INVESTIGATING THE EFFECTS OF INCREASE IN BUILT-UP LAND ON THE SWAT RIVER DISCHARGE

By

(Leader - CMS 356423	Captain Murtaza)
(Member 1 - CMS 356417	Captain Asim)
(Member 2 - CMS 356426	Captain Umar Gillani)
(Member 3 - CMS 356454	Captain Hamza)

Department of Water Resources Engineering and Management

Military College of Engineering

National University of Sciences & Technology (NUST)

Islamabad, Pakistan

(2024)

INVESTIGATING THE EFFECTS OF INCREASE IN BUILT-UP LAND ON THE SWAT RIVER DISCHARGE

By

(Leader - CMS 356423 Captain Murtaza)

(Member 1 - CMS 356417 Captain Asim)

(Member 2 - CMS 356426 Captain Umar Gillani)

(Member 3 - CMS 356454 Captain Hamza)

A thesis submitted to the National University of Sciences and Technology, Islamabad,

in partial fulfillment of the requirements for the degree of

Bachelor of Science in
Civil Engineering

Supervisor: Dr. Muhmmad Amjad

Military College of Engineering

National University of Sciences & Technology (NUST)

Islamabad, Pakistan

(2024)

DEDICATION

Dedicated to our parents, who have prayed for us since ever, and our teachers, without whose support this effort would never have been completed.

THESIS ACCEPTANCE CERTIFICATE

We

(Leader – CMS 356423 Captain Murtaza Yawar Changezi)

(Member 1 - CMS 356417 Captain Asim)

(Member 2 - CMS 356426 Captain Umar Gillani)

(Member 3 - CMS 356454 Captain Muhammad Hamza)

has been vetted by undersigned, found complete in all respects as per NUST Statutes/ Regulations/ Masters Policy, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of Bachelors degree. It is further certified that necessary amendments as point out by GEC members and foreign/ local evaluators of the scholar have also been incorporated in the said thesis.

Signature: ______________

Name of Supervisor Dr. Muhammad Amjad

Date: 14/05/2024

Signature (HOD): ______________

Date: 14/05/2024

PLAGIARISM UNDERTAKING

I solemnly declare that research work presented in the thesis titled " INVESTIGATING THE EFFECTS OF INCREASE IN BUILT-UP LAND ON SWAT RIVER DISCHARGE " is solely my research work with no significant contribution from any other person. Small contribution/ help wherever taken has been duly acknowledged and that complete thesis has been written by me.

I understand the zero tolerance policy of the HEC and National University of Sciences and Technology (NUST), Islamabad towards plagiarism. Therefore, I as an author of the above titled thesis declare that no portion of my thesis has been plagiarized and any material used as reference is properly referred/cited.

I undertake that if I am found guilty of any formal plagiarism in the above titled thesis even after award of BS degree, the University reserves the rights to withdraw/revoke my BS degree and that HEC and NUST, Islamabad has the right to publish my name on the HEC/University website on which names of students are placed who submitted plagiarized thesis.

Student Signature: ____________

Name: Capt Murtaza Yawar Changezi

Student Signature: ____________

Name: Major Muhammad Asim

Student Signature: ____________

Name: Capt Muhammad Umar

Student Signature: ____________

Name: Capt Muhammad Hamza

CERTIFICATE OF APPROVAL

This is to certify that the research work presented in this thesis, entitled "INVESTIGATING THE EFFECTS OF INCREASE IN BUILT-UP LAND ON SWAT RIVER DISCHARGE" was conducted.

(Leader – CMS 356423 Captain Murtaza Yawar Changezi)

(Member 1 - CMS 356417 Captain Asim)

(Member 2 - CMS 356426 Captain Umar Gillani)

(Member 3 - CMS 356454 Captain Muhammad Hamza)

Under supervision of Dr. Muhammad Amjad.

No part of this thesis has been submitted anywhere else for any other degree. This thesis is submitted to the Department of Water Resources Engineering & Management, Military College of Engineering, Risalpur in partial fulfillment of the requirements for the degree of Bachelor's in Civil Engineering.

Name of Student: Capt Murtaza Yawar Changezi Signature: ____________

Name of Student: Maj Muhammad Asim Signature: ____________

Name of Student: Capt Umar Gillani Signature: ____________

Name of Student: Capt Muhammad Hamza Signature: ____________

Supervisor Name: Dr. Muhammad Amjad Signature: ____________

Name of HOD: Dr. Muhammad Amjad Signature: ____________

AUTHOR'S DECLARATION

We

(Leader – CMS 356423 Captain Murtaza Yawar Changezi)

(Member 1 - CMS 356417 Captain Asim)

(Member 2 - CMS 356426 Captain Umar Gillani)

(Member 3 - CMS 356454 Captain Muhammad Hamza)

hereby state that my BECE thesis titled " INVESTIGATING THE EFFECTS OF INCREASE IN BUILT-UP LAND ON SWAT RIVER DISCHARGE " is my own work and has not been submitted previously by me for taking any degree from National University of Sciences and Technology, Islamabad or anywhere else in the country/ world.

At any time if my statement is found to be incorrect even after I graduate, the university has the right to withdraw my BECE degree.

Name of Student: Capt Murtaza Yawar Changezi Signature:______

Name of Student: Maj Muhammad Asim Signature:______

Name of Student: Capt Umar Gillani Signature:______

Name of Student: Capt Muhammad Hamza Signature:______

Dated: 22nd April 2024

Acknowledgements

All thanks and praise to Allah Almighty. We bow our heads before **Almighty Allah** to provide us with opportunities and resources to ultimately shape our research work. There are several individuals whose contributions have been vital to the completion of this project. **Asst Prof Dr. Muhammad Amjad**, our project advisor, was the beacon of guidelines and the driving force behind this research. He contributed valuable ideas, invaluable guidance, and enthusiastic encouragement throughout our research work. Also, we pay our gratitude to our faculty members and teachers for guiding and helping us whenever it was needed.

All Syndicate members

TABLE OF CONTENTS

List of Tables

Page No.

List of Figures

Page No.

Abstract

Floods pose a formidable threat to communities, livelihoods, and property globally, exacerbated by the escalating effects of climate change. Pakistan, in particular, faces recurrent and devastating floods, with the Swat Watershed experiencing a history of catastrophic flooding. This research paper investigates the effects of land use changes on runoff in Swat Watershed. Our study aims to understand how urban development and other land cover changes affect runoff patterns using GIS and hydrological modeling. Despite the region's vulnerability to floods, GIS-based research is lacking in this area. Our objectives include assessing runoff variations, modeling rainfall-runoff transformation, and integrating GIS data to uncover the causes and consequences of floods. We utilize various data sources, such as DEM data, Landsat imagery, precipitation records, and discharge data. Our findings fill a gap in the literature about the Swat Watershed, providing insights for effective flood management and land use development.

Keywords: Swat watershed, Land Use Land Cover, Swat, Urban development, rainfall-runoff, GIS, Hydrological Modeling, Flood, DEM data, Landsat imagery, precipitation records

CHAPTER 1: INTRODUCTION

1.1 Background

Floods represent significant natural calamities on a global scale, threatening people, their livelihoods, and property. Their occurrence is increasing in frequency and intensity, partly attributed to the influence of climate change. Pakistan is especially vulnerable to floods, having experienced numerous devastating floods in recent years.

The Swat Watershed, situated in Pakistan, has experienced a history of devastating floods, notably in 1992, 2005, 2010, and most recently in 2022. These recurring flood events have left a lasting impact, affecting not only the immediate communities but also the wider region. Among the numerous factors exacerbating flood risk in this watershed, a notable concern is the transformation of natural, vegetated land into urban and residential areas. This shift in land use reduces the land's capacity to absorb rainfall and accelerates surface water flow, amplifying the vulnerability to flooding.

In response to these pressing challenges, this research paper undertakes a comprehensive exploration of the intricate relationship between LULC changes, particularly the conversion of natural land to urban development, and the escalating flood risk within the Swat Watershed. Our goal is to unveil the underlying causes and consequences of flood occurrences in the region. Additionally, we aim to provide valuable insights and recommendations for more effective flood management, land use planning, and mitigation strategies. Ultimately, our research strives to mitigate the devastating impact of floods on this vulnerable region and flood-prone areas worldwide.

1.2 Problem Statement

The Swat River Watershed faces a recurring and severe threat in the form of frequent floods, which have extensive consequences for the region's inhabitants, property, and economy. Despite being prone to floods, there is a noticeable lack of Geographic Information System (GIS)-driven efforts directed towards examining the temporal and spatial spread of surface runoff., a pivotal indicator of regional water resources influenced by changes in LULC in the area.

LULC modifications, particularly the transformation of vegetated land into built-up areas, are widely acknowledged for their significant impact on surface runoff coefficients, consequently exacerbating the risk of flooding. However, there exists a scarcity of research focused on comprehending the repercussions of LULC alterations on discharge, specifically within the Swat River Watershed. This knowledge gap poses challenges in formulating effective flood mitigation strategies for the region.

1.3 Literature Gap

The existing body of literature reveals a significant gap in research, particularly in the context of the Swat Watershed. One notable aspect of this gap is the limited attention given to this specific watershed, which is crucial given its susceptibility to various environmental challenges, including urbanization and its associated effects. While numerous studies have explored urbanization's impact on hydrology and land use changes, there is a lack of research that delves into the unique characteristics and challenges of the Swat Watershed.

Furthermore, within this watershed, there is a conspicuous absence of comprehensive Geographic Information System (GIS)-based initiatives aimed at evaluating the temporal and spatial distribution of surface runoff. This absence of analytical tools and studies focused on surface runoff dynamics in the context of LULC changes hampers our ability to understand and address critical issues related to water resources and flood risk management. Therefore, it becomes evident that there is a pressing need for research endeavors and GIS-based initiatives tailored to the Swat Watershed, which would not only enhance our understanding of the region but also contribute to the development of effective strategies for sustainable water resource management and flood mitigation.

1.4 Objectives

The objectives of this study include:

a. Assessing the impacts of LULC on runoff variations

b. Hydrological modeling for rainfall-runoff transformation

c. Integration of GIS-based LULC data

d. Comparison with the observed runoff data

1.5 Scope of Study

The Swat River Basin's urbanization is examined in this study along with its effects on population growth and administrative policies. It evaluates how urbanization affects water supply during dry seasons and increases surface runoff and flood threats. It also examines how climate change contributes to the aggravation of these problems. The study aims to provide recommendations for improved urban development and sustainable watershed management in light of these complex relationships.

Researchers and decision-makers involved in fields including water resource management, district and disaster management, as well as specialists in flood prediction in the Swat River Basin, may find the study's findings useful.

CHAPTER 2: LITERATURE REVIEW

Studies that were conducted in various countries, were examined during our research. Different articles related to extreme events specifically in Pakistan were also examined to have certain degree of knowledge on the current development in this field. Few of the papers would be discussed in this section.

Li et al., (2020) examines the impact of urbanization on watershed hydrology in the United States, focusing on the balance between precipitation, water yield (Q), and evapotranspiration (ET) in watersheds. Urbanization, characterized by changes in land use and climate, significantly alters this balance. Using the SWAT watershed model, the study simulates urbanization effects on runoff, infiltration, and ET. Data from various sources, including land use, soil, climate, and hydrology databases, inform the model. Calibration and validation processes are conducted on 10 watersheds. Key findings reveal that urbanization can increase runoff by up to 50%, reduce infiltration by up to 50%, and decrease ET by up to 20%. The impact varies with watershed characteristics, such as slope and vegetation cover. The southeastern US experiences the most significant changes due to urbanization, driven by impervious surface expansion and vegetation loss. Urbanization plays a major role in altering watershed water balances. The study emphasizes the importance of considering these effects in water resources management and recommends proactive planning for managing the impacts of urbanization on watersheds.

Zimale et al., (2017) focused on improving watershed management practices in humid region. Watershed management practices globally have proven effective in mitigating soil erosion, improving water quality, and enhancing water availability. However, their long-term success in the humid African highlands has been limited due to high rainfall, steep slopes, and fragile soils making the region prone to soil erosion and flooding. Additionally, deforestation and agricultural expansion contribute to land degradation. This study aims to establish general principles for implementing watershed management practices in subhumid and humid Ethiopian highlands by analyzing runoff and erosion in relation to landscape features and climate. Recommendations will be based on these findings. The author identifies two main runoff and sediment sources in the humid

Ethiopian highlands, degraded lands and periodically saturated bottomlands. For degraded lands, proposed soil and water conservation measures include infiltration furrows, ripping along contours, planting fruit trees, and adopting no-till agriculture. For periodically saturated bottomlands, measures involve tree planting, creating dams, and ponds. Challenges in humid highland watershed management include balancing agriculture, water supply, and environmental protection, addressing root causes like deforestation, and developing region-specific practices. Effective watershed management relies on comprehensive data collection, GIS and remote sensing for land use and hydrology analysis, erosion control strategies, and water quality monitoring. Community engagement through education and participatory decision-making is essential. The study underscores the importance of tailoring conservation measures to specific watershed conditions and emphasizes community participation. It draws upon previous studies in the Ethiopian highlands, highlighting the effectiveness of measures like infiltration furrows and traditional methods such as terracing and tree planting.

Banu (2016) focused on the watershed projects in India. Most watershed projects in India are implemented with the twin objectives of soil and water conservation and enhancing the livelihoods of the rural poor. A watershed is a geographical area that drains to a common point, which makes it an attractive unit for technical efforts to conserve soil and maximize the utilization of surface water and subsurface water for crop production. Watershed management is crucial in Tamil Nadu due to its vulnerability to droughts and floods, coupled with high population density straining water resources. With agriculture supporting 56% of the population, the net sown area has declined due to urbanization, industrialization, and marginal/small farmers' dominance, raising concerns. Tamil Nadu implemented a community-based watershed development scheme across 755 watersheds in 155 blocks of 23 districts, chaired by collectors and overseen by the District Watershed Development Agency and village-level committees. Several watershed development programs are in place, including the Restructured National Watershed Development Project for Rainfed Areas (NWDPRA), Watershed Development Fund (WDF), Integrated Wasteland Development Programme (IWDP), and Drought Prone Areas Programme (DPAP). The objectives of the scheme include promoting participatory watershed development and forming watershed associations based on local needs within a six-year project period. Research methodologies used in watershed management studies vary, encompassing both quantitative and qualitative methods. Watershed development programs significantly impact crop productivity, technology adoption, socio-economic conditions, and the environment in Tamil Nadu. Their success hinges on participatory implementation and tailored approaches to local needs, requiring continuous monitoring and evaluation to achieve their objectives.

Pathak et al., (2013) reviews the impacts of an Integrated Watershed Management (IWSM) program in Gokulpura-Goverdhanpura village, Bundi district, Rajasthan, India, initiated in 2006. The program aimed to holistically manage natural resources, including soil, water, and life forms. It involved participatory planning, monitoring, and capacity building. Phase 1 (1997-2001) focused on availability of water and erosion control through water harvesting structures. Phase 2 (2002-2005) addressed land degradation, livelihoods, and food security with improved agriculture and micro-enterprises. Challenges included financial constraints, lack of technical expertise, community participation, and political support. The authors suggest overcoming these challenges through increased investment, technical support, capacity building, and political backing. The program positively impacted socio-economic conditions, reducing poverty, improving food security, education, healthcare access, and overall quality of life. The study recommends replicating IWSM programs in similar regions, emphasizing cost-effectiveness and sustainability. Key aspects included water harvesting structures, afforestation, community participation, and success in low rainfall semi-arid regions.

Fajar et al., (2022) examines the spatial and temporal distribution of surface runoff in the upstream Citarum watershed in West Java, Indonesia, with a focus on the impact of LULC changes . The study utilizes RS and GIS methods to identify LULC classes in spatial and temporal terms. The authors employ the maximum likelihood approach to analyze the past trends using Landsat data and the Cellular Automata-Markov model for future predictions Based upon the LULC, the authors used the rational formula for calculation of runoff. They found that urbanization and plantation are 2 main LULC classes that leads to increased runoff, highlighting the importance of LULC in watershed management. The paper addresses the gap in understanding the hydrologic behavior of the

Citarum watershed, which is the main contributor of flood in Jakarta, Indonesia and emphasizes the need for proactive sub-watershed management to mitigate runoff from increased urbanization and plantations.

Asdaka et al., (2018) addresses the issue of flooding in Jakarta, focusing on integrated watershed management as a solution. Jakarta's vulnerability to flooding is attributed to its flat topography, land subsidence, natural factors such as coastal location and high rainfall, and anthropogenic factors like land-based economic activities and poor city planning. The study employs a hydrological simulation method utilizing the ANSWERS model to understand the impact of land use/land cover, particularly deforestation, in upper watershed on downstream flooding. The research finds that while deforestation in the upper watershed does contribute to increased runoff, the main cause of flooding is changes in the central watershed, that is due to increased urbanization and poor city planning. The study highlights the importance of considering both natural and anthropogenic factors in understanding flooding patterns and suggests that addressing issues in the middle watershed area is crucial to mitigating Jakarta's flooding problem. This research provides valuable insights into watershed management strategies tailored to Jakarta's specific challenges.

Parsasyrat and Jamali (2015) studied the Zarrin-Shahr watershed in the Iranian province of Isfahan, which focuses on the consequence of land use / land cover changes, particularly rise in impermeable surfaces like roads and buildings. The effects of these alterations are examined using the Santa Barbara urban hydrography model within the Stormwater Management and Design Aid (SMADA) framework. Using Arc-GIS software, the researchers first created the appropriate maps of the area and gathered annual and 24-hour rainfall data. The findings of the study on Pol Kalleh and Lenj stations were studied, and the results indicate that changing green urban environments to residential areas significantly increases maximum floodwater discharge, particularly in low return periods.

Butt et al. (2015) conducted a study on land cover and land use changes observed in the Simly watershed, Pakistan, utilizing multispectral satellite data from Landsat 5 and SPOT 5 for the years 1992 and 2012, respectively. Analysis through ArcGIS 10 resulted in significant transitions from Vegetation and Water cover to Agriculture, Bare soil/rock, and Settlement's cover, with reductions of 38.2% and 74.3%, respectively. These alterations in land cover and use posed a serious threat to watershed resources. The achieved overall classification accuracies were 95.32% and 95.13%, meeting the standard criteria of over 90% accuracy (Lea & Curtis, 2010). The study concludes that land cover and land use practices in the study area have undergone significant changes, as evidenced by declines in Vegetation and Water classes (38.2% and 74.3%, respectively) and increases in areas covered by Settlements (80.1%), Agriculture (163.7%), and barren land (63.3%). The expansion of Settlements and Agriculture areas in the watershed resulted from mismanagement and inadequate land use planning, leading to adverse effects on water quality, accessibility, and depletion.

Boggs and Sun (2011) conducted a research study utilizing long-term monitoring data to quantify the annual water balance, stormflow characteristics, and seasonal flow patterns of an urbanized (UR) watershed covering 0.70 km2, and compared it with a fully forested (FOR) watershed covering 2.95 km2 in central North Carolina. The objective was to evaluate how historical urbanization impacted watershed hydrology and to provide valuable reference data for urban watershed planning. Results indicated that the mean annual discharge coefficient (discharge/precipitation) in the UR and FOR watersheds from 2000 to 2007 was 0.42 and 0.24, respectively. The UR exhibited approximately 75% more stormflow than the FOR, with a lower mean evapotranspiration (ET) rate of 58% compared to 77% in the FOR. Peak flow rates and stormflow volume in the UR were notably higher, such as 76.6 mm/day versus 5.8 mm/day for peak flow rate and 77.9 mm/day versus 7.1 mm/day for stormflow volume, compared to the FOR. The study concluded that intense urbanization led to elevated peak flow rates and annual discharge volumes in the watershed. Furthermore, the UR consistently demonstrated higher flow rates across various temporal scales, including annual total flow, peak flow, and stormflow and baseflow volumes, in comparison to the FOR. Therefore, the research emphasized that urbanization significantly alters watershed hydrology in the region.

Khatami and Khazaei (2014) explored the utility of Geographic Information Systems (GIS) in water resources management, particularly in hydrological modeling. They highlighted the necessity of integrating GIS with hydrological modeling and provided examples from case studies such as the Wadi Madoneh Basin in Jordan, Kuronagi River in Japan, and San Antonio River Basin in Central Texas, USA. The study emphasized the promising potential of GIS applications in hydrological modeling, as evidenced by the good agreement between results obtained from GIS models and observed data in cases like the Kuronagi River and Wadi Madoneh. GIS-based models offer benefits in various hydrological analyses, including terrain analysis using Digital Elevation Models (DEMs) to calculate slope and aspect, essential for watershed studies. Moreover, GIS allows for the integration of diverse geographic data layers to create new integrated information, facilitating the derivation of hydrological variables like evaporation from temperature and Relative Humidity (RH). GIS-based approaches also enable the production of efficient and easily understandable maps and figures through different generalizations and visualization methods, aiding in comprehensive hydrological analysis and planning.

Xu et al. (2019) investigated the influence of forestation on runoff within the Qingshui River Basin of Wutai Mountain, China. Their findings revealed that the ratio of evapotranspiration to precipitation peaked at an elevation of 1800 meters above sea level (m a.s.l.). Below this elevation, evapotranspiration was primarily influenced by precipitation, while above 1800 m a.s.l., it was governed by energy factors. The study ranked runoff coefficients for different vertical vegetation belts as follows: farmland > grassland > subalpine meadow > evergreen coniferous shrub forest > deciduous broad-leaved forest. Grassland was identified as the primary contributor to runoff, accounting for approximately 39.10% of the annual water yield in the QRB. Furthermore, the study noted that increasing forest cover could lead to elevated evapotranspiration and subsequent reduction in runoff, highlighting the complex relationship between vegetation types and hydrological processes.

Ping (2010) conducted an analysis to assess the impacts of sublayer and land-cover changes on flooding. In this paper, Fuping sub catchment, mainly mountainous area, was selected as a typical study area to make analysis. The trends of precipitation, flood peaks and volumes were analyzed by regression method.T he parameters in hydrological model were also calibrated before 1980 and after 1980,then we used the parameters after 1980 to simulate the floods before 1980,and quantified the effects of the LULC change on floods. Our conclusion suggests that while land cover change has a minor impact, accounting for less than 5%, on large floods, it exerts a more significant influence on floods with return periods ranging from 3 to 10 years, contributing to approximately 10% to 30% of their occurrence.

Baban and Yusof (2001) utilized remote sensing coupled with Geographic Information System (GIS) technology to map the distribution of land use/cover on Langkawi Island, Malaysia. Processing a Landsat Thematic Mapper (TM) satellite image from March 1995 through IDRISI, a raster-based GIS software, resulted in an overall accuracy enhancement to 92%, with a notable 9% increase in individual class accuracy for inland forest classification, reaching 90%. Their qualitative analysis highlighted topography as the primary determinant influencing the spatial arrangement of land use/cover types across the island. This study underscores the efficacy of remote sensing and GIS methodologies in providing valuable information regarding land use/cover distributions.

Nischitha (2019) conducted a study focusing on the application of remote sensing and GIS technology for land use land cover classification and change analysis in Thirthahalli over a span of two decades. The research utilized multitemporal Landsat satellite imagery from 1997 and 2017 to map land use land cover changes. Employing a Supervised classification method using the Maximum Likelihood technique, the study identified classes such as forest, agricultural plantations, agricultural croplands, wastelands, water bodies, and settlement areas. The findings underscored the effectiveness of remote sensing and GIS technology in analyzing land use land cover changes in Thirthahalli taluk, revealing significant alterations primarily in forest, agricultural plantations, and settlement areas.

Zech et al. (1994) introduced an innovative approach to rainfall-runoff modeling designed for watersheds that are partially urbanized. They developed a digital terrain model (DTM) that utilized GIS techniques to represent both the undeveloped and urbanized sections of the catchment. Each cell in the DTM grid was assigned a water budget, computing runoff and interflow amounts. Water volumes generated in each cell were then transported along the steepest slopes with a velocity dependent on the slope, until reaching the outlet and contributing to the resulting hydrograph. The model underwent testing in a partly urbanized catchment equipped with rain and flow measurement stations. Comparative analysis with other models, notably SWMM and WALLRUS, suggested that the proposed model exhibited high accuracy. Additionally, sensitivity analysis highlighted the tool's flexibility.

Yasmeen et al. (2017) conducted a flood analysis of the Tarbela sub-catchment utilizing remote sensing (RS) data and geographical information system (GIS) techniques. The study primarily focused on rainfall-runoff modeling to estimate surface runoff in the Tarbela catchment using the hydrologic simulation model HEC-HMS with HEC-GeoHMS. Various geospatial datasets, including drainage area, stream network, and slope, were generated using Arc Hydro extension of ArcGIS and ASTER DEM of 30m resolution. Soil type and land cover/use characteristics were considered influential factors in surface runoff, derived from LANDSAT satellite imagery. Curve numbers for Tarbela sub-catchments were developed based on soil maps and land cover/use data. In-situ weather data and ERA-Interim dataset were utilized for gauged and un-gauged areas of the catchment, respectively, while historical climatic data from 1900-2014 was obtained from the Climate Research Unit (CRU). The NRCS runoff curve number method was employed to estimate precipitation excess and generate flood hydrographs. The HEC-HMS simulation model output was validated against discharge data at the catchment outlet, demonstrating the effectiveness of geospatial techniques, such as remote sensing and GIS, in flood modeling and prediction for the Tarbela sub-catchment, facilitating flood control measures.

The Swat Watershed, situated in Pakistan, has experienced a history of devastating floods, notably in 1992, 2005, 2010, and most recently in 2022. These recurring flood events have left a lasting impact, affecting not only the immediate communities but also the wider region. Among the numerous factors exacerbating flood risk in this watershed, a notable concern is the transformation of natural, vegetated land into urban and residential areas. This shift in land use reduces the land's capacity to absorb rainfall and accelerates surface water flow, amplifying the vulnerability to flooding.

In response to these pressing challenges, this research paper undertakes a comprehensive exploration of the intricate relationship between LULC changes, particularly the conversion of natural land to urban development, and the escalating flood risk within the Swat Watershed. Our goal is to unveil the underlying causes and consequences of flood occurrences in the region. Additionally, we aim to provide valuable insights and recommendations for more effective flood management, land use planning, and mitigation strategies. Ultimately, our research strives to mitigate the devastating impact of floods on this vulnerable region and on flood-prone areas worldwide.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

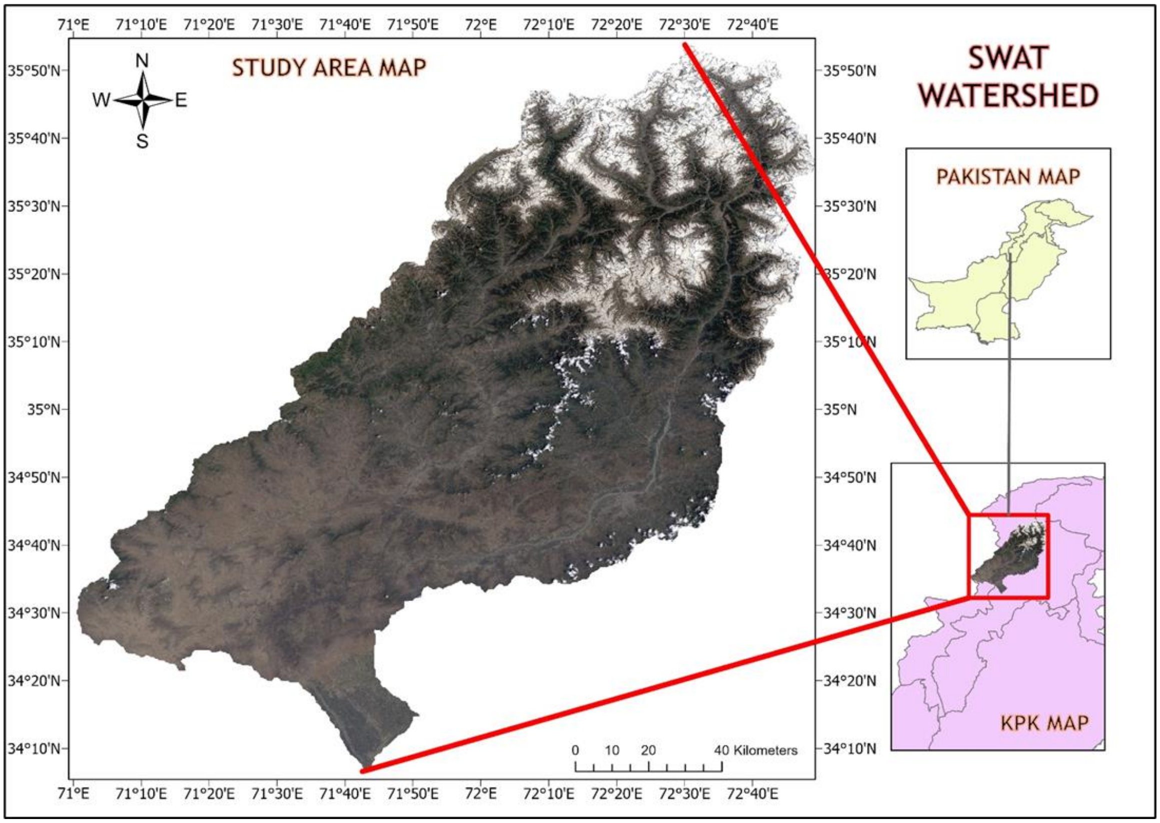

Figure 1: Location map of the Swat Watershed

This study is conducted in the Swat Basin of Khyber Pakhtunkhwa (KPK), situated within a latitude and longitude range of 34° 10′ 00″ North to 35° 50′ 00″ North latitudes and 71° 00′ 00″ to 72° 40′ 00″ East Longitude. Geographically, it falls within the Hindu Kush Himalayan range, covering a total area of 5,687 sq miles. The region's topography varies, with snow-covered mountains in the north and plains with farmland along the riverbank in the south. Swat has an average elevation of 990 m (3,230 ft), results in a climate that is cooler and wetter in comparison to other regions of Pakistan. Northern regions receive precipitation influenced by winter precipitation originating from the Mediterranean Sea, often in the form of snow. Conversely, southern areas experience summer monsoon rainfall. Winter temperatures are low, facilitating snow and glacier accumulation, while high summer temperatures trigger snow and glacier melt.

Originating from the Hindu Kush Mountains, the Swat River flows southward through varied terrain, merging with the Ushu and Gabral rivers at Kalam before continuing its journey through the Swat District. It eventually joins the Panjkora River in District Dir Lower and converges with the River Kabul at Nisatta in District Charsadda. The river's channel features steep sections in the north and gentler stretches in the south, leading to flash floods upstream and river floods downstream. Despite these challenges, the Swat River sustains diverse wildlife, serves as a vital irrigation source, and supports hydroelectric power generation through existing plants like Jabban, Dargai, and Daral khwar, with additional projects proposed for further development. However, the region is vulnerable to significant flood risks, especially during the monsoon season from June to September, attributed to factors such as climate change, complex terrain, and human interventions.

In response to these pressing challenges, this research paper undertakes a comprehensive exploration of the intricate relationship between LULC changes, particularly the conversion of natural land to urban development, and the escalating flood risk within the Swat Watershed. Our goal is to unveil the underlying causes and consequences of flood occurrences in the region. Additionally, we aim to provide valuable insights and recommendations for more effective flood management, land use planning, and mitigation strategies. Ultimately, our research strives to mitigate the devastating impact of floods on this vulnerable region and on flood-prone areas worldwide.

To better understand different land cover on the Swat watershed, we have selected 4 sub-watersheds for detailed analysis. These sub-watersheds encompass diverse characteristics and are integral parts of the larger Swat Basin, namely:

1. Batkhela Sub-watershed
2. Chakdara Sub-watershed
3. Swat City Sub-watershed
4. Saidu Sharif Sub-watershed

These sub-watersheds have been strategically chosen to represent various land use patterns, human settlements, and environmental conditions within the Swat Basin. This selection aims to provide a comprehensive understanding of how different land covers influence the hydrological dynamics and vulnerability to floods in these specific areas.

Table 1: Sub-Watersheds: Coordinates and Area

Sr	**Sub-Watershed**	**Latitude**	**Longitude**	**Area (km^2)**
1.	Batkhela	34°33' to 34°38'30" North	71°51’ to 72°8' East	182.97
2.	Chakdara	34°38'30" to 34°48'15" North	71°56' to 72°6'30" East	163.79
3.	Swat City	34°38'15" to 34°46'45" North	72°30' to 72°16'30" East	194.70
4.	Saidu Sharif	34°47'30"to 34°54'15" North	72°19' to 72°24' East	67.84

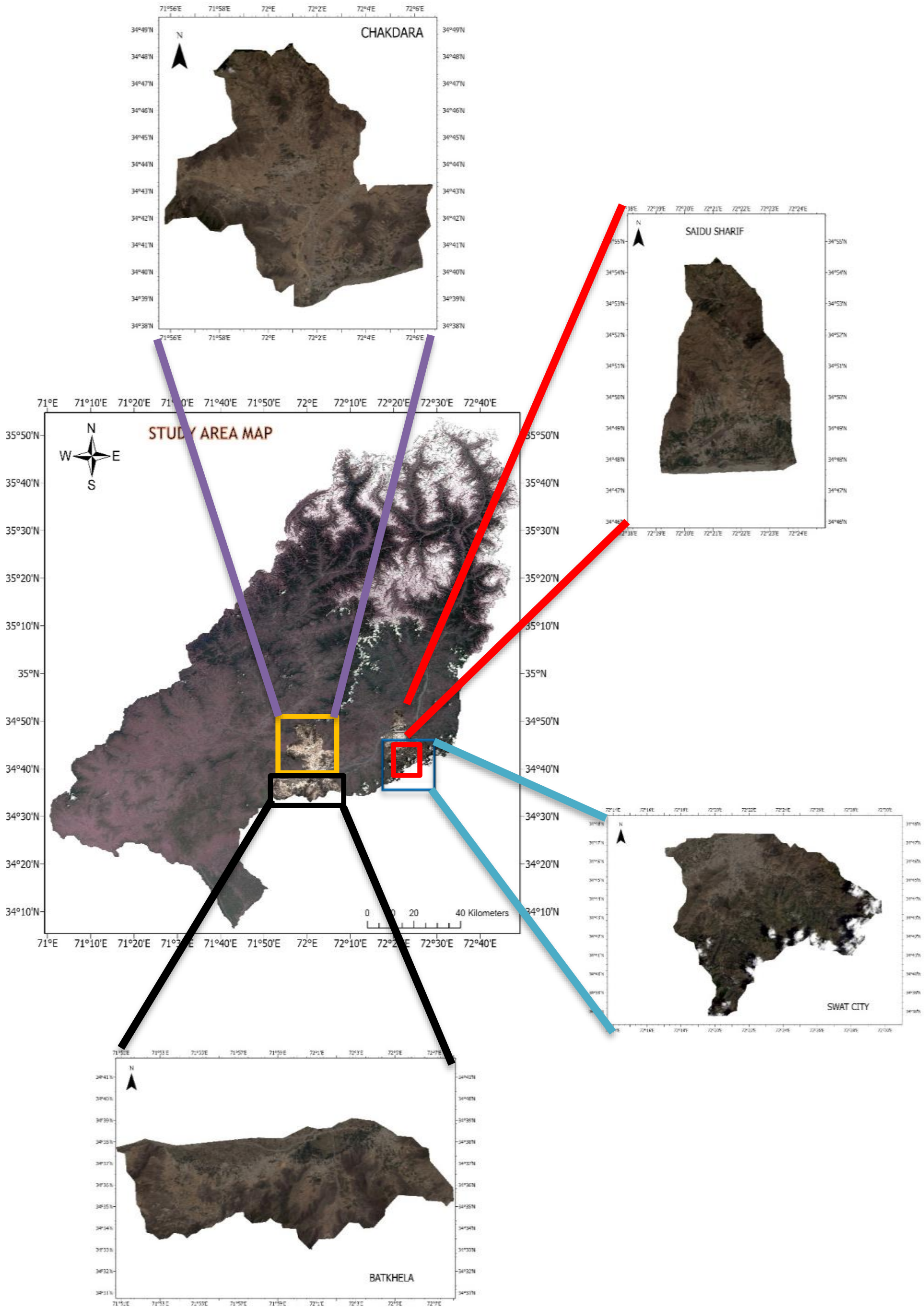

Figure 2: Location map of the sub-watershed in Clockwise

3.2 Data Sets

Table 2: Data and their sources

Sr	Type of data	Source of extracted data	Extracted data
1.	DEM	https://www.usgs.gov/core-science-systems/national-geospatial-program/national-map	Swat Watershed Boundary
2.	Landsat 4,5 Imagery	https://earthexplorer.usgs.gov	Satellite images of Swat watershed for LULC for **year 1991** and **2001**
3.	Landsat8 Imagery	https://earthexplorer.usgs.gov	Satellite images of Swat watershed for LULC for **year 2011** and **2022**
5.	Precipitation data	https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5	Rainfall data for 1950 – 2023, Spatial Resolution: **25km**
7.	Temperature data	https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5	Rainfall data for 1950 – 2023, Spatial Resolution: **25km**
8.	Discharge data	https://www.wapda.gov.pk/	Daily discharge value from **Chakdara gauging station**

To examine how LULC impact discharge values, we gathered data from various sources, as indicated in the table above. To define the boundary of the Swat watershed, we used DEM data from the USGS website (https://www.usgs.gov/core-science-systems/national-geospatial-program/national-map).

For our LULC analysis, we accessed multi-temporal data spanning from 1990 to 2023 from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/). These datasets included Landsat imagery with a 30-meter resolution. Specifically, we used Landsat 4 and 5 satellite imagery for the years 1991 and 2001 and Landsat 8 satellite imagery for the years 2011 and 2022 to input LULC information.

We collected precipitation and temperature data from satellite sources available at ERA5-Land (https://www.ecmwf.int/en/era5-land). While, Discharge data was obtained from the Chakdara gauging station, managed by the Water and Power Development Authority of Pakistan (https://www.wapda.gov.pk/).

By integrating and analyzing these diverse data sources, we were able to calculate discharge values and conduct our research effectively. LULC modifications, particularly the transformation of vegetated land into built-up areas, are widely acknowledged for their significant impact on surface runoff coefficients, consequently exacerbating the risk of flooding. However, there exists a scarcity of research focused on comprehending the effects of LULC alterations on surface runoff specifically within the Swat River Watershed. This knowledge gap poses challenges in the formulation of effective flood mitigation strategies for the region.

3.3 Methodology: Flow Chart And Explanation

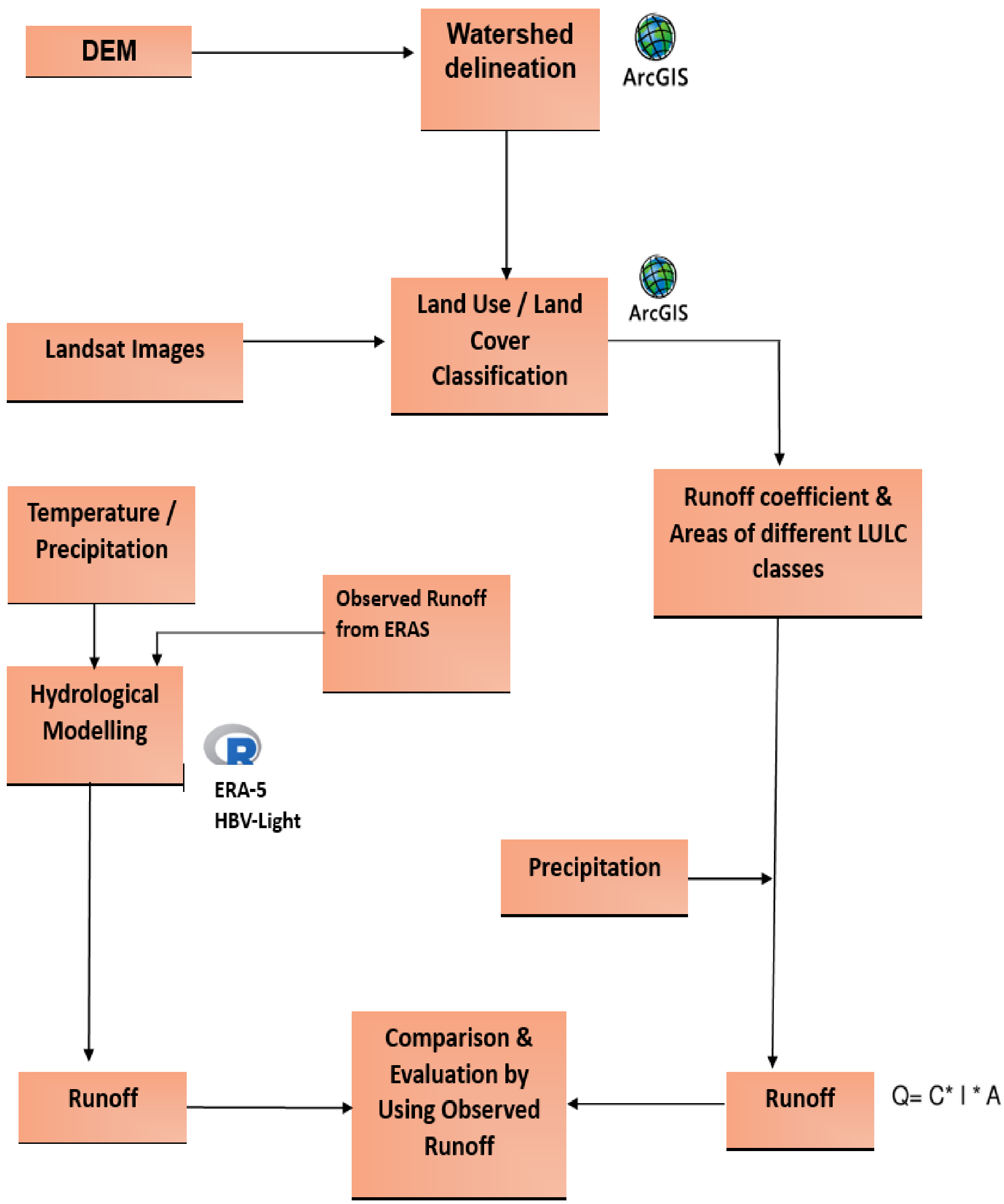

Figure 3: Steps adopted for the calculation of discharge

3.3.1 Acquisition of DEM Data and delineation of watershed

DEM data was acquired from the USGS National Map and it was used for the Swat watershed delineation. The data represents elevation information for the Earth's surface in a gridded format. Each grid cell (pixel) contains a numerical value representing the elevation above sea level. This data is typically stored in meters or feet. The data set chosen was 1/3 arc-second NED (National Elevation Dataset). This dataset has approximately 10-meter resolution. This implies that each pixel within the grid corresponds to a specific elevation measurement, representing a 10-meter by 10-meter area on the Earth's surface. The dataset was then imported in ArcGIS Pro in a form of .tif file. The steps that were followed in ArcGIS Pro is as follows:

a. Filling the DEM
b. Generating Flow Direction from filled DEM:
    1) Using the DEM data, we create a flow direction grid. This grid shows the direction of water flow at each pixel. The elevation raster data was converted to **flow direction grid**.
    2) Based on the flow direction, we created the **flow accumulation.**
    3) Then, we created manually the various **outlet points** of all sub watershed in form of shape file to delineated the Swat watershed .
    4) Using the flow direction and outlet point data set as input, we **delineate** the **watershed**.

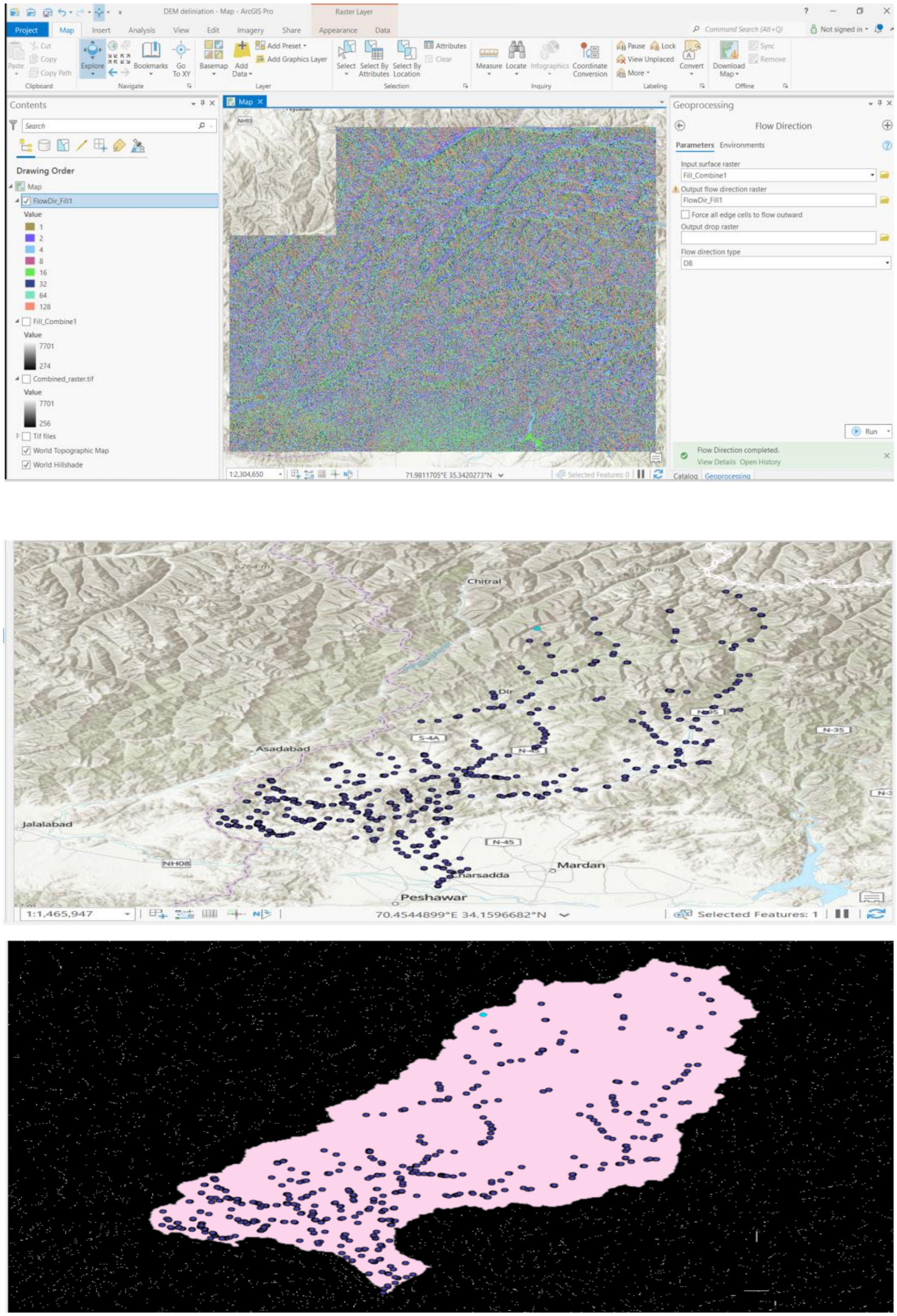

Figure 4: Process of Watershed Delineation

3.3.2 Supervised Classification

We performed the supervised classification of the 4 sub-watershed, that is Batkhela, Chakdara, Swat City and Saidu Sharif. For each sub-watersheds we utilized satellite imagery from two Landsat satellites: Landsat 4-5 Thematic Mapper (TM) and Landsat 8-9 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) to assess LULC changes in our selected study area. For temporal consistency. We focused on imagery captured during June, July, and August.

A total of four specific years (1991, 2001, 2011, 2022) were selected for the analysis of LULC of each of 4 sub-watersheds, enabling a comprehensive assessment of LULC changes over the specified timeframe.

After acquisition of satellite data, we perform Supervised Classification on each of above mentioned years. In this method we categorize pixels in satellite imagery into distinct classes or clusters by training samples manually in order to understand patterns and features within an satellite image. Below are the steps to perform supervised classification:

a. We will import all the bands of satellite images for a particular year. The number of bands will depend upon the type of Landsat satellite.
b. Then, we perform Band Composite to have a single image and assign it natural color
c. Then we pansharpened the raster image using the high resolution panchromatic band as input (usually band 8 in Landsat).

d. We performed Mosaic to New Raster, to merge satellite images and then we will clip the study area with Satellite Image

e. Now, we will perform Supervised Classification, accessing it through classification wizard and choosing supervised classification. Then, we train the sample manually selecting pixels so that it represents a particular class. We followed the classification schema known as NLCD2011, and choose 5 classes; **1) Barren 2) Deciduous Forest 3) Developed 4) Evergreen Forest & 5) Water**

f. So based on the class information, we calculate the **area** occupied for each class and took the **runoff coefficient** from table 3:

Table 3: LULC descriptions and surface runoff coefficient

Sr.	LULC Type	Description	Runoff coefficient
1.	Barren	It consist of the dry, barren land	**0.5**
2.	Deciduous forest	It consists of deciduous forests, garden plants and crop fields	**0.4**
3.	Developed	It encompasses various land uses such as residential, commercial, industrial zones, villages, settlements, and transportation infrastructure.	**0.8**
4.	Evergreen forest	It encompasses natural forests untouched by human exploitation or disturbance.	**0.01**
5.	Water	It includes all bodies of water such as rivers, reservoirs, ponds, and other aquatic sources.	**0.05**

3.3.3 Calculation of Estimated Runoff through Rational formula

After getting the classified image. We can conduct area calculations to quantify the extent of each class within the study area. The “C” value is taken from the table 3. Whereas, the rainfall intensity value was acquired from ERA5-Land data.

So, after entering all the parameters of the rational formula we calculated the runoff for each sub-watershed, covering years of 1991, 2001, 2011 and 2022.

$$Q = C * I * A \qquad (1)$$

$$C = \frac{\sum A1*C1+A2*C2+A3*C3+\cdots+An*Cn}{\sum A1+A2+A3+\cdots+An} \qquad (2)$$

Where:

a. Q is the peak flow in cubic meters per second.
b. C is the surface runoff coefficient (weighted).
c. I is the average rainfall intensity in meters per hour.
d. A is the watershed area in square kilometers.

3.3.4 HBV lite model

The Hydrologiska Byråns Vattenavdelning (HBV) model, developed by the Swedish Meteorological and Hydrological Institute (SMHI) in the 1970s, originally aimed to support hydropower operations. It was chosen for its simplicity in data requirements and parameterization compared to other models, making it practical and efficient. Operating on a daily time scale, the HBV model utilizes daily precipitation and potential evapotranspiration (PET) inputs to simulate discharge. It encompasses three primary hydrological processes: snow and snow cover, soil moisture and evaporation, and groundwater dynamics. However, for the selected months (June, July, August, and

September), which lack snow, the snow routine component of the HBV model was excluded from this analysis. Details regarding the calibration and validation time periods are provided below.

Table 4: Time period defined for Calibration and Validation

Process	Years	Months
Total (1950-2022)	73	876
Calibration (1950-2000)	51	612
Validation (2001 – 2022)	22	264

3.3.5 Gap optimization for defining parameters

The Gap optimization process was employed to establish the model parameters. The process begins by defining the acceptable ranges for each parameter of the model. These ranges, then, determine the boundaries within which the optimization algorithm will search for the best parameter values, and give the best efficiency. The model was run using GAP optimization for all four sub-watersheds, each with its unique parameter set.

Table 5: Parameters used for GAP Optimization

Main Hydrological Process	Parameters	Definition	Units
Soil and evaporative routine	FC	Maximum value of soil moisture storage	mm
	LP	Fraction of FC above which actual ET equals potential ET	-
	β	Shape parameter for the soil moisture distribution function	-
	K_0	Near surface flow routing rate constant	Day^{-1}
	K_1	Interflow routing rate constant	Day^{-1}
Groundwater and response routine	K_2	Baseflow routing rate constant	Day^{-1}
	UZL	Threshold for surface flow	mm
	PERC	Maximum rate of recharge between the upper and lower groundwater boxes	mm. Day^{-1}
Routing routine	MAXBAS	Length of triangular weighting function in routing routine	day

Table 6: Maximum & Minimum Value for each parameter determined for every subwatershed.

Sub-Watersheds	Parameters	Minimum Range	Maximum Range
Batkhela	FC	50	1000
	LP	0	1
	β	0.1	10
	K_0	0.1	0.9
	K_1	0.01	0.3
	K_2	0.001	0.1
	UZL	0	1000
	PERC	0	100
	MAXBAS	1	3
	Parameters	**Minimum Range**	**Maximum Range**
Chakdara	FC	250	700
	LP	0	1
	β	1	8
	K_0	0.1	0.7
	K_1	0.01	0.8
	K_2	0.001	0.1
	UZL	0	500
	PERC	0	300
	MAXBAS	1	2.5
	Parameters	**Minimum Range**	**Maximum Range**
Saidu Sharif	FC	50	900
	LP	0	1
	β	0.1	10
	K_0	0.1	0.9
	K_1	0.01	0.5
	K_2	0.001	0.1
	UZL	0	500
	PERC	0	100
	MAXBAS	1	3
	Parameters	**Minimum Range**	**Maximum Range**
Swat City	FC	200	900
	LP	0.01	1
	β	1	5
	K_0	0.1	0.9
	K_1	0.01	0.4
	K_2	0.001	0.1
	UZL	0	100
	PERC	0	30
	MAXBAS	1	1

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Analysis of Estimated Runoff through LULC

The LULC analysis was conducted for four distinctive sub-watersheds, namely Batkhela, Chakdara, Swat City, and Saidu Sharif. The main objective of this segment was to examine and interpret the changes in LULC patterns across these areas over a four-year period encompassing 1991, 2001, 2011, and 2022, in order to estimate runoff.

The LULC classification was executed, dividing the area into five primary classes: Barren, Deciduous Forest, Developed, Evergreen Forest, and Water. Sequential imagery was utilized to illustrate the transformation in LULC patterns over the mentioned years. The visual representation depicted substantial alterations, highlighting the dynamic nature of the landscape.

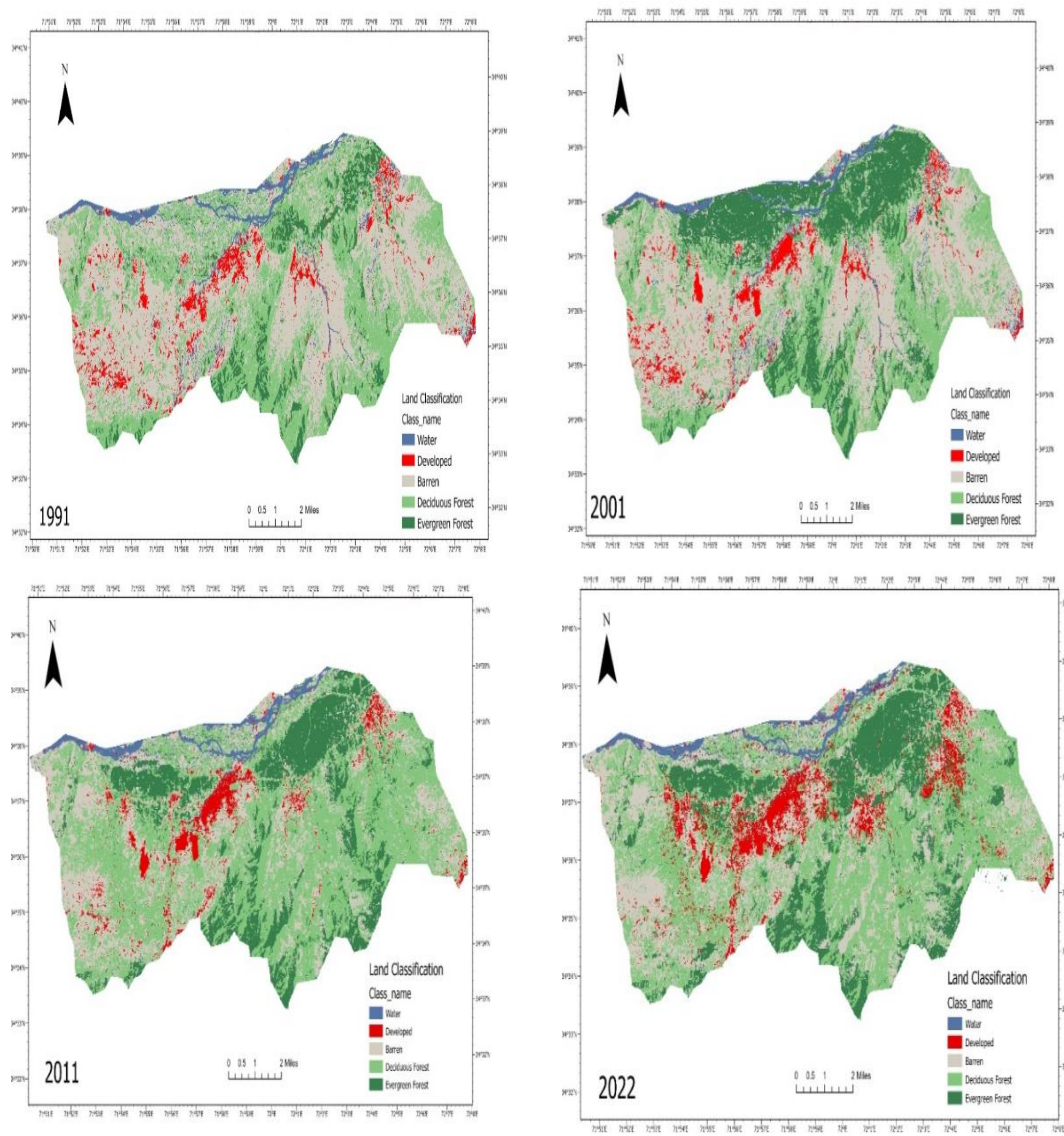

Figure 5: The LULC for years 1991, 2001, 2011, and 2022 for general area Batkhela

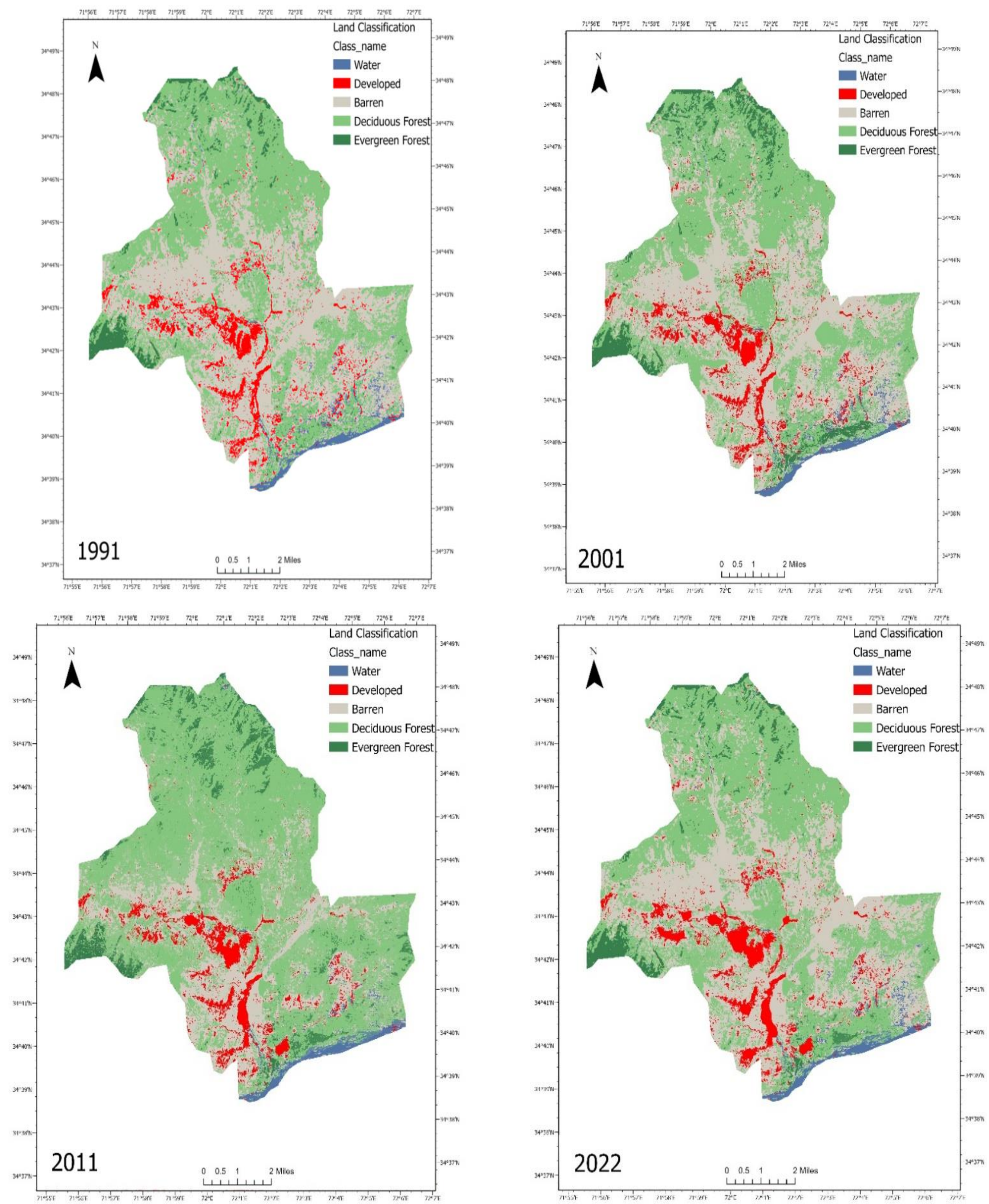

Figure 6: The LULC for years 1991, 2001, 2011, and 2022 for general area Chakdara

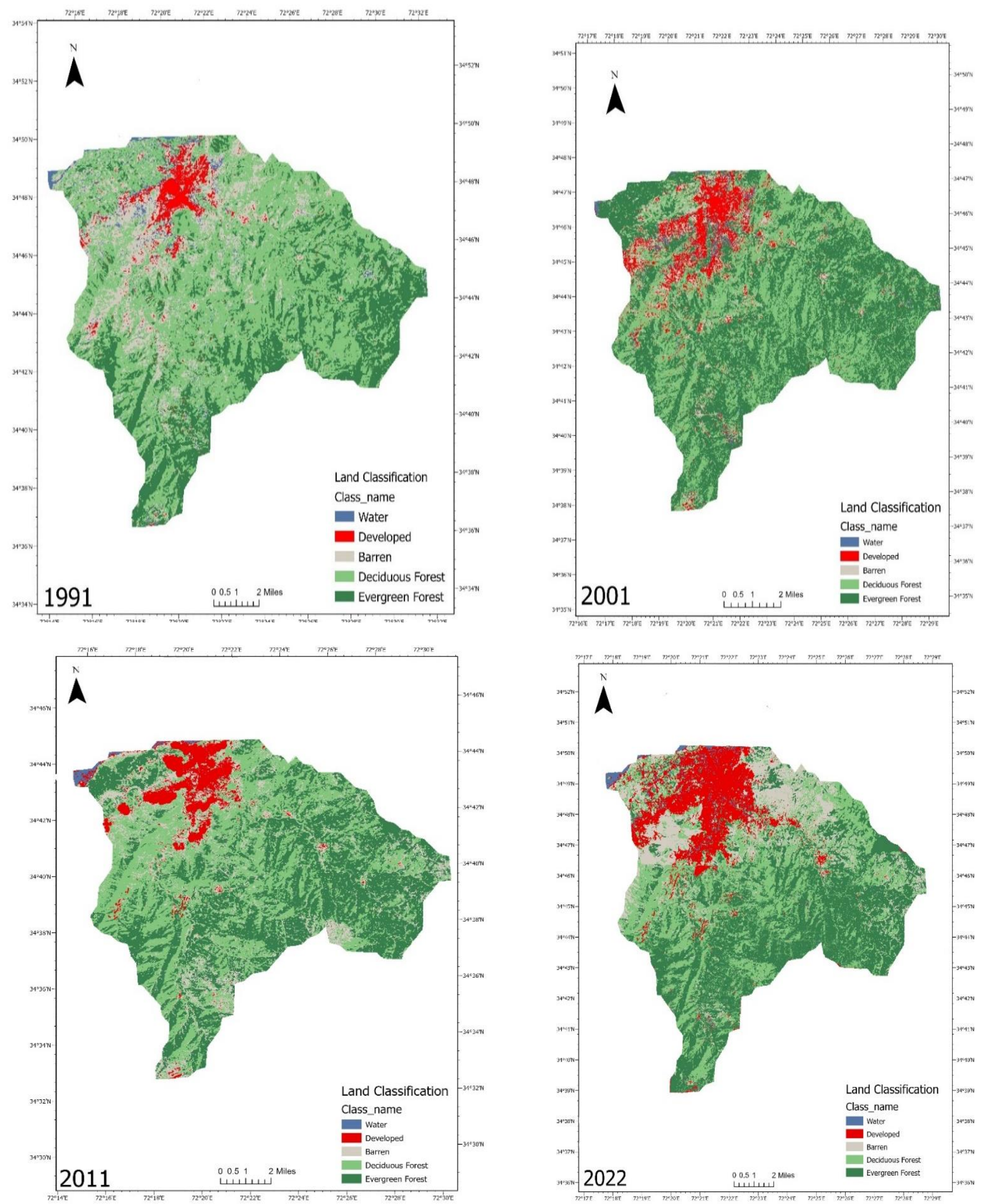

Figure 7: The LULC for years 1991, 2001, 2011, and 2022 for general area Swat City.

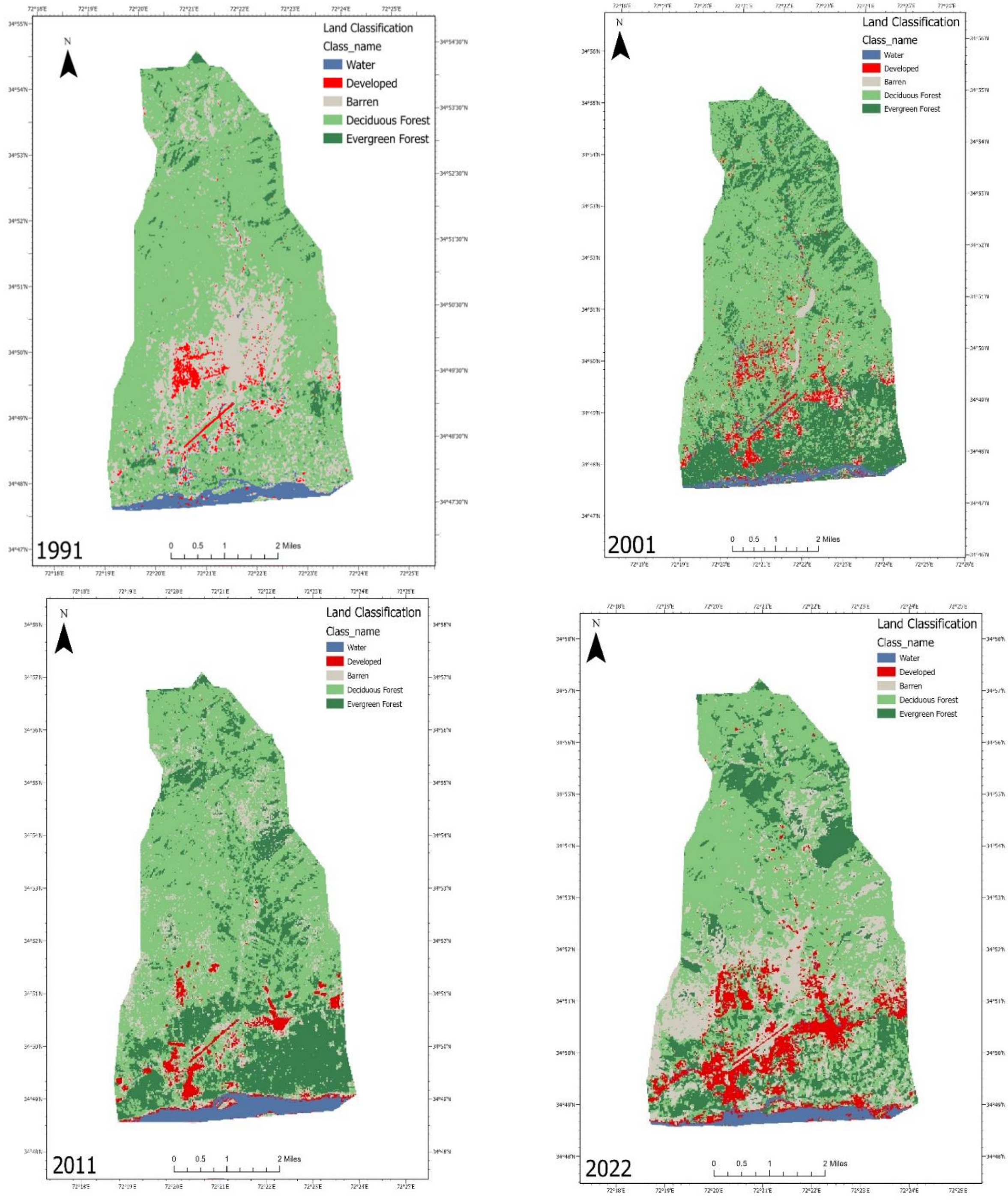

Figure 8: The LULC for years 1991, 2001, 2011, and 2022 for general area Saidu Sharif

4.1.1. Quantitative Analysis: Graphical Representations and Tables

Graphical representations were employed to visually present the changes in different LULC classes for each sub-watershed. The graphs illustrated an intriguing trend, notably showcasing a consistent increase in the Developed area over the years across all sub-watersheds. This trend was further substantiated by the tabulated data indicating the shift in square kilometers (km²) for each specific LULC class.

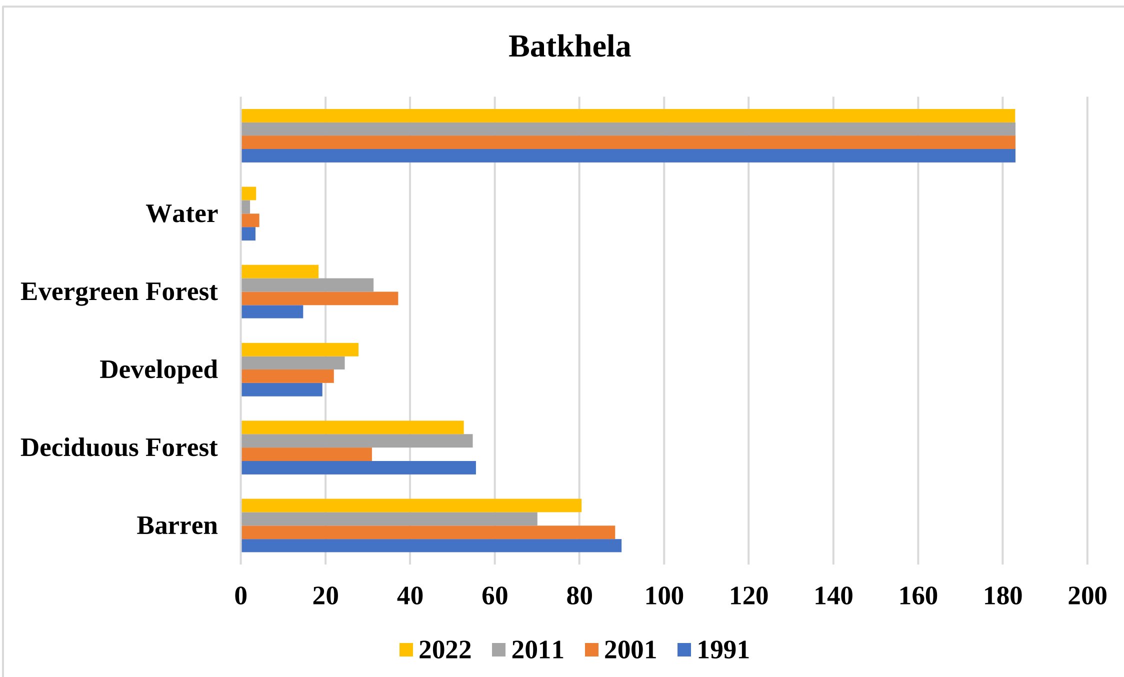

Figure 9: The graphical comparison of LULC changes for years 1991, 2001, 2011, and 2022 for general area Batkhela.

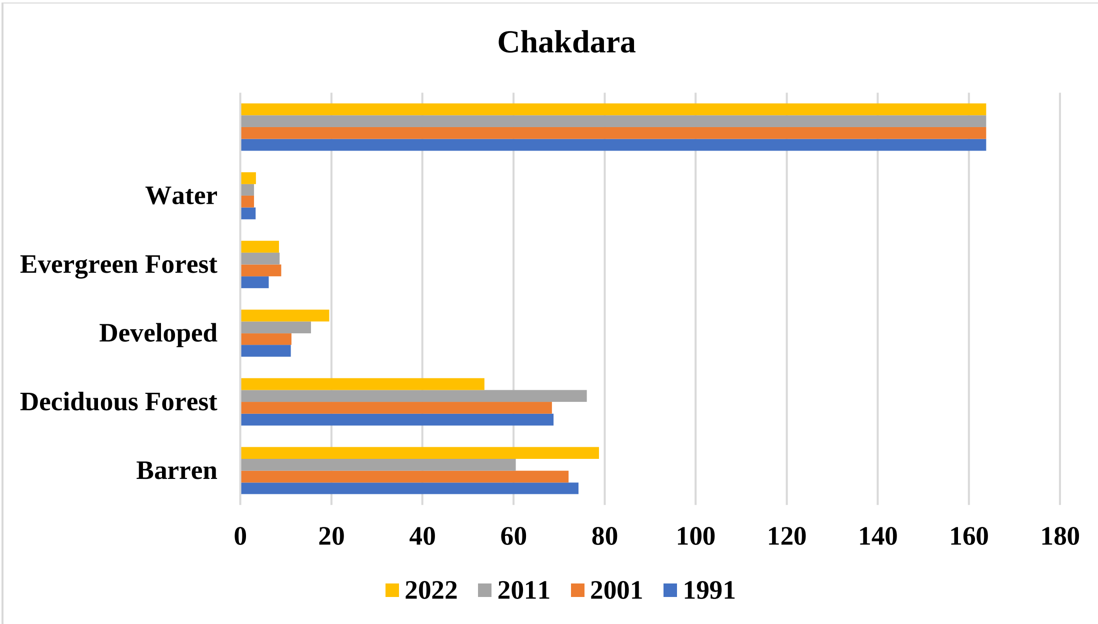

Figure 10: The graphical comparison of LULC changes for years 1991, 2001, 2011, and 2022 for general area Chakdara

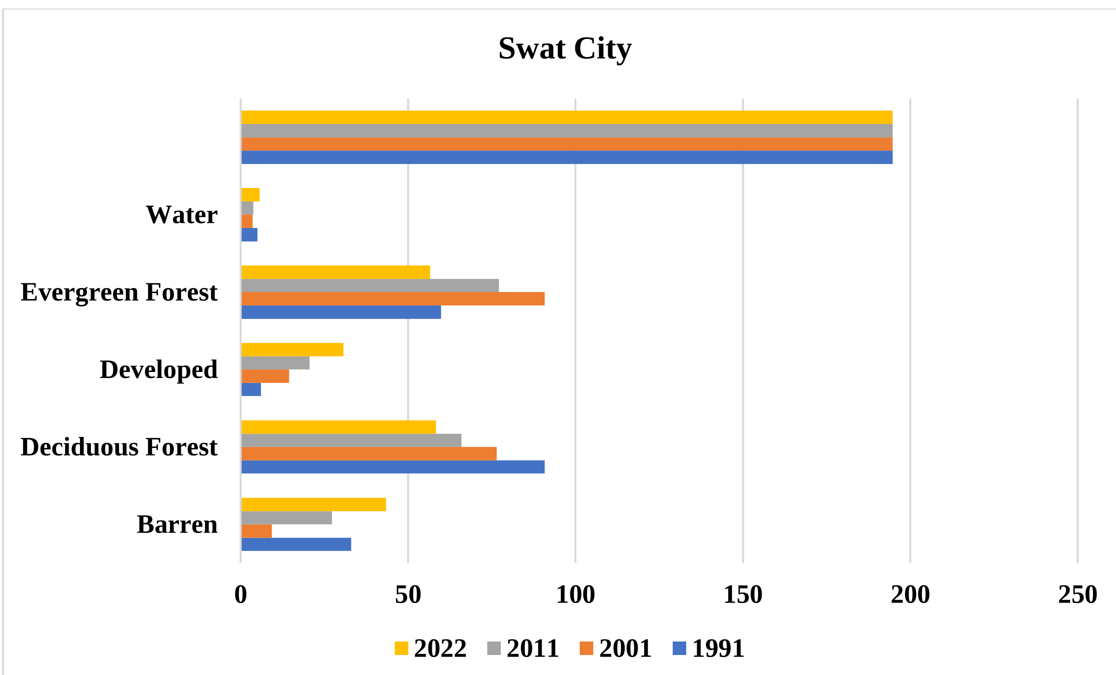

Figure 11: The graphical comparison of LULC changes for years 1991, 2001, 2011, and 2022 for general area Swat City

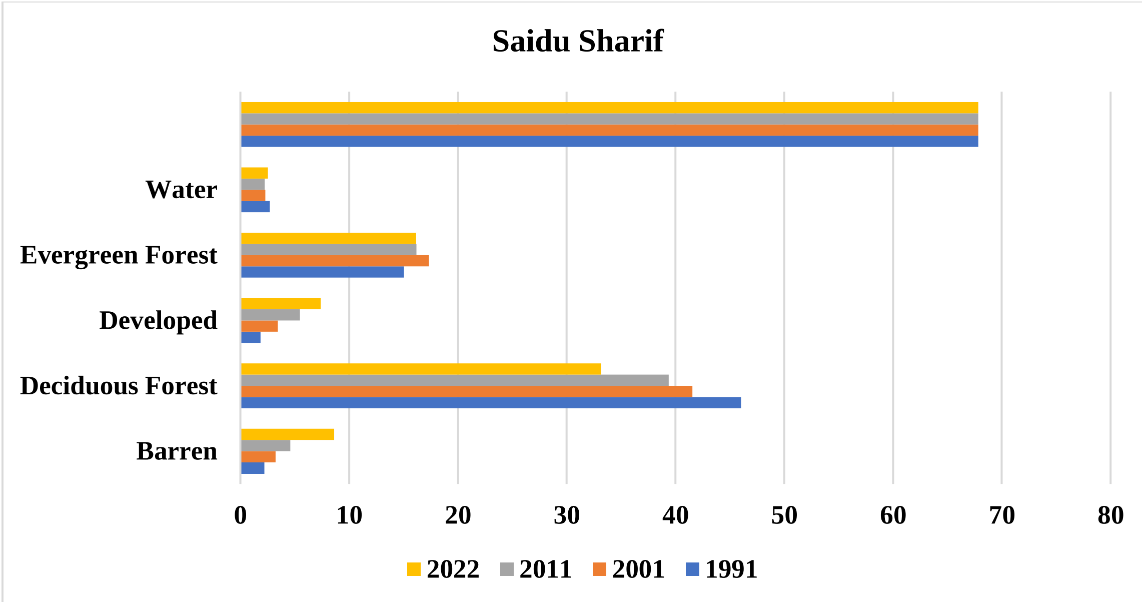

Figure 12: The graphical comparison of LULC changes for years 1991, 2001, 2011, and 2022 for general area Saidu Sharif

Table 7: LULC changes for Batkhela

Name	1991	2001	2011	2022
Barren	89.96279	88.44147	70.09432	80.511
Deciduous Forest	55.53336	30.99056	54.79268	52.69
Developed	19.25405	22.01125	24.52859	27.8131
Evergreen Forest	14.746126	37.15524	31.40209	18.3371
Water	3.477	4.3800	2.1613	3.6195
	182.97	182.97	182.97	182.97

Table 8: LULC changes for Chakdara

Name	1991	2001	2011	2022
Barren	74.27722	72.1093	60.512823	78.75464
Deciduous Forest	68.81619	68.42159	76.1109	53.6251672
Developed	11.09564	12.24169	15.52146	19.5093482
Evergreen Forest	6.215338	9.018543	8.632163	8.01590691
Water	3.392546	3.006754	3.015109	3.43928303
	163.79	163.79	163.79	163.79

Table 9: LULC changes for Swat City

Name	1991	2001	2011	2022
Barren	32.96736	9.352269	27.29185	43.417878
Deciduous Forest	90.7727	76.446	65.92463	58.27135
Developed	6.066085	14.49222	20.62277	30.684035
Evergreen Forest	59.84594	90.80761	77.13405	56.626657
Water	5.049976	3.60647	3.730842	5.705007
	194.70	194.70	194.70	194.70

Table 10: LULC changes for Saidu Sharif

Name	1991	2001	2011	2022
Barren	2.196404	3.244183	4.593273	8.628898
Deciduous Forest	46.04186	41.54142	39.369756	33.159232
Developed	1.847902	3.440651	5.478504	7.379517
Evergreen Forest	15.0465	17.33172	16.184471	16.165244
Water	2.716917	2.288084	2.222576	2.516959
	67.84	67.84	67.84	67.84

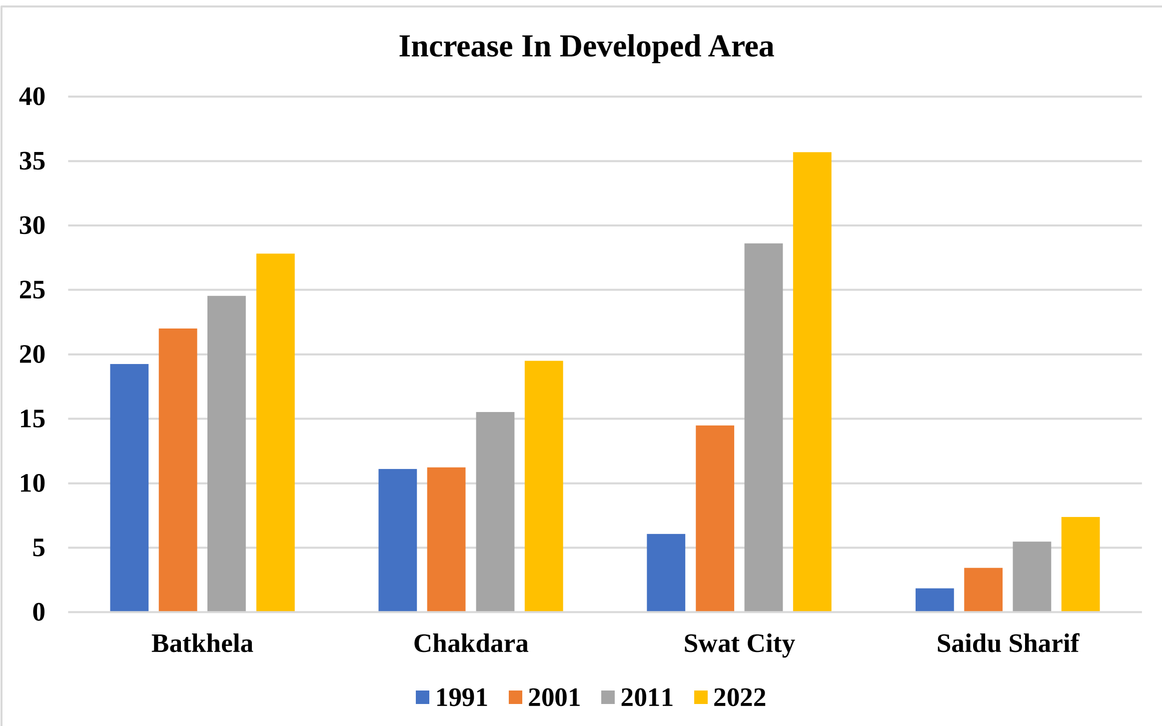

Figure 13: Graphical Representation of Increase in Developed Area

Table 11: Summary of Changes In Developed Area

Name	1991	2001	2011	2022
Batkhela	19.25405	22.01125	24.52859	27.8131736
Chakdara	11.09564	11.24169	15.52146	19.5093482
Swat City	6.066085	14.49222	28.62277	35.684035
Saidu Sharif	1.847902	3.440651	5.478504	7.379517

4.1.2. Discussion of Finding

The findings revealed a discernible shift in the landscape composition, particularly witnessing an upward trajectory in the Developed class. This suggests potential urbanization or infrastructural expansion within these regions. The observed increase in Developed areas was accompanied by fluctuations in other classes, emphasizing the dynamism in environmental conditions.

4.1.3. Estimation of Runoff

We utilized the Rational formula, incorporating precipitation data sourced from ERA5, alongside various land cover areas and coefficients of discharge, to compute the discharge values for each sub-watershed. These calculations were performed specifically for the months of June, July, August, and September, enabling us to derive the estimated discharge for each sub-watershed during these periods.

Table 12: Estimated Discharge calculated for each sub watershed for the months of June, July, August, September along with years 1991, 2001, 2011 & 2022

	Batkhela	Chakdara	Saidu Sharif	Swat City
Jun-91	7.68	6.57	28.23	31.45
Jul-91	5.47	15.52	48.97	33.22
Aug-91	16.38	32.40	62.59	35.76
Sep-91	20.42	38.51	26.22	30.14
Jun-01	11.98	11.55	17.01	11.72
Jul-01	5.32	10.16	17.28	25.28
Aug-01	7.92	15.46	11.99	26.78
Sep-01	7.32	15.08	11.96	10.93
Jun-11	10.81	13.75	16.53	10.78
Jul-11	14.62	12.95	18.71	22.31
Aug-11	14.82	9.77	17.85	22.42
Sep-11	9.17	8.69	11.74	16.73
Jun-22	19.89	9.77	10.21	18.62
Jul-22	22.91	19.95	22.65	15.56
Aug-22	11.56	16.55	22.61	15.91
Sep-22	8.42	13.19	18.49	24.15
Total	**194.69**	**249.863**	**363.04**	**351.754**

4.2 Statistical Analysis

4.2.1. Calculation of modelled discharge through HBV lite

By defining the parameters though Gap Optimization and specifying the calibration and validation period, we calculated the observed and modelled discharge values, which is then compared with estimated discharge values.

Table 13: Calculated Discharge for Batkhela & Chakdara

Batkhela	Q-est	Qobs	Qmod	Chakdara	Qest	Qobs	Qmod
Jun-91	7.68	4.51	6.63	**Jun-91**	6.57	5.46	1.28
Jul-91	5.47	6.28	22.13	**Jul-91**	15.52	20.23	12.49
Aug-91	16.38	19.24	18.67	**Aug-91**	32.40	29.63	35.49
Sep-91	20.42	23.28	10.43	**Sep-91**	38.51	35.12	39.10
Jun-01	11.98	8.86	7.79	**Jun-01**	11.55	16.02	13.81
Jul-01	5.32	7.51	6.42	**Jul-01**	10.16	12.59	16.95
Aug-01	7.92	10.93	5.18	**Aug-01**	15.46	18.25	20.98
Sep-01	7.32	11.84	6.03	**Sep-01**	15.08	18.75	13.10
Jun-11	10.81	8.26	7.96	**Jun-11**	13.75	15.16	11.43
Jul-11	14.62	16.55	15.85	**Jul-11**	12.95	17.23	13.77
Aug-11	14.82	12.12	10.76	**Aug-11**	9.77	14.23	16.82
Sep-11	9.17	6.31	5.87	**Sep-11**	8.69	11.74	7.10
Jun-22	19.89	15.17	20.34	**Jun-22**	9.77	11.45	7.78
Jul-22	22.91	25.15	26.21	**Jul-22**	19.95	24.03	18.67
Aug-22	11.56	14.34	12.67	**Aug-22**	16.55	20.14	26.36
Sep-22	8.42	5.52	5.72	**Sep-22**	13.19	15.72	8.23

Table 14: Calculated discharge for Saidu Sharif & Swat City

Saidu Sharif	Qest	Qobs	Qmod	Swat City	Qest	Qobs	Qmod
Jun-91	28.23	26.04	25.35	**Jun-91**	31.45	29.17	35.60
Jul-91	48.97	51.24	44.62	**Jul-91**	33.22	38.51	41.27
Aug-91	62.59	60.03	55.03	**Aug-91**	35.76	38.18	34.79
Sep-91	26.22	23.79	21.70	**Sep-91**	30.14	27.53	29.76
Jun-01	17.01	14.86	14.22	**Jun-01**	11.72	14.32	16.94
Jul-01	17.28	14.87	19.39	**Jul-01**	25.28	22.31	25.18
Aug-01	11.99	14.71	16.31	**Aug-01**	26.78	24.30	21.49
Sep-01	11.96	14.56	15.36	**Sep-01**	10.93	14.28	10.51
Jun-11	16.53	14.94	10.87	**Jun-11**	10.78	14.38	12.93
Jul-11	18.71	15.38	10.65	**Jul-11**	22.31	19.34	16.45
Aug-11	17.85	15.37	19.57	**Aug-11**	22.42	17.32	12.27
Sep-11	11.74	9.21	16.38	**Sep-11**	16.73	20.31	20.97
Jun-22	10.21	12.68	13.36	**Jun-22**	18.62	14.36	10.46
Jul-22	22.65	24.44	22.89	**Jul-22**	15.56	19.34	18.86
Aug-22	22.61	25.47	30.77	**Aug-22**	15.91	23.33	21.44
Sep-22	18.49	15.47	12.03	**Sep-22**	24.15	14.32	12.68

4.2.2. Comparison of estimated discharge with observed and modelled discharge

For comparison among the estimated, observed, and modeled discharge, we conduct specific statistical analyses. These assessments gauge the model's performance by comparing it with the estimated discharge, calculated using LULC data. This approach provides a more quantitative assessment of the model's accuracy in predicting discharge and its proximity to real data.

Using the discharge data, we applied following statistical tools which are as follows:

1. Mean and Standard deviation
2. Nash-Sutcliffe efficiency (NSE)
3. Correlation between estimated, observed and modelled discharge
4. Root Mean Square Error (RMSE)

For calculation of NSE and RMSE, the modelled and observed discharge is compared with estimated discharge calculated using LULC.

Table 15: Calculation of Mean, SD, RMSE & NSE for each sub water shed

Statistical Tool	Discharge	Batkhela	Chakdara	Saidu Sharif	Swat City
Mean (cusecs)	Q_{est}	12.17	15.62	22.69	21.98
	Q_{obs}	12.24	17.86	22.07	21.96
	Q_{mod}	11.60	16.46	21.78	21.35
SD (cusecs)	Q_{est}	5.49	8.51	14.11	8.09
	Q_{obs}	6.30	7.19	14.09	7.98
	Q_{mod}	5.96	10.09	12.38	9.59
RMSE (cusecs)	Q_{obs}	2.96	3.34	2.50	4.50
	Q_{mod}	3.23	4.45	4.92	5.80
NSE (%)	Q_{obs}	0.69	0.84	0.97	0.67
	Q_{mod}	0.63	0.71	0.87	0.45

Table 16: Calculation of Correlation Coefficient for each sub water shed

Statistical Tool	Discharge	Batkhela	Chakdara	Saidu Sharif	Swat City
Correlation Coefficient	Q_{obs}	0.87	0.96	0.98	0.83
	Q_{mod}	0.84	0.90	0.94	0.79

4.2.3 Explanation of the Statistical Analysis

4.2.3.1 Mean and Standard Deviation

The mean value is calculated for each of sub-catchment showing the average timated, observed, and modelled discharge for each sub-catchment.The standard deviation tells us about the spread of data from mean. So from the table, we can observe that the standard deviation of discharges (Qest , Qobs and Qmod) of Saidu Sharif and Chakdara has the most spread out data points , where as the data of Swat city is moderately spread out and the data of Batkhela has less variability and it is closer to the average.

4.2.3.2 Root Mean Square Error (RMSE)

The RMSE is calculated for each of the sub-catchment area by comparing estimated discharge with modelled and observed discharge. mean value is calculated for each of sub-catchment showing the average estimated, observed, and modelled discharge for each sub-catchment. Root Mean Square Error (RMSE) is a measure of the differences between values predicted by a model or estimator and the actual observed values. It provides a single value to represent the overall accuracy of the model's predictions, with lower RMSE values indicating better agreement between predicted and observed values.

Formula used is as follows:

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i-1}^{n}(y_i \quad \hat{y}_i)^2}$$

where:

- y_i **is the actual value**
- $\hat{y}_i$ **is the predicted value**
- n **is the number of observations**

So summarizing the RMSE values for each sub-catchment:

a. **Interpretation of RMSE for Batkhela:** The RMSE between observed and estimated discharge in Batkhela is 2.96 cusecs, while the RMSE between estimated and modelled discharge is 3.23 cusecs. This indicates the average magnitude of the differences between the estimated/modelled and observed discharge values in Batkhela.

b. **Interpretation of RMSE for Chakdara:** The RMSE between observed and estimated discharge in Chakdara is 3.34 cusecs, while the RMSE between estimated and modelled discharge is 4.45 cusecs. This suggests that the model's predictions for Chakdara have a larger deviation from the estimated values compared to Batkhela.

c. **Interpretation of RMSE for Saidu Sharif:** The RMSE between observed and estimated discharge in Saidu Sharif is 2.50 cusecs, while the RMSE between observed and modelled discharge is 4.92 cusecs. This indicates that the model's predictions for Saidu Sharif have a larger deviation from the Batkhela and Chakdara, when we compare the estimated discharge and modelled discharge.

d. **Interpretation of RMSE for Swat City:** The RMSE between observed and estimated discharge in Swat City is 4.50 cusecs, while the RMSE between estimated and modelled discharge is 5.80 cusecs. This suggests that the model's predictions for Swat City have the largest deviation from the estimated values among the four sub-catchments.

4.2.3.3 Nash-Sutcliffe Efficiency (NSE)

NSE is a measure used to evaluate the performance of hydrological models. It indicates how well the model predictions match the estimated data. It compares the accuracy of the model's predictions to what was actually observed. A value of 1 means the model perfectly predicts the observed data, while a value of 0 or less means the model's predictions are no better than simply using the mean of the observed data. Formula used is as follows:

$$\mathbf{NSE} = \mathbf{1} - \frac{\sum_{t=1}^{T}\left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T}\left(Q_o^t - \overline{Q}_o\right)^2}$$

Table 17: NSE value range

NSE Value	Qualification
≤0	Unacceptable
0 – 0.4	Weak (Unsatisfactory)
0.4 – 0.6	Moderate (Satisfactory)
0.6 – 0.8	Good (Satisfactory)
0.8 – 1	Optimal (Satisfactory)

It was performed for four subwatersheds and we compare the estimated discharge with modelled and observed discharge. In the case of Batkhela, the NSE values of 0.69 and 0.63 indicate a moderate performance of the model. However, there is room for improvement to enhance its accuracy. Conversely, for Chakdara, the NSE values of 0.84 and 0.71 suggest a relatively good performance, with the model demonstrating consistency in matching both modelled and observed discharge. Saidu Sharif exhibits even stronger model performance, with NSE values of 0.97 and 0.87, indicating a very close match between observed and modelled discharge. On the other hand, Swat City displays weaker model performance, particularly when comparing estimated discharge with modelled discharge, as evidenced by NSE values of 0.67 and 0.45.

4.2.3.4 Correlation Coefficient

We also performed a correlation coefficient measure which measures the strength and direction of the relationship between two variables, ranging from -1 to 1. A correlation coefficient closer to 1 indicates a strong positive correlation, meaning that as one variable increases, the other variable also tends to increase. Conversely, a correlation coefficient closer to -1 indicates a strong negative correlation, meaning that as one variable increases, the other tends to decrease. A correlation coefficient close to 0 suggests little to no linear relationship between the variables. We perform this measure by comparing the estimated discharge with modelled and simulated discharge.

For Batkhela, there's a strong positive correlation between observed and modelled discharge, with correlation coefficients of 0.87 and 0.84, indicating good performance with slight room for improvement. Chakdara shows a very strong positive correlation, with coefficients of 0.96 and 0.90, suggesting accurate representation of the relationship between all variables. Saidu Sharif exhibits an exceptionally strong positive correlation, with coefficients of 0.98 and 0.94, indicating high accuracy in modeling the relationship between the variables. Swat City also shows a strong positive correlation, albeit slightly weaker compared to others, with coefficients of 0.83 and 0.79, suggesting decent performance with some scope for enhancement.

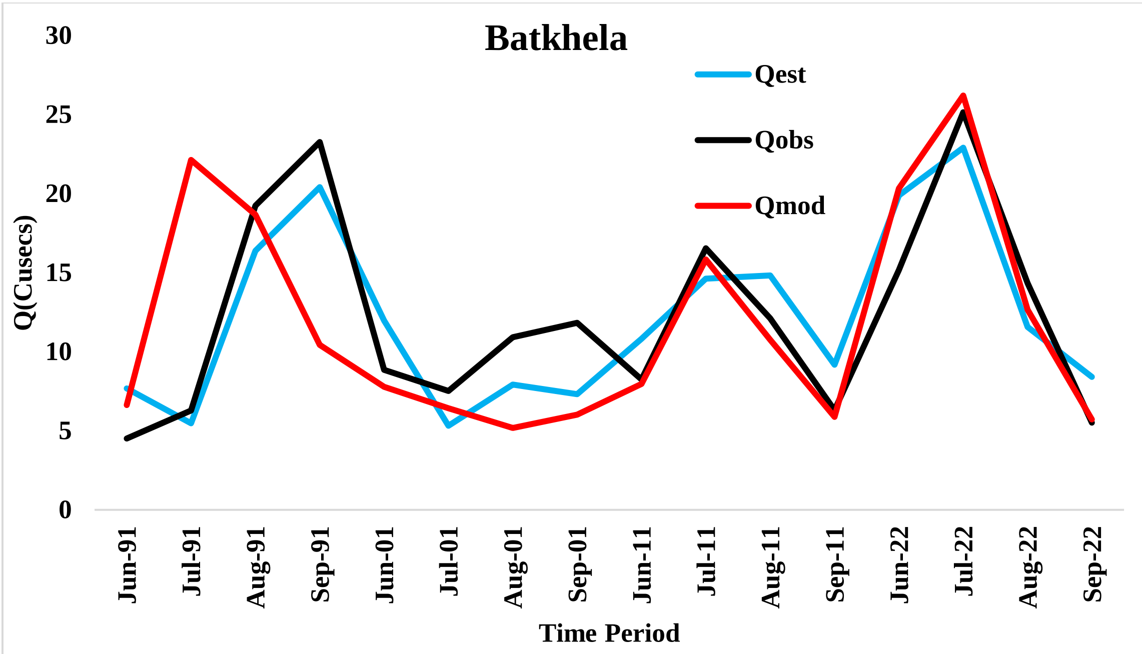

Figure 14: Relationship between Q_{est}, Q_{obs} and Q_{mod} for Batkhela Sub watershed

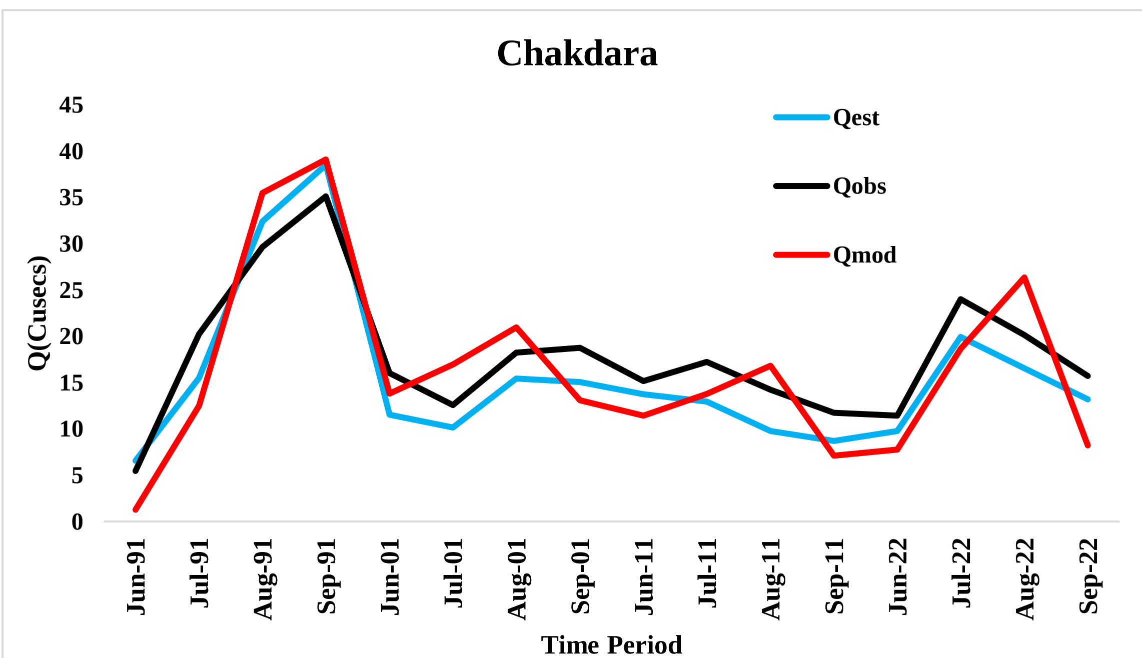

Figure 15: Relationship between Q_{est}, Q_{obs} and Q_{mod} for Chakdara Sub watershed

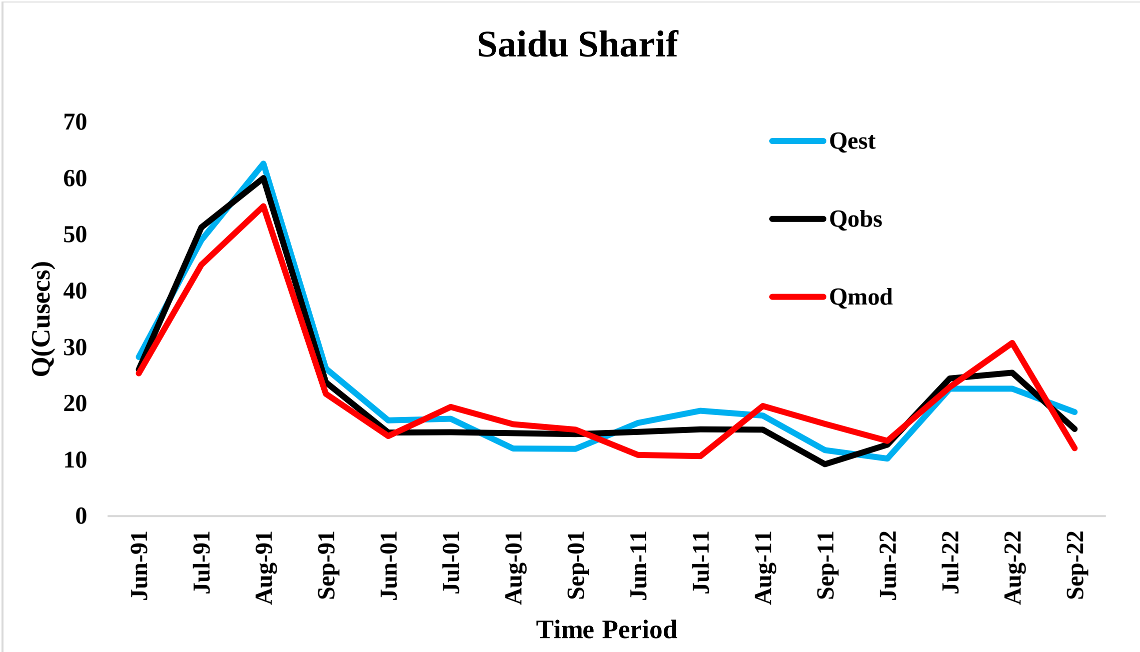

Figure 16: Relationship between Q_{est}, Q_{obs} and Q_{mod} for Saidu Sharif Sub watershed

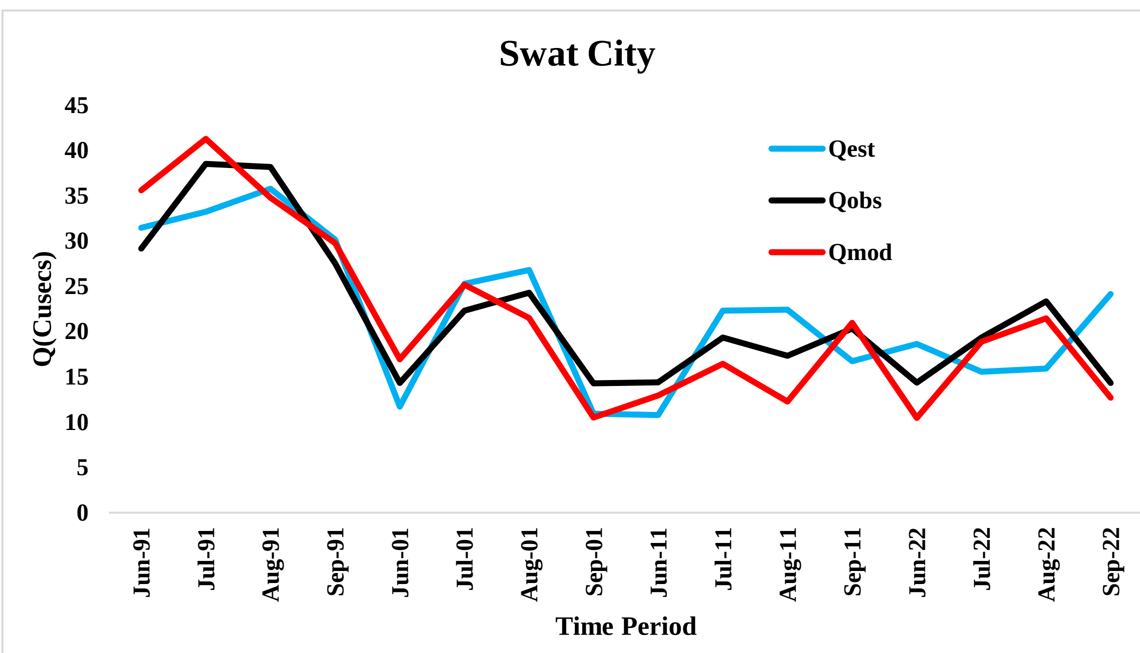

Figure 17: Relationship between Q_{est}, Q_{obs} and Q_{mod} for Swat Sub watershed

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

a. In the study, the calculation of estimated runoff through the Rational Formula began with area calculations derived from classified imagery, providing a quantitative assessment of land use and land cover (LULC) extents within the study area. By incorporating "Runoff coefficient" values and rainfall intensity data from ERA5, runoff was computed for each sub-watershed across the years 1991, 2001, 2011, and 2022.

b. Using GIS based LULC data, we observed an upward trajectory in the Developed class. Through the application of the Rational Formula and supervised classification in ArcGIS, coupled with ERA5 precipitation data, the study successfully quantified runoff contributions from different sub-watersheds, aligning with the objective of estimating runoff data based on LULC changes.

c. The HBV lite model, calibrated and validated from 1950 to 2022, along with gap optimization refining parameters for each of the four sub-watersheds, provided an efficient and reliable approach to simulate discharge, thus fulfilling our objective of hydrological modeling for rainfall-runoff Transformation.

d. The statistical analysis highlights variations in model performance across the 4 sub-watersheds, with Batkhela showing relatively consistent results, Swat City indicating the need for improvement in prediction accuracy, and Saidu Sharif demonstrating high efficiency and correlation in discharge estimation.

Recommendations

a. The methodology in this paper relies heavily on modelled and observed discharge values, neglecting in-situ data collection. In-situ measurements, obtained through instruments like stream gauges, offer real-time and accurate information about water flow dynamics within a watershed. By directly measuring discharge, researchers can validate model outputs and improve calibration. Future studies should prioritize in-situ data collection through strategically placed monitoring stations. This approach would yield a comprehensive dataset for model validation and refinement, ultimately giving us better results.

b. To achieve a deeper understanding of watershed dynamics, future studies should extend data collection beyond the current four-month period (June to September) and include more years beyond 1991, 2001, 2011, and 2022. Expanding the temporal scope enhances insight into long-term trends, seasonal variations, and the impacts of climate change on hydrological patterns.

References

1. Li, C., Sun, G., Caldwell, P. V., Cohen, E., Fang, Y., Zhang, Y., ... Meentemeyer, R. K. (2020). Impacts of urbanization on watershed water balances across the conterminous United States. Water Resources Research, 56, e2019WR026574. https://doi.org/10.1029/2019WR026574
2. Zimale, F. A., Tilahun, S. A., Tebebu, T. Y., Guzman, C. D., Hoang, L., Schneiderman, E. M., & Langendoen, E. J. (2017). Improving watershed management practices in humid regions. Hydrological Processes, 31, 3294-3301. https://doi.org/10.1002/hyp.11241
3. Banu, V. (2016). Watershed Development Programmes in Tamilnadu. Shanlax International Journal of Economics, 4(3), 51.
4. Pathak, P., Chourasia, A. K., Wani, S. P., & Sudi, R. (2013). Multiple Impact of Integrated Watershed Management in Low Rainfall Semi-Arid Region: A Case Study from Eastern Rajasthan, India. Journal of Water Resource and Protection, 5, 27-36. doi:10.4236/jwarp.2013.51004
5. Yulianto, F., Khomarudin, M. R., Hermawan, E., Nugroho, N. P., Chulafak, G. A., Nugroho, G., Nugroho, U. C., Suwarsono, S., Fitriana, H. L., & Priyanto, E. (2022). Spatial and temporal distribution of estimated surface runoff caused by LULC changes in the upstream Citarum watershed, West Java, Indonesia. Journal of Degraded and Mining Lands Management, 9(2), 3293-3305. doi:10.15243/jdmlm.2022.092.3293

6. Samie, M., Ghazavi, R., Vali, A., & Pakparvar, M. (2019). Evaluation of the effect of land use change on runoff using supervised classified satellite data. Global NEST Journal, 21(2), 245-252.
7. Asdaka, C., Supian, S., & Subiyanto. (2018). Watershed management strategies for flood mitigation: A case study of Jakarta's flooding. Weather and Climate Extremes, 21, 117–122. https://doi.org/10.1016/j.wace.2018.08.002
8. Parsasyrat, L., & Jamali, A. A. (2015). The Effects of Impermeable Surfaces on the Flooding Possibility in Zarrin-Shahr, Isfahan Municipal Watershed. Journal of Applied Environmental and Biological Sciences, 5(1), 28-38.
9. SS, B. A. S. R. A., & Aziz, N. (2015). Land use change mapping and analysis using Remote Sensing and GIS: A case study of Simly watershed, Islamabad, Pakistan Egypt. *J. Remote Sens. Sp. Sci*, *18*(2), 251-259.
10. Boggs, J., & Sun, G. (2011). Urbanization alters watershed hydrology in the Piedmont of North Carolina. *Ecohydrology*, *4*(2), 256-264.
11. Lea, C., & Curtis, A. (2010). Thematic accuracy assessment procedures: National Park Service vegetation inventory, version 2.0. *Natural resource report NPS/2010/NRR—2010/204. National Park Service, Fort Collins, Colorado*.
12. Khatami, S., & Khazaei, B. (2014). Benefits of GIS application in hydrological modeling: A brief summary. VATTEN–Journal of Water Management and Research, 70(1), 41-49.
13. Xu, F., Jia, Y., Peng, H., Niu, C., Liu, J., Hao, C., & Huang, G. (2019). Vertical zonality of the water cycle and the impact of land-use change on runoff in the

Qingshui River Basin of Wutai Mountain, China. Hydrological Sciences Journal, 64, 2080 - 2092. https://doi.org/10.1080/02626667.2019.1655146.

14. Ping, F. (2010). Effects of sublayer and land-cover change on flood in Daqinghe River Basin. Journal of Arid Land Resources and Environment.
15. Baban, S., & Yusof, K. (2001). Mapping land use/cover distribution on a mountainous tropical island using remote sensing and GIS. International Journal of Remote Sensing, 22, 1909 - 1918. https://doi.org/10.1080/01431160119220.
16. Nischitha, V. (2019). Analysis of land use land cover changes in Thirthahalli taluk using remote sensing and GIS. Geo Eye. https://doi.org/10.53989/bu.ge.v8i2.5.
17. Zech, Y., Sillen, X., Debources, C., & Vanhauwaert, A. (1994). Rainfall-runoff Modeling of Partly Urbanized Watersheds - Comparison Between and Distributed Model Using Gis and Other Models Sensitivity Analysis. Water Science and Technology, 29, 163-170. https://doi.org/10.2166/WST.1994.0662.
18. Yasmeen, Z., Zaidi, A., & Afzaal, M. (2017). Rainfall Runoff Modeling using Geo-spatial Techniques in Tarbela Sub-catchment. Pakistan Journal of Meteorology, 12