An Integrated Remote Sensing And Field Based Approach To Flash Flood Susceptibility Evaluation Using Geomorphological Methods, A Case Study From River Swat, North Pakistan

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2023

DEDICATION

To me, the people who supported me and who I've brought along with me in my life are just as important as any research I conduct. So I'm including my dedication here as well as information about the research itself.

To my mom, my father, and my brothers

To my fellows from

Quaid-i-Azam University Islamabad

I hope every day that I can make you proud.

ACKNOWLEDGEMENTS

Undertaking this M.Phil has been a truly life-changing experience for me and it would not have been possible to do without the support and guidance that I received from many people. I would like to first say a very big thank you to my supervisor **Professor Dr. Mona Lisa** for all the support and encouragement she gave me, during both the long months I spent undertaking my field work in Swat region and also the time i spent at University. Their immense knowledge, motivation and patience have given me more power and spirit to excel in the research writing. Conducting the academic study regarding such a difficult topic couldn't be as simple as she made this for me. She is my mentor and a better advisor for my study beyond the imagination and prepares my dissertation without her guidance and constant feedback this M.Phil would not have been achievable.

I am also pleased to say thank you to Mr. Yaseen Mohammad who made my access simpler to the research facilities and gave an opportunity to become part of their team. I am grateful to my parents, siblings, and friends who remembered me in their prayers for the ultimate success. They gave me enough moral support, encouragement and motivation to accomplish the personal goals.

ABSTRACT

The current research worked focused on the integration of fieldwork investigation with remote sensing data for the susceptibility of river swat to assess the flash flood susceptibility mainly in the sections where field observation was noted at base of Kalam, Behrain and Madyan cities along these Khuwazkhela and Mingora. In this regard, comprehensive field work was conducted, and data is collected including GPS location, Geomorphology Mapping with the aid of DEM, and formations etc to show the main impacts of the event and identify the man-made causes. These data are then integrated with Remote sensing data digital elevation model is utilized that comprise of different maps i.e., Elevation, Slope, Aspect, Drainage density, Soil, Lithology, and Land cover. For effective evaluation of the susceptibility in swat area DEM and ASTAR data reveals that the river swat is flowing in great risk of flooding. It should be recognized as extensive and usual natural events forms part of prolonged landscape evolution. Field observation investigated most of the critical factors along the river for unexpected disastrous event and it is observed that the areas of Kalam, Bahrain, and Madyan in map view possesses higher elevated regions where destruction are caused at higher intensity and further risk are high causes of most material flash flow in future. Additionally, the latest equation for moving boulder and its impact can be seen clearly from the mathematical modeling developed that significantly increase outcomes of flash flood susceptibility evaluation. Thus, by recognizing these floods areas can put up correct assumptions and mitigation measures.

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LIST OF ABBREVIATIONS

GIS	Geographical Information Systems
DEM	Digital Elevation Model
FPA	Flood Prone Areas
HKH	Hindu Kush Himalayan
MMT	Main Mantle Thrust
PDMA	Provincial Disaster Management Authority
HWM	High Water Marks
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
USGS	United State Geological Survey
LULC	Land Use / Land Cover
RS	Remote Sensing
GDP	Gross Domestic Product
CA	Cartographic Approach

CHAPTER 01 INTRODUCTION

INTRODUCTION TO STUDY AREA

1.1: District Swat

Swat is a district in the province of Khyber Pakhtunkhwa. According to the 2017 national census, the population of Pakistan's Malakand Division is "2, 309, 570," making it the province 15th-largest district. The district's total geographic area is 5065.28 square kilometers, with 965.28 square kilometers of cultivated land and 4100.00 square kilometers of uncultivated terrain. The receiving forest area is 1367.05 square kilometers according to Iqbal et al 2015. The rural population is around "1,612,803" (69.86%), whereas the urban population is roughly "695,821" (30.14%).

The study is focused on the Swat Valley, which is located within 34° 47′ 28.126″ North latitudes and 72° 23'26.266" East longitudes, as can be seen in Figure 1. Swat has an average elevation of 934 meters (3,064 feet), leading to a significantly cooler and wetter environment than the other parts of Pakistan. Swat is among of the most popular and wonderful tourist attractions spot, with lush woods, alpine meadows, and snow-capped peaks. The environmental situation of Swat varies according to altitude, with mountains in the Kohistan region covered with snow all year. The highest reaches of the swat region are cooler and frequently receive snowfall throughout the winter. Drier, high temperatures in the lower Yousafzai Plains, where summer temperatures can exceed 104 °F (40 °C), in spite of the lower plains experiencing periodic snow.

The Swat Valley is surrounded by natural geographical borders and lies on the Swat River, the headwaters of which originate in the well-known mountainous Hindu Kush. Mountains encircle and isolate the valley on all sides. The valley is encircled by mountains on all sides and divided by gorges. More than half of the valley (1238.13 out of 2374.10 square miles) is hilly and mountainous and has been originated as a consequence of the erosional process of the Swat River and its tributaries. The Swat River passes through the valley's center, dividing it into nearly equal parts. Although the valley's is establish and shaped like a broad 'V,' which assists in trapping winds, thus the amount of precipitation at the valley's top edges is high and abrupt. The Panjkora River valley lay across the mountain ranges to the west, the Gilgit Valley to the north, and the Indus River gorges to the east. The vast Peshawar valley is located to the south, over a series of low mountains. The Swat River, which collects water from 17 major tributaries, drains Swat. The northern most area of the Swat district is made up of grasslands with steep valleys of Swat and Kohistan, a region where multiple glaciers nourish the Usho and Gabral rivers (also known as the Utrar River), which merge at Kalam to form the Swat river, which serves as the spine of the Swat Valley and district. Swat is then distinguished by dense forests that traverse the length of the Kalam Valley's steep gorges, extending to Bahrain and Madyan. The river then runs gently for 160 km over the lower Swat Valley's wider Yousafzai Plains until it reaches Chakdara. The Swat River flows southwest through the Peshawar plain before joining the River Kabul near Nisatta after a 320 kilometer journey.

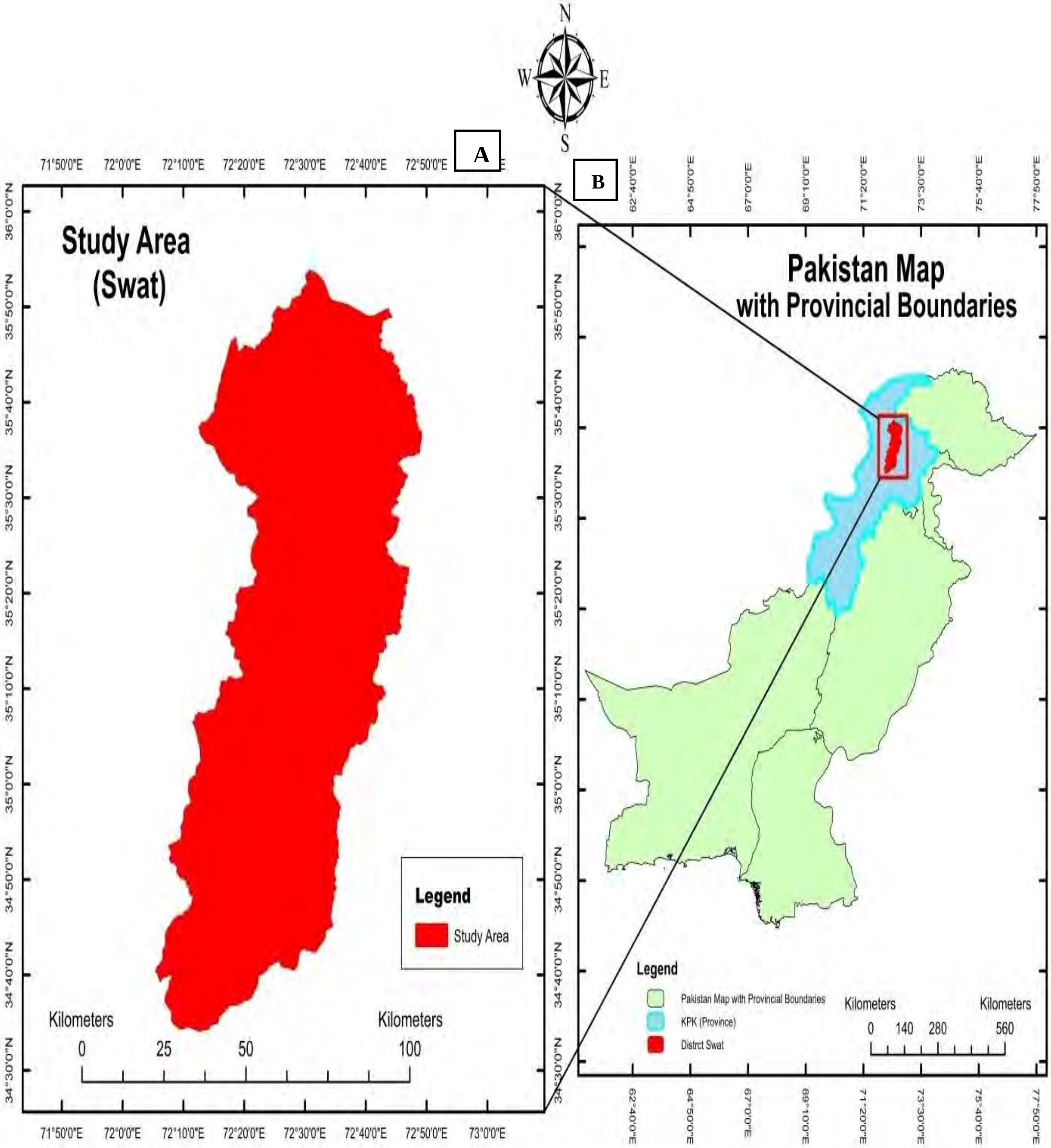


Figure 01: Presenting the location of the study area with geographic boundaries. **(A)** Represents the study area (swat). **(B)** Represents provincial boundaries.

The major justification for choosing this location is because the Swat district has had multiple flash flood catastrophes in the recent few decades.

1.2: Topography and Geomorphology

The study area divides into six sections but main 3 points which the total area was covered with three main cities Bahrain, Madyan, and swat. Madyan is a famous highland area in the Swat District, which is around 55 km when coming from Mingora. A seven-mile just a short drive separates Madyan and Bahrain these two localities. Behrain the name means "two waters." It is situated near the confluence of the Daral and Swat rivers. Bahrain is located 66 kilometers with Saidu Sharif as well as 10 kilometers from Madyan.

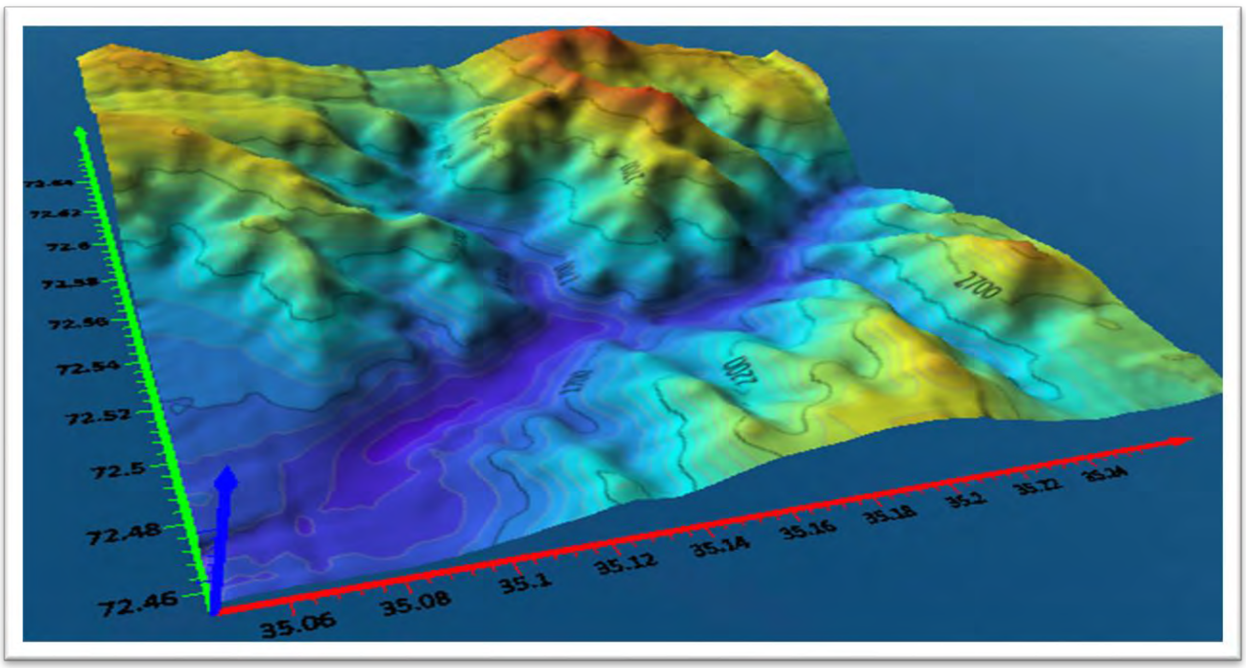


Figure 2 represent the Topography of the study area.

Geomorphology initiatives to better comprehend and appreciate landforms and natural landscapes according to Bauer, 2004 which is based on an operational perspective; it also identifies and analyzes the mechanisms and landforms associated with hazardous circumstances. Some earth scientists' look to make their studies more precise in terms of understanding the specific mechanisms, geomorphologists are concerned with the interactions of a wide variety of factors controlling the Earth's surface dynamics, including its role of anthropogenic activities. Consequently, the quantity and quality of disaster prevention, related investigations undertaken by geomorphologists have improved their concern which was marked in recent years. Geomorphological approaches have animate, and very often facilitated applied disaster investigations, and their progress. . Geomorphology contributed not only to the understanding of that type of events but also to generate and apply the theoretical and methodological currents within the disaster of science and the evident links with social scientists. As a result, geomorphological approaches have been utilized with an emphasis on hazards and risk categorization, as well as instrumentation for the land planning, prevention and mitigation. For prevention of Disasters we have understanding on the dynamics of the Earth, however including the relationships among landforms and processes so the methodologies and techniques used in geomorphology have significantly progressed. Such procedures include:

First, the geomorphological mapping; Geomorphological mapping is a collection of procedures used to systematically document the morphology of the ground, landforms, landscape formation procedures and materials which make up the Earth's surface by Griffiths et al, 2011 and Lee, 2001. Second, the detailed survey using digital magnification of aerial imagery in combination with a field trip. The final outcome is a geomorphological map on which specific geomorphological conditions down to meter scale may be recognized. Cartographic approaches (science of maps), which are presently utilized for the evaluation of geomorphological risks, including approaches for input development (e.g. maps of posing and triggering elements and inventory of previous geomorphological processes or instabilities) according to Lazzari et al, 2018 and Lupiano et al, 2019. The last step Geographical Information Systems GIS for risk assessment in the sense of hazard assessment for risk analysis and risk management whereas vulnerability analysis in respect with geomorphic risk assessment, geomorphological hazards and worldwide impacts of climate change. The high terrain area of upper swat, where snow and glaciers are remarkable, but heavy precipitation also contributes to the emergence of widespread natural phenomena such as debris flow, flash floods, rock fall, and landslides. Also the DEM (digital elevation model) clearly demonstrates that the research region comprises tough hilly terrain with altitude variations ranging from 925 meter to 1383 meter. Ten most affected countries in terms of population where, Pakistan is on top ranking with exposure to climate-related risks, according to Global Climate Risk Index Croft and colleagues 2017.

1.3: General Discussion

The occurrence of a threatening condition that arises from a natural phenomenon occurs in a specific area and at a certain time considered as a natural hazard by Alcántara Ayala, 2002. Therefore, a hazard can lead and turn into a disaster when they represent a threat to catastrophic occurrences with atmospheric, geological, and hydrological sources (example, dry spell, earthquakes, floods, rock falls, and landslides), which can result in injuries, death, and social and environmental disturbance. Flash floods have caused unprecedented disasters and crises in the previous 12 years, resulting in fatalities, injuries, and damage to infrastructure, irrigation networks, drinking water supplies, crops, and vegetation Arnous and Warraich 2012. Progressively geomorphologists have become increasingly involved with hazards and recognized that the increase in population density had led to the occurrence of disasters due to human occupancies of hazard prone zones that had previously been avoided, authorities at the international and national levels were not then sufficiently aware of the future likely scenarios linked to global climate change, and consequently to the need for establishing and implementing adequate hazard and risk assessment strategies. Under the same conceptual umbrella, without any hesitation, progress in geomorphology has been related to the increase in attention to environmental concerns, notably the worldwide knowledge of climate and land use change, vulnerability, hazard assessment, risk control, and catastrophe avoidance. Purpose has led to a new direction in modem geomorphology Coined by Haff 2002,'neo geomorphology', studies the aim of anthropically driven Earth surface processes and landforms evolutions. Initially, the description of Fieldwork, topography maps, and aerial photos were used to create the drainage networks. Hajam et al. 2013, Ramu et al. 2013, Waikar and Nilawar 2014, Martins and Gadiga 2015 employ remote sensing and geographic information systems that can analyze geospatial data to depict drainage networks. According to the study, the use of remote sensing data in conjunction with GIS has resulted in substantial advancements in flash flood research, which has helped to reduce damages and losses. Geospatial techniques and processes are time-saving and cost-effective tools for watershed processing, mapping, and assessment, as well as assessing flash flood risk by Pradhan 2010, Rahaman et al 2015, Aldharab et al 2019, Lama and Maiti 2019.

Bubeck and Abdalla et al., state that mapping and describing flood-prone areas is an important step in risk assessment and flood mitigation. Forecasting flood-prone locations is particularly advantageous in this situation for minimizing flash flood damage; different flood risk modeling systems have been developed. The last extreme precipitation in the study area on August 2, 2020, caused a flash flood in the Shahgram, displacing around fourteen persons from the Madyan localities of Shahgram and Tirat Swat, but now the pattern is repeated, with a total loss of 1100 fatalities recorded across the country, with KPK swat area responsible for 5 fatalities because flash floods completely destroyed over 40 homes and sweeps three bridges and several wooden bridges, Flood susceptibility and maps used to identify flood prone regions (FPAs), as well as understanding and reducing flash flood difficulties, are crucial for recognizing and handling flash flood challenges, as well as ensuring correct and sustainable development. Because of the region's severe climatic variations and complex physiography, flash floods are a dangerous and recurring phenomenon. Keep in mind that the study's purpose is to estimate the susceptibility evaluation of the Swat River to flash floods.

1.4: Previous Work

On whole globe flooding is most recurrent phenomenon extreme precipitation cause in monsoon particularly in region of south Asia in same scenario if it is measure with great loss of lives and properties damage, for continual struggle with optimum strategy amongst most crucial aspects in flash flood. As a consequence, the combination of geomorphological mapping, GIS, flood history, and aftermath episode surveys can provide a powerful tool for assessing flash flood hazard reduction strategies flood-prone nations. Hence these measures also answered to the question which arise that where will flood occur and how much severe to be, economically most difficult for that zones where such kind of devastation occur especially in Pakistan KP province.

Continuing the present study of KP swat area with Geomorphological features of natural hazards and risk, particularly flooding and slope movements, were studied in impacted regions in swat by using various remote sensing and GIS approaches before. As a result, the idea of morphometric approach on Swat River watershed for 17 sub basins occurs normally with minor variances. Thus by developing the digital elevation model then it was utilized to delineate the watershed and drainage network using the ArcHydro tool of ArcGIS. A total of 15 morphometric parameters have been used for flash flood modeling. The study's findings were used to construct spatial potential flash flood risk maps using two different methodologies based on knowledge of flash flood prone sub basins According to Jamal Nasir et al., 2020. According to the morphometric grading techniques, approximately 59 percent of the entire sub basins are vulnerable to flash floods. Flooding has the largest influence on drainage density, frequency, bifurcation ratio, basin length and width, stream length, and form factor in the remaining sub basins they are moderate to low grade with intensity. Application of remote sensing data when using the GIS environment it is more effective for the assessment of hydrological response at the sub basin. So it reveals that data resolution plays key role in the reliable and applicable of adopted methods. Also the study employed a 30 meter resolution ASTER for delineation of drainage network which may be considered as coarse resolution, but the comparison of delineated drainage network with the manually digitized stream from topographical map shows conformity. The watershed boundary delineated with flow direction was within one pixel of the boundary digitized manually from the topographical map.

Using several types of geospatial data sets, census data, and field measurements, a GIS-based multi-criteria method was used to represent flood vulnerability in the particular region of District Shangla, Khyber Pakhtunkhwa. The incorporation of characteristics such as hydrologic soil types, geology of the area, poverty score, income level, family structure, construction materials in structures, and organizational capability significantly enhanced vulnerability research methods. To construct the topographic maps, high-resolution spatial landscape data from developing technologies such as Light Detection and Ranging (LiDAR) and DEM of 10m resolution were employed, and DEM of 10 m resolutions was also used for enhanced outcomes by M.Hussain, M, tayyab, et al 2021.

Same work done also for Peshawar city, combining of ArcGIS and remote sensing, flood resilience with same example of Peshawar city in which the model presented with multiple parameters although the flood hazard's being exposed and final susceptibility, controlling capacity and utilization are the main limitations of the approach. Because the region is extremely susceptible to urban flooding due to a large number of residents, rapid growth in urbanization with devalued circumstances, and a lack of advanced technologies for early warning mechanisms, with a precision of 90% the model was utilized in assess of urban flood resilience. This was based on the premise that an effect of floods happens to adversely affect property when it comes into immediate interaction with floodwater, three presumption indications (commercial structures, residential properties, and government infrastructures) were used to assess urban vulnerability to flooding. Weight assigned to every indication that were subsequently processed in ArcGIS using the GIS-based AHP tool to build the susceptibility evaluations by M. Tayyab, J.Zhang, and M. Hussain et al 2021.

Pakistan, are more vulnerable to climate change and contribute more directly to disastrous floods. Taking into account bursts of precipitation that often fall as rain but can occasionally turn to snow, climate models predict that as the world heats, the frequency of floods in South Asia, such as Pakistan, India, and Bangladesh, would rise. Because glacial regions where climate change phenomena may collide are more likely to contribute directly to disastrous floods. Melt glaciers also exert strain on natural channels and rivers, and the combination of the river's natural level and the increased precipitation can generate unexpected and catastrophic outburst flooding that deliver water bouncing into tight valleys downstream. Flood take up time to be built by the way some time the phenomenon may occur quickly commonly as in situation of time population may warned but such catastrophe characterized by rapid rise, and that moving are extremely dangerous.

1.5: Aims and Objectives of the study

- To prepare flood risk maps i.e. Elevation, Slope, Aspect, Drainage, Density, soil, Lithology and Land cover to show the potential risk assessment and impacts of flooding in the flood risk areas of river swat and its vicinities for future.
- Geomorphological methods with Field based approach to Flash Flood susceptibility evaluation using integration of GIS and RS techniques.
- Evaluations of risks present there to identify and mitigate risk for life and properties with theoretical interpretations to manage Land use.

We may identify and anticipate Flash Flood vulnerable locations through scientific study of Flash Flood, and so reduce Flood damage risk via through effective planning. To achieve the aims of Flash Flood susceptibility analysis techniques have been applied, and verified in the study area.

CHAPTER 02

GEOLOGY OF THE AREA

2.1: Geology of study area

Lower Swat is located in the Himalayan foothills and is known as the lower Himalayan. The Swat Mountains, which extend from Peshawar Basin to Kohistan, with heights ranging from 400m to 5500m. The area to the north and west of the river, but close to Chakdara and Garai town, is of significance for studying Himalayan collision and tectonics with 35°N and 72ºE. Main Mantle Thrust (MMT) separates Indian plate rocks from amphibolites that are thought to be portion of the accreted Mesozoic Kohistan island arc sequence according to Tahirkheli et al 1979. The Main Mantle Thrust Zone represents the boundary between Indian plate and Kohistan-Ladakh arc in Pakistan. They include discontinuous faults slices and then, it was further subdivided into Nawagai, Dargai, Kishora, Shergargh fault system. Seismic activities in the Swat area were caused by active faults and tectonic processes with deep down crustal mantle changes and most of the earthquakes come from the Hindu Kush according to Perveiz Khalid et al 2014.The northern area of Pakistan is primarily subjected to compressional and transpressional stresses as a result of the continuous collision of the Eurasian and Indian continental plates, which began with the creation of the Himalayan Mountains.

2.2: Alpuri Group

Stratigraphy distinguishes From the Precambrian to the Cambrian, the Manglaur formation was unconformably overlain by the Alpuri group before being partitioned further into Carboniferous or younger Marghazar formation and then Triassic or younger Kashala and Saidu formation Figure 3.3 A. Since Martin 1962 and, several workers have interpreted the stratigraphy of the region and rocks. According to Kazmi and other researchers 1984, they segmented into the lower Swat through the Buner schistose group, Swat granite gneisses, Manglaur schist, Alpurai schist, Saidu schist, and the Indus melange groups are some of the rock types found in the Swat region. Granites of distinct Tertiary ages are found in the lower Swat series, which is located at south of the MMT. The Manglaur formation is invaded mostly by Swat granitic gneisses, which are composed of many individually identified plutons Figure 3.3 F. The Indus suture melange group overthrust the Saidu schist, and Marghazar is visible as a tiny portion. As from the Indus melange Mingora ophiolitic extends westward, and oceanic rocks appear in the form of thrusts Emeralds have been identified in talc-carbonate sections at Garai town south according to Hussain et al, 1992. The Kohistan arc amphibolites, metasedimentary, and Meta igneous rocks are being overthrust by the Indus melange group in the region north-west of the Swat River Further they are subdivided in The Kohistan arc, the Indus melange group, and the Indian shelf sediments. Sediments from the Indian shelf The Alpurai group sit irregularly on the Manglaur formation and Swat gneisses. (A) The Marghazar formation is named after the Marghazar locality, which is located 6 km south of Saidu. It is composed of dark-gray worn phlogopite marble, garnetiferous muscovite schist, epidite biotite schist, amphibolite schist, psammitic schist, feldspathic quartzite, calcite marble, amphibolite, and unusual graphitic schist, according to Di Pietro, 1990 as mentioned in Figure 3.3 G. (B) Kashala formation is named from Kashala Mountain, which is located around 13 kilometers southwest of Saidu. It runs along the roadside from nearby Remora to Khazana village Dir. Several hundred meters thick beds of schist, schistose marble, white marble, dark-gray foliated marble, and quartzite being there. (C) The second large unit of the Saidu formation which overlies Kashala formation ranges from tens of centimeters in the melange zone to hundreds of meters away in the south fine to medium grained grey to black phyllite. (D) The Chakdara granite is seen to the northwest of the Swat River. It is mostly medium grained and foliated and spans from Chakdara Fort north to Dir. The Kohistan, on the other hand, consists of being made up of epidote amphibolites. It is hundreds of meters thick and reaches from Kabal (Swat) to Dir district the contact with the greenstone of the melange terrane is a thrust contact, a Jurassic to Cretaceous Indus melange group by Shams, 1980. Upper swat after a long traverse Between Mingora and Kalam, a road runs roughly north to south beside the Swat River by Martin, Siddiqui, and King's 1962. The study of the noritic rocks, amphibolites, and basic and intermediate igneous rocks of upper Swat, Pakistan, correlates to the Hornblendic Group in general, although the northern section of the research area is considerably more complicated, with mixed lithology from south of kalam area onward by NW utror volcanic, with composition rhyolite. The Schistose and metasedimentary rocks with Paleozoic age and igneous rocks of Tertiary age are finally the rocks looking coarser to finer igneous rock. Madyan and Bahrain collectively have pyroxenite and nuratic gabbros and same area, collect like Mankyal Madyan, is pegmatite rich according to literature. The south of Madyan valley to a greater extent of N the gabbros are coarser while diorites also may coarser with grain size the rocks were distinguished by well developed joints and were closely placed together to the east and west of the river. Madyan pegmatite with falser structure may be seen at a distance of around 4 to 5 km to the west. Contact between amphibolites, gabbros and diorites which have been not clear because the area fully dominated with Amphibolites especially as the southern part of the area. E margin of river pass with epidot and amphibolite with a stage of metamorphism. Diorites and metasediments contacts of Kalam group may be seen as intrusive which is due to local fault and main point is porphyritict intrusion of pyroxene of quartz diorite in metasediments support mainly this idea. Further if we look the lithology towards N and W with more outcrops pyroxenites association and small hornblende bodies about more than 6 sq km and the Timergara there may also have been small amount of amphibolites with differentiation of metamorphic to dioritic magma been metamorphosed but same type of rock consisting of 10 km Northwestern part of Matta area hornblende and N of Khwazkhela most of rock containing olivine.

2.3: Kalam Group

As from the sequence the top area for study observations Kalam area was also chosen where the sedimentary exposure of micaceous quartzite, schist and phyllite which have overlies with shale and limestone. In certain regions, the colors are varied, such as dark pink, bright green, and brown. The quartzite and schist are mostly narrow beds and having thin bands but mostly dominant in amphibolites. The siltstone, shale, and limestone are red green in appearance and overlie the quartzite, schist, and phyllite, while the limestone is light grey and has calcite veins Figure 3.4 and Figure 3.5 E. They are fossiliferous and include algae and coral. Limestones with thin beddings in certain areas and fossils all rest in the limestones are wiped out as a result of modest metamorphism. According to Bard 1983, the calc-alkaline volcanoes located higher on the Kalam series might be intraformational aggregates, volcanic (andesitic) agglomerates, or andesitic flows. About to Utror village volcanic unit of about 8 km thick and dominantly made up of approximately schistose met andesitic agglomerates. This unit's metamorphic and sedimentary rocks are intruded by a variety of plutonic rocks, primarily quartz diorites and granites by Jan and Mian 1971. Basically, the rock unit is made up of silicic and intermediate lavas, grey, green, red, and white volcanic rocks, and fine grain homogenous tuff. Variations in color, texture or mineralogy and pyroclastic rocks banding are the cause of Metamorphism was modest in the rocks. Breccia is also visible in the section exposed to the south-west of Kalam, which contains pebbles from the Kalam group of sediments, which suggests that Utror volcanic is younger than the Kalam group, with ages ranging from the Cretaceous to the Paleocene.

CHAPTER 03

GEOMORPHOLOGICAL OBSERVATIONS AND ASSESSMENT

3.1: Methodology

With the approach of GIS and geomorphological observations to determine the examined area vulnerability to flash floods, the methods used to create a susceptibility evaluation maps imply multiple methods like data from a literature review, field observations, and Remote Sensing. So the results of these approaches were based on observations made, 2022 in Swat area. Using while the example of a flash flood, Figure illustrates the overall workflow for the current task. The areas that were most hit by the flash flood of August 27, 2022 were highlighted; the river Swat field survey first includes the geomorphological observations.

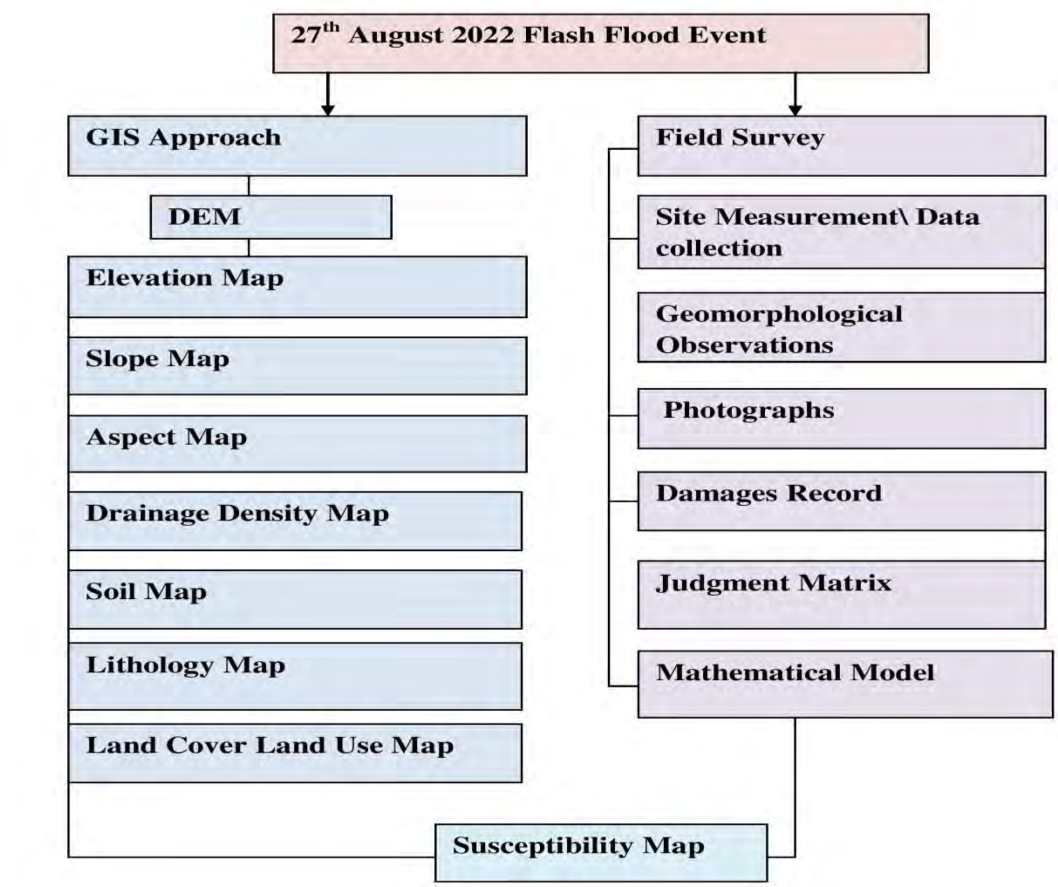
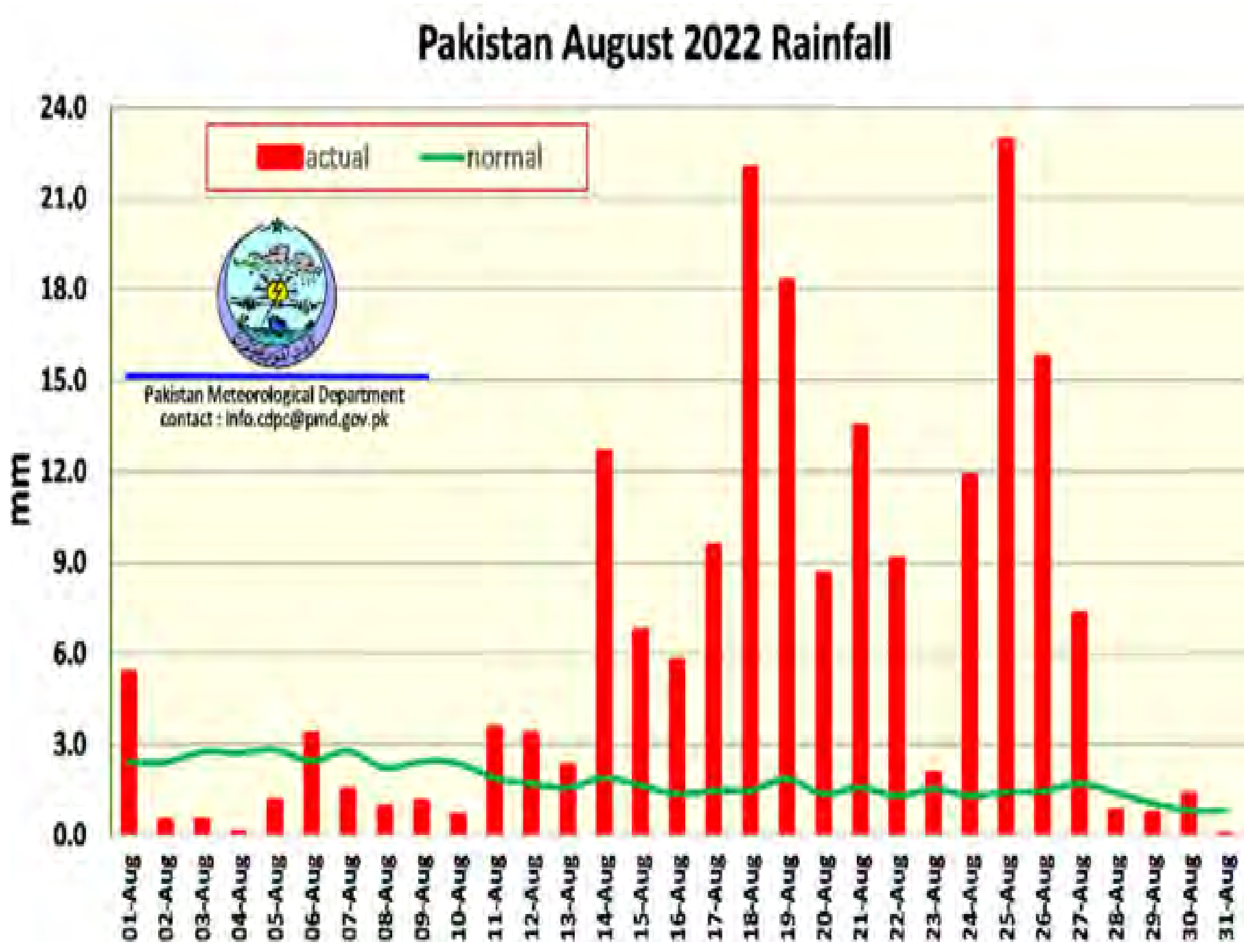


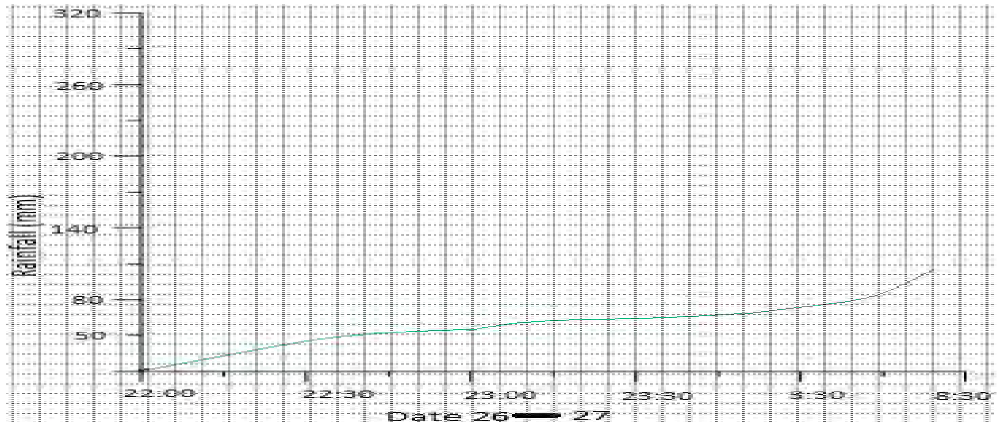
Figure 3.1 Workflow illustrating the methodology adopted in this work

3.2: Regional study of extreme floods Phenomena

About the flash floods on August 27, 2022, three important issues have been highlighted: human interference in the river channel, arbitrary buildings on the river Swat, and an excessive rate of rainfall according to Provincial Disaster Management Authority (PDMA) The largest 24-hour rainfall total ever recorded is 90 mm; Timergara recorded 80 mm, Kalam 71 mm, Mirkhani 55 mm, Malam Jabba 54 mm, and 51 mm of rain. During the past 62 years it was largely above average over KP (163.9mm/+58%) the previous monsoon precipitation in July 2010 also caused extensive river damage and flash floods in various Swat River tributaries, putting several communities unreachable as a result of damaged infrastructure and destroyed bridges, 988 homes were destroyed, expelling 2751 residents, 26 water supply networks, standing crops, and gardens were entirely devastated by the floodwaters. (ACTED 2010), making it the fourth worst flood total since 2010.



(A)



(B)

(C)

Figure 3.2(a) Rainfall data from 13 stations study area for August of 2022 (Webpage: http://www.pmd.gov.pk/cdpc/home.htm)13 PMD stations broke their 24-hours rainfall record and 21 stations set a new monthly total rainfall record. Figure b and c illustrate date and time with respect to source location.

3.3: Geomorphological Observations Based on field Survey

After the summer floods of 2022, field mapping and reconnaissance activities are carried out in the district Swat. The variation in rainfall's spatial and timing distribution, as well as the fluctuating geological and geomorphological conditions, that determine how the relief evolves. A rainfall had a more significant impact on the River Swat, as well as in some areas of the Swat and Kalam basins in these areas overflows significantly exceeded up to flood plains limits where towns and villages are built near to valley slopes and adjoining, leaving the flood plains unoccupied Figure 3.3 h. Therefore, flood waters cause significant damage. In the River Swat, the major events of lateral erosion and accumulation processes were also found (the region of heavy rain) and downstream from kalam to Bahrain then towards Madyan and in many localities of swat area so the area also affected by major anthropogenic activities around influx from Figure 3.3. Variable geomorphological processes are triggered by different watercourse tracks taking into an account the grade of the stream, the volume of flowing water, the inclination of nearby hills, and so on. Huge rainfalls, on the other hand, have an impact on river basins produced by various types of rocks Figure 4.1.6. It is important to emphasis the continuous processes of relief modification on higher gradient tracks (particularly in upstream locations) where unabsorbed water rushes quickly from mountains to channels as we examine from slope map. The valley complex's steep slopes, overflow was restricted, bed erosion prevailed over lateral erosion, and loose sediments were carried away at some regions.

In these days Aug 25^{th}, 26th and 27th, 2022 the Meteorological Station measured huge precipitation after the 2010 flood. The following flood hazard known the Provincial Disaster Management Authority reported that in River Swat at Chakdara flow of water is 75,843 Cusecs, in Khwazkhela 40,872 and at Panchkora 30,222 recorded at that time the alert was issued by Provincial Disaster Management Authority. Unfortunately, during the intense time, human structures (bridges, main highways) Along the river and channels in the study area were reduced in critical cross sections of the rivers, causing overflows and intensification of the phenomenon, whereas there were no right constructive protected boundaries, which was the main reason we discovered that the lack of dams in the area was sufficient to reduce the dynamics of the flow towards the downstream. The study area consists of six sections which were also described before in different sections at the starting point from the area adjacent to Kalam and base of Bahrain; where the geomorphology is observed from field survey point of view.

So we start the first section and the field analysis helps us at the study area by clear observations of intense damages. How’s the geomorphology disturbed? As the present interpretation from field evidences likely mention which provides the total information which can assist in mitigating the impact on environment and geohazards derived damages. The survey route was designed in such a way that the regions of interest covered within 101 photographs for flood limit and their impacts could be determined.

3.4: The critical cross-sections and intensification phenomenon of source area:

- **Bahrain base Sections onwards to district showing different geomorphological features**

The research area was conducted at the junction of river swat where the first section begins in the direction of Kalam and ends in a Bahrain city 6G5x+Fx9 Khyber Pakhtun Khwa. The area is about 5.3 thousand Km^2 average elevation about 4.6 thousand feet and maximum altitude of 1383 m with accuracy of GPS about 2 meters bounded to the east and west by the mountains of respectively Figure 1. Here GPS focus on Bahrain valley which is located between 35° 12′34″ North latitudes, and 72º 330'464"East longitudes. The second section from Bahrain bazaar is the well-known place Zaro Kali with an altitude of 1392 meters. The third Section starts from Madyan city with altitude of 1309 meters. The fourth section Madyan Road at well-known site Churrai with altitude difference of 1315m located at 185317.86 sq meters. The fifth section Qandeel (Garai) 3Fxx+9wx Gps relation with Kalam at the lower part of the Madyan city. And the last Sixth section was carried out at Bahrain road at main point of tourist spot Faiza ghut altitude 0f 925 meters.

All of the above sections were identified exclusively with geomorphological approaches and GIS mapping. Combination of thoughts in source area and their correlation here interpreted from main field evidence with help of quality documentation the Damages caused by flash floods, both human structures, infrastructure, and agricultural fields, has been purely recorded.

3.5: Flash flood impacts on environment

The human infrastructure along the river of the study area was completely destroyed at that critical time. Overflowing flood usually appears in places where no extreme stream gradient in expanded valleys. Because the river bend it may have sideways erosion, thus Bank of river are affected, and property was harmed and also overflow of flash flood erodes the urban area and the sediments were carried out down the river from north to south drifted. At the same time, rising river levels may expand floodplains by sides. A river incision into the stony riverbed was identified during field in numerous areas the riverbed became deeper by flood flow up to 0.2 meters Figure 3.3 h. Incision of bed in these points of the river was also due to the loose bedrock or it may be caused by tectonic disposition. Bed erosion and removal also steepen valley slopes by making them less stable as floods occur, so it’s due to gravity and variations in saturation conditions Figure 3.6 J showing how much the water is speedy Figure 4.2 slope map showing that total study area is covered with high slope more than 45 degree as it is classified into five classes. The loss of huge property with several fatalities this indicates and also allocates certain circumstances in which the flow of water was obstructed by manmade structures, so the water level surged over the threshold level, forcing the river Swat to overflow.

Figure 3.3 A. Aerial photographs illustrating the damages caused by the 2022 flash flood at Bahrain section. The main Bahrain and kalam roads were fully destructed. The outcrop exposed along the roadside show succession of Alpuri group of rocks particularly Kashala and Saidu formation.

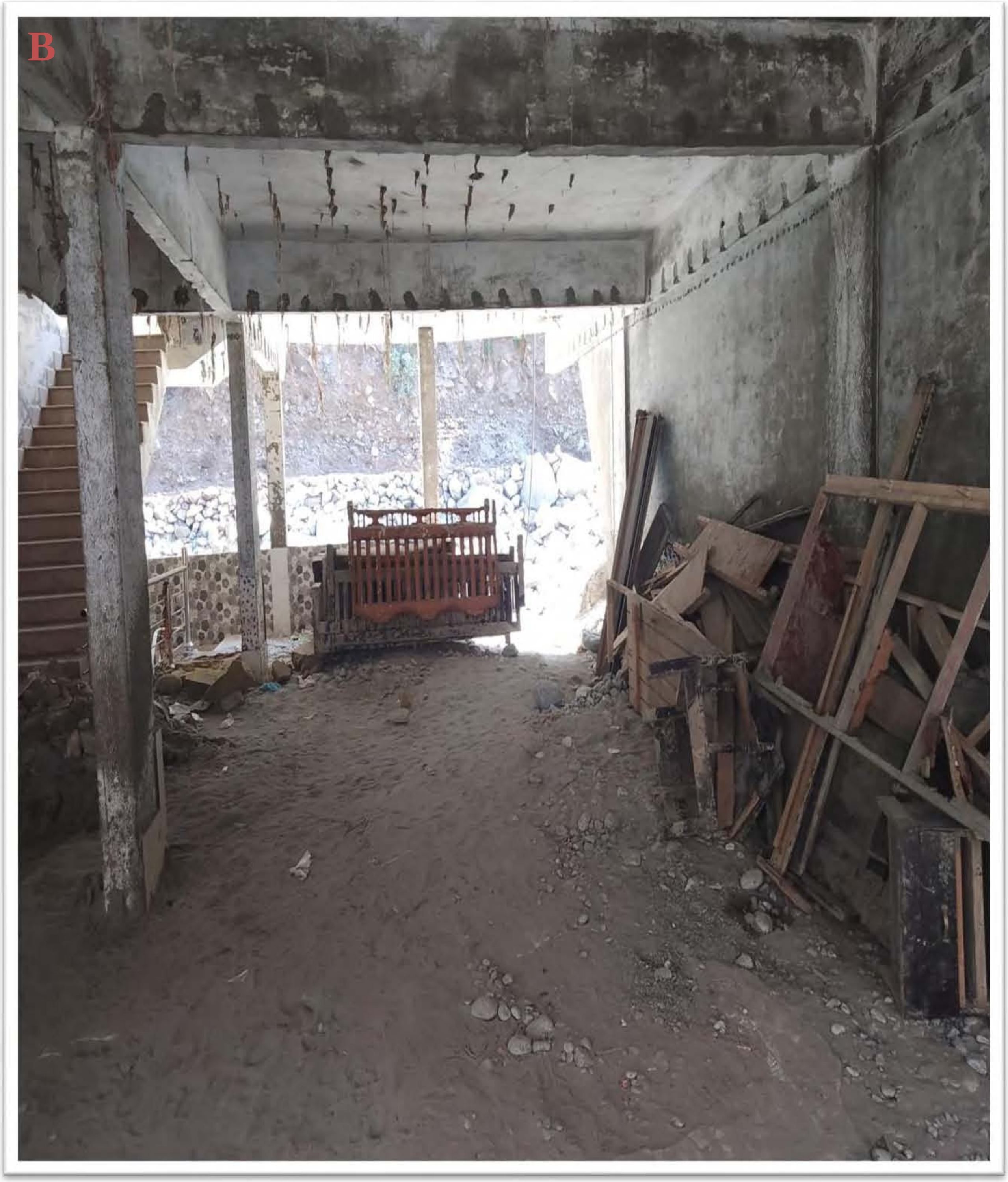


Figure 3.3 B Photo from the flash flood intensity how’s the local people buildings were damaged and these local community were serves on infrastructure like shops and markets.

Figure 3.3 C The buildings are completely destructed and cracked during 2022 flash flood. Figure showing the buildings which are the most expensive first class hotels of the main Bahrain city.

Figure 3.3 D Homes of the local people of Bahrain area which is completely destructed. The debris flows over the homes concocts of silt, clays, and shale materials. The cracks and fractures developed in the affected homes.

Figure 3.3 E Lower part of Bahrain city markets showing greater destruction of infrastructures. The road and building indicate the intensity during flash flood.

Figure 3.3 F Channel from Zaro kali connecting to river swat due to high slop and strength of flood carried debris flow. The transported boulders are mainly comprised of Manglaur formation i.e. Swat granitic gneisses

Figure 3.3 G The highway connecting Madyan to Bahrain covered By Landslide materials. The flow consists of materials from Marghazar formation i.e. dark grey marble, amphibolites graphitic schist.

Figure 3.3 H and **I** Qandeel section the infrastructures and main highway slides to the river. The river banks are destroyed Terraces are also damaged and fractured as indicated in figures.

The impact on communities was magnified since the channels were shaped by walls and embankments, resulting in runoff water on these channels and the river heights exceed to 14 feet Figure 3.4 a. Debris, which mainly plant and wooden pieces, has ruined different facilities such as bridges, roads, and houses if we look around the area in addition, multiple landslides occurred as a result of the huge runoff and as a result, the highway was closed. Figure 3.4 b shows the highway connecting Central North Madyan city, which was covered by a landslide material in that area.

3.5 .1: Judgment matrix on the field survey findings of flash flood impacts (Damages record) on each study area

Flash Flood damage Criteria	From Kalam to Mingora and Effected Area
Settlements	Kalam, Bahrain, Zaro Kali, Churrai, Qandeel (Garai)
Infrastructures	Roads, Bridges, Water supply networks, Hotels and Irrigation
Commercial Zones	Medium to High Effects
Agriculture Areas	Extended Effects close to the river and Plain Area

The above Figure demonstrates the flood event's impact on each of the research area. The majority of the high flown areas were agricultural, and significant damage was done in many populated areas as well as the transportation network (bridges, roads) etc. As from the above statement the greatest levels of high water marks HWM in cities of study area (mud line) were 14 feet Figure 3.4 A and C. The dimension of the flooded area was enlarged in the area where tributaries meet to the main river. Although the district swat drainage network restricted that of valley in comparison to the others but somehow the several regions were marked at high drainage density as from Remote sensing data along the river in study area, the August flooding caused significant damages.

Figure 3.4 A Mud lines at 1.8 m, High water mark indicating the peak discharge of the flash flood of river swat in Bahrain cracks and fractures developed in the building indicating the severity of flash flood.

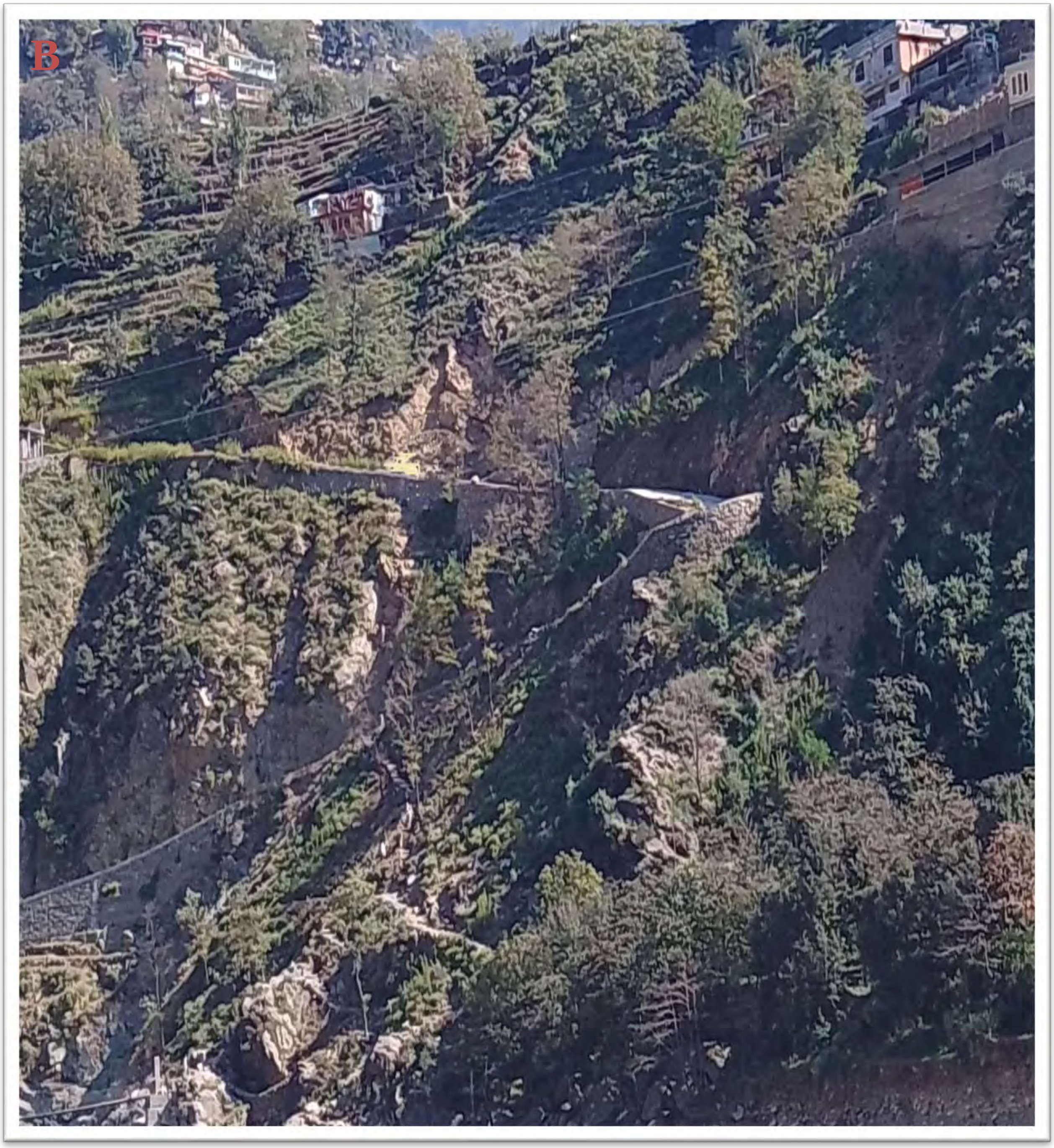


Figure 3.4 B The highway connecting Central Madyan (cham gari), road covered by landslide materials. The outcrops are mostly siltstone, shale, limestone and dominantly amphibolites belonging to kalam group of rocks.

Figure 3.4 C Impacts of debris floods on buildings and accumulation part of the catastrophic. Mainly debris of granitic rocks of Kalam group is widely spread and over flown in these infrastructures.

Figure 3.4 D showing Daral Hydropower also effected during 2022 flood and also the lower part of the project area is severely damaged and flown by the river.

3.6: Sensitive Factors behind extreme catastrophic event

The combination of severe rainfall in a short period of time and high river slopes caused several landslides upstream and substantial damage at numerous houses, as water height exceeded several meters in certain spots during the 2010 monsoon. Multiple transportation links were also demolished, along with agricultural damages, because the majority of the study region is characterized by steep slopes and high elevation. Most signs of previous floods tend to dissipate with time, however some relief patterns created by eroding or conglomeration processes, such as major erosion steps, channel changes, or slope deformations, can be observed even after extended periods of time. The depositional phenomenon was active throughout the study area as in some particular areas they were at extremes. The main focus which was sited at starting from base of Madyan the valley floor occupies the depositional materials. Sediments consist of all types; on glance sequences of deposition was the result in increasing datum of the valley river. The sediments were graded according to bed and suspension load, some of very large blocks exceeding up to meters and moved from hundreds of meters as Figure 3.3 h.

Figure 3.5 E impacts of flood, connecting Bahrain to Mankyal top (Churrai) road completely eroded. The outcrop succession belongs to Kalam group of rocks.

Figure 3.5 F Impacts of flood on debris flow and lateral erosion the bridge collapse at Madyan city they are alternate route built for the city now the river outflow stocks below the bridge.

Figure 3.5 G Impacts of debris floods on overpass of Qandeel Gari. They were completely destroyed in flash flood as shown in figure

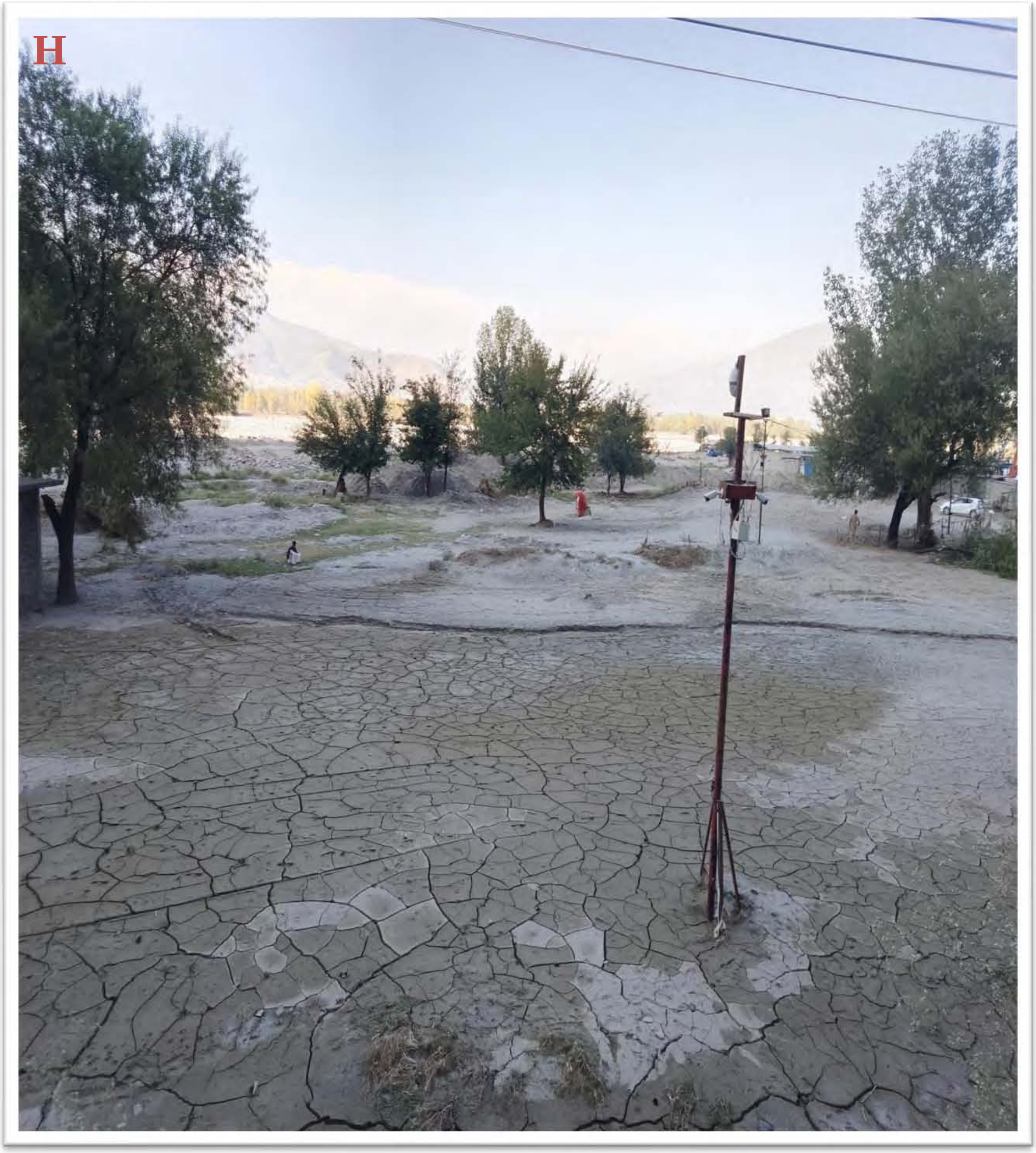


Figure 3.5 H Dynamics change and landform evolution depositions of muds on sands, mud cracks at faiza gut point. Such mud cracks are developed and over flown by flood at several places.

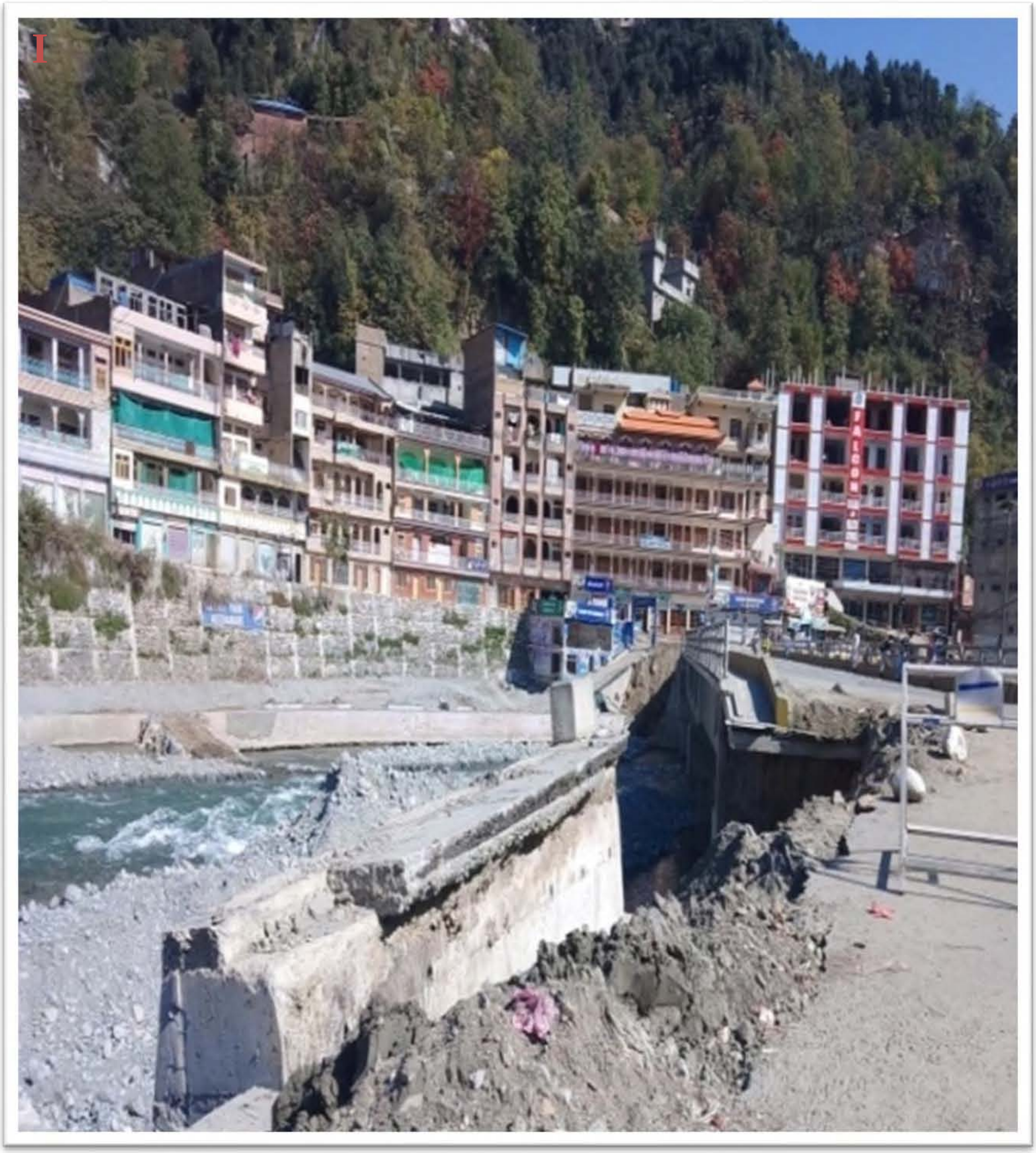


Figure 3.6 I The main two line concrete bridges which connect Madyan to Bahrain is completely destroyed along with a large section of road.

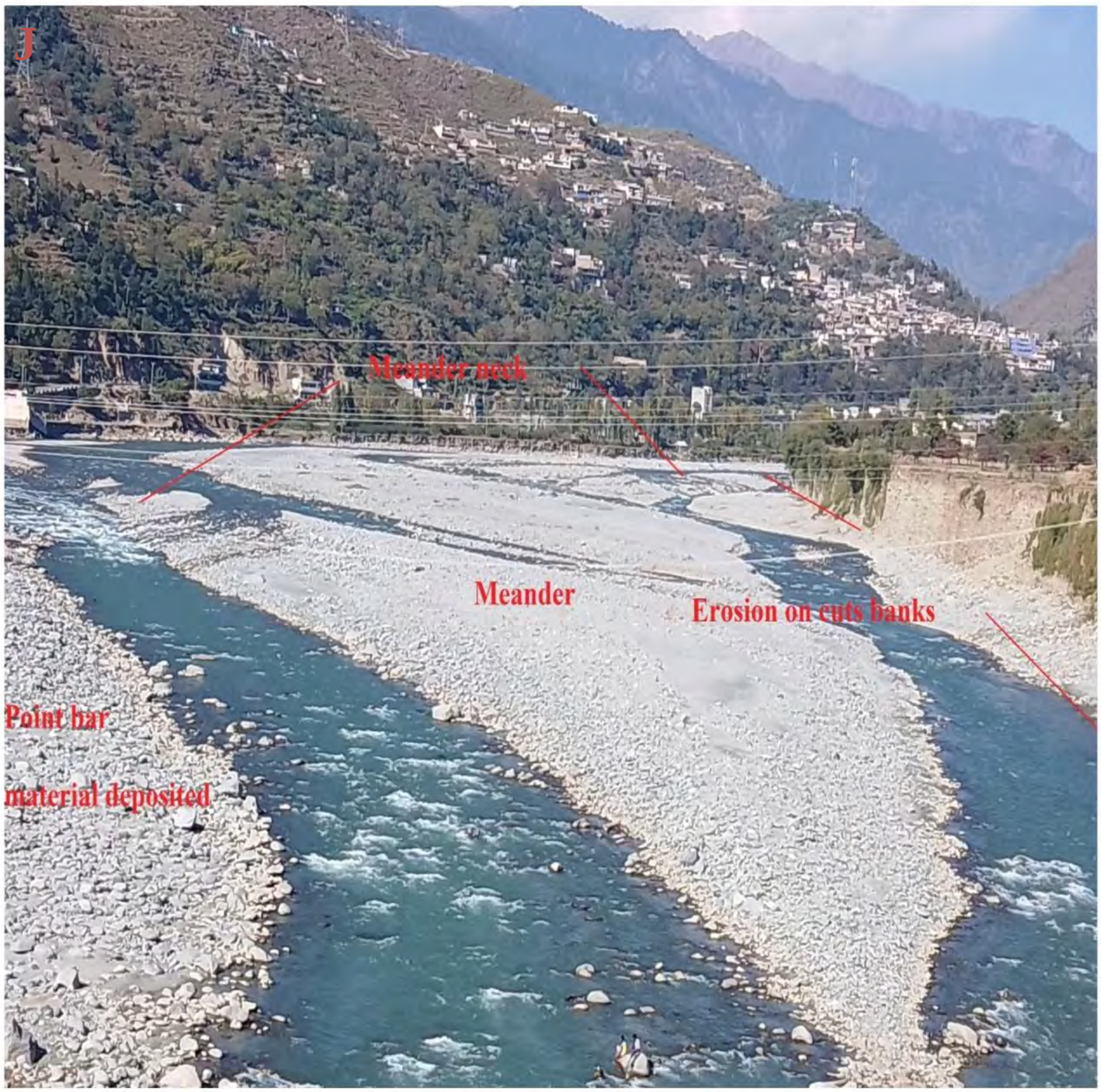


Figure 3.6 J River bed of the swat River after flood in August 2022 (Photo from field trip in September after the flood). As figure show the heavy loaded meander is developed in river swat comprises of heterogeneous sediments over flown into the river banks and point bar.

In the case of flash floods, these occurrences have a restricted geographical scope but can have significant geomorphic consequences and generate substantial damages by J.Demek and J.Kopecký 1997. For example the flash floods of 27 august precipitations caused extremely severe sheet flooding and gully erosion. The terrain changes (gully erosion, landslides, debris buildup, etc) during this brief event were bigger than in the preceding 20 to 30 years. If we talk about second key point form feature of the basin is the circulatory ratio It has the potential to affect drainage efficiency and, as a result, the vulnerability to flash floods. Additionally, if precipitation in a circular or circulation basin covers nearly a similar distance, it is likely to arrive at the basin outflow at the same time, resulting in a significant peak departure. In contrast, the runoff from the prolonged and extended basins there may have one primary exit thus it is projected to spread out over time, resulting in a smaller peak discharge. A low circulation ratio implies a small probability of flash flood, whereas a high value indicates a large runoff potential and, as a result, a high risk of flash flood Malik et al., 2019. Through scientific methods it is essential, and it is necessary to move with caution to adverse impacts for nature, some precautionary manners and measure must be followed by designers of modern buildings. They should assess the appropriateness of specific places while keeping in mind any risks or hazards, e.g. Flooding, landslides, and earthquakes are all potential hazards. They are more precisely to account and examine landslides and other abrupt or slow recent geodynamic phenomena in river basins, with a focus on their interactions with geomorphological processes occurring during and after floods. The Swat River basin and its sub-basins have a significantly varied area, thus larger basins catch more precipitation will occurs as compare to smaller basins, and resulting in greater peak discharge. Moreover, wider basins alter stream numbers, stream orders, basin length, and basin width, all of which have an impact on runoff. GIS based approach when integrated with geomorphological evidences in the study of district swat which is susceptible and in risk at some regions, and examine these areas where the flood probability present because of critical factors which were investigated along the river swat.

CHAPTER 04

SUSCEPTIBILITY EVALUATION THROUGH REMOTE SENSING

4.1: Flash Flood Susceptibility Assessment

Large scale maps have been used for synthesizing thematic maps in study areas. GIS based approaches to assess the flash flood susceptibility are mainly the sections which were identified during field observation major settlements were noted at base of Kalam, Behrain and Madyan cities along these Khuwazkhela and Mingora GIS data characterized it by high and very high susceptible areas; High susceptibility is highlighted in locations where the essential critical factors for flood spreading exist in a specific location; significant values can be found around rivers and big cities that have settled through time. The findings of the study, such as when morphological evidences are combined with GIS, significant advances in flood study are made, which helps to lessen the damage and losses caused.

4.1.1: Thematic data layers

Thematic data layers are collection of information data containing a similar characteristic or attribute and are stored in the same spatial data layer. A GIS is a collection of geographic data presented as thematic layers on a map. The choosing of elements and the generation of associated thematic data layers are critical features of any evaluating susceptibility mapping model. Geology, weather circumstances (meteorology of precipitation), the slope morphology, drainage, land use, anthropogenic activity, and seismicity in district Swat are the main components regulating instability in a terrain. The district swat has rough mountainous terrain with altitude variation of about 1383 meters. These elements are typically divided into two categories: preparation factors that create the flood susceptible and slope movement, and triggering factors that cause the flood to occur by Crozier, 1986. In the studied region, slope, aspect, lithology, soil type, drainage density, and lineament density each were existed. The preceding flash flood and its associated terrain variables in such case they are influenced by the selection of these elements and their classifications. Flood hazard assessment data consisted of several spatial data categories from available resources and being digitized, georeferenced and from field data thus these inputs may be further used for flash flood, satellite ASTER and thematic data layers were developed utilizing information gathered from existing maps.

4.1.2: Digital Elevation Model (DEM)

DEM are often used in geographic information systems and constitute an especially common foundation for digitally formed relief maps. The primary input of data was a DEM from the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) database, with column 3601, cell size X= 0.00027777778, and Y= 0.00027777778, a pixel depth of 08 Bit, and a scale of 1:50,000.We downloaded data from the Earth explorer (USGS). There are 04 granules which are connected with the polygon of Swat DEM data that was downloaded from https://search.earthexplorer. In order to construct various topographic characteristics linked to the flood and landslide activities of the research area, the Digital Elevation Model (DEM) was essential. It was used to determine elevation, slope aspect, slope angle, drainage density, and cut and fill volumes.

Another significant and widely used parameters Elevation for flash flood susceptibility that has a direct or indirect relation to flood because it illustrates how the shape of the surface affects the pattern, direction, velocity, and depth of the flood flow. In this study, elevation was categorized into seven groups to determine the relationship with flash flood. The word elevation model is also used currently to describe a representation of the earth's surface that includes topography and heights that are related to a defined orthometric height. These maps are based on extensive studies that use high resolution elevation data, and the resulting flood maps represent both the floodwater surface and the spatial extent of the floodplain. Map advancement demands elevation data for floodplain mapping in order to show current circumstances in the area or to be enhanced with new information. Since then, there has been a lot of land development and urban expansion, which has changed the form of the land surface significantly.

Classes of Elevation with values in meter		
Classes	From	To
1	0	770
2	770	1380
3	1380	2040
4	2040	2770
[illegible]	[illegible]	[illegible]
6	3500	4180
7	4180	5910

Table 01: It represents seven classes of elevation range (meters) chosen from the Elevation map.

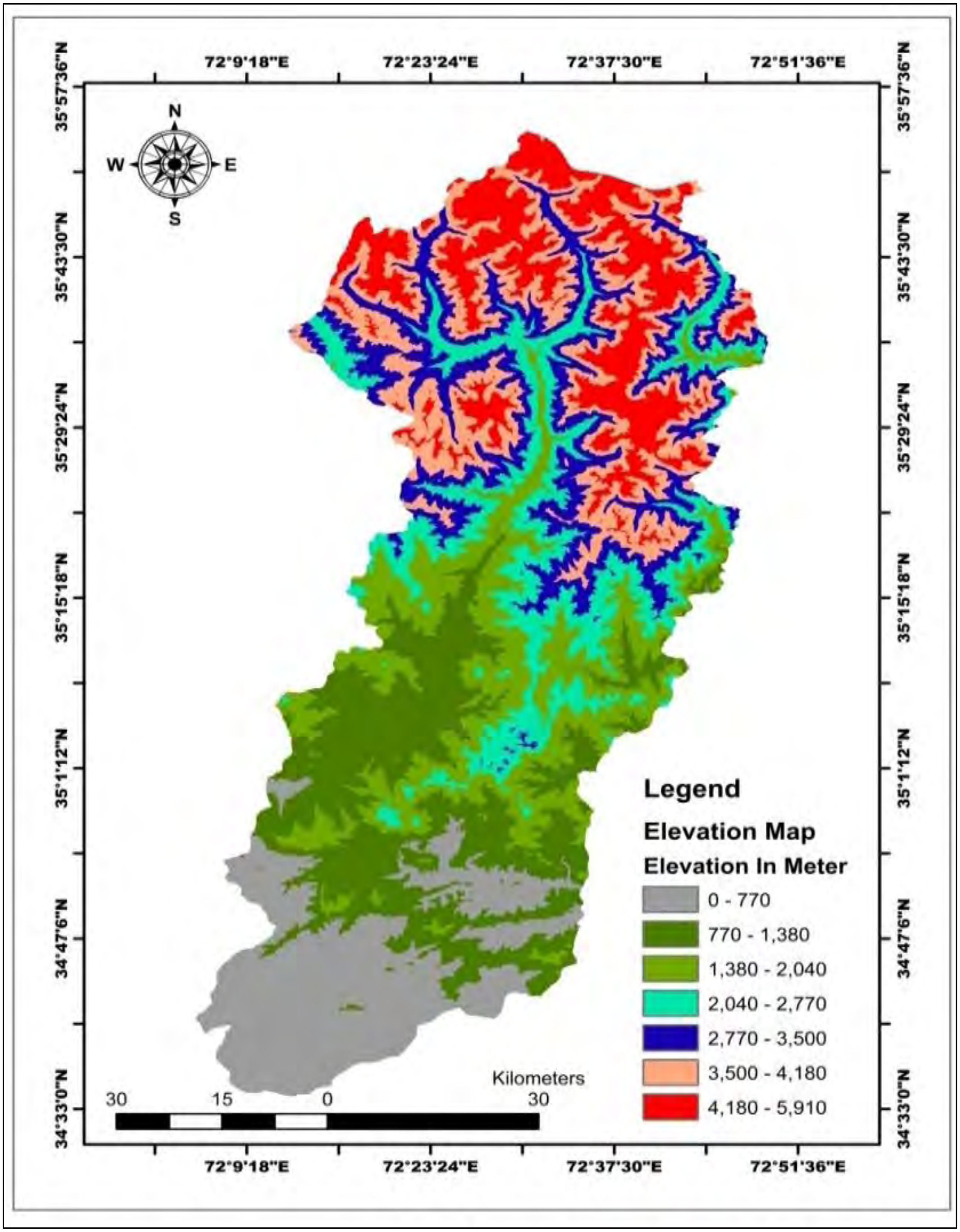


Figure 4.1 Elevation Map of district Swat showing elevation ranges.

4.1.3: Slope and Aspect

One of the most important topographic elements determining the probability of flash floods is the Slope. In general, as the slope increases, so does the possibility of flood and landslide occurrence. Gravity and shear strength increasing as slope values increase motivate material activation by decreasing the material's equilibrium. We obtained the slope using ASTER's Advanced Spaceborne Thermal Emission and Reflection Radiometer DEM, from which we discovered the slope instability of Swat district. Up streams and the River affected by huge rainfall to great extent and in District valleys, overflow significantly exceeded flood plains limits. Cities on adjacent to hills as from field evidences Figure 3.3 h so they cause significant damages, Watercourse tracks affect stream gradients, the volume of water flowing, and slope inclination through a variety of geomorphological processes. It is connected to lithology, organic and inorganic soil composition, and drainage sajjad et al. River basins produced by various types of rocks are impacted by heavy rains. It is important to draw attention to the continuous processes of relief changes on higher gradient tracks, notably in upstream regions where unabsorbed water rushes quickly from mountains to channels. Steep sided valley, overflow was limited, bed erosion loose sediments are washed away by water courses and their tributaries. In order to control erosion, slope gradient is necessary. The possible risk of slides on terrain with greater or high slopes is widely known. In general, runoff features may be seen in slopes with uniform, concave, convex, and complicated shapes. They were classified into five classes with at least from 15° interval as per slope classification. All of the area occupied by > 45° slope these classes are high risk to flood and landslides.

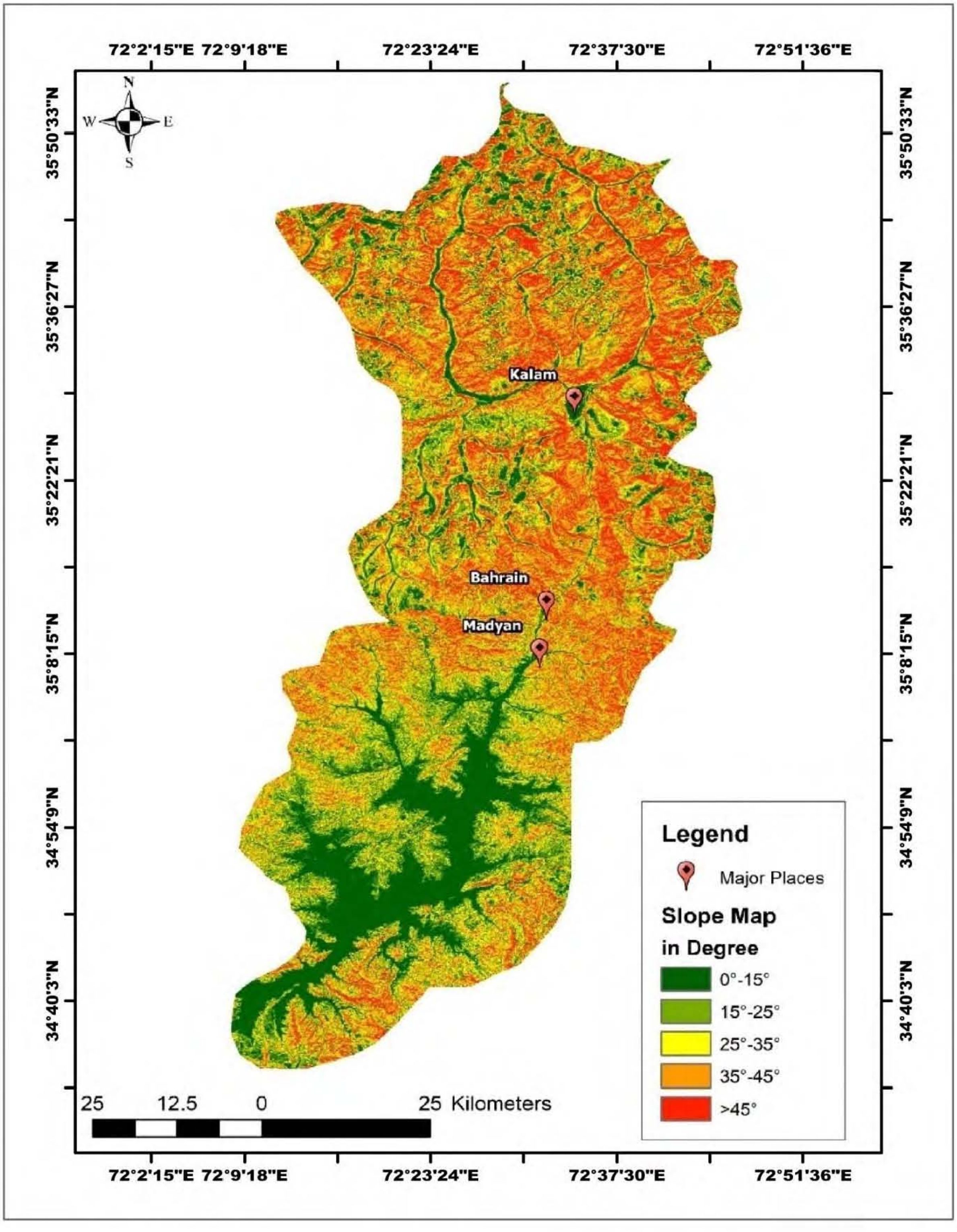


Figure 4.2 Slope Map of district Swat showing slope in degree and indicates > 45°presenting high slope area.

Aspect can be defined as the orientation or direction of the highest slope of the terrain surface determined in geographic direction of azimuthal degree N because of raster format and computational limits aspect distribution having sensitive principle directions. The study area has been split into nine divisions based on the direction: Flat, North, Northeast, Southeast, South, Southwest, West, and Northwest. In this case, we used the DEM database for the aspect In order to create a thematic layer of aspect and display its distribution in Figure 4.3, aspect was taken from the spatial analytical tool.

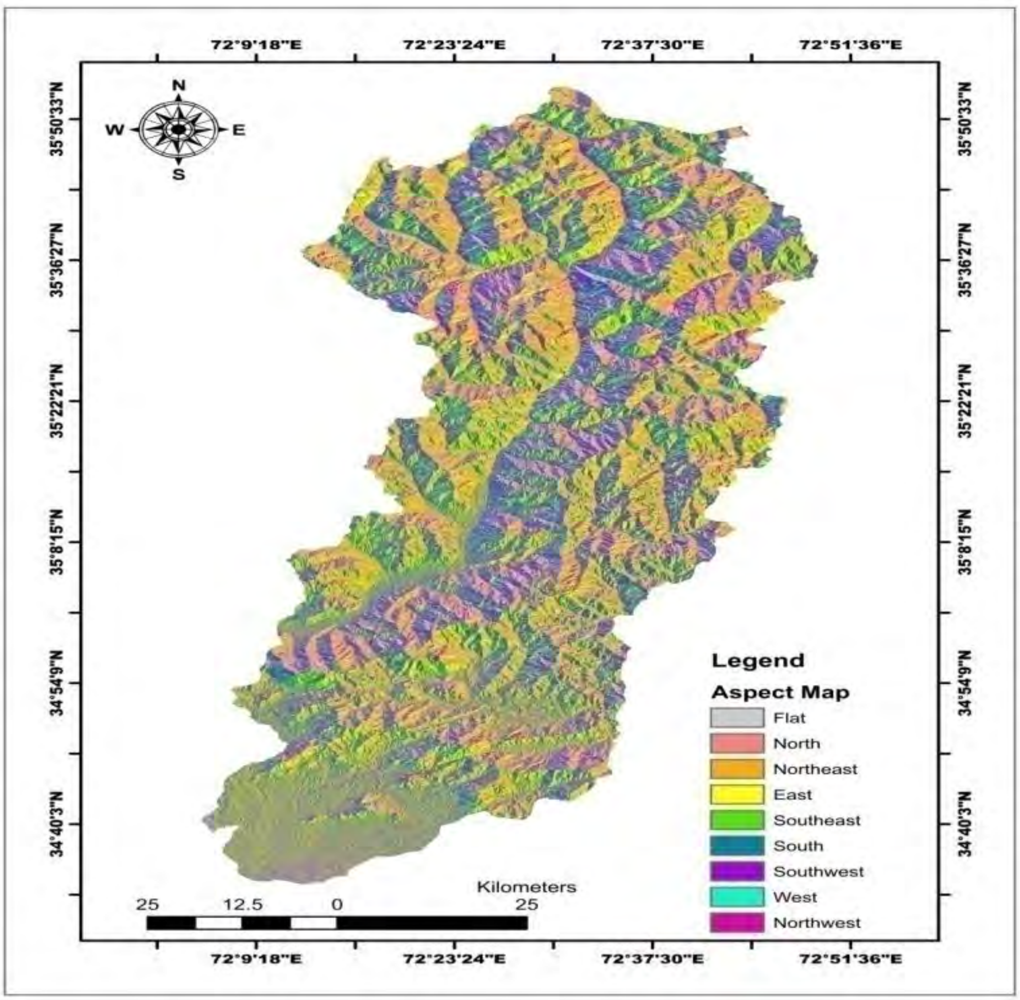


Figure 4.3 Aspect Map of district Swat showing Direction of slope and the respective directions are indicated in the index of map.

4.1.4: Drainage density

Drainage density is a measure used to characterize the physical properties of a drainage basin. Drainage density is defined as the entire length of channel in drainage, as first reported by Robert E. Horton 1932. The balance between the erosive strength of the overland flow and the resistance of surface soils and rocks is shown by drainage density, which is a measure of the network's texture and is regarded as an essential indicator or important index. The whole study area drains into the Swat River, which receives water from seventeen tributary channels that start in the Swat district's high valleys and alpine meadows and proceed from Kohistan, where many glaciers feed the Usho and Gabral rivers (sometimes known as the Utrar River) join near Kalam to form the Swat river it enters the Peshawar plain after 320 km and eventually meets the Kabul River at Charsadda (Nisatta). The study location is a hilly terrain that receives roughly 44 mm of rain each month both the lowest and highest temperatures have remained constant at 6.2°C and even 20°C, respectively because high mountains keep much of the monsoonal wind and moisture at bay, the summer season normally receives normal precipitation but heavy rainfall triggered widespread in the month of August 25, 26, 27/2022 contribute in the study area to record August rainfall total (monthly, daily and yearly). Shape, size, soil types and Topographic derivatives are critical and contain vital information for the flood flow event in the area. The drainage map has been produced using the topographic maps DEM and satellite images as supplementary input. For the drainage in this particular instance, we used the DEM database from the spatial analytical tool; we used a Hydrology tool for drainage density maps in research. The region was considered at risk to determine that they are buildup in a way of flow as Figure 4.4 and drainage density layer divided it into three categories for those raster pixels, equal interval ranges of five risk classes were used. It has been determined that river densities are maximum (means to gather rain water rapidly) along the bank of the river and there will be high discharge rate, therefore water absorption capacity decreases as density increases, and hence a flash flood is expected in that area.

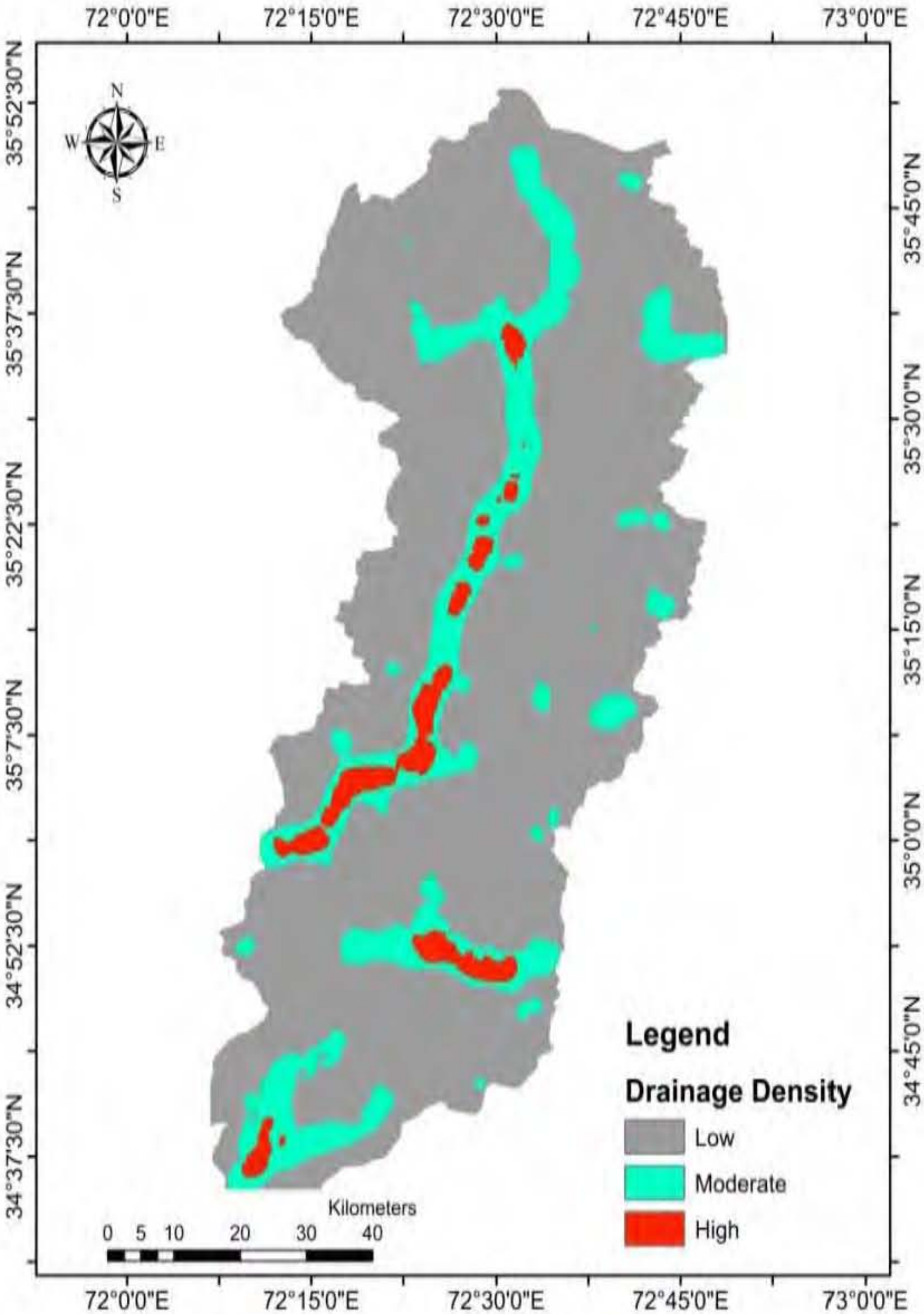


Figure 4.4 Drainage density Map of district Swat showing different classes on the bases of its density. The index shows Low, Moderate and high drainage densities along the river swat.

4.1.5: Soil

The topsoil cover is necessary on a slope with substantial runoff, which may result in floods. Soils on dissected erosional surfaces vastly differ according to the parent materials. The soil map we conducted from previous literature which further I digitized in ArcGis software. We classified soil maps into five classes which are loamy, clayey, loamy shallow, moronic and Rock outcrop and loamy very shallow soil. In our study area the large area is covered by loamy very shallow soil which is coarse loamy. Soil made up of sand which having particle size greater than 63 micrometer slit size >2 micrometer less amount of clay < 2 micrometer the best soil for vegetation however the types may include in maps but triangular classification may include slit, sand and clay by percent, Properties of such soil with draining fluid retaining and used as ancient construction material. Rocky outcrops are described as visible exposures of bedrock or other geologic formations at the Earth's surface. And the moranic type soil is made up from the unconsolidated (regolith and rock) sometimes referred as Glacier till where it’s rounded particles ranging size from boulder to gravel and sands its exposures from unexplored area.

Soil properties with less permeability May leads to flooding also to reduce protecting it with vegetation cover from steep slopes and erosive rainfall leads soil erosion and from physical properties of the soil susceptibility to water erosion moderate to high and rare in areas where aggregated.

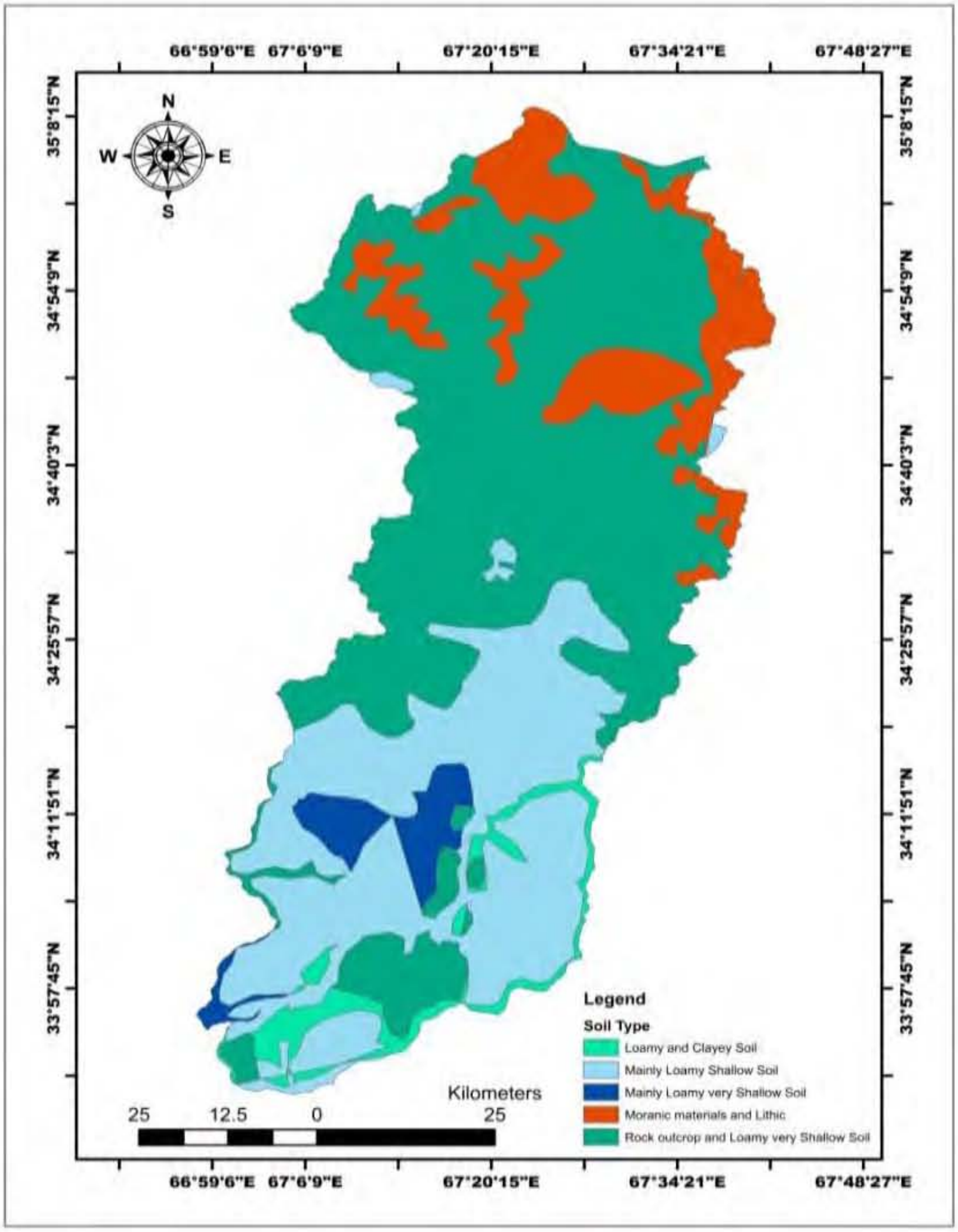


Figure 4.5 Soil map of district swat illustrates types of soil Digitized from previous literature (Jamal Nasir et al 2020) Flash flood risk modeling of swat river sub-watershed: a comparative analysis of morphometric ranking approach and El Shamy approach.

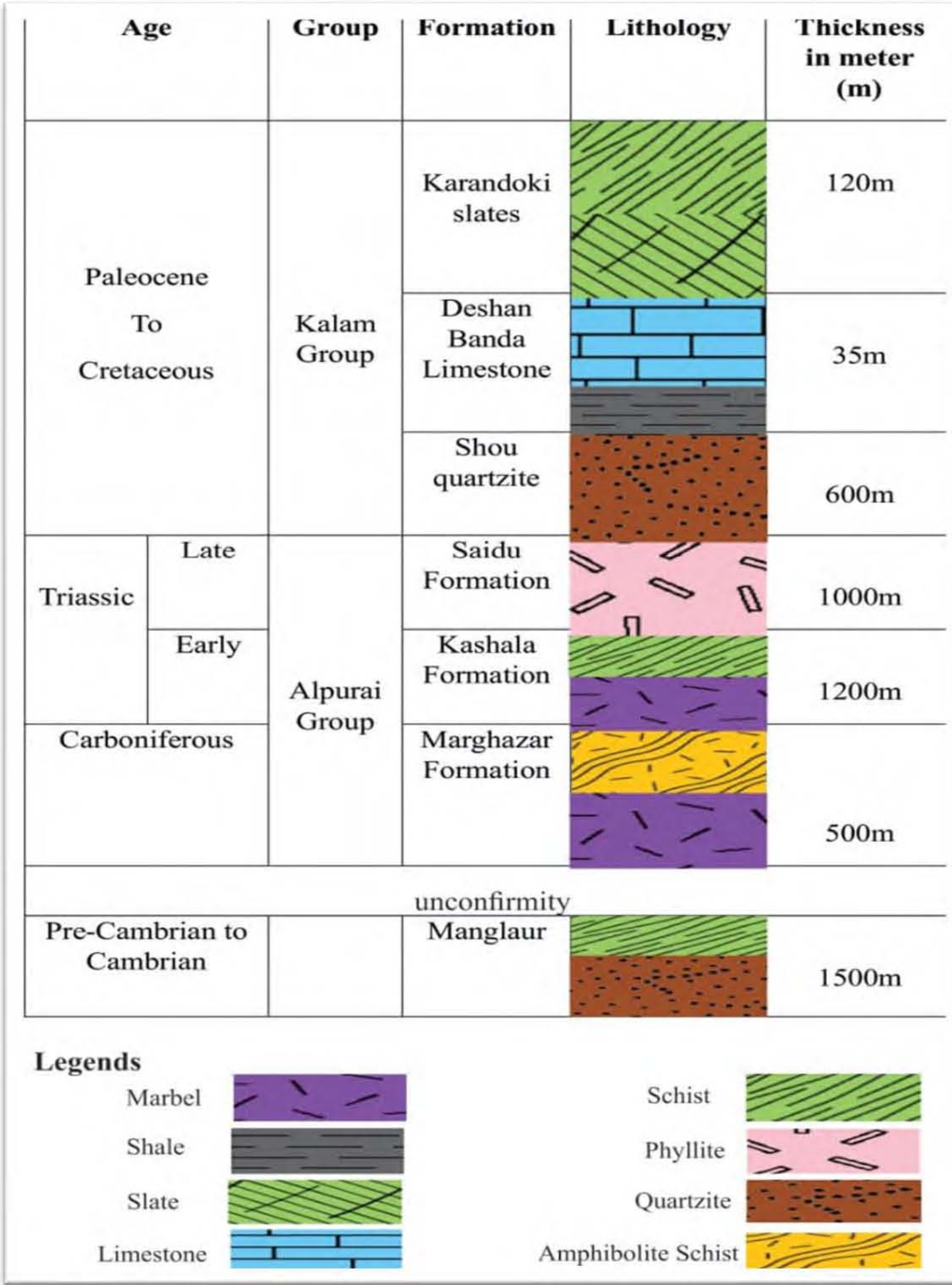
4.1.6: Lithology

The lithology of rocks reflects their basic physical properties. It is largely made up of three distinct types of rocks: igneous, sedimentary, and metamorphic. Generally rocks having specific behaviors to flash flood in the study area Swat, details of following rocks are described in detail and mentioned in previous chapter geology of the area that includes Alpuri group of rocks, which consisted into several formations then Kalam group of rocks having different lithologies. Rocks identified in the area include the Mingora Ophiolites, Swat Granite Gneisses, Manglaur Schist, Alpurai Schist, Saidu Schist, Indus Melange Group, Amphibolites of the Kohistan Arc, Calcite marble, amphibolite schist, psammitic schist, feldspathic quartzite, epidote biotite schist, metasedimentary schist, and metaigneous schist.

Chakdara granite metamorphic to dioritic, sedimentary exposure micaceous quartzite, schist and phyllite Lithological units are an important factor for susceptibility mapping, in which various forms behave differently depending on the type of material there is somehow the igneous lithology is dominant so the capability of water absorption is less as we discuss that depend on nature of the materials. Formations and Groups in that region where our study focus they are digitally captured, examined, and categorized into five classes by using GIS application and Map indicating that most of the region is covered with igneous and metamorphic rocks ranging in size from cobbles to boulders their movement inflicts such havoc during that flood event then we Correlate the data with traditional model of mathematical equation force on boulders.

4.1.6.1: Lithostratigraphy of the study area

Lithostratigraphic table of the study area includes Chrono-Stratigraphy, Groups, Formations and thickness (meter) of rock bodies that were exposed in lower swat area and continued till Kalam group of rocks. The lower Swat area divided into Manglaur Formation which is overlying unconformably by Alpurai group of rocks. Alpurai group was subdivided into Marghazar, Kashala and Saidu Formations. Recent deposition of Kalam group subdivided into three Formations that are Shou quartzite, Deshan banda limestone and Karandoki slates. This table was constructed from the literature Stratigraphy of Pakistan by S.M.Ibrahim Shah 2009.



Age		Group	Formation	Lithology	Thickness in meter (m)
Paleocene To Cretaceous		Kalam Group	Karandoki slates		120m
			Deshan Banda Limestone		35m
			Shou quartzite		600m
Triassic	Late	Alpurai Group	Saidu Formation		1000m
	Early		Kashala Formation		1200m
Carboniferous			Marghazar Formation		500m
unconfirmity					
Pre-Cambrian to Cambrian			Manglaur		1500m

Table 02: Lithostratigraphic table was classified on basis of Age, group, Formation, Lithology and thickness of the study area.

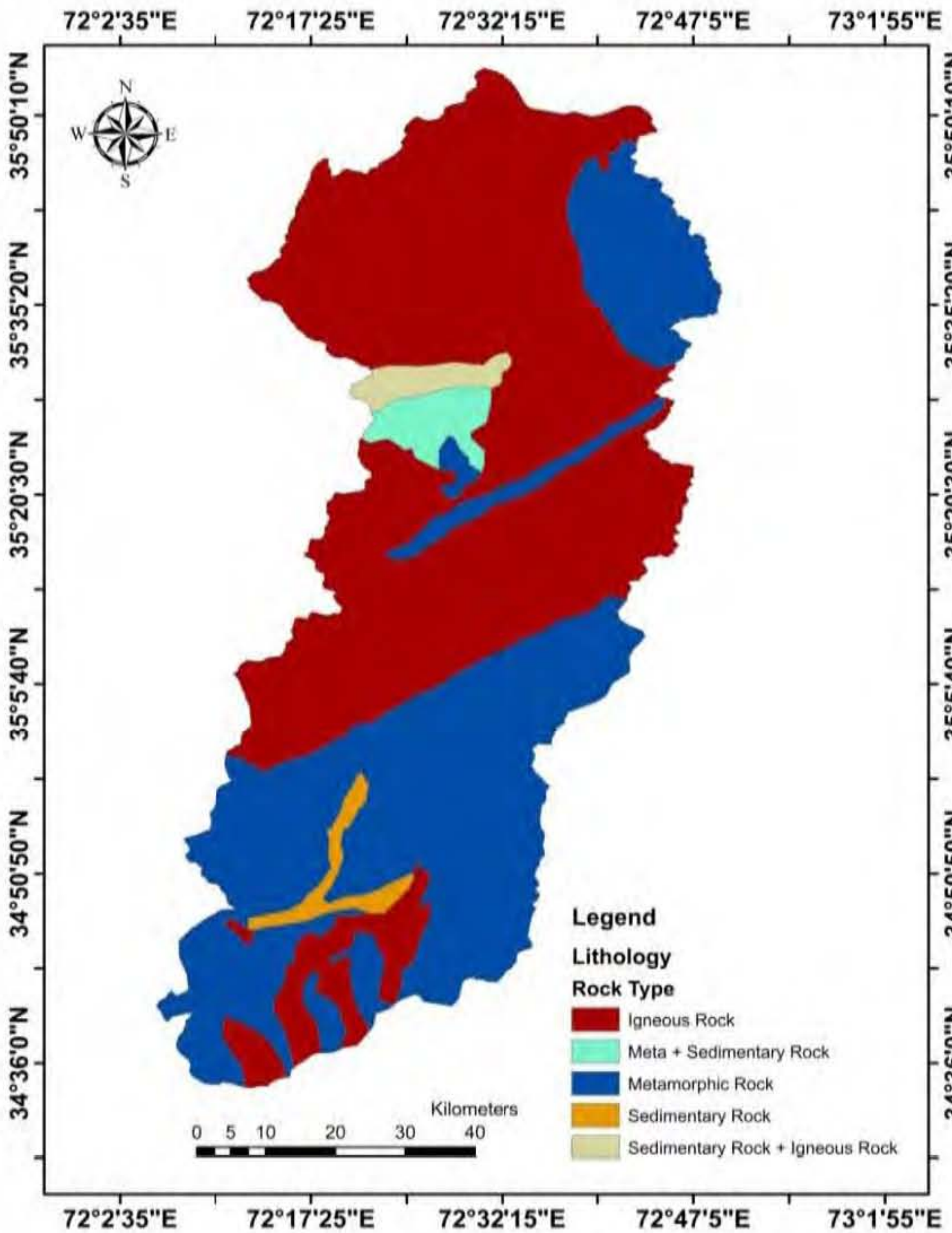


Figure 4.6 Lithological Map of district Swat showing different types of lithologies in study area. The legend presents color variations for different lithologies.

4.1.7: Mathematical equation model for moving boulders

At following disastrous catastrophe, the majority of cities in the Swat region were dealing with the residents, and the same narrative for the reason of the tragedy was offered. When there is rapid flow during a flood the area is highly mountainous terrain in which Boulders moving during flash floods with high velocity and cause considerable damages to infrastructures and casualties same with study area Figure 4.6.1 b, c and 3.4 c. The flow conditions from the size of larger fragments contained within flash flood deposits in condition are often assumed to be constant in time, i.e. steady flow, or vary instantly between periods of constant conditions from upstream to downstream. It is expected to demonstrate an overestimation of the river Swat's peak flow velocity or discharge rate. Flash floods are distinguished by extremely fast changes in flow that create considerable transitory forces in addition to mean drag flow. As from the area of Kalam to Bahrain in map view if we compare to geomorphological survey the higher elevated regions such destruction are caused and further in risk where high runoff causes most material flash flow. It is difficult to determine the flow parameters of flash floods; however several published hypotheses, such as Doyle et al. 2011, demonstrate the nature of the fast changes. Boulder movement and devastating materials with addition of impulsive force generate shaky flow of flood, and discuss.

Consider acceleration a (t), boulder velocity us (t), and flow velocity u (t) during force down slope. Relative When a frame is fixed to a bed, F equals mass multiplied by acceleration F = ma, where m is the inertial mass of the body. According to Newton's equation of motion, F = ms du_s/d_t, there is a net force acting on a boulder with inertial mass ms and velocity us (t). Force F is the sum of drag F_d, impulsive force F_a, and friction force F_f acting on the boulder and the bed, respectively:

$$F = F_d + F_a - F_f (1)$$

The drag force $F_d = 1/2\ C_d\ A\rho_f\ (u_{o-}u_s)^2$ where $C_d = 1$

The lift coefficient, Cl, is frequently much less than the drag coefficient, Cd. Many boulders, however, are non-aerodynamically designed, and a typical boulder experiences zero lift when it is above the bed and surrounded by water, as well as when the boulder is half buried, exposing just the upper surface to flooding. The flow front lift is relatively little when lift = 0 in proportion to the impulse force.

The Laplace partial differential equation was used to approximate boundary conditions via the surface of the boulder. As a result, A is the cross sectional area magnitude of Ma is proportional to the volume of the boulder V. and ρ_f the density of a boulder the impulsive force $F_a = k\, \rho_f V\, a(t)$,

Where the dimensionless constant is k that only depends on the shape and orientation of the boulder in example as the added-mass is estimated from values of square in which k = 1/2 and for the vertical cylinder shape so k = 1. And V is the volume of the boulder. The Force of friction is $F_f = \lambda(\rho_s - \rho_f)Vg$, which equals to M_a where the λ coefficient of friction, and $(\rho_s - \rho_f)Vg$ is the buoyant weight. These values were substituted in Eq. 1:

$$F = \frac{1}{2}\rho_f A\, [u_o - u_s(t)]^2 + k\rho_f V a(t) - \lambda\, (\rho_s - \rho_f)Vg \qquad (2)$$

The buoyant weight and friction forces are also affected by the size of the rock. When a boulder is mobile and moving at the same speed as flood water, $F_d = 0$; nevertheless, F_a can still function, especially if the boulder becomes stuck in the quickly shifting flow of the flash flood front.

Divide Eq.2 by $\rho_f V g$:

$$\frac{F}{\rho_f V g} = \frac{1}{2Lg}[u_o - u_s(t)]^2 + k\frac{a(t)}{g} - \lambda\left(\frac{\rho_s}{\rho_f} - 1\right) \qquad (3)$$

Where L is the length; $\therefore L = \frac{V}{A}$ when the boulder is at rest $u_s = 0$ $and\ F = 0\ in\ Eq. 2$ While the boulder is stationary, the frictional force F_f increases with the applied force to an upper limit, when it moves; accordingly the friction coefficient λ lies within the range restricted: $0 < \lambda < \lambda_{max}$

$$u_o{}^2 \geq 2Lg\, \left(\left(\frac{\rho_s}{\rho_f} - 1\right)\lambda_{max} - k\frac{a(t)}{g}\right) \qquad (4)$$

Impulsive force contributes to the drag force needed to move the rock bodies and results of some volumetric decrease in flow speed. However, due to the quick pace of action, it is often hard to obtain precise information and energy conditions. These sediment loads can instead be assessed using a turbidity meter.

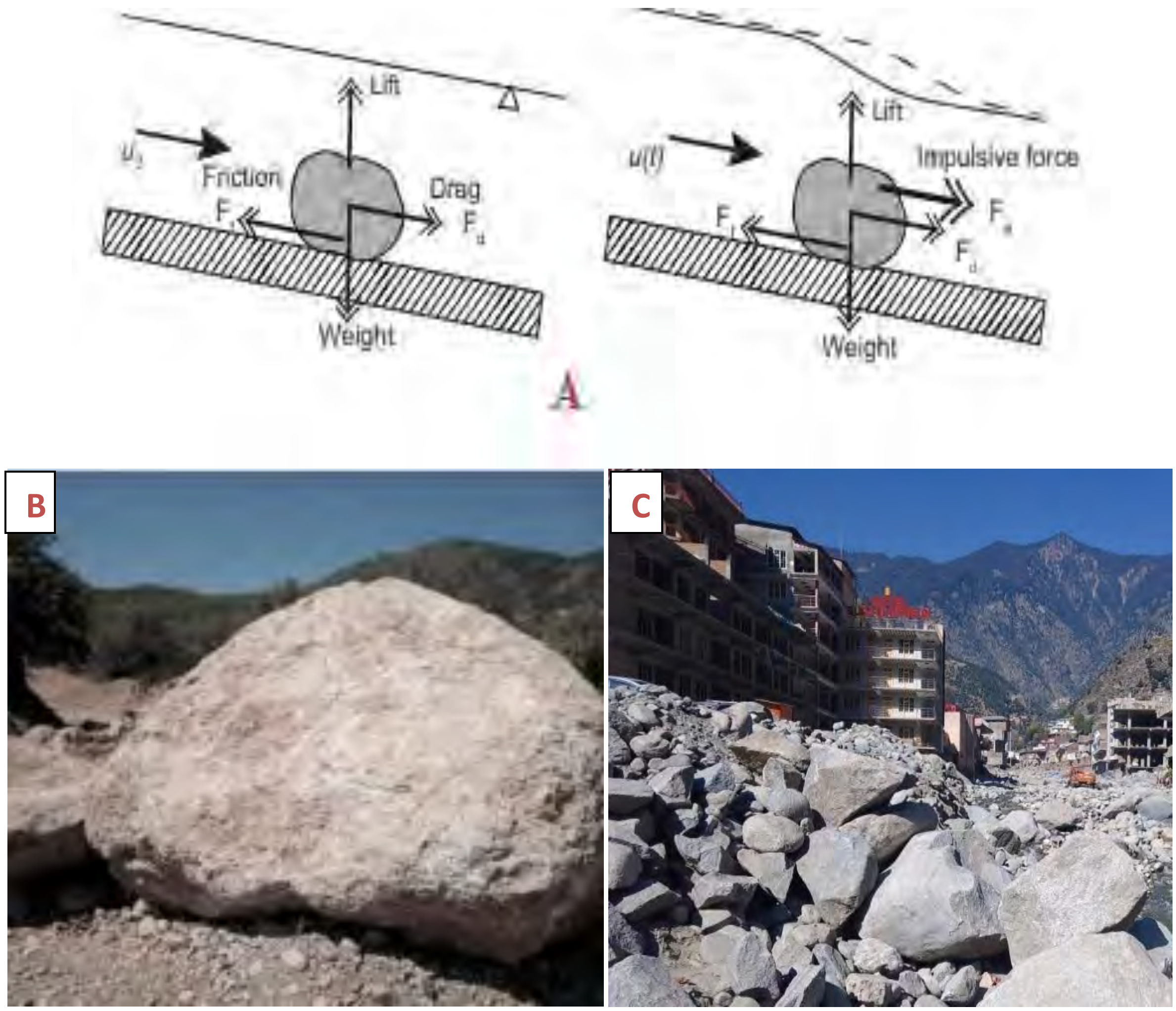


Figure 4.6.1 A Model of force on boulders **B** and **C** Images from a field in the area of Bahrain showing movement of boulders during flood.

If it is assume to measure the flow velocity of fluids, from such the sizes of grain to deposits making a considerable assumption that all present materials will shifting but the huge blocks are moving first however, due to quick activity they have larger area for resistance, it is sometimes impossible to acquire reliable information.

4.1.8: Land Use Land Cover

Land use patterns have a significant impact on flash floods; the ongoing study attempts to identify flood-prone locations in the higher portions of the Swat River basin. Also, mapping those areas which are suffering from floods and the urbanization headway also minimize deforestation and to limit residency in these locations can keep away great quantities resulting from these events happening. The current Land Use Land Cover map, 9 land use classes were identified. The predominant class in the study area is snow and glacier and mostly the flood affected area with barren land in upper part at peak of Bahrain and lower part of the study area are mostly predominant class with dense forest and Comparing to a barren region, with woody vegetation on the river bank is serves for the slope. The process of digitizing monitored land cover mapping in the Arc GIS environment included creating new layers in Arc Catalog, inserting features to those layers in Arc Map, and classifying their classes as water, agriculture, barren, range land, Alpine pasture, settlements, snow and glacier, and shrubs/bushes classes.

In general, a land-use map of a hilly terrain indicates the distribution of water bodies, forest cover, and various land-use practices. We digitized a land-cover image from prior research to create this map. Whereas we saw that the regions coated with natural trees, Natural high shrubs, Agriculture in sloping valleys, bare areas, and Glacier and water bodies were correctly classified. Thus by recognizing these floods areas can put up correct assumptions and mitigation measures and also, identifying the regions that may suffer from flooding.

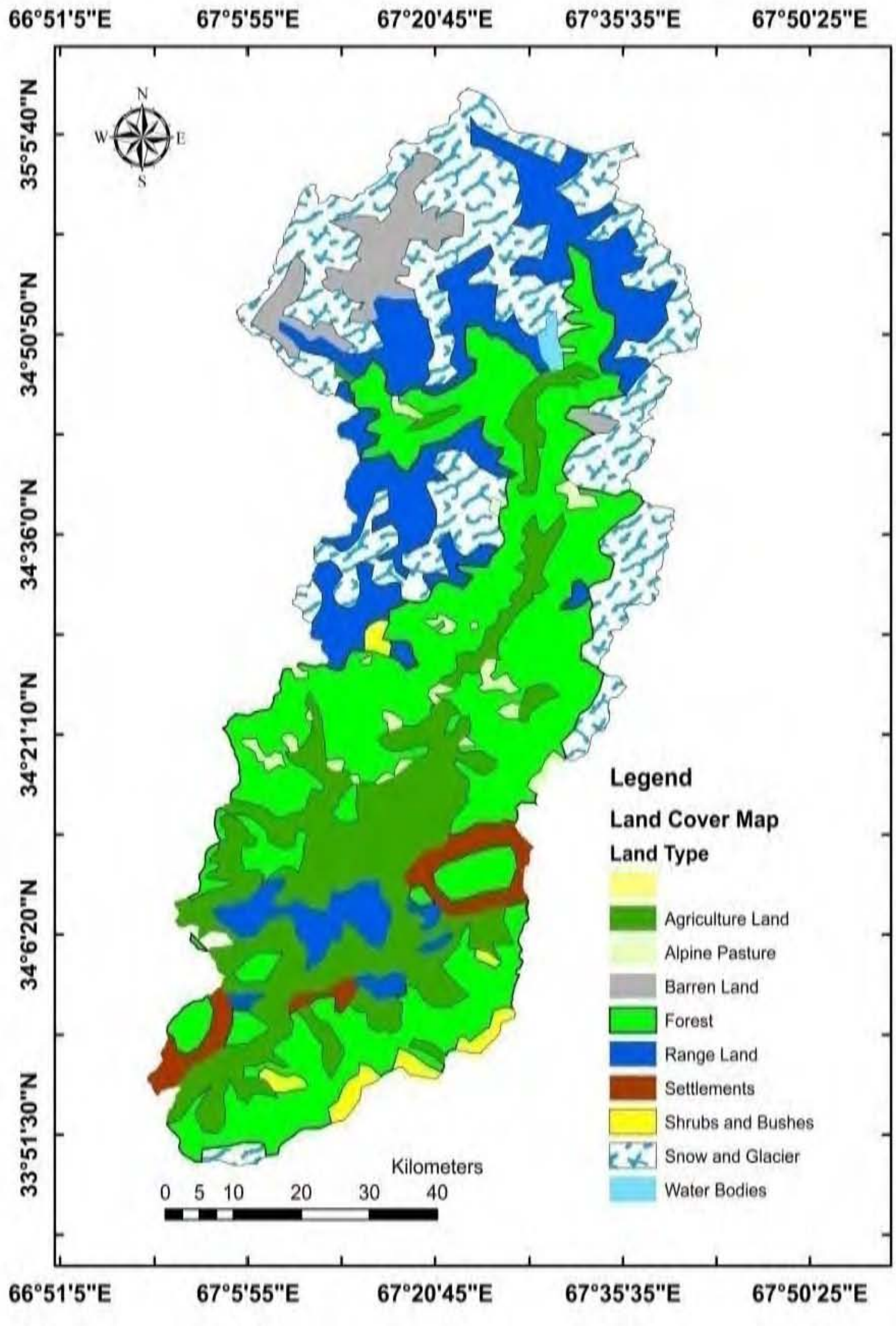


Figure 4.7 Collection of land cover classification assessment in district Swat area.

4.1.8 Susceptibility Map of District swat

Weighted overlay method (WOM) is a simple and direct tool of Arc GIS to produce a susceptibility map Bachri and Shresta, 2010. Many researchers used WOM Basharat et al., 2016. We used an overlay of raster layers of all controlling factors to prepare a susceptibility map. Raster layers of each controlling factor were reclassified and weighted according to their importance. All layers were combined by using the weighted overlay tool based. The completion of this process resulted in the ultimate production of flash Flood susceptibility map of the district Swat. The weighted overlay method is useful for making decisions in flood-prone areas as well as Landslides.

Susceptibility assessments were completed for areas that were completely destroyed by the 2022 flash flood. The mentioned parameters typically employ the method briefly overview of each parameter same like elevation, higher elevations might indicate reduced susceptibility same connected with lower elevation be more prone to flash floods as we assume from the geomorphological observations that significant damages were happened as the contacted regions along the River Swat in area of Behrain, Madyan and then lower swat till Khwazkhela the rushes flow from above four thousand meter height such accumulated fluids make over flow on threshold valves and make the flood plains more to expand. Slope may increase flash floods due to faster runoff as the weighted of slope classified in five classes from 15° interval. The area occupied by > 45° slope these classes are high risk to flood and landslides.

Different aspects direction can influence solar radiation and evaporation rates effecting flash floods. The type of rock can impacts water infiltration and runoff influence same as we past from lithology of the area as much of the area were based on igneous lithology and that spatiality and specifically spot with in the area, same it includes in the Chrono-Stratigraphy, Groups, Formations and thickness (meter) of rock bodies that were exposed in lower swat area and continued till Kalam group of rocks.

Soil drainage also contributes in higher surfaces runoff that increases in flash flood risk with the presence of the weighted parameter in range of very clayey soil to moranic. Land covers such as urban areas, land use; deforested areas may highly impact the area for flash flood susceptibility the swat area lesser part from kalam were the dominant class is snow and glacier and mostly the flood affected area with barren land towards the upper part. The method assign waits to each parameter for their importance e.g. elevation and slope might have higher weights if they considered more influential. Such specific methods and weights used can vary based on local context, available data and the expertise of those involved in the analysis. Additionally involving hydrogeology and geology can enhance the evaluation of susceptibility in the area. The susceptibility map show risks in some region flash flood risk factor were classified in 3 classes from Low to High.

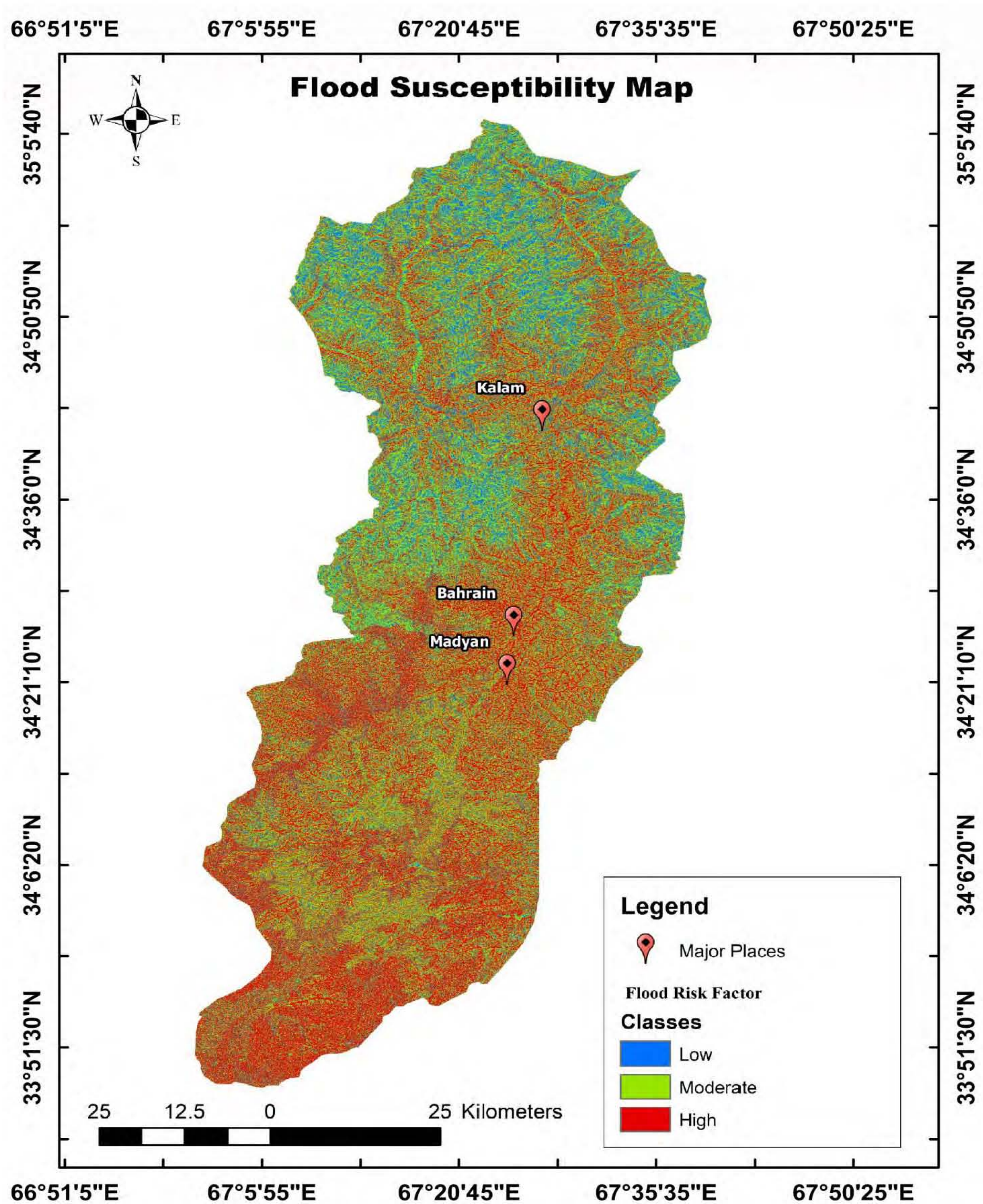


Figure 4.8 Flash flood susceptibility ranking of the Swat River based on weighted Overlay approach.

Map Validation

The most significant and very necessary segment in prediction modeling is to validate the forecast outcomes. The prediction model and image are completely meaningless and have no scientific importance until they are validated. We propose many basic validation approaches so that our prediction findings may be understood effectively in relation to the future Flash flood hazard. After obtaining a prediction image, enough validation should be based on a comparison of the forecast findings and the unknown target pattern, i.e. the areas impacted by future Flash floods. Assume that the research region has floods from the past. A straight analogy with the goal pattern is not possible since the target pattern (the future prediction of flash flood) is uncertain. The following most effective strategy is to replicate the comparison by utilizing a portion of previous floods as if it represented the goal pattern. To replicate the comparison, we must limit the use of all prior flash flood data in the study region. By splitting the data, one subset of the data is utilized to generate a prediction picture, while the other subset is used to validate the prediction findings. It would be impossible to confirm the results without the partition. The validation approaches suggested here are based on the splitting of previous flash floods.

CHAPTER 05

RESULTS AND DISCUSSION

By integration of field data and Remote Sensing it has been concluded that the river swat and its vicinities are quite prone to the flash flooding event and it is evident form the case study of flood occurred in 2022. Further, the Susceptibility evaluations to be done with the help of DEM mapping, and Field base Approach for the Elevation, Slope, Aspect, Drainage density, Soil, Lithology, and Land cover. The more important elevation parameter which relate to flash flood by showing surface direction, velocity and depth of flow the terrain show maximum elevation about more than four thousand meters so it is classified in seven classes Figure 4.1. Slope and Aspect are important topographic parameters picked up from DEM Aster the area totally covered with high slope more than 45 degree gravity and strength may rise and base with growth of slope values it weakens the balance and control erosion of materials Figure 4.2. Aspect show direction of maximum slope it is calculated in geographic direction N a spatial analytical tool from Dem data base and categories into nine types: flat, north, northeast, southeast, south, southwest, west, and northwest Figure 4.3. Drainage density is a vital factor for defining texture since it reveals the erosive force of overland flow as well as the repulsion of soils and rocks. River swat drained the whole area and it is feed by seventeen rivers such a broad drainage the river swat entirely possess moderate drainage density throughout its flow while certain places have high drainage density as shown in map 4.4 which is classified into three classes. Soil distribution is common, and it is erosional surface they were classified into five classes, loamy, clayey, loamy shallow, moronic, Loamy very shallow soil Figure 4.5. Most of the area covered by very shallow stony soil beside from those moranic materials also well exposed in certain area. The detail lithology portion of the northern side mostly contain igneous rocks while the southern portion contain metamorphic rocks till Madyan some area contain rear Meta igneous and sedimentary rocks which are located in Bahrain Figure 4.6. Lithologies mainly contributing some factors for the susceptibility of flash floods, different formations have varying behavior to the nature of the material i.e. impermeability of mostly igneous rocks and distance from the outcrop.

The moving boulder and its impact clarify form the mathematical modeling developed Figure 4.6.1. Flow is very rapid in case of flooding particularly more evident in our case study of river swat, so, the impulsive force helps with drag force which compels the boulder to transport with high velocity causes damages to human and even the infrastructures in the vicinity of river swat. It can also be seen that the areas of Kalam and Bahrain in map view possesses higher elevated regions where destruction are caused in high intensity and further in risk with materials flash down.

However, the map of Land use Land cover generated through integration of Remote Sensing and Arc GIS further delineates nine classes Figure 4.7. The principal class is snow and glacier and mostly the flood affected area with barren land in upper part at peak of Bahrain and lower part of the study area major class with dense forest and vegetation on river swat woody vegetation works for slope as compared to barren area. The Susceptibility map categorizes flood risk factors into three classes based on elevation, slope and aspect, soil, lithology, drainage density, land cover Land use these parameters weighing show the Susceptibility found in area of swat district into Low range in specially upper part Kalam sequence coming to moderate to High ranges in areas of particularly Behrain, some in Madyan and then swat lower parts in greater in risk. Thus by recognizing these floods areas can put up correct assumptions and mitigation measures and also, identifying the regions that may suffer from flooding.

Conclusions

It is finally concluded that, the study area have inter relationship of fieldwork data interpretation and remote sensing techniques for precise susceptibility evaluation of river swat. Susceptibility map indicates risk factors from low to high in ranges in the areas, which are susceptible and further in risk at some regions and examine during field survey. For that purpose the Geomorphological evidences and identification of mapping measures are important. To develop mitigation plans with proper allocation of resources and construction as from moving materials from high terrain. Further understanding the dynamics of floods risks to play down health and life deface and economic consequences so it is evaluated that,

- Long continues channel with no barrier for storage.
- Most of the building or infrastructure is created at the bank of river swat corridors on behalf of people encroachment they are unstable allocated at foothills with some extant they do not show strength against climatic conditions which is further susceptible.
- Huge complexity in development of the area in Land use because of policymakers and land developers the rapid development on river swat mountains slopes that’s the reason beyond to contribute and expand floods severely.
- Manage the areas of loose deposits at high terrain as moving Boulders during Flash Flood in many sites flood front are steep (high solids content) with very rapid changes in conditions. OR
- The discharge area should necessarily to increase for upcoming scenario of rapidly changing flow conditions at the flood front subsequent bores or surges.
- There was no Early Warning from our scientific community which may need.
- Unfortunately sudden climate changes, cause huge precipitation metrological station measured and record flow of river with such huge discharge at Khuwazkhela 40,872 cusecs and Panchkora 30,222 cusecs they are too much different from normal discharge.
- Evolution of landforms at down the river swat from flash flood the muds, stony materials and large debris products deposited on same soil agricultural land may risk from barren.
- Susceptibility evaluation shows that river swat in the area of Kalam, Bahrain, Madyan, and some area of lower Swat Khwazkhela are more prone to flash flood and above prevention master plan must to implement.

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