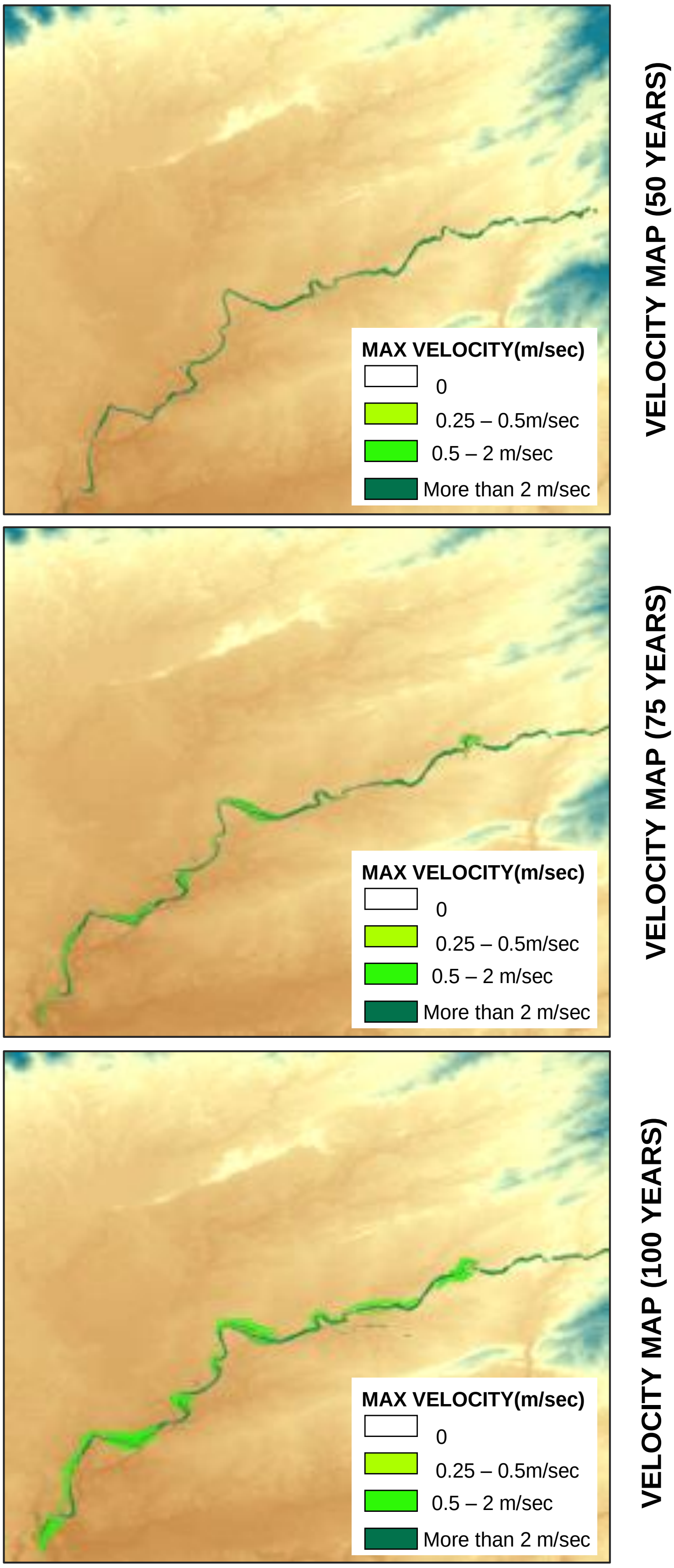


FIGURE 4.8: Maximum water velocity map for 50, 75 and 100 return period

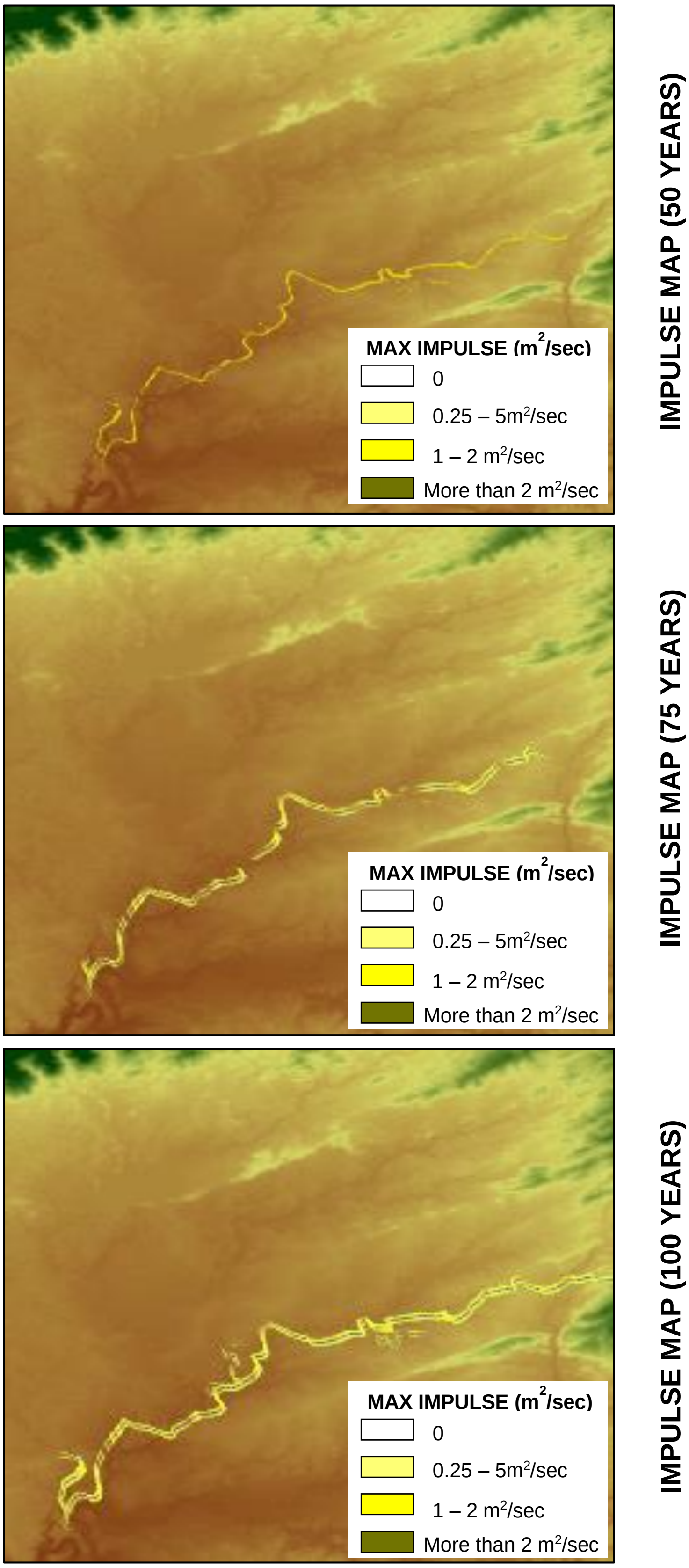


FIGURE 4.9: Maximum impulse map for 50, 75 and 100 return period

that studied area is prone to urban sprawl and is subjected to for flood risk due to change in land cover. To achieve the appropriate and acceptable outputs for flood hazard assessment, the flood risk was schematized using SOBEK 1-D/2-D model.

Chapter 5

Discussion

5.1 Background

As a result of the cumulative effects of continuing urban growth, such as increased soil destruction, or covering by buildings, constructions, and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.), and climate change. Urban areas will become increasingly exposed to pluvial flooding's incidence and consequences due to the phenomena of urban sprawl. The influence of urbanization and flood risk on actual life is discussed in the chapter under discussion. The impacts in terms of environmental sustainability are also taken in consideration.

5.2 Influence of Urbanization for Flood Risk

The majority of Pakistan's main cities, as well as provincial capitals, are affected by urban sprawl. If current trends toward increasing land cover change continue, the risk of pluvial flooding is anticipated to deteriorate even more. The development of more pervious surfaces, on the other hand, could be considered a climate change adaptation. Better understanding of the relevance of both changes in urban land cover and climate change in exposing urban areas to flooding will provide valuable insights for future climate-proofing Flood planning and forecasting are both important aspects of city development. Decision-makers and city planners will be aided in efficiently prioritizing resources among various adaptation and mitigation strategies with the help of precise geographic information on the relative importance of urban growth.

The study's main focus is on the use of a combined remote sensing and flood-model methodology to investigate geographical and temporal variations in urban pluvial flooding exposure caused by changes in urban land cover (imperviousness). Whereas, urban drainage planning and cloudburst control are some examples which requires similar modelling effort which is done out for most European towns using considerably more advanced flood models. The methodology adopted and described in the study here is well suited to large-scale mapping (i.e., at the city level). The effects of urban growth and spread on flooding vulnerability range significantly across geographical areas and for intense precipitation with different return periods. Changing levels of imperviousness are important in influencing the breadth and depth of floods in areas with relatively high infiltration rates. The decreasing impact of land cover change as precipitation intensities rise (for shorter return durations and higher impacts), it's clear that adopting pervious surfaces as adaptation measures is most efficient for the least severe storms, but offers no noticeable protection against flooding during extremely heavy precipitation.

Changing degrees of imperviousness plays a major role in influencing the breadth and depth of floods in areas with relatively rates of high infiltration. The decreasing impact of land cover change as rainfall intensities increase (shorter return periods and greater impacts) The use of pervious or permeable surfaces as an adaptation measures is most successful for the least severe disasters, which is self-evident while, providing no distinct protection against flooding during extremely high precipitation.

The findings of this study can be combined with the covers of urban land forecasts to generate estimates of projected changes in flooding regimes as a result of future urban expansion. Figure 5.1 depicts the increase/decrease in the extent of forests, bare lands, urban areas/impervious lands, and water bodies, as detailed in Chapter 4. Assuming that existing trend of urban development continue for the next

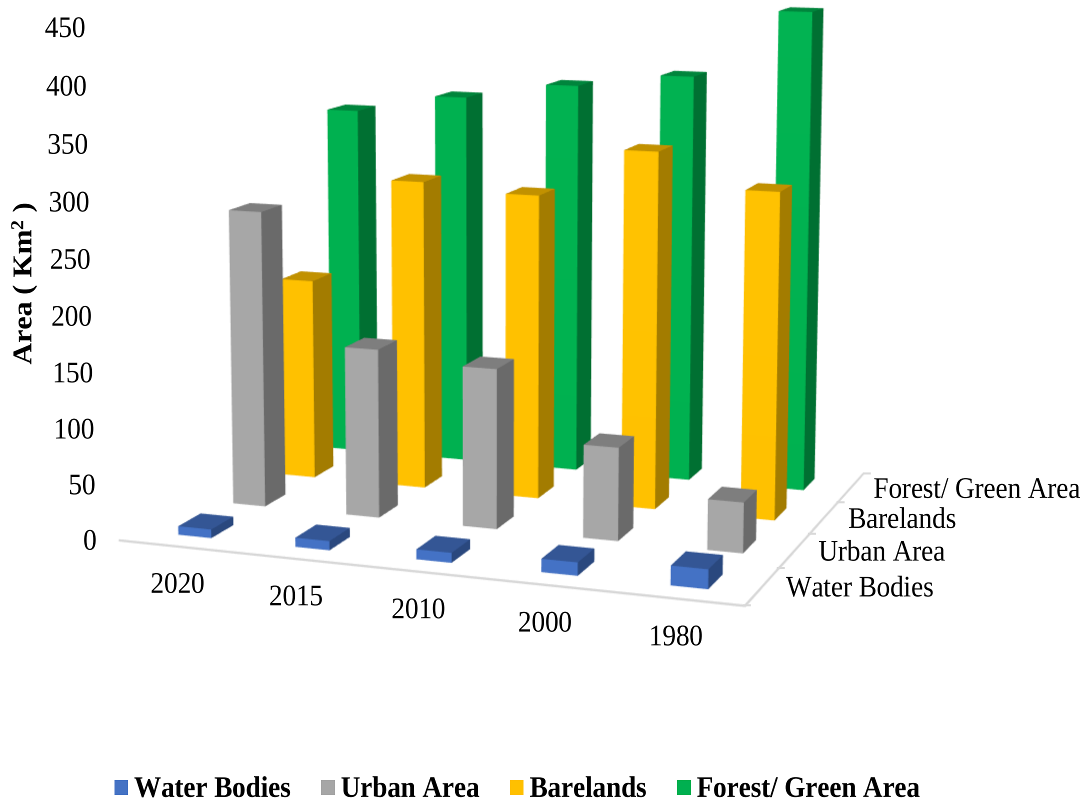


FIGURE 5.1: Change in use of landcover from 1980-2020

hundred years. Similarly, Table 5.1 shows the change in the area of landcovers of bare lands, forests, urban areas and water bodies from year 1980 to 2020 with their relevant increase or decrease percentage.

TABLE 5.1: Land cover classes of ICT for different years assessed based on satellite images.

Landcover Classes	**1980**	**2000**	**2010**	**2015**	**2020**	**Remarks**
Bare lands Km^2	298.34	328.79	283.31	290.06	189.91	Fluctuates with season
Forest/ Green area Km^2	447.95	384.6	371.71	356.2	338.74	Decreased (24.37%)
Urban Area Km^2	45.07	83.71	145.14	154.4	272.71	Increased (83.47%)
Water Bodies Km^2	17.05	11.64	8.82	8.18	7.736	Decreased (45.35%)

Similarly, the change in land use in near the stream of Gumrah Khas is represented in Figure 5.2 and Table 5.2. Figure 5.2 depicts the decrease in forest/ green areas. However, the density of the forests is also decreasing with passage of time as also shown in Figure 4.1. The decrease in waterbodies and increase in urban areas are also observed in vicinity of the stream.

TABLE 5.2: Land cover classes of catchment for different years

Landcover Classes	**1980**	**2000**	**2010**	**2015**	**2020**	**Remarks**
Bare lands Km^2	9.985	10.297	10.100	9.943	10.322	Fluctuates with season
Forest/ Green area Km^2	11.830	11.429	10.840	10.523	8.575	Decreased (27.5%)
Urban Area Km^2	1.070	1.153	1.953	2.942	4.020	Increased (73.33%)
Water Bodies Km^2	0.114	0.109	0.105	0.097	0.081	Decreased (28.94%)

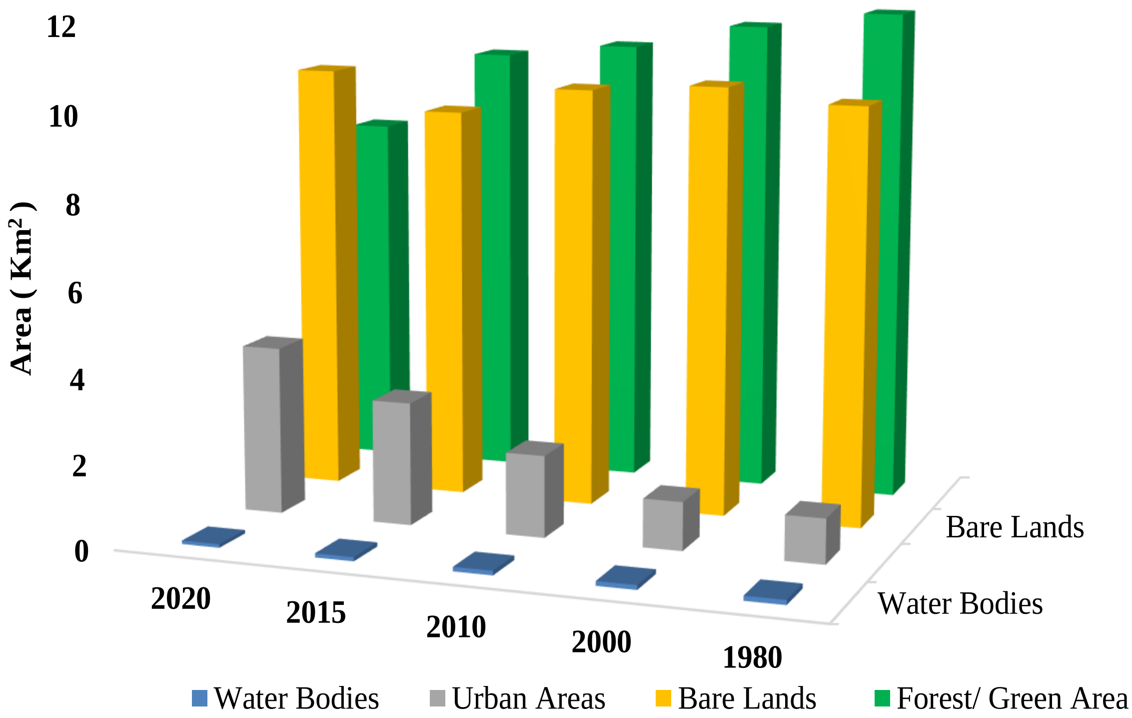


FIGURE 5.2: Change in land use of catchment area from 1980-2020

5.3 Flood Risk and its Vulnerability

In this study, the impact of urbanization and based on willingness-to-pay estimations, assessment of flood risk when it comes to how much society should be willing to sacrifice, to spend on adaptation measures. From the standpoint of a decision-maker responsible for urban sprawl adaptation, adaptation costs should be accepted by society that are at least proportional to the unavoidable costs of flood damage.

Assuming that a specific urban sprawl scenario is emerging, it is important to compare the costs of adaptation with the risk reductions obtained by various strategies. At the local level, all elements (number of infrastructures) that fall into a specific hazard zone based on their return times of 50, 75, and 100 years can be identified as shown in Figure 4.7-4.9 which is represented in tabular form in Table 5.2 in terms of water depth only. However, the impulse map and maximum velocity hazards can be visualized from Figure 4.7-4.9.

TABLE 5.3: Flood risk based on water depth

Type of assessment	**Criteria assessment**	**Classification**	**Risk zones**
Hazard	Water depth	0.0-0.5	Low
		0.5-1.5	Medium
		1.5 2.0	High
		Above 2 m	Very high

Identifying particularly relevant data and modelling methodologies using a very precise context-specific data and modelling approach sensitive and valuable assets that must be preserved through climate change adaptation strategies is one technique to deal with the significant level of ambiguity that surrounds risk evaluations in urban areas. Furthermore, the findings reveal that exceedingly uncommon and historical/cultural values may need to be taken into account in in order to influence the overall outcome of a standardized risk assessment, this environment must be considered. As a result, when it comes to adaptation and decision-making, a approach with precautionary measure in relation to certain assets may be necessary to consider. Using this as an example, society should strive to defend against flooding for the next 100 years as precipitation intensities increase. When compared to fluvial and coastal floods, where the potential threat is intense and obvious, heavy precipitation might be defined as an invisible hazard. This is most likely one of the reasons behind the public's poor perception of the risk of pluvial floods. These people are not aware and do not perceive for the increased threat of pluvial flooding because they do not consider it as a problem.

5.4 Ensuring Sustainability in terms of Environmental and Social Impacts

People in developing countries, particularly those with low incomes, will be harmed by climate extremes because they normally live near the water bodies which are relatively cheap to live. Climate change is anticipated to increase the frequency and intensity of heavy precipitation events in many parts of the world. These events can have an impact on areas that have never been impacted previously, such as those located far from rivers. As a result, additional research on the risk perception of heavy precipitation, raising personal risk perception, and adopting pluvial flood prevention measures is critical. There are few viable emergency techniques to recover the significant damage caused by pluvial floods since warning intervals are so short. To defend against future pluvial floods, several of the necessary precautions are especially crucial. Therefore, in case of pluvial flooding some of the adequate precautions are particularly important:

- Construct quick water breaks like dry walls and retain existing agricultural lay out and encourage farming practices which would increase content of organic matter in the existing soil by top dressing, crop rotation for improving crops and the efficient dealing with the previous crop remains.
- Introduce permanent vegetation on the sideways of river and ensure a sufficient section for down flow and encourage the growth of grass on the whole

surface and in case of plantation of trees. If this is not possible then grass should be grown between the rows

- The construction of structures like dams or barrages to save the flood water for the later use is one of sustainable solutions to floods which not only works like a protection strategy against a flood but also saves the flood water.

Urban regions are characterized by a huge number of people and valuables occupying a small space, in addition to the threat of pluvial floods. As a result, significant flood protection is required in these places to avert flooding. Unlike fluvial and coastal flooding, which occur near the waterbody, pluvial flooding can occur in locations far away from rivers and coasts that have never been flooded before.

5.5 Summary

This research focuses on a specific case study of urban flooding risk assessment owing to urbanization. The result shows that, in terms of actual expectations and decision-making, about future climatic scenarios, the economic assumptions are used which are critical in defining the risks of disastrous climate events and, as a result, the level of cost-effective adaptation from the perspective of society. Due to uncertainty in climatic projections and economic assumptions, the real risk of flooding as a result of extreme precipitation varies in approximately equal parts of the world. Furthermore, this area requires more methodological improvement, which will improve risk assessment.

Chapter 6

Conclusion and Recommendations

6.1 Conclusion

The risk estimate for flooding in small locations is quite uncertain, especially when using downscaled precipitation data, which is used for urban pluvial flooding in most studies of the studies. The findings from the three focal points examined here suggest that changes in land cover within cities can have a significant impact on their vulnerability to flooding, as well as their ability to adapt to a changing climate. The occurrence and impact of pluvial floods will become increasingly vulnerable in urban areas as a result of the combined effects of prolonged urban expansion, such as higher levels of land cover change and as a result of climate change, the frequency and intensity of strong precipitation will rise. According to the findings of the discussion, the impact of urban sprawl and development on exposing cities to floods is comparable to what can be projected by the end of the century under the RCP 8.5 scenario. The proposed approach represents a strategy for flood mapping based only on the use of DEMs that are now freely available on a global scale. However, the results from the study are concluded as follows:

- The urban population has grown rapidly over the last four decades (1980-2020), and this tendency is projected to continue in the future.

- The results of the urbanization analysis undertaken here clearly reveals that the urban population has nearly increased six times in the last four decades.

- The area of water bodies is decreased from 17.05 km^2 to 7.73 km^2 with decrease of 45.4%. Bare lands are decreased from 298.3 km^2 to 189.91 km^2 with decrease of 36.4%. However, the impervious lands and urban areas are increased by 83.47% by increase in area of 45.07 km^2 to 272.71 km^2. Furthermore, the forest/ green area is decreased by 24.37% with reduction of 447.95 km^2 to 338.74 km^2.

- Peak discharge is increased as a result of urbanization, and the time before the peak comes during an event is shortened. Due to continued development, the areas impacted by flash floods and floodplains are expanding.

- For this study, a resolution of 30m was chosen for the pictures or grid cell, which fulfilled the aim of representing the surface for flood modelling in the area for analyzing the impact of urbanization.

- Land cover change dynamics are essential for distinguishing in this study's analysis of the ICT study region. There are a few important caveats that are to be keep in mind and to be mentioned. Multispectral Scanner System (MSS) involved in Landsat 3 sensor data with a spatial resolution of around 57 m was used in the 1980 land cover map, which is coarser spatially than Landsat 8 and 5 (i.e., 30 m), potentially compromising the spatial uniformity and accuracy of derived land cover maps.

- A flood hazard and risk assessment research are a methodical approach that identifies damage-prone areas. It is location and user specific, and it necessitates a deeper understanding of flood features and behavior in order to deploy mitigation measures effectively.

- It may be concluded that, despite the presence of a large amount of data, such as discharge data, it was possible to conduct a non-traditional analysis of flood frequency probability.

- The flood model's simulation results indicated the area's flood characteristics of water depth, water velocity, and impulse map for various return periods.

The flood's spatial extent was determined using reference vector images, with friction levels within the channel having a direct influence.

- Flood hazard maps can be used to determine the degree of risk and susceptibility of the physical elements at danger, based on their importance and requirement.

The study clearly shows that the flood modelling approach in terms of analyzing and mapping the simultaneous importance of urbanization and climate change, the remote sensing technique used here can be easily transferred. Changes in urban flood exposure that apply to a variety of geographic locations, both globally and regionally. To provide decision-makers with appropriate understanding of how to prepare future pluvial flood-proofing for cities continued research into the primary causes determining total exposure, susceptibility, and risk is essential. For a variety of purposes, satellite images provide superior coverage of urban land cover. The use of satellites images in present era is beneficial to explore the change in land cover and to analyze the flood risk.

6.2 Recommendations

Under developed countries are especially vulnerable against the effect of environmental change and outrageous occasions of flood events specially because of their low livelihoods, feeble frameworks and organizations, and low limit with regards to adapting to environmental change. This suggests that damages related with flood events are frequently intense. To mitigate the effects of disastrous events in accordance with urban sprawl, following recommendations are made for both future studies and for local administrative bodies.

6.2.1 Recommendation for Future Study

- The use of high-resolution images below than 30m might be useful to accurately predict the varying trends of both urbanization and flood risks.

- The climate change effect by using the RCP models should be studied in depth because of the current trends following RCP 8.5 scenarios.

- Owing to the availability of data on an individual level for the elements at risk such as units of buildings, tracks, green bodies etc. Furthermore, vulnerability assessment studies on an individual level are possible, and the current work should be used as a foundation for future research.

- The characteristics of flood are dependent on DEM models. The major issues of flood modeling are related with the interpolation method of DEM. In this research method ANUDEM method is considered which uses the Topography method to Raster function in Arc GIS used to create the surface-based models. However, the effects of different interpolation methods and accuracy assessment may vary for different DEM techniques. Therefore, there is a need to study the variation in results through different DEM techniques.

6.2.2 Recommendation for Local Managerial Authorities

- In order to plan for the deployment of structural measures against disaster events, a new preventative plan is required.

- Flood mitigation includes both conventional and unconventional, should be investigated. Construction and repair of banks and dykes, widening of riverbeds where practicable, and spatial planning methods can all help to improve infrastructure for the development of flood defense mechanisms. Changes in land use, the construction and restoration of supporting structures in safe zones, the relocation of high-risk elements to a safer location, and the creation of early warning systems are some of the traditional recommended methods.

- It is essential to raise public knowledge about the potential for damage and the area's vulnerability to flooding. In terms of risk communication between people and authorities, there should be transparency.

- During the planning and decision-making phases, the support committee might benefit from the primary phase of risk assessment.
- Vulnerability and risk conditions for preparing prevention plans for predictable natural threats should be developed/improved for the cities. Not only should administrative units be active in risk management, but people should be involved in the acceptable responsibility of risk on individual level.

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