GEOSPATIAL ANALYSIS OF FLOOD SUSCEPTIBILITY IN DERA GHAZI KHAN, ALONG RIVER INDUS

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A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of B.S in Environmental Sciences

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DEDICATION

We dedicate this thesis to our beloved parents who stood by our side and supported us wholeheartedly.

ABSTRACT

Pakistan faced one of the most devastating floods in 2010 and the severity of the floods have risen since then, hitting Pakistan with distressing floods in 2022. This study focuses on developing flood hazard maps using GIS centered Flood Hazard index (FHI), for Areas under DG Khan division including DG Khan, Taunsa, Layyah, Kot Addu, Kott Chutta, and DG Khan Tribal areas. Seven flood parameters were contemplated including Rainfall, Land use/Land cover (LULC), Flow accumulation, Distance from the river, elevation, and slope. These parameters are obtained from USGS Earth Explorer and CHRIPS. The analysis was conducted by using three steps: Map Reclassifications of each parameter, Weighting, Weighted Overlay Analysis. Each parameter is reclassified and given appropriate weightage. Assigned percentage weight for each parameter indicates relevant importance to the severity and occurrence of flood. Using ArcGIS 10.4.1 all the parameters are unified to create Flood hazard index (FHI) map which indicated that 20.70% of the study area from 2010 and 41.80% from 2022 came under Very High-Risk zones. High risk zones spanned 65.93% of AOI in 2010 and 58.27% in 2022 and the remaining area was coming under low-risk zone. High susceptibility to floods was shown by the areas within the vicinity of river Indus i.e Taunsa, Layyah, Northern areas of DG Khan, western regions of Kot Addu. High risk areas increased from the year 2010 to 2022 as indicated by FHI. The proposed methodology would be helpful in early preparedness and tackling with floods in an effective manner.

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ABBREVIATIONS

AOI	Area of interest
DEM	Digital Elevation Model
DG khan	Dera Ghazi Khan
FHI	Flood Hazard Index
GIS	Geographic Information System
JPEG	Joint Photographic Experts Group
PNG	Portable Network Graphics
SRTM	Space Shuttle Radar Topography Mission (SRTM)
TIFF	Tagged Image File Format
USGS	United States Geological Survey
WOA	Weighted overlay Analysis

CHAPTER 1
INTRODUCTION

Globally, flood catastrophes are happening more repeatedly and with greater relentlessness (Syvitski & Brakenridge, 2013). Such extreme conditions that harm both people and property can be found in the atmosphere, biosphere, hydrosphere, and lithosphere of the natural environment. These conditions are known as natural hazards. Among the most devastating hydrometeorological disasters are floods (Hoque, et al., 2019). Such tragedies often result in significant financial losses, environmental damage, and fatalities. The socioeconomic structure of the human settlement is significantly impacted by these extreme events (Ahmad, et al., 2010). Hydro-meteorological hazards, like floods and storms, make up the majority of natural disasters, just like other natural hazards do. In 2010, it was discovered that 42 million people worldwide had been displaced by natural disasters such as storms and floods (UNEP/OCHA, 2012). According to UN estimates, 23 million persons were impacted because of floods from 1995 to 2015, and 157,000 people lost their livelihood (Wilhelm, et al., 2018). Overpopulation is making people more vulnerable to flooding than any other natural disaster. The leading factor behind destruction worldwide is flooding. (Milly, et al., 2002).

An increasing number of unexpected disasters, for instance droughts, extreme heat waves, and average rainfall of different amounts, are likely to occur over a considerable portion of the planet, as stated by the Inter Panel on Climate Change (IPCC) (Atta-ur-Rahman & Khan, 2013). Devastating floods have struck Pakistan, Bangladesh, India, Nepal, China, and Bangladesh throughout the prior thirty years (Aldous, et al., 2011). Because the world's population is growing at an unsustainable rate and disregards the vicinity of flash flood risk areas, flash floods go off repeatedly in urban areas. City populace densities are increasing concurrently. Flash flooding has significant negative social and economic effects in urban areas (Aslam, et al., 2017). Regardless of how close floods or other natural hazards are to the area, this is all the result of the urban population's growth. The impact and austerity of flood events are believed to ominously surge in future climate scenarios, according to several estimates from recent research (Shah, et al., 2018).

Along with that, other circumstances as rapid development, population expansion, and economic growth would increase the risks of flooding (Shah, et al., 2020). The residents of the area are constantly at risk, as are their houses and the surrounding vicinity (Miranda & Ferreira, 2019).

1.1 Floods in Pakistan

Pakistan is situated in an area where there are numerous natural hazards (Tariq M. a., 2011); Qaddafi, 2010). Pakistan is extremely vulnerable to various disasters due to the geological landscapes, which include mountains and floodplains (MA. Khan, 2007). Ninety percent of all-natural disasters in Pakistan have disastrous effects, with floods being the most common cause (Hashmi, et al., 2012). Floods are acknowledged as primary natural disasters that Pakistan faces (Rahman A-u, 2011). Historically, the river indus including the tributaries have caused flooding throughout the nation. Because of its geophysical and climatic conditions, Pakistan is a country prone to disasters. The nation continues to be highly vulnerable to various natural disasters. The economy of Pakistan has suffered over the past 65 years as a result of various flood disasters, totaling a collective financial shock of over US$ 39.055 billion (Sajjad, et al., 2019). In 2010, Pakistan experienced its worst floods ever recorded. The deluge claimed approximately 1985 lives, injured 2,946 others, destroyed over 1.6 million homes, and severely damaged 20 million more (Rana & Routray, 2018).

A vast and highly dynamic alluvial landscape on Earth is the floodplain of the Indus River (Meadows, 1999). The terrain is shaped by climatic and geomorphological variables, and it is distinguished by intense seasonality, ongoing river course variations, and dynamic processes of alluvial sediment deposition and erosion. In that regard, there is a complicated interaction between the fluvial environment and human settlement and economic activity (Dong, et al., 2017). The area has been heavily populated at various points in history, and it is currently one of South Asia's most productive agricultural regions while also hosting dense human populations. However, river and flood plain have high potential of effecting the local economy and the settlement (Garcia, et al., 2018).

Floods normally occur during the monsoon season in Pakistan due to excessive rainfall in upstream watershed of Chenab and river Indus (PPDMA., 2021). Consequently, areas in floodplains experienced high-magnitude floods, which had a devastating effect on lives and property as well as the nation's economy as a whole (NDMA, 2021). Even though there is no way to completely stop this devastating flood threat, its consequences could be mitigated using efficient flood risk mapping, GIS based mapping. (Sajjad, et al., 2022). Flood mapping can be facilitated by the most economical method of providing comprehensive data for all stages of a flood catastrophe, is remote sensing (Naeem, et al., 2021).

In poor and most vulnerable areas, the poorest households have been disproportionately affected by floods. Those regions most affected are those in which, even before the floods, human development outcomes were the lowest. Particularly for the regions of the nation that have not benefited from the advancements of the previous 20 years, this is a chance to start over and build a better future as the nation recovers from this natural calamity (Ali, et al., 2020). Future success for Pakistan depends on improving its ability to withstand shocks and strains brought on by climate change, particularly for the poorest citizens. To do this, vulnerabilities must be addressed at their root causes and improvements must be made. As a result of the 2010 floods, there have been 33 million people impacted which has submerged one-third of the nation. There may be close to 8 million displaced people. Beyond the damage caused by the 2010 floods, the disaster's scope is unmatched in Pakistan. Recovering from this disaster will require a concerted, global endeavor (Aslam, et al., 2018).

1.2 Climate change and floods

Climate change is changing how water moves around the Earth (the water cycle), causing more severe weather conditions (Kellens, et al., 2013). In the last few years, there have been more disasters that have caused a lot of damage and loss of lives around the world (Bertilsson, et al., 2019). Flooding has impeded economic development in addition to disrupting social progress in recent years. This worldwide pandemic has caused death, property damage, and financial hardship in numerous countries (Khan, et al., 2021). Pakistan ranks eighth out of all the countries impacted by climate change according to the Global Climate Change Risk Index (Saqib, et al., 2016). Floods are mostly caused by several factors like expanding cities without a plan, interfering with natural streams, and problems with buildings like bridges and culverts. These things can make floods worse, even if it is not raining very much (Faccini, et al., 2018). Since the 1950s, the number of settlements in hazardous areas has increased significantly (Plate, 2002). People migrate to flood plains for economic reasons, creating vulnerable shelters with dikes (Benson, 2004). Settlement and living in flood-prone regions contributes to the rising loss from disasters; the proportion is particularly noticeable in emerging nations wherever the already frail economies deteriorate further (Hansson, et al., A Framework for Evaluation of Flood Management Strategies,480, 2007). The main causes of flood disasters are changes in the environment, which include rising sea levels, extreme weather brought on by global warming, and trends toward urbanization in developing nations. According to Jha et al. (2011), the ratio will even pick up speed over the next 50 years (Jha, et al., 2011).

Pakistan has been tallying the economic and financial losses resulting from the devastating floods. Numerous observers believe that one of the reasons for the economy's decline is recurrent floods (Ahmed, et al., 2014). Even in regions where total precipitation is declining, storms that receive more moisture produce more intense precipitation events, which raises the risk of flooding (Maiti S, 2007). A minor alteration in the average temperature can lead to a significant shift in the frequency of extreme events, which could have significant effects on communities (Hartmann & Lisa, 2013).

Pakistan is among the most vulnerable nations to extreme weather conditions and has suffered multiple catastrophic floods, the most recent of which was comparable in scope to the 2010 event that took place in 2022 (Douville, 2021). Pakistan is situated at the intersection of two weather systems that produce precipitation: Summer monsoon rains from the east and southeast are terminated by one system, while winter westerly disturbances from the Mediterranean Sea are terminated by another. It is commonly known that as a result of climate change, these systems become more variable (Otto, et al., 2023). Pakistan is more vulnerable to extremes of this kind due to these changes, whether they be temporal or spatial. Even though Pakistan has an elevated level of vulnerability, it is a low-middle-income country. Climate change has led to more frequent and severe floods (Hashim, et al., 2012). One of its impacts in Pakistan is concentrated rainfall during the monsoon season, which causes flooding in river catchments. These floods are often intensified by monsoon currents and wind conditions, leading to devastating consequences (Lian, et al., 2015).

1.3 Geospatial tools for flood mitigation

To develop efficient mitigation strategies, it can be helpful to assess and map the different scopes of vulnerability over time and space by obtaining spatially consistent information on vulnerability indicators (Hoque, et al., 2019). Risk-based strategies have gained popularity recently as an effective way to slash the probability of flooding (Sajjad., et al., 2020). A hazard risk and vulnerability assessment, also known as HRVA, analyses the risks that could have an effect on a communal to determine the risk that every hazard that is directed to the public as well as to susceptible community members. Flood risk is quantified by the likelihood that certain events will occur and their effects (Tahirkaili, 2003). The assessment of flood risk can be done through several methods, including the evaluation of hydrological and meteorological parameters, socioeconomic factors, and a combination of these factors in addition to evaluations based on geographic information systems (Ologunorisa. & Abawua., 2005). To support the sustainable development and risk reduction strategies, it is critical to assess climate change or disaster event, such as floods, vulnerability (Birkmann, et al., 2013). The main goals of disaster management in nations like Pakistan that are vulnerable to natural disasters are crisis response, recovery, and disaster assistance (De Andrade & Szlafsztein., 2018). A comprehensive understanding of the base situation and the extent to which assets, capital, location, and population are which can be struck by a hazard can be obtained through vulnerability assessment and mapping (Blaschke, 2015). To create a realistic vulnerability scenario for flood vulnerability assessment, suitable vulnerability indices, indicators, and their integration are essential (Jamshed, et al., 2017).

Flooding has disastrous effects, and because of government negligence, its aftermath is worse (Schwoebel, 2010). Plate (2002) states that flood hazard management is a system-building process that calls for innovative methods to ensure its optimal design. According to NDRMF (2007), the primary obstacles to flood restoration are political willfulness, corporate interests, and corruption (NDRMFP, 2007). Flood-related organizations cannot control floods in a particular area through the implementation of any scheme. People in areas where hazards are common are therefore wary of what lies ahead for their region (Gaurav, et al., 2011).

The limitations of existing urban infrastructure on future infrastructure development that could help alleviate the flash flood problem should be noted when addressing the management issues related to flash floods (Jonkman & Kelman, 2005). Planning steps to shield these sites from future damage is made easier when flash flooding-prone locations are predicted. Planning new construction and infrastructure is aided by these forecasts as well (Hanif, et al., 2013). The ability to provide quick and precise flood information will be essential to reducing the damage caused by flash floods. Therefore, accurate assessment of the potential for flooding in areas susceptible to flash floods is necessary in addition to better and more effective flood risk management (Borga, et al., 2007).

The departments that work at the federal and provincial levels in Pakistan are primarily responsible for managing flood risks. However, innovative approaches and techniques to address this hazard often need to be developed, which calls for reconsideration (Mustafa, et al., 2019). These institutions fall into the risk-managing and crisis-managing categories based on the type of services they provide. Institutions that manage risk manage both structural and non-structural measures, while those that manage crises are more focused on relief, rescue, and rehabilitation efforts (Safdar, et al., 2019). Over the past sixty-seven years, the Pakistani government has made a lot of relief efforts. The flood policies consist of numerous acts and ordinances. Systems for managing flood emergencies and organizing personnel are currently being developed. Nevertheless, statistics and data on the flood-to-damage ratio show no decline. The government's humanitarian efforts fall short of expectations (Sadia, et al., 2016). According to Chaudhry (2006) and Hansson et al. (2007), Pakistan lacks a responsive early warning system for floods, even though such a system can help mitigate the effect of any disaster (Hansson, et al., "A Framework for Evaluation of Flood Management Strategies", , 2007); (Chaudhry, 2006).

1.4 Dera Ghazi (DG) Khan

Also referred to as D.G Khan, Dera Ghazi Khan is in Pakistan's Punjab region of southwest. This city in Pakistan has the 19th largest population. It is home to the Dera Ghazi Khan Division and District headquarters, and it is located westward of the Indus River. The DG Khan district stretches toward the slopes and highlands of the Sulaiman Mountains and includes a portion of the alluvial plains west of the Indus River (Akhtar, 2018). The main city of the district, DG Khan, was built on the west side of the old town as a military base for British soldiers and government workers when Britain ruled the area. After the 1909 flood, the new city emerged as the central location for managing the area and conducting trade.

DG Khan is situated on the Indus River's western bank, and it experiences two linked events. The region exhibits a distinct seasonal character due to the regular movement of the river's main channels across a vast floodplain caused by seasonal floods. The region has historically been utilized for agropastoral activities despite its arid climate because of the use of water, Indus-deposited sediments, and hill torrents (Akhtar A, 2013).

Located on the left bank of the Indus River, District D G Khan is in the southern region of Punjab Province (Tariq & de, 2012). Its citizens' lives and means of subsistence are in danger from a variety of human-caused and natural hazards. Storms, heat waves, earthquakes, and floods are examples of natural disasters. Fires, riots, auto accidents, pollution, and health outbreaks are examples of human-caused hazards (Kirsch, et al., 2012). Local governments must recognize and comprehend the risks and hazards that may jeopardize the sustainability and safety of their communities. In light of the thorough examination of the area's risks and vulnerabilities, DDMA, with technical support from PDMA, will create the District DRR/DRM Plan at the local level. mapping the resources that the public and private sectors have to offer. The District Disaster Management Plan will also contain the roles and responsibilities that are clearly defined for district line departments to conduct both before and after a disaster (Hashmi, et al., 2012).

The local companies and various household chores employ the residents of the DG. Khan (Aryal, 2014). Through their participation in ranch chores and the care of domesticated animals, women in Punjab are driven to advance horticulture (Komi, et al., 2016). Even though they have been in the cultivation industry for a long time, they still need to be knowledgeable about fundamental leadership skills because of the male-centric culture that limits them and favors men in basic leadership positions. Every day, women engage in farming activities for 12 to 15 hours (Alam & Collins, 2010).

The detrimental effects of floods cause agricultural land to temporarily become useless because of the surplus floodwater that accumulates on the land. Consequently, the sole source of their primary subsistence, the crops is destroyed. Gender relations are eventually affected by such conditions, which further destabilize communities and multiply poverty (Sultana, 2010). Though they disproportionately affect women, the above-mentioned conditions have a significant impact on the community as a whole. Rural women experience greater emotional distress when it comes to family members, household losses, the loss of valuables, and dowries because they are less integrated into society and are therefore more vulnerable (Karvinen, et al., 2016).

DG. Khan is a semi-arid region that is well-positioned and connected to Pakistan's other four provinces. This community is completely helpless against flooding because it is located between the Indus River, a common location for flooding, and the Sulaiman Mountains, which have a sudden floodwater system framework that causes flooding in areas that are slope-oriented downward (Evans, et al., 2010). The main sources of income and yields are rice, sugarcane, and cotton. These crops are the local community's main source of income. The population of this region, which migrated to the Gulf countries for business, is another distinctive feature. According to Khwaja and Aslam (2018), remote settlements are now a noticeable source of income that supports families (Khwaja & Aslam, 2018).

1.4.1 Contributing factors which make D.G. Khan susceptible to floods.

Floods in 2012 affected 0.622 million people in the city, which is prone to flooding (NDMA, 2013). Several towns and cities experienced severe flooding. It is in rural areas that the damage becomes more severe. Nevertheless, half of the city is flooded out. The Dhera Ghazi Khan Canal bursts due to abundant precipitation and concurrently failing dikes. Inundations were severe due to the canal breach. Furthermore, it was discovered that the politician's plots resulted in the removal of the dikes. Based on observations, there is a significant risk. Destructive floods harm crops and infrastructure. Findings, however, indicate that rural areas are more susceptible to riverine flooding. For the government, providing health facilities is still a significant challenge. It is difficult to get appropriate medication before, during, or after floods. Inadequate health facilities are available to treat all infected individuals, and the system to prevent and combat diseases related to water quality appears to be insufficient (Mustafa & Wrathall, 2011)

1.4.1.1 Precipitation and Poor Infrastructure

Although flooding is typically attributed to natural forces like heavy rainfall, it is more often the result of managerial failures and the vulnerability of dikes. 330 mm of rain falls on D.G Khan annually on average. July is the month with the most rainfall recorded. Flash floods are not likely to occur due to insufficient average precipitation. Flooding in this region is caused by poor management and vulnerable infrastructure. A weak flood management mechanism is the conclusion drawn from the history of floods in the area. Put simply, it represents the government's realization that it bears some of the blame for the damage. The floods can result in significant infrastructure damage due to development in flood-prone areas. Regulations can be implemented to prevent construction in flood-prone areas and improve safety for future generations (Mahar & Zaigham, 2021).

1.4.1.2 Indus Waterway and monsoon rains

Pakistan experiences floods frequently, due to the Indus River and the country's monsoon terrain. Melting Himalayan glaciers frequently make the floods worse, and future projections indicate that the situation will only get worse (Qaddafi, 2010). Pakistan's coastal region is also extremely susceptible to cyclonic flooding. Pakistan experiences flooding as a result of heavy precipitation brought on by the monsoon season, which lasts from July to September (Wang, 2006). Pakistan's topography separates the country's flooding characteristics into three distinct physiological zones. The most destructive are the plains of the Indus River, which make up 311,766 km^2 or 40% of the total area (Rehman & Kamal, 2010). The Indus Plains support a sizable population and a thriving economy. But in this area, floods can be disastrous. The Indus River rises in the Himalayan glacier streams of Tibet and flows northeastward into Pakistan. In Pakistan, particularly during the summer monsoon season, it is the main cause of floods. The Indus plains become inundated as a result of glacier melting and the ensuing monsoon rains (Gaurav, et al., 2011).

1.4.1.3 Torrents Originating from the Suleiman Ranges

The fourth significant and prominent mountain range in Pakistan is the Suleiman Range. It is situated in Pakistan's Punjab provinces southwest (Singh, et al., 2008). Compared to other northern mountain ranges in Pakistan, the Suleiman range has a different climate, low annual average, and elevation. Rainwater coming down from the Suleiman Ranges often leads to sudden and strong floods in Dera Ghazi Khan and surrounding districts (Saleem, et al., 2023). These areas are often located distant from the catchment areas that produce these floods, which is the reason due to weather circumstances in these regions can differ significantly. Torrential floods may occur suddenly without any warning signs or weather symptoms (Zhang, et al., 2019).

By determining the potential Wador Hill torrent's catchment area and adding the nearby torrent's drainage system that passes through Dera Ghazi Khan City, the area has been further refined (Milly, et al., 2002). The eastern portion of the city receives direct water flow starting at the Wador catchment area. The entire range encompasses the Piedmont region, the affected city area, and the possible area of the Wador floods. The

Wador catchment area, a ridge (2325 m) on Dera Ghazi Khan City's west side, and a flatter area (105 m) on its east make up the refined area (Ahmad, et al., 2011).

1.4.1.4 Climatic conditions

The region experiences less than 150 mm of annual rainfall on average, placing it in an arid zone. The region has a more abrupt climate, with temperatures ranging from 13 to 50°C during the hot summers and cold to mild winters. Since the westward of the city experiences hill torrents, the region is classified as non-irrigated (World Bank 2006). The estimations of changes in rainfall in future projections are not consistent. The consequences of climate change may cause the current level of hazard to rise in the future. It would be wise for projects in this area to be long-term resilient to the risk of river flooding.

The Southwest Punjab of Pakistan has seen flooding as a result of strong monsoon rains brought on by La Nina, a significant low air pressure system, and climate change. As a result, it is anticipated that the floods, which are mostly caused by hill torrents from regions like Dera Ghazi Khan (Vehoa, Sanghar, Vidor, etc.) and Rajanpur (including Kaha, Chachar, etc.) will last until the end of August (Ashraf, et al., 2013). During the monsoon season, the peak discharges are highest in these areas. Abundant rains and floods have uprooted the trees in the hill torrent ecologies of southwestern Punjab, which are already rare because of the severe arid climate. This will have detrimental effects down the road by making the environmental outlook worse and increasing aridity in the spate ecologies of southwest Punjab (Borga, et al., 2007).

1.4.1.5 Environmental Challenges of the Indus Delta

A flood does not occur without external factors. The event was a result of the continuous degradation of the Indus Delta. The entire delta has been significantly impacted by alterations to the environment resulting from changes to the river and large-scale projects. Studies have found that less freshwater and different levels of salt in the water have caused problems along the coast (Petrie, et al., 2017). This includes erosion, salty water getting into the land, ruining good soil, not enough clean water to drink, loss of certain plant life, and fewer fish to catch. These changes have made the communities in these regions more vulnerable to extreme weather events like floods (Miller, 2006).

1.5 Review of Literature

In Pakistan, floods are a common disaster. It kills hundreds of people and destroys infrastructure every other year. Pakistan has experienced floods that have claimed thousands of lives. It is challenging for developing nations like Pakistan to manage and lessen the threat posed by flooding (Meyer, et al., 2008). The difficulties that people encounter as a result of flood disasters are examined in the study conducted by Ahmed, et al., (2014). The study examines the flood crisis that occurred in the district of Dera-Ghazi Khan in 2012. A quick survey was created for the sample population to gather the data. We have used the Chi-square distribution and correlation technique to determine the degree of association between various variables. Those affected by flooding face difficult obstacles when floods occur, and the management process appears insufficient to allay public fears. Effective planning for the design of the impacted areas, technological proficiency, and collaboration can reduce the severe effects of flood disasters (Ahmed, et al., 2014).

Garcia, et al., (2018) conducted a study, which examined the floods that occurred in Dera Ghazi Khan in 1909. The researchers examined the evolution of the city and the impact of the river on the landscape within Indus Plain. Alongside maps and historical analysis, another method used to evaluate longstanding variations in the Indus River basin was the analysis of images acquired using various GIS based methods, including the application of novel algorithms designed especially for the study of geography and cyclical water accessibility (Opolot, 2013). This study examined three primary factors: the representation of historical water patterns through remote sensing images, the impact of river shape changes on human settlement patterns, and the response of individuals to these alterations. The research examines the transformation of the Indus River basin over an extended period and its impact on the culture and archaeology of the region. This evaluation offers vital information for three purposes; recognizing elements of the morpho dynamics and their potential influence on the cultural heritage; identifying traces of the dynamics and their preservation in the archaeological record; and describing how historical records can aid in interpreting remote sensing information (Garcia, et al., 2018).

Feroz, et al., (2022), investigated the effects of floods in Dera Ghazi Khan, Punjab, Pakistan's rural areas. One of nature's most destructive disasters, flooding disproportionately affects different genders and causes havoc across the nation. Particularly in isolated locations, flooding poses a persistent threat to the resilience of communities. The situation is made even worse by poverty and a lack of awareness, which also leads to some gender-based problems in areas affected by flooding. Severe gender-related problems that D.G. residents face have been brought to light by this study. Due to men's work schedules, floods are a serious natural disaster that disproportionately affects women. Floods significantly affect a community's physical, social, and psychological components, which directly affects men’s and women's lives and increases their vulnerability. Therefore, making both sexes even more vulnerable. Following a natural disaster, people experience a terrible sense of helplessness and suffering. Because it is important to foster community resilience in both men and women, the current case study has focused on the vulnerability of the community (Feroz, et al., 2022).

Human activity has been disrupted in every area of Dera Ghazi Khan City by the threat of flash flooding posed by the Wador Hill torrent. A study by Munir & and Javed, (2016), identified the possible appropriate locations to build dams with assessible assessment leading to determination of the capacity of constructed dams. This can be helpful to cater for floods and reusage of the water in water short areas. Inside the stormwater management model's (SWMM) environment, the established procedure likewise includes the design of a water conveyance approach. for runoff generation, consuming the curve number method with meteorological and topographic data, the efficacy of the dams was examined using the runoff and transport module of the SWMM model. Two sites could be used to construct dams. With a combined facility of about twenty-seven million cubic meter, these sites can hold enough water to withstand sudden, powerful surges. To guarantee a regular flow of water to the outlet from the dam site (Dera Ghazi Khan Canal), several channels have been designed. The findings of this study could be useful in creating plans to lessen the impact of extreme weather. Other regions of the world could use a similar strategy to lessen the impact of flash floods (Munir & Javed, 2016).

A great deal of harm and devastation is inflicted by floods in Pakistan. During the rainy season, river areas are unable to control the heavy rain brought by westward winds.

Pakistan has not prioritized measuring the rainfall and water flow from areas lacking equipment due to budget constraints. Saleem, et al., (2023), conducted a study in 2023 on Koh e Suleiman hill torrents, which were ten in total, a region in Rajanpur and DG Khan. This region experienced flooding in 2022 by reason of heavy rain. The research used a type of computer program called HEC-HMS, the Hydrologic Modeling System to measure how much water runs off the land and to map out where streams are located. Furthermore, the patterns in rainfall were studied using statistics (Saleem, et al., 2023).

The study found that the amount of water going into the Indus River is 0. 5 MAF for 25 years of rain, 0. 6 MAF for 50 years of rain, 0. 7 MAF for 100 years of rain, and 0. 8 MAF for 200 years of rain. In addition, after looking at how water flows in these hilly areas, the study suggests places where water can be stored. These places can hold 0. 14, 114, and 113 million acre-feet of water. Implementing these options can contribute to making spate irrigation more effective in averting floods in the future.

Through the use of photographs taken from a remote location, we can assess the level of floods in the impacted regions. It is essential to map floods to determine the initial extent of the damage. Sajjad, et al., (2023), utilized satellite technology to determine the extent of flooding in District Dera Ghazi Khan in Pakistan. Landsat data and the MNDWI index were utilized to determine the extent of the flood. The study also identified the extent and duration of the floods. As per the findings, the study area experienced flooding for almost five weeks. With the help of this suggested geospatial technique, flooded areas can be identified and subsequently targeted for emergency response. Thus, this study makes a substantial contribution to flood monitoring and provides a fresh viewpoint on flood mapping (Sajjad, et al., 2023).

Riverine flooding in rural areas is one of the more frequent extreme events brought on by climate change that occurs globally. Risk perception can be influenced by risk communication, which is one efficient method of lowering the risk of flooding. A study by Ali, et al., (2022), measured how people perceive and communicate risk in Pakistan's flood-prone rural districts of Dera Ghazi Khan. Based on the distances from rivers, rural communities were separated into two zones, namely Zone A; communities residing within 0 to 3 km, and Zone B; communities residing within 3 to 6 km of area. Following a comprehensive review of the literature, the Likert scale was used to assess the chosen risk perception and communication indicators. Chi-square and t-tests were used to determine differences between the two zones after 420 samples were gathered using Yamane's sampling method through a household survey.

To determine the socioeconomic factors influencing risk perception and communication, the study employed linear regression. The findings indicated that compared to those who lived closer to the river, those who lived farther away had higher risk perception and better risk communication. This is because individuals who had previously experienced flooding were more aware of the dangers. The study also discovered a significant relationship between risk communication and perception of flood danger. Furthermore, it was shown that risk perception and communication are impacted by proximity to the hazard. Individuals who perceived risk more highly were also more inclined to take initiative-taking steps to prepare for and mitigate floods, as well as to become more interested in learning about risk communication. The present study underscores the significance of risk communication in augmenting the significance of flood risk mitigation (Ali, et al., 2022).

To comprehend the perception of the local community, the Participatory GIS technique is developed in a combination of spatial domains for post-assessments of flash flood disasters. A study by Munir, et al., (2015), surveyed 1273 houses in the impacted regions of Dera Ghazi Khan (D) using the established methodology. The inundation level of the flash flood about the local topography was analyzed using kriging, a geo-statistical technique. The damage/loss function scheme is used to make quantitative assessments of physical vulnerability (Wright, 2010).

The study focused on the impact of flash floods on buildings and populations. By analyzing the water depth, duration of the flood, and the construction type of the buildings, the researchers created a map of the affected areas and the level of risk they faced. The study found that vulnerability is related to the construction type of the buildings. However, areas with a higher population density, closer proximity to the source of the flood, and longer duration of the flood are at a greater risk. These findings can be used to develop relief programs and coping mechanisms for such occurrences at the regional level (Munir, et al., 2015).

1.6 Problem Statement

Low-lying areas near mountainous catchments are vulnerable to flooding, which can range in intensity from low to high. Because mountain ranges are present in these regions, Pakistan's north, northeast, and southeast, are particularly vulnerable to severe flooding (NA Khan, 2014). The socioeconomic standing of the area is severely damaged by torrential floods, which continue to threaten D.G Khan. Dera Ghazi Khan is a small area that is exposed to several hazards, among all of the hazards, floods occur more frequently and are the deadliest. The river Indus experiences flooding as a result of strong monsoon rains brought on by La Nina, a significant low air pressure system, linked to average summer monsoon precipitation, and climate change. Thus, the southwest and areas in the southern Punjab of Pakistan, become more susceptible to floods. The area D.G. Khan is classified as a high-risk district for flooding in Pakistan. The area is frequently affected by low to medium-intensity flash floods. In 2012, a high-intensity flash flood occurred, breaking the previous highs of flooding in D.G. Khan (Munir, et al., 2015). In terms of climate conditions and climate change, precipitation trends in the Indus River exhibit deviation. Extreme precipitation events are becoming more frequent in many regions, which increases the risk of flooding even though the processes that cause floods are intricate and unpredictable (Buchanan, 2014).

Therefore, the present study aims to identify contributing factors that make the area more vulnerable to floods, pinpoint locations in the study area where floods occur more frequently and rapidly and assign weights to different contributing factors. All the data derived from this study can be used in policymaking, awareness, communication, and flood risk management. To create a flood risk assessment that will be helpful for policymaking in the future, the study will also combine remote sensing, geospatial tools, and past research to make flood risk maps for the area of interest. The goal of the analysis is to lessen the hazards for local socioeconomic activity and human life. There are several uses for the developed flood risk maps and management plans. Since the study area is one of the regions of southern Punjab, Pakistan, which is more prone to flooding, the data gathered would also help address flood-related issues in the area. The study aims to accomplish these objectives in a spatial setting.

1.6.1 Research objectives

- Development of risk assessment maps for considering the different climatic and topographical parameters and
- Determination of flood hotspots

Chapter 2

Methodology

2.1 Study Area

Dera ghazi khan (DG khan), a city of Punjab situated in southwestern (SW) fragment of Punjab margined by Dera Ismail khan on the north, Rajanpur at the south border, Indus River on east and Loralai and Dera Bugti districts of Baluchistan on western region. DG khan has a geographical stretch of 30.4078 N and 70.5265 E covering an area of 11,294 square kilometers (Sajjad et al. 2022). Koh e Suleman range separates it from Baluchistan province in the west.

The study area also includes a few regions of DG Khan division i.e. Kot Chutta, DG Khan Tribal areas, Taunsa, Layyah and Kot Addu. Every Area is margined by River Indus from one side.

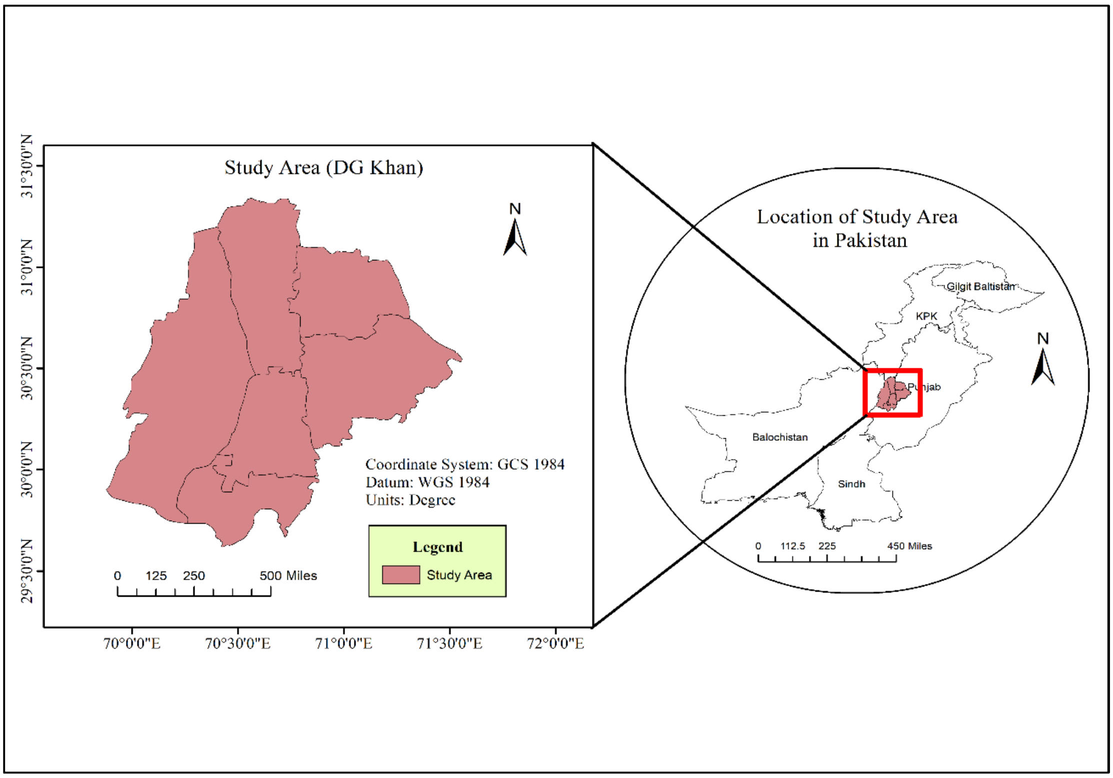

Figure 2.1 Study area map of Dera Ghazi Khan Kot Chutta, DG Khan Tribal areas, Taunsa, Layyah and Kot Addu, Punjab, Pakistan

2.2 Methods and Materials

For supervised classification of Water, Barren, Vegetation and Settlement, the images of LANDSAT 4-5 Satellite for the year 2008 to 2012, and images of LANDSAT 8-9 satellite for the year 2019 to 2022 were occupied from United States Geological Survey (USGS Earth Explorer) including the flood months i.e. April, May, June, July and August.

2.2.1 Data Acquisition-Satellite imagery

The below table display which imagery was taken with month and year included, its resolution, its row & path, resolution, and the source of data acquisition.

Table 2.1 Log of satellite imagery data collection from Landsat 4-5 & 8-9

Sr no.	Year of DC	Month of DC	Satellite	Path/Row	Resolution	Datum
1.	2010	April-August	Landsat 4-5	151/038 151/039	30m × 30m	WGS 84
2.	2022	April-August	Landsat 8-9	151/038 151/039	30m × 30m	WGS 84

2.2.2. Raster processing of Land use and land cover (LULC)

After data acquisition, a few steps are taken to formulate land use and land cover map. These include a) Composite map of the data, b) Mosaicking c) Masking d) Maximum likelihood classification.

2.2.2.1. Clipping

The geoprocessing tool, "Clipping" includes the partitioning of one data set with the help of one or multiple features of another data set. This produces a unique data set, referred to as Study Area or Area of interest (AOI). AOI encompasses the area where the study is aimed ("Clip Analysis", n.d.).

Clipping tool was used to separate AOI, that is, DG Khan Division (Dg Khan, Kot Chutta, DG Khan Tribal areas, Taunsa, Layyah and Kot Addu)

2.2.2.2. Imagery Inclusion

Following the separation of Study area, a polygon, we proceeded to input area imagery scored from USGS. Two images for each year covered the Area of interest and had overlapping regions.

2.2.2.3. Composite of Data

"Composite tool" is used to combine original band sets and formulate a new raster data set containing a distinctive order and band combination. The new raster data set can be exported in the form of TIFF, PNG, JPEG, etc. Both spatial extent and Coordinate references from the original raster imagery are incorporated in output raster ("Composite Bands", n.d.).

2.2.2.4 Mosaicking

Mosaicking is utilized to blend and join two or more images into a single unified one. Overlapping sections are now precise and are combined. In ArcGIS, single raster can be achieved by searching for **"Mosaic to new Raster (Data Management) tool"** ("What is a mosaic?", n.d.).

2.2.2.5 Masking

To remove the extra part of the image and overlay it on the study area, Masking tool is used. Masking involves concealing excessive parts of the image and limiting it to the area of interest. It is achieved by searching **“Extract by mask (Spatial Analyst) tool”** in ArcGIS (“Extract by Mask”, n.d.).

2.2.2.6 Maximum Likelihood Classification

ArcGIS is trained to read polygons or pixels assigned as classes. The computer then examines the overall area for each class throughout the map. The training sample manager panel is utilized to take the training samples. Near 250 samples were taken for each class involving Settlement, Vegetation, Water, and Barren. Signature file was employed to perform maximum likelihood classification which stipulated us with the total area covered by each class.

2.2.2.7 Classification

The ultimate Land use/Land cover (LULC) map, after accomplishing all the above-mentioned processes, is created enfolding all the required parameters i.e. Settlement, Vegetation, Water, and Barren.

2.2.2.8 Area Calculation

Area for each class is calculating using attribute table in ArcGIS 10.4.1.

- After maximum likelihood classification, right click on the LULC layer to open the Attribute table.
- Add field from the top left icon and label the field as Area.
- “**Count**” in the attribute table signifies the number of pixels in the AOI per unit class.
- From **“Field Calculator”** multiply the resolution (30m) with count and click OK.
    - **[COUNT] *30 *30**
- Area is calculated.

Table 2.2 Inventory of Land use & Land cover types across the Area of interest

Sr. no.	**LULC Type**	**Description**
1.	Vegetation	Encompasses numerous forms and arrangement of plant life. Specific to the area of interest it looks after density and distribution of: Agricultural area Forest Other plants
2.	Water	Spatial arrangement and area of surface water primarily covering River Indus
3.	Settlement	Settlement reflects human habituation within the area of interest. The settlement area may include: Cities Towns Villages Infrastructure
4.	Barren	Land devoid of vegetative cover, ecological diversity and certain environmental conditions sufficient for vegetation cover. Within the area of interest, the area near Baluchistan i.e. Koh e Suleman range

2.2.3 SRTM Digital Elevation Model

USGS Digital Elevation Model with spatial resolution of 30 meters, is utilized to calculate essential topographic parameters that are as follow:

- Elevation
- Slope
- Flow accumulation
- Distance from river

SRTM Data was downloaded through USGS Earth Explorer. To download area of interest is added and through “Data sets” tab choose Data Elevation > SRTM > SRTM 1-ArcSecond Global.

Six DEM tiles covered the Study area, spanning from 29 to 31 degrees north and 69 to 71 degrees east.

In ArcMap obtained data is converted to raster data sets and are reclassified according to the given ranks.

2.2.4 Climatic Parameters

Meteorological data, specifically rainfall data was collected within the time frame of May till August for year 2010 and 2022.

The dataset with 4.8 km spatial resolution, and one-month temporal resolution, was collected from Climate Hazard Group Inferred Precipitation with Station data (CHRIPS) assessable through www.chc.ucsb.edu/data

2.3 Weighted Overlay Analysis

Based on relative significance numerical weighing factor is assigned to each thematic layer. These layers are overlayed and this prosses is termed weighted overlay.

Raster formats are converted into integer format. Before weighted overlay, the “Reclassification tool” in ArcGIS 10.4.1 can be utilized to convert all the floating-point raster into integers.

- New values, demonstrating reclassifications of original raster inputs, are appointed to the input raster using an evaluation scale.
- ArcGIS 10.4.1 was employed to run Weighted Overlay Analysis involving the following steps:
- In ArcGIS click **Add Raster** button, which launches the **Add Weighted Overlay** dialog box. Raster inputs were added and were adjusted where required. All the raster inputs now became functions of the dialogue box.
- Weight, according to importance, is assigned to the input raster in the form of relative percentages. The percentages are totaled up to be 100%.

The percentage weight reflets the importance of each parameter. For our study Rainfall holding 25% weight holds the greatest importance. As per 2010 and 2022, known as La Nina years rainfall intensified and was one of the major sources for the hill torrent and flooding (Vehoa, Sanghar, Vidor, etc.). Distance from the river indus and Flow accumulation are given 18% and 20% of weightage respectively as they both are of almost same importance (Dou, 2018). Land use and land cover (LULC) 15%, slope, 12%, and elevation is given the worth of 10%.

- Cell values are finally multiplied by the corresponding weight percentage, executing weighted overlay analysis.
- The output raster is generated.
- This process is repeated for generating FHI Map for the years 2010 and 2022.

Table 2.3 Flood parameters with their respective percentage weightage

Sr no.	Parameter	Classes	Ranks	Weighted value
1.	**Rainfall**	290< 250-290 210-250 <210	4 (Very High) 3 (High) 2 (Moderate) 1 (Low)	25%
2.	**Flow Accumulation**	700< 700-650 650-600 600-0	4 3 2 1	20%
3.	**Distance from river**	<15 15-30 30-50 50-75	4 3 2 1	18%
4.	**LULC**	Water Settlement Vegetation Barren	4 3 2 1	15%
5.	**Elevation**	<500 500-1000 1000-1500 1500<	4 3 2 1	12%
6.	**Slope**	0-5 5-15 15-30 30<	4 3 2 1	10%

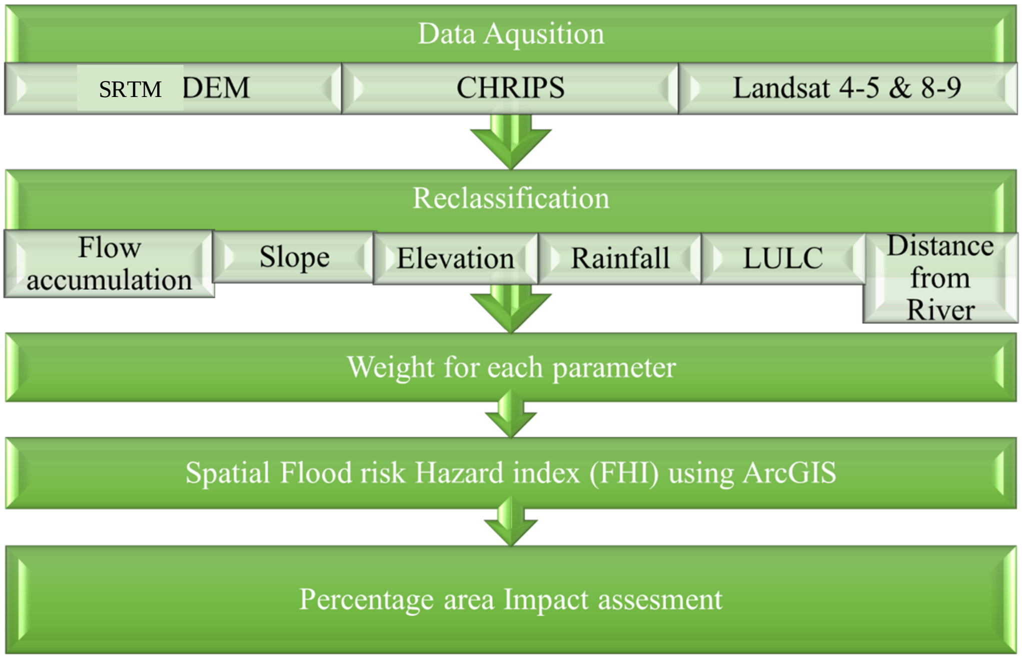

Figure 2.2 Working flow chart for Flood hazard Index generation using ArcGIS.

Chapter 3

Results and Discussion

3.1 Formation of Conclusive Topographic and Digital Elevation Model (DEM) Maps

3.1.1 Land use and Land Cover Trends

Maximum likelihood classification technique was used in ArcGIS 10.4.1 to construct land use and land cover classes for year 2010 and 2022 which were mainly hit by the devastating floods. LULC map is classified into four categories that are Water, Settlement, Vegetation and Barren land.

For year 2010, analysis of 16959.35 km^2 total area reveals landscape composition. Prescence of water was characterized to be present within the span of 474.4152 km^2, settlements 3266.461 km^2, 5338.892 km^2 accommodated lush vegetation, and barren land stood at the area of 7879.583 $km^{2.}$

In the year 2022, land cover distribution within the classes was as follow: 418.8852 covered by water, settlement occupied 4859.139, vegetation spanned 7730.99, and 3950.337 was covered by barren land.

Over the years, a noticeable rush in human development can be seen, reflected in the area covered by settlements. Even though the area covered by water remained reasonably steady, a minor decrease is noticeable in the year 2022. The assessment reveals a positive curve for vegetation in year 2022, while the barren land displayed negative trajectory from year 2010 to 2022.

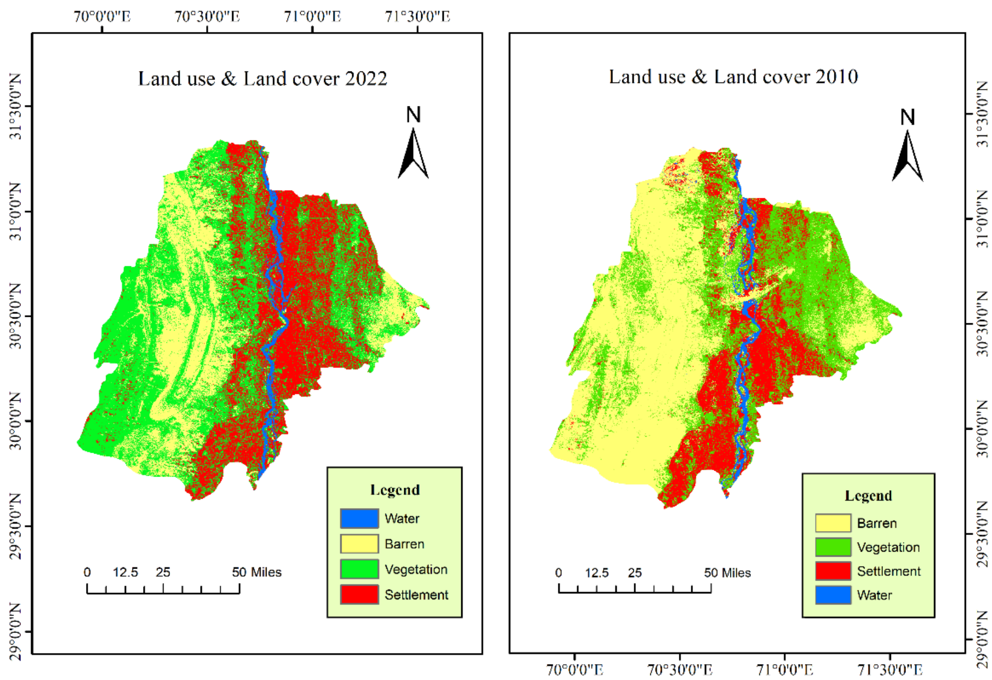

Figure 3.1 Land use and land cover classes for year 2010 & 2022

Table 3.1 Extent of each LULC class within Area of interest

Sr. no.	Class	Area Covered (sq km) Year 2010	Area Covered (sq km) Year 2022
	Water	474.4152	418.8852
	Settlement	3266.461	4859.139
	Vegetation	5338.892	7730.99
	Barren	7879.583	3950.337
	Total	16959.35 km^2	16959.35 km^2

3.1.2 STERM DEM maps

3.1.2.1 Slope

Slope is one of the chief contributors to floods as, lower slope is related with higher probability of floods incidence. Figure 3.2 shows the classes of slope with their ranked values. Slope greater than 30 degrees with the lowest rank are reclassified as Gentle slopes. 15 - 30 degrees and 5 – 15 degrees reclassified as moderate to high risk. The extreme rank is given to the areas present at 5 degrees and less are reclassified as High risk.

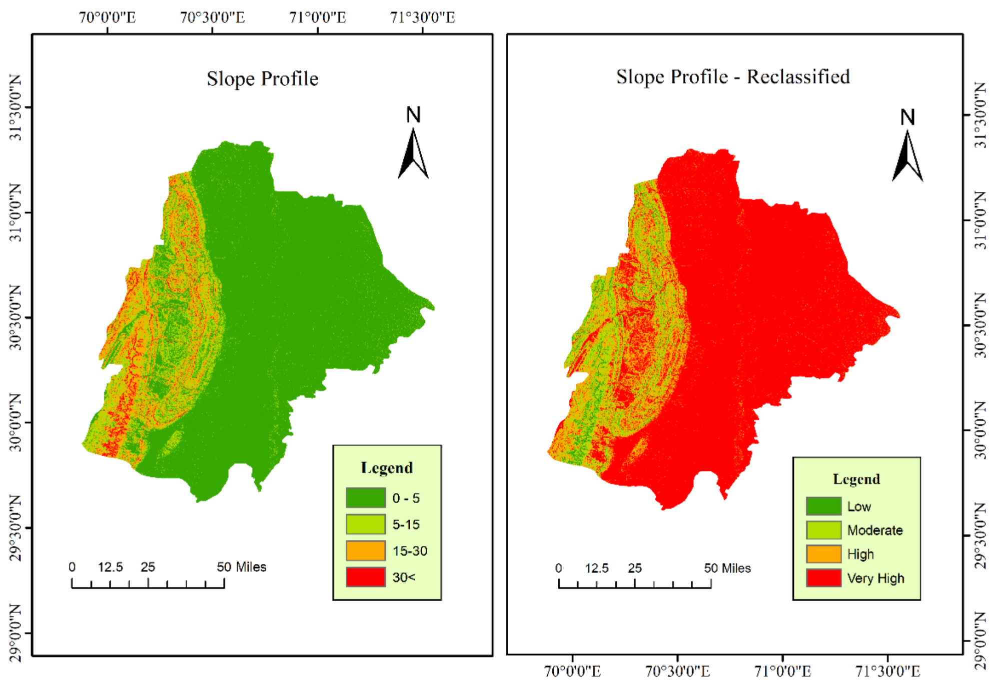

Figure 3.2 Slope profile & Reclassified slope profile for the Area of interest

3.1.2.2 Elevation

The dynamics of water flow are intricately tied to topography and slope plays a determining role in surface runoff and infiltration. Elevation profile is examined which is ranging from 500m - 1500m. it is evident that the elevation increases from east to west which leaves the western region more susceptible to floods.

Flood susceptibility based on elevation: the area of interest is divided into 4 classes. The lowest elevations of 500 m and less are ranked as class 1 and are deemed highly susceptible, reclassified as class 2 with elevation 500m to 1000m is labelled as high hazard class. Class 3, the moderate hazard class with elevation level 1000 to 1500 m. Gaining rank class 4, elevations more than 1500 meters go down into low hazard class.

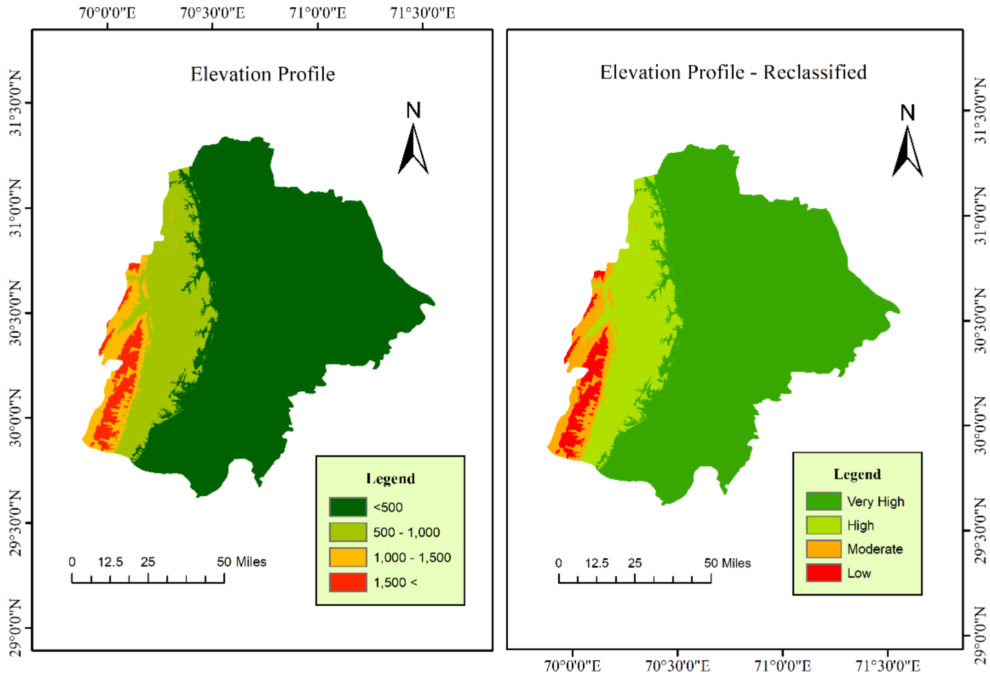

Figure 3.3 Elevation profile & Reclassified Elevation profile for the Area of interest

3.1.2.3 Flow Accumulation

Both flow accumulation along with distance from river are crucial in flood risk and are given almost same weightage. Concentrated water flow is signified by flow accumulation, here more flow accumulation is coupled with high flood risk.

The results show the correlation between the area of concentrated flow and flow accumulation. Most of the area comes under the value of 600 m. The area is divided into 4 classes reflecting the degree of flood risk. Progressing from low risk to high risk, flood risk is lowest where the value exhibits 0 – 600m, moderate (600m – 650m), high (650m - 700m) and the highest at 700m and above.

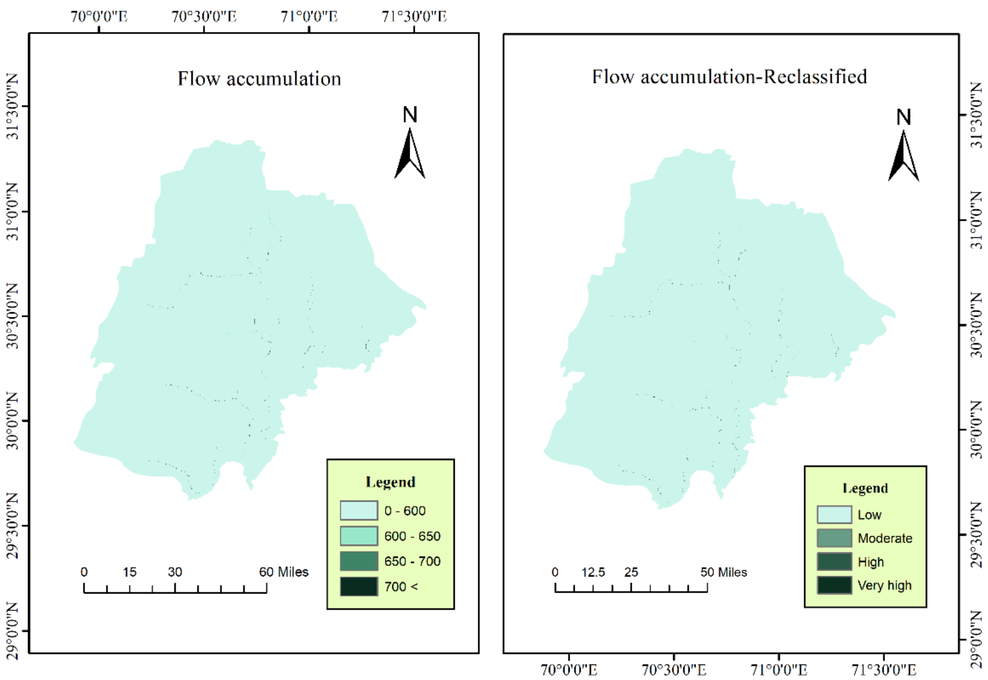

Figure 3.4 Flow Accumulation & Reclassified Flow Accumulation for the Area of interest

3.1.2.4 Distance from River

Flood velocity and impact decreases as the distance from the river increases (Glenn, 2012). This is one of the key reasons why distance from river is allocated with highest weightage in the methodology. Study area is divided into 4 classes and are reclassified as: area within 15 km range is classified as very high-risk area. 15km – 30 km and 30km – 50 km as high to moderate risk. 50km – 70km and above was given the lowest class.

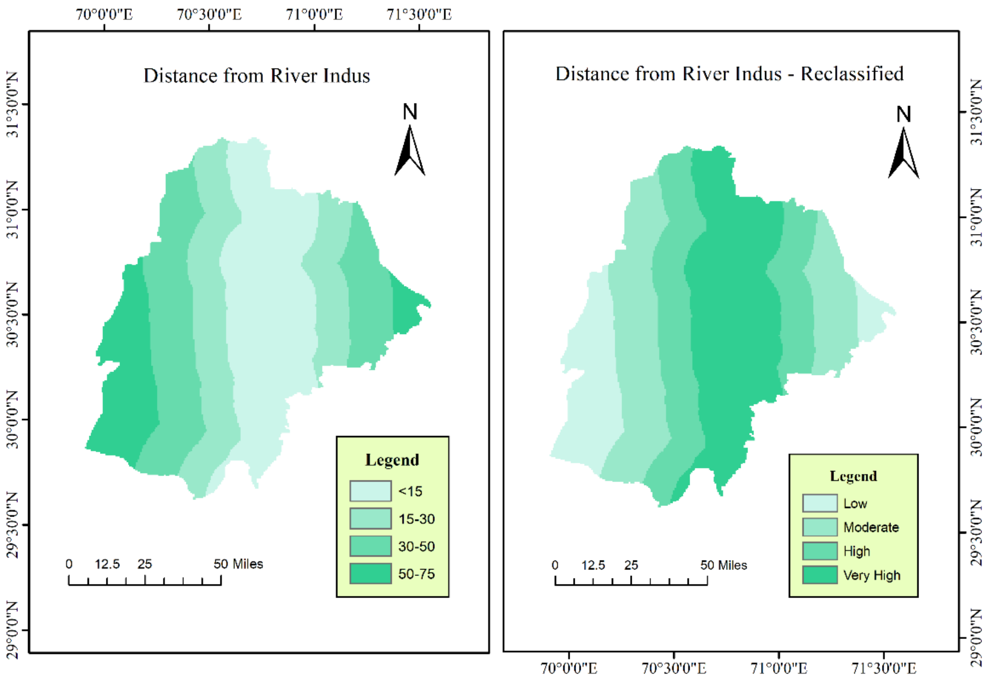

Figure 3.5 River proximity map across the area of interest

3.1.3 Precipitation Maps

Rainfall intensity is an ultimate flood hazard parameter (Tehrany MS, 2014). The intensity of rainfall is directly linked with river levels and flow accumulation.

For year 2010, the northern areas exhibit higher precipitation values. The classification of rainfall is ordered as precipitation levels outdoing 290mm are assigned as very high risk, high risk (250mm to 290mm), moderate risk (210mm - 250mm), and less than 210mm as very low risk.

For the year 2022, rainfall trends are intensified in the northern regions of the study areas. After reclassification rainfall above 290mm is associated with very high risk, 250mm to 290mm with high risk, 210mm to 250mm as moderate and rainfall values under 210mm as the lowest rank.

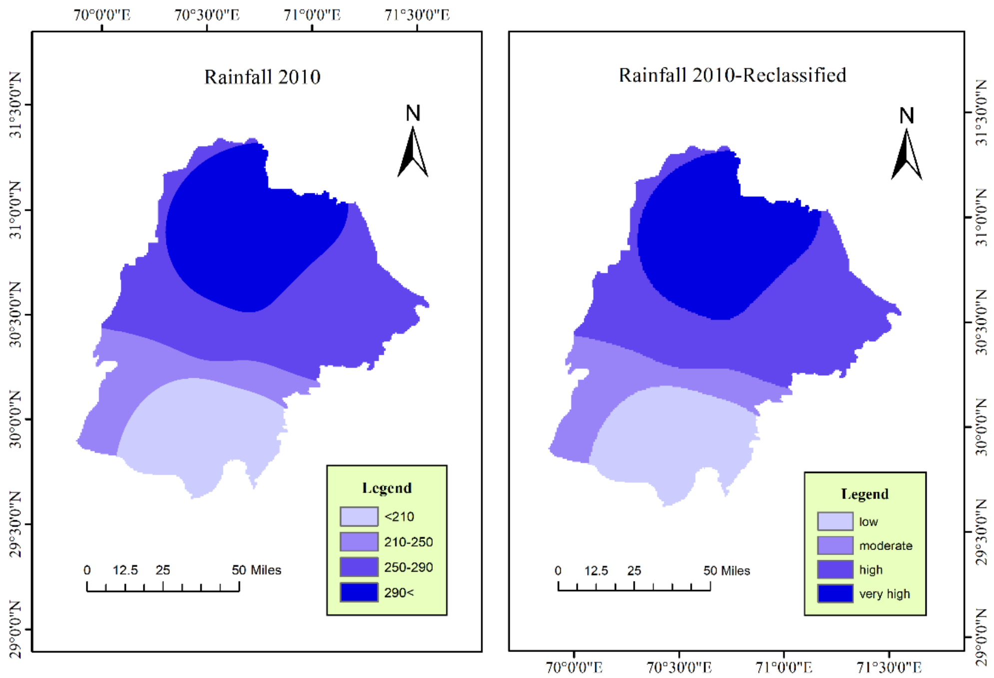

Figure 3.5 (a) Rainfall trends within the study area - year 2010

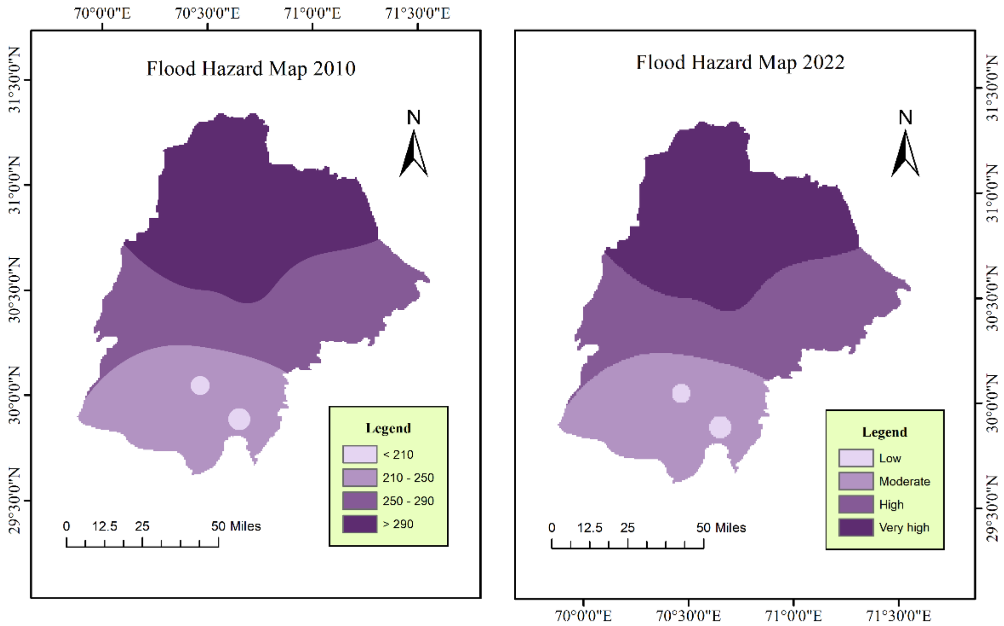

Figure 3.5 (b) Rainfall trends within the study area - year 2022

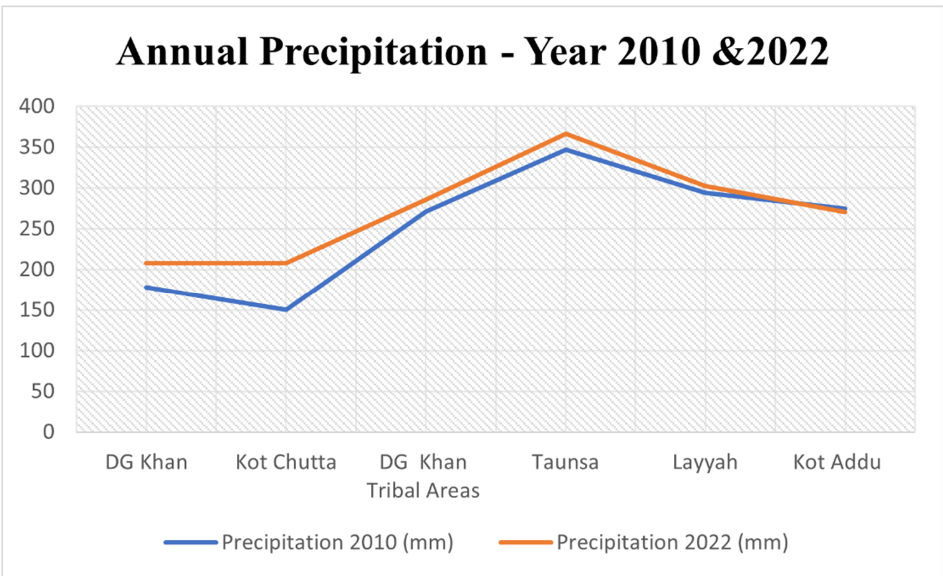

Figure 3.6 Trend of Rainfall across different regions of the study area

3.2 Flood Hazard Index (FHI) Map.

The flood hazard index (FHI) map is an important display representing the intensity and frequency of the flood for different regions throughout the area of interest. By running Weighted Overlay Analysis using ArcMap 10.4.1, FHI was carefully computed.

FHI consists of six parameters with their percentage weightage (figure 2.3) as: Rainfall (25%); Flow Accumulation (20%); Distance from river (18%); LULC (15%); Slope (12%); Elevation (10%). These parameters were selected based on relevance to flooding and literature review to create a final raster using Arc Map.

The flood hazard map was reclassified, and three classes were established. Classes depicted the vulnerability to flood i.e. Low Risk, High Risk and Very High Risk.

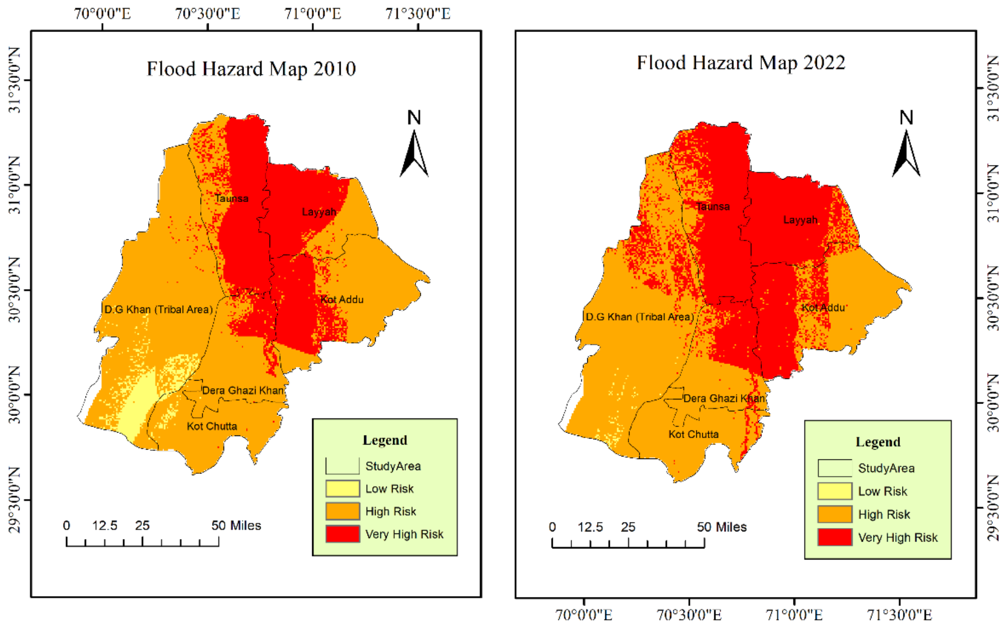

Figure 3.7 Flood Hazard Index (FHI) map

For year 2010, 9.2799 km^2 covering 20.70% of the total area was revealed to be highly vulnerable to flood reclassified as very high risk. 20.5983km^2 (65.93% of total area) and 1.3626 (4.36% of total area) were classified as High and Low risk respectively.

FHI map confirms Northern Parts of DG khan, Eastern extent of Taunsa, and western extents of Layyah and Kot Addu are under ‘Very High Risk’ class, which leaves them highly vulnerable to floods. DG khan Tribal Areas, Kot Chutta, southern parts of DG Khan, Eastern parts of Kot Addu and Layyah fall under the category of ‘High Risk’. ‘Low Risk’ accommodates certain parts of DG Khan tribal areas.

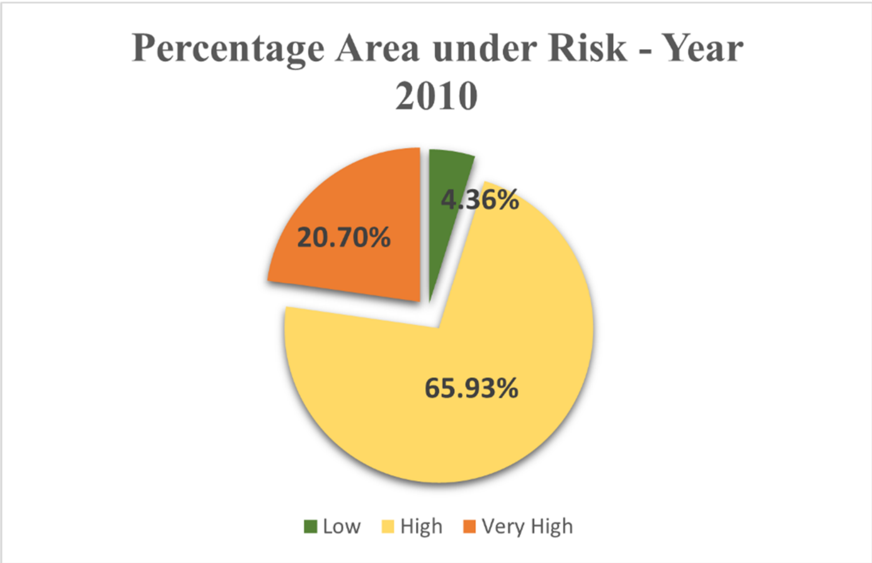

Figure 3.8 (a) Percentage of Area of Interest under Low, High and Moderate Risk for year 2010

For the year 2022, FHI maps indicate that 13.068km^2, covering 41% of AOI, falls under ‘Very High Risk’ zones. 58.27% of AOI spanning 18.2061km^2 is under ‘High Risk’. ‘Low Risk’ areas cover only 0.2%, 0.09km^2 of study area.

Areas under very high risk include Layyah, Taunsa, the Northern part of DG Khan and DG Khan Tribal areas, and western part of Kott Addu. Kot Chutta and some parts of DG Khan and DG Khan Tribal areas fall under high risk.

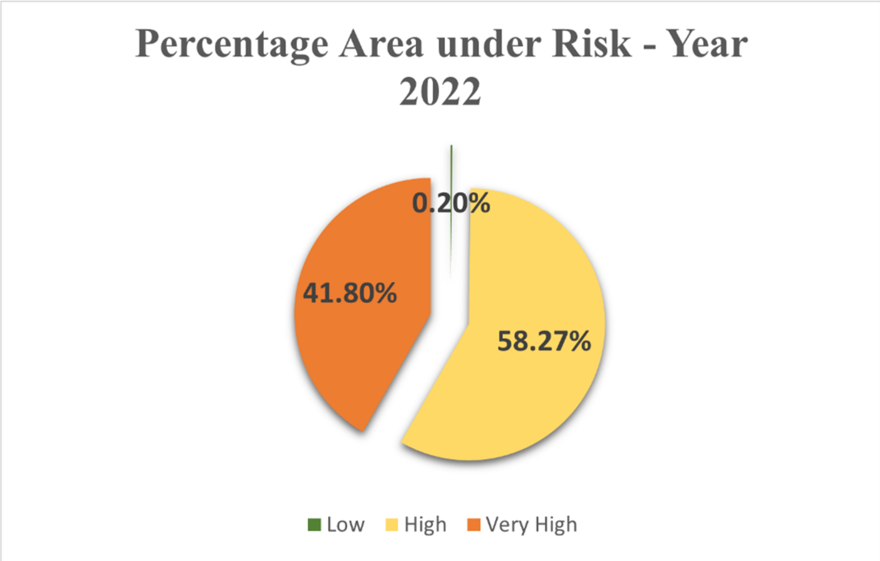

Figure 3.8 (b) Percentage of Area of Interest under Low, High and Moderate Risk for year 2022

The years 2010 and 2022 are marked as flood years, the comparative analysis of the Flood Hazard Index (FHI) map indicates a significant increase in vulnerability in year 2022. The area classified as Very High risk escalated from 20.70% to 41.80% with an additional area of 7.6392 km^2, reducing Area under High risk to 58.27%. 4.27km^2 was compromised from low vulnerability class and subsequently was added under high and very high risk.

CONCLUSIONS

1. In this study, Flood hazard index (FHI) maps for the years 2010 and 2022 were created by considering seven parameters (Climatic and Topographic) that contribute to floods. These parameters embody Rainfall, Flow accumulation, distance from river, elevation and slope. Topographic parameters were acquired from USGS Earth explorer and climatic parameter i.e. Rainfall was acquired from Climate Hazard Group Inferred Precipitation with Station data (CHRIPS) and reclassified maps were created for every parameter. The importance of each parameter is determined by appointing a percentage weightage. Influenced by la Nina, rainfall was intensified and was more frequent in the year 2010 and 2022. In account of that rainfall was given the highest weightage. Beside rain fall, flow accumulation and rainfall are the major contributing factors so, these three parameters mutually hold 63% of total weightage. Subsequently, each criterion is merged using ArcGIS 10.4.1 resulting in the formation of map visualizing highly prone zones and hence forming Flood Hazard Index.
2. After combining all the parameters in ArcGIS, FHI is created which indicates that in year 2010, 20.70% and in year 2022, 41.80% of study area comes under very high-risk zones. 65.93% in 2010 and 58.27% of AOI, in 2022 came under High-risk zones. 4.36% and 0.20% in 2010 and 2022 respectively came under low-risk zones. Areas closest to the river Indus showed high susceptibility to floods i.e. Layyah, Taunsa, northern parts of DG Khan and western parts of Kot Addu. FHI map indicates the increase in high-risk areas from 2010 to 2022.

RECOMMENDATIONS

1. In this study, the methodology that unified GIS and WOA (Weighted overlay analysis), cost friendly and a speedy method, can provide an initial assessment and early preparedness advantage to the local community and government during flood season.
2. A profound, collaborative, and detailed flood assessment can be done by the discission makers using this study and can be helpful to apprehend factors majorly contributing to floods.

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