Article

Flood Assessment and Damages for Swat River Watershed of Pakistan

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Abstract: Climate change may significantly influence flash floods due to the accelerated frequency of extreme precipitation events. Climate change causes a shift in the frequency and intensity of precipitation, which ultimately results in more intense rainfall events. In this study, flood assessment and damages has been presented for the Swat River watershed and in other parts of Pakistan. Flood damages tends to increase in future with the increase in the intensity of extreme climatic events across the country. Study emphasize the use of hydrological modeling and Geographic Information System (GIS) based technology for flood control and management across the Swat region. Furthermore, the Rainfall-runoff model (HEC-HMS), is expected to be constructed for a Swat River watershed that examined in the context of potential future climate change scenarios.

Keywords: climate change, prevention, mitigation, disaster management

1. Introduction

This is done in order for the model to be able to produce an accurate quantitative assessment of the total amount of water resources that are accessible. Global warming is an undeniable phenomenon, according to the Intergovernmental Panel on Climate Change's Fifth Assessment Report (Robinson 2020), global warming is an undeniable phenomenon. Climate change causes a shift in the frequency and intensity of precipitation, which ultimately results in more intense rainfall events (Seggel and De Young 2016). Pakistan's landscape is diverse, with northern alpine regions surrounded by glaciers and southern lowlands bordering the Arabian Sea. Pakistan has five main rivers that flow through it from the south to the north: Indus, Jhelum, Chenab, Sutlej, and Ravi (Mehmood 2018).

In addition to causing more damage over time, flooding and other climatic natural catastrophes have also been getting worse and happening more frequently. The frequency of damages from urban flooding is rising as urban areas continue to develop and attract investment. In the few years prior, flash floods that occur in natural streams as a result of isolated heavy rains in mountainous and semi- hilly topography in Pakistan really demonstrated their potential for harm (Douglas et al. 2008).

Heavy, continuous rainfall in river catchments, periodically enhanced by snowmelt flows, is the main contributor to Pakistan's ongoing flood problems. This is especially true during the monsoon season. Occasionally, monsoon currents that originate in the Bay of Bengal cause severe and disastrous floods in some or almost all of the Indus River system (Tariq and Van de Giesen 2012).

Kundzewicz et al. (2014) elaborated that Pakistan recognized the necessity for early flood warning and forecasting systems not long after it was founded in 1947 because of the persistent flooding that has been occurring across the nation. After a disastrous flood hit Pakistan in 1976, a full-fledged Flood Forecasting System (FFS) was set up. The system was further developed after looking into its flaws and gaining knowledge from the devastating floods of the 1990s. Although the system has improved over time and is now sufficiently inclusive, more tangible efforts are still needed to make it more effective and self-sufficient.

Shahzad et al. (2018) using historical information on yearly flood peak outputs, it was anticipated that the Indus River basin will experience flooding. According to Adb 2013 report, Pakistan's major flood sources include the River Jhelum, the River Kabul, the River Chenab, and the lower and upper reaches of the Indus River. The River Indus system, which includes several barrages and seven gauge stations, is regarded as Pakistan's largest and most significant system. It is also believed to play a greater part in the country's power generation and irrigation system According to the findings, new dams and barrages need to be estimated for construction, and they also need to be updated. Occasionally, monsoon currents that originate in the Bay of Bengal cause severe and disastrous floods in some or almost all of the Indus River system.

Flash floods are the most dangerous natural disasters on the planet, resulting in thousands of deaths and billions of dollars in damage each year. Pakistan has seen seventeen major floods, the most damaging natural hazard there, costing the nation 12 billion USD in economic losses since independence (Baqir et al. 2012).

The terrible flood that hit Pakistan in 2010 was the worst in the country's recorded history, and it caused a lot of damage (Atta-ur-Rahman and Khan 2013). In 2010 resulted in the deaths of more than 1900 people, as well as the destruction of 17 million acres of farmland, 1.5 million homes, and the displacement of 20 million people (Shahzad et al. 2018). Even during the monsoon season, flash floods and riverine flooding are most prevalent in terrain that is steep and semi-hilly. This is because rivers tend to follow the contours of steep and semi-hilly terrain. The River of Swat and Kabul recorded a new record flow of 400,000 cusecs during the flood that occurred in 2010, surpassing the previous record flow of 250,000 cusecs that was established in 1929. The abnormally high flow that occurred during the flood in 2010 was responsible for the destruction of Charsadda, Peshawar, and other communities (Alam et al. 2015). The flow regime is essentially a description of the flow structure, In Pakistan, climate change will be expected to cause significant glacier melt and deicing of mountain peaks as well as extreme monsoon rain showers a rise in the intensity and frequency of floods on the Swat River in Pakistan. Extreme rainfall in 2003 had a devastating impact on Sindh province. Extreme monsoons in 2007, badly affect Baluchistan, Sindh, and KPK (Baqir et al. 2012).

Among numerous natural hazards, flash floods caused the most mortality (ratio of the number of persons who died to the entirety of individuals that were affected) worldwide, (Kron 2005). Because of the unpredictable nature of flash floods and difficulties in forecasting, emergency solutions are limited in extreme events. Changes in climate and fast urbanization have the frequency and the magnitude both increased of natural catastrophes linked to severe hydrologic events in metropolitan areas. Climate change increases the risk of flash floods around the planet. Flash floods are mostly caused by short-term extreme precipitation. Extreme weather and flash floods are likely to become more exacerbated as a result of climate change (Zhang et al. 2021).

According to Anjum et al., (2016), the devastating flood that occurred along the Swat River in 2010 had an effect on about 20 million people, and it was responsible for the deaths of 2,000 people. September from 2011 to 2014, thousands of homes have been destroyed, as well as thousands of acres of fertile land, and thousands of people died due to flash floods. In 2020 only Karachi had 484 mm (19 inches) of rain, the highest rainfall recorded in the previous 90 years. In Swat River, all regimes are active and occur at the junction of the monsoon and westerly. Cloudburst also often occurs at this junction point.

Now the westerlies have more influence than easterlies, because of climate change (Atta-ur-Rahman and Khan 2011). To fill this gap, this research looked at 20 years' worth of flood patterns in the Swat River to extrapolate what would happen during a flash flood. In this study, we only focused on climate change while Land cover changes were constant, due to climate change their regimes were at a point, so the purpose of the research was that for how long this condition will remain the same. Extreme flood events have been occurring in recent decades so to prevent flash floods, the situation demands efficient and long-term flood management. This study will project the behavior of flash floods for the next 30 years in the Swat River based on historical precipitation and discharge time series data during the last 30 years (1990–2020), utilizing the Global Circulation Model (GCM) Approach

2. Previous Flood Studies In Pakistan

Flooding as a result of climate change is the major cause of mortality and infectious illnesses throughout the entire world. The nature and complexity of a flood risk, which can be produced by one or a combination of fluvial, flash, pluvial, subterranean, and coastal floods, is mostly responsible for the consequences of massive flooding (Gain et al. 2015; McMichael et al. 2006).

Mahmood et al. (2019), presented those extreme floods are also one of the most serious hydro-meteorological hazards in Pakistan, causing human suffering. In 2010, twenty million people have been displaced by flooding in Pakistan. Nearly 2 million hectares of cropland were destroyed, resulting in financial damage of over USD 10 billion (Arora 2019).

Extreme hydrologic events such as floods, droughts, and heat waves might be caused by climate change. Climate change has a significant impact on hydrological events and may further modify runoff and flow in river systems. Typhoon Rumbia and the resulting floods threatened eight provinces in China in 2018, costing 1400 USD million. To reduce flash flooding (Park and Lee 2019), has presented a study that urban flood catastrophe risk appraisal and control strategies have been developed regularly. For lack of a better description, the research used empirical models with features that directly or indirectly impact flood incidence, and proposed an area's flood vulnerability (Tehrany et al. 2014; Wu et al. 2020).

Aerts (2020) individual preparation has been emphasized as an essential feature of flood risk perception in certain research as it indicates subjective influence over the risks determined via internal experience. Individual conduct has a significant impact on flood risk, based on their financial condition and risk assessment (which is influenced by their values, sentiments, experiences, and cultural viewpoints), even worse, intense precipitation on sub-daily intervals is increasing faster than daily, which is hazardous for flash flood risk assessment (Morrison et al. 2019; Yuan et al. 2019).

Amarnath & Rajah (2015) evaluated in their study that how well remote sensing data may be used to estimate the size of the 2010 Indus Flood in Pakistan. Heavy rainfall between July and September of 2010 caused the floods to intensify and become more severe than ever before. Besides human intervention, there was also a belief that this disaster had been exaggerated because of human intervention. The accumulation of flow was analyzed using the STRM data from the Shuttle Radar Topography Mission (SRM), highlighting the reaches that are most likely to be breached based on the accumulation of flow based on the STRM data. In order to mitigate risks and identify vulnerable areas, it was recommended that mitigation strategies be established.

According to Mechler & Bouwer, (2015) in the Pakistani Indus River Basin, a study has been done on the nature and connection between the South Asian monsoon and flood dangers. As a result of human encroachment into flood-prone areas, it was reported that floods affect about 75 million people and that 20,000 people are killed annually as a result of floods. Pakistan is periodically faced with a number of flood hazards due to its geographical location. The flood of 2010 was the largest flood disaster Pakistan has ever experienced, and it had terrible effects on the entire country.

Huong & Pathirana (2013) explained in his study that the rate of flood occurrences has grown substantially, with metropolitan areas being particularly badly impacted. Major flash flood events in Europe have an average lag time of fewer than 5 hours. Floods aren't only natural disasters they're also the consequence of environmental and hydrological conditions that have been exacerbated by human activity (Sanders et al., 2019).

3. Flood History In Swat River During Last Decade

Due to the heavy rains in 2010, the area was badly hit by floods since the rivers were unable to hold enough water. The Swat river flow at Munda headworks was measured at 300,000 Cusec in 2010 (Moazzam et al. 2018). On July 29, 2010, a record 274 mm of rainfall, causing flash floods that affected 308 million of people on KPK and resulted in 1156 fatalities.

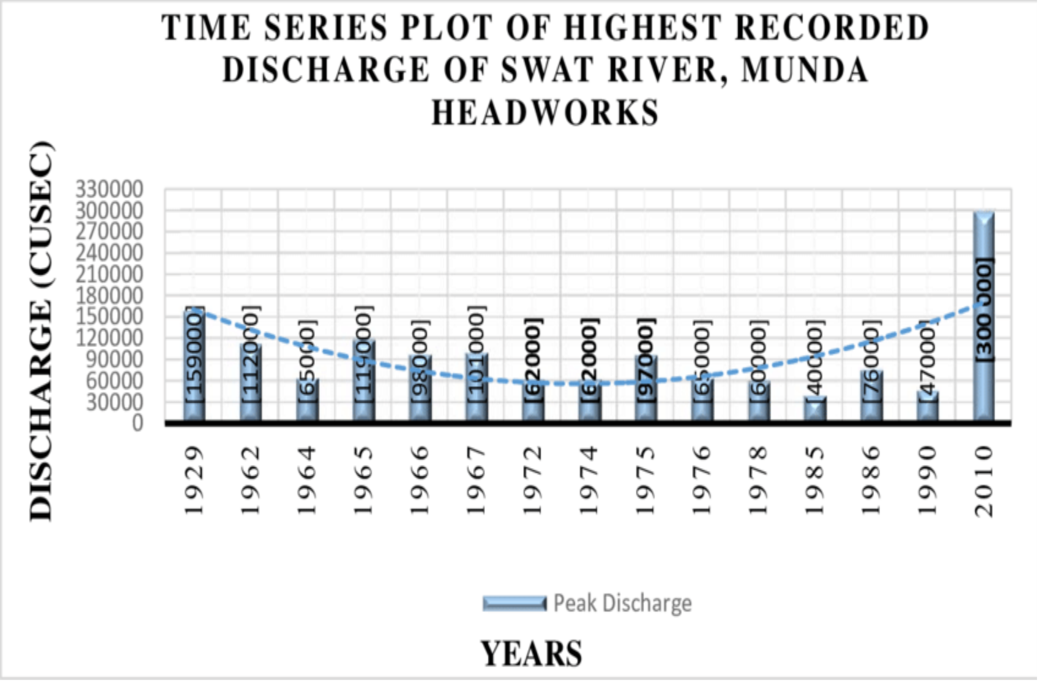


Figure 1: Highest Recorded discharge of Swat River, Munda head work (Baqir et al. 2012).

4.Flood Damages In Swat River During Last Decade

Figure 2.2 displays the amount of people who were injured and lost their lives as a direct result of the worst floods Pakistan has ever witnessed in terms of both rainfall and water temperature (Farhan et al. 2020).

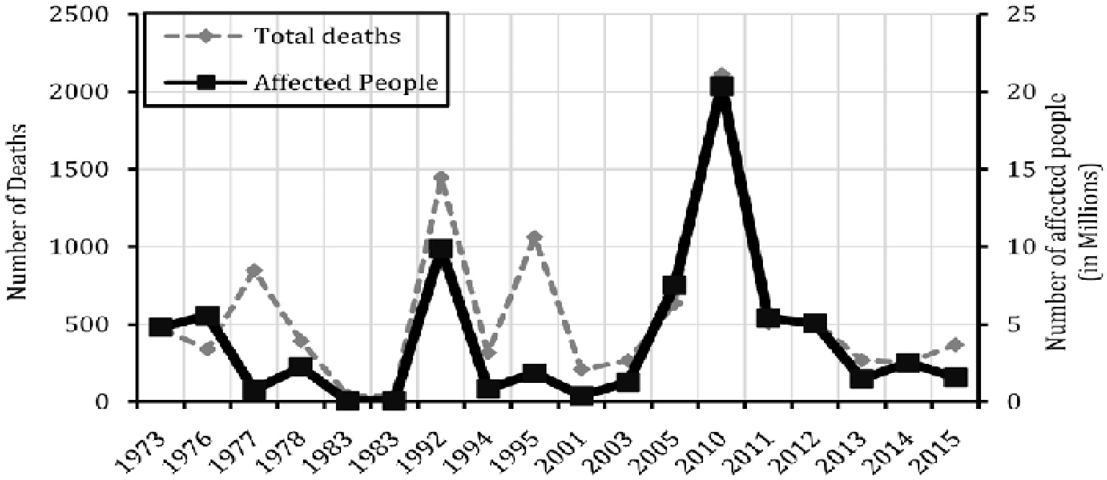


Figure 오류! 지정한 스타일은 사용되지 않습니다.: Number of those harmed and lost as a result of Pakistan's terrible floods (1973- 2015) (Farhan et al. 2020).

The deadliest flood was in 2010, when over 1900 people perished and 20 million people were impacted. In the past before 2010, the subsequent two floods with the highest death toll were recorded 200 mm in 1992 and 1995. According to figure 2.3 the highest amount of yearly rainfall that was ever recorded was 904 mm in the year 2003. This was followed by 710 mm, 667 mm, 642 mm, and 595 mm in the years 1983, 1996, 1994, and 2010, respectively. In spite of this, the year 2010 had the most amount of yearly rainfall 595mm during the monsoon season (July to September).

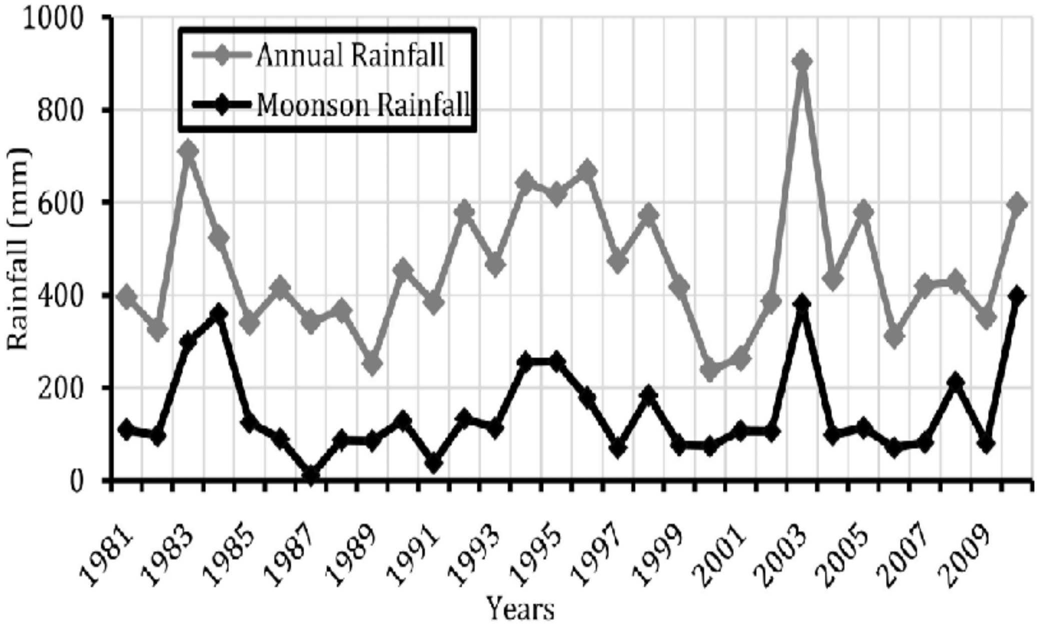


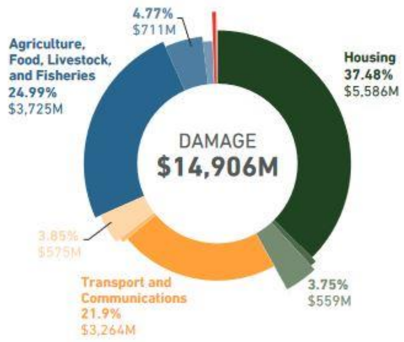
Figure 2; KPK monsoonal and annual rainfall (Moazzam et al. 2020).

These floods affected 9.8 and 1.8 million people, respectively, and caused the deaths of 1446 and 1063 individuals (Moazzam et al. 2020). This was followed by the years 2003, 1984, and 1983, which had totals of 381 mm, 359 mm, and 298 mm of precipitation, respectively. Sangati (2009), was noted that the data on land use, hydrological soil types, and precipitation, all of which vary geographically and over time, are utilized as model variables in order to simulate the amount of precipitation and runoff that occurs during flash floods. The framework is utilized in the planning, designing, and actual execution of flood control projects, the regulation of floodplain activities, the monitoring of water use, the local and regional planning of watersheds, the analysis of water availability, the design of urban drainage systems, the prediction of flow, the evaluation of the effects of urbanization on waterways, the layout of reservoir spillways, the estimation of flood damage reductions; and real-time implementation (Kiedrzyńska et al. 2015).

5. Assessment of Damages, Losses of Flood In Pakistan

The 2022 floods have shown Pakistan's high vulnerability to climate change despite contributing less than one percent of global greenhouse gas emissions. One third of the country has been under water, and between June and August 2022, torrential rains and a combination of riverine, urban, and flash flooding led to an unprecedented disaster in Pakistan. According to the National Disaster Management Authority (NDMA), 33 million people have been affected. Nearly 8 million people have displaced because of flood. The unprecedented scale of the disaster in Pakistan exceeds the damage of the 2010 floods. It requires a collective, international effort to recover from the effects of this natural disaster. The floods caused the loss of the lives of more than 1,700 people, one-third of which were children. Rain-induced floods, accelerated glacial melt, and resulting landslides devastated millions of homes and key infrastructure, submerging entire villages and destroying livelihoods. The initial flood assessment suggested that the national poverty rate will increase by 3.7 to 4.0 percentage points, pushing between 8.4 and 9.1 million people into poverty. As of October 11, 94 districts were declared as "calamity hit," accounting for more than half of all districts in the country. The majority of them belongs to the provinces of Balochistan, Sindh, and Khyber Pakhtunkhwa (KP).

The total damage is estimated at PKR 3.2 trillion (US$14.9 billion), total loss at PKR 3.3 trillion (US$15.2 billion), and total needs at PKR 3.5 trillion (US$16.3 billion). The sectors that suffered the most damage is housing at PKR 1.2 trillion (US$5.6 billion); agriculture, food, livestock, and fisheries at PKR 800 billion (US$3.7 billion); and transport and communications at PKR 701 billion (US$3.3 billion). The transport and communications sector has the highest reconstruction and recovery needs at PKR 1.1 trillion (US$5.0 billion); followed by agriculture, food, livestock, and fisheries at PKR 854 billion (US$4.0 billion), and housing at PKR 592 billion (US$2.8 billion). The provinces of Sindh and Balochistan account for approximately 50 percent and 15 percent of recovery and reconstruction needs, respectively.



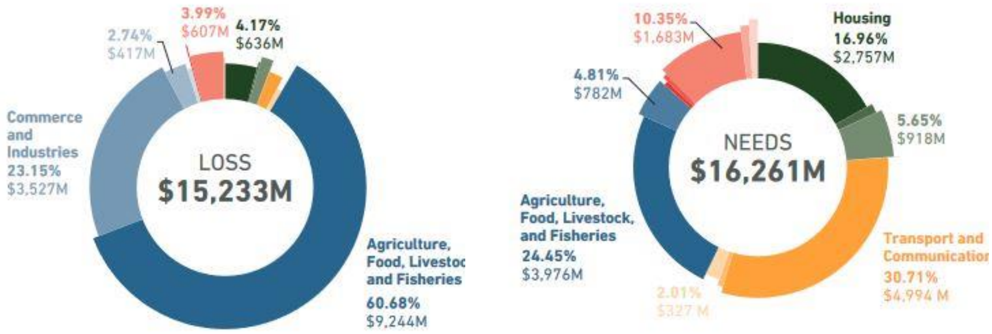


Figure 3: Distribution of damage, loss, and needs by sector of 2022 flood in Pakistan.

6. Mitigation Strategies Through GIS And Hydrological Modeling

One of the key geomorphic units for assessing and managing severe hydrological events like extreme floods in the watershed. The anatomy and shape of the watershed are measured mathematically using morphometry (Bodoque et al. 2015). Stream order, stream length, stream number, stream density, drainage frequency, watershed size, perimeter, shape factor, and circulatory ratio are some of the basin variables that are numerically analyzed in morphometry (Nasir & Ahmad, 2020).

Tabios & Salas (1985) proposed the Thiessen Polygon technique, which weighs the effects of the region closest to the station in the shape of a polygon. As a result, it seeks to account for any errors brought on by the uneven distribution of rain gauges.

It is considered that understanding hydrological challenges and practical applications requires simulating and projecting rainfall runoff flows in gauged and ungauged catchment areas. For efficient system administration, analysis, and design in the complex interaction among rainfall and runoff, water resources must be measured (Devia et al. 2015). Rainfall-runoff modelling is a tool that engineers and water resource managers may use to handle initiatives using water resources (design, construction, and operation) to decrease the consequences of drought and flooding. Watershed modelling, on the other hand, necessitates not only an adequate and substantial set of spatiotemporal data (such as topography, land use/covers, soils, rainfall, and flow monitoring data), but also an accurate calculation of runoff amount, as well as the development of flood and drought strategy. Additionally, a thorough comprehension of the rainfall-runoff dynamics unique to a given watershed is necessary (Chu & Steinman, 2009).

Ibrahim & Ahmed (2016) they successfully experimented on the model of HEC-HMS and validate it in the watershed of the Indian Hoovinahole gauged and used accurate parameters that were initially calibrated to predict rainfall runoff and estimate stream flow and peak flow in the nearby ungauged Doddahalla farm watershed.

In order to replicate the flow regimes in southern California using unmeasured locations, the HEC-HMS rainfall modelling system was utilized. After the HEC-HMS model had been calibrated and confirmed at a number of gauge locations, it was then assigned to each unmeasured location. Specifically when modeling in ungauged catchments employing physiographic factors for example terrain, vegetation, soil, land use, and the hydrological parameters, the input data, and the model structure are the primary determinants of how hydrological models behave (Mazor et al. 2018; Sengupta et al. 2018).

The hydrological model (HEC-HMS) that makes use of geographic information system (GIS) and remote sensing techniques can be of assistance in evaluating the hydrology and water resources of the selected river catchment area. The catchment area of the Keseke River, which is located in the South Ome River basin, is an example of this type of river catchment (Meresa 2019).

Numerous studies have utilized the HEC-HMS model to assess urban flooding, flood damage minimization, planning for flood warning systems, regulating floodplains, frequency of floods, operation of reservoirs and systems, environmental discharges, and river restoration, water supply planning, (Hussain, Wu, & Yu 2021) and often used physical instrument for simulating hydrologic processes is the HEC-HMS. Physically based hydrologic models are often preferred and regarded as appropriate in ungauged catchments. The majority of these investigations made it abundantly evident that the model simulation's outcomes were site-specific, with various combinations of a model set incorporating base flow segregation, routing, and loss algorithms responding differently (Scharffenberg et al., 2016).

Using a Geographic Information System, (Arseni et al. 2020) did a study on the evaluation of flood estimates (GIS). According to the research, hydraulic structural flow data are lacking. By building assessment stations downstream and upstream of the specific dam location, it was established that a link can be created for the site. The beginning stages of developing empirical equations were carried out in the upper Chenab River basins. A computerized assessment model and GIS software were utilized in order to conduct an analysis of the typical river flow and watershed arrays. The calculations accurately assumed peak floods by a wide margin. The usage of these equations in other areas needed preferences since they were only applicable in certain places.

Ali et al. (2011) utilized an empirical land use change model in conjunction with an event scale, rainfall-runoff HEC-HMS model in order to evaluate the effects of prospective LULC changes on the storm-runoff production in the Upper Lai Nullah Basin. Within the scope of this study, the impacts of LULC modifications on the hydrological output of the Lai Basin were analyzed throughout a range of time periods in order to provide potential alternatives for the use of land in the future.

A system of flood forecasting's main goal is that it lessens the loss of humanity, their properties, and businesses by giving users and emergency management, particularly in Pakistan, precise warnings with plenty of lead time (Parker 2017). The effectiveness and prediction accuracy of the hydrologic model defines the lead time. Utilizing projected hydro-meteorological data is one of the few approaches to integrating predictions that were called meteorological predictions, in flood forecasting systems with hydrologic models. Models of numerical weather prediction at the regional scale are applied in the process of forecasting the weather. Because there are many distinct kinds of hydrologic models, the applications for these models can vary greatly, based on the specific results that are desired as well as the quantity of hydrologic data that is readily available. The models found may be classed based on whether they depict the region under investigation as a whole or in fragments, and the hydrological processes can be explained empirically, physically, or theoretically (Refsgaard & Knudsen, 1996).

Azam et al. (2017) reported that the HEC-HMS Model was used in his study to estimate runoff at the Mushim stream watershed in Korea, and they said that they did this using the model, as it is essential for providing warnings of early floods. The capabilities of HEC-1 are improved with the inclusion of HEC-HMS, which has the capacity to do both ongoing and distributed modelling and simulation. For the development of EFWS, the use of HEC-HMS along with the accuracy of validation and calibration are essential. In controlled and natural environments, the HEC-HMS model could mimic rainfall-runoff and systems of routing. A number of scholars from all around the world have successfully constructed the simple conceptual model known as HEC-HMS. Due to the concept of semi-distributed modeling, it is preferable to the Flood Hydrograph model that is Revitalized for peak flow simulation (Al-Mukhtar and Al-Yaseen 2019).

The Revitalized Flood Hydrograph (ReFH) rainfall runoff model was used in both the (Bukiil and Jeungpyeong) watersheds in Korea, and the results of this application were compared with those obtained from the HEC-HMS model (Joo et al. n.d.). The ReFH model and the HEC-HMS both have the flood events included into them through the use of calibration and validation processes.

The lumped notion and the semi-distributed modelling concept are essential components of the ReFH model, particularly when applied to the peak flow of a large watershed. Taking into consideration the fact that the model of soil moisture accounting is seen as being suitable for rural catchments and is based on the hydrological cycle that occurs naturally in natural catchments, one can say that this model is appropriate for rural catchments. When the precipitation runoff begins in the mountain area, it was simulated using the semi-distributed model HEC-HMS and the highly decentralized model Basin Pollution Calculation Center (BPCC), and the findings revealed that there was a little difference between the two models (Poncelet et al. 2017).

Sanyal & Lu (2004) recommended that because of the geographical nature of the effects and rainfall that impact hydrologic processes, Geographic information systems (GIS) has grown to be a significant component of hydrologic research. GIS are essential for parameterizing distributed hydrologic models. This is carried out in order to prevent glaring simplifications brought about by the lumping of parameters at the scale of the river basin during the representation. From a DEM, hydrologic data including flow accumulation, watershed borders, flow direction, and stream networks are extracted using GIS tools (digital elevation model). This study made use of GIS and HEC-HMS to evaluate the model's performance.

Major flash flood events in Europe have an average lag time of less than 5 hours (Marchi et al. 2010). An hourly time period was utilized to examine excess precipitation for the CN method using the Hydrological Modeling System. This system splits the watersheds into moderate sub basins and is distinguished by its focus largely on land reform, soil qualities, and geographical factors. To identify precipitation occurrences that exceed thresholds with enough forewarning and advance planning to reduce the impacts of the impending extreme flood. The creation of water-related mobile phone demonstration apps in a variety of use cases, such as water delivery, hydrological data gathering, flood control, and information sharing about water quality (Gichamo et al. 2012).

In an effort to improve Europe's readiness for riverine floods, the European Commission established the European Flood Awareness System (EFAS) in 2002 (Thielen et al. 2009). However, during the past ten years, the hydrological community has been more interested in using ensemble prediction systems (EPS) for flood warnings that extend longer than 48 hours as opposed to single (deterministic) predictions (Molteni et al. 1996). The Central American Flash Flood Guidance (CAFFG) system, which is the most fundamental form of the fully automated flash flood guidance system, has been implemented in seven of the nations that make up Central America. The FFG software was utilized in the creation of the CAFFG system by HRC, with assistance from NWS and financial backing. The CAFG system will serve as the basis for the Flash Flood Guidance System that is now in the planning stages (Molteni et al. 1996).

Flood Warning System in Slovak Republic using the Slovak Hydro-Meteorology Unit, abbreviated as SHMU, has so far been responsible for the construction of two low-scale local systems that are administered by the community in the immediate vicinity (HSAF 2010).

Different hydrologic models have been developed; how they are used depends on the type of findings required and the data's accessibility. For the Early Flood Warning System, the HEC-HMS model was selected as the best option because it can replicate both uncontrolled and regulated precipitation-runoff and routing processes. The program was designed by the US Army Corps of Engineers' Hydrological Engineering Center (HEC). HEC-HMS is HEC-1's replacement and succeeded (USACE, 1998). The features of HEC-1 were enhanced by HEC-HMS, which also offers new capabilities for distributed modelling and continuous simulation. A mathematical model is used to determine how the dendritic watershed reacts to rainfall as runoff values change with the watershed's soil and land use patterns. Models from the HEC-HMS are used to calculate each component of runoff. These models include direct runoff, loss, routing, and base-flow models.

The HEC-HMS model has seen a lot of action in the field of precipitation forecasting. There are several instances available of this model being used in Korea for purposes such as determining the expected maximum flood or doing straightforward rainfall-runoff modeling throughout the flood season (Azam et al. 2017). Even for only one rainfall event, the rainfall-runoff process is dependent on the soil type, topography, and land cover status of the watershed.

When applied to Cedar Creek, Crooked Creek, and Fish Creek in Indiana, the results of the spatially distributed direct hydrograph trip time method (SDDH) and the released-based distributed hydrologic model (STORE DHM) are compared (Kang et al., 2016). The results of these analyses show that STORE DHM is superior to both HEC-HMS and SDDH in terms of the overall hydrograph form and flow magnitude.

LISFLOOD is the hydrological model utilized by EFAS (Kumar et al. 2021). A hybrid system is formed when a conceptual and physiological rainfall-runoff simulation and a routing model in the river channel are merged. Large river basins have been the focus of LISFLOOD's design. The extensive use of cutting-edge Geographical Information Systems (GIS), particularly as a foundation for dynamic modelling, is a distinctive aspect of LISFLOOD.

Research has been conducted to create a coastal flooding early warning system using a combination of modern sea-state monitoring equipment, numerical ocean models for forecasting, historical datasets and experiences, and computer science (CoFEWs). Data from the history, knowledge about the present, and projections about the future might be provided through the system that has been suggested (Melet et al. 2020).

Van Shaar et al., (2002) compared to soil type and topography, changes in land cover have a greater impact on hydrological response. (Ali et al. 2011) integrated an empirical land use change model with an event scale, rainfall-runoff model in order to evaluate the effects of possible land use change on the storm-runoff production in the Lai Nullah Basin, Pakistan. This was done in order to determine how a change in land use might affect the production of storm runoff in the basin. Based on the development trend and Islamabad Master Plan, the future land use situation was predicted. The calibrated HEC-HMS model was used to a variety of potential future land use scenarios in order to examine the prospective effects of land use on the production of storm runoff.

It is possible to utilize HEC-HMS and HEC-RAS to evaluate the influence of climate change and land development on future flood risks in Vernonia, Oregon, United States of America, by anticipating changes in the watershed features of the area (Tripathi et al. n.d.). The data indicate that expanding urbanization and impervious surface led to a considerable rise in the severity of floods, which worsened flood damage by prolonged the inundation time and raising peak flow. The flood runoff in the Namgang-Dam Watershed, located in South Korea, was modelled using HEC-HMS, and the simulated runoff was compared to the observed runoff from the years 2004 to 2008. (Eum et al. 2010) in order to bring the discrepancy between the simulated and observed values closer together, the computation of the curve number based on the theoretical maximum preservation of forest areas was performed using three separate cases. These examples were chosen at random. The findings demonstrated the need of utilizing curve number for forests in order to limit the amount of estimation errors that were made as a consequence of the large disparities that were found between the simulated data and the real data.

The date of the prediction is established based on the hydrologic model that is part of the Early Flood Warning System (EFWS). If the prognosis period is made to be longer, then people will have more time to make preparations for floods. Therefore, the capability of the hydrologic model to provide accurate predictions about the future depends on how successfully it does this task.

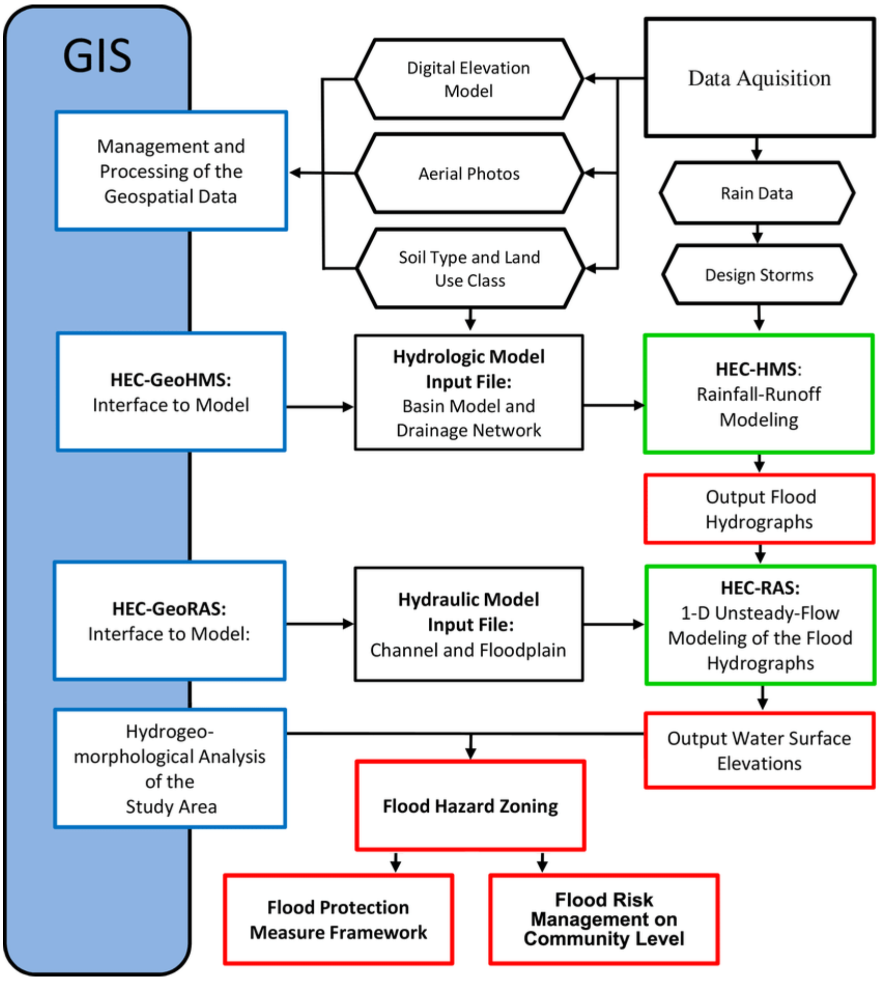


Figure 5: Flow chart for the application of GIS and hydrological modelling in flood risk management (Heimhuber, V., Hannemann 2015)

For the purpose of making accurate runoff predictions, the HEC-HMS Model was selected because of its central role in EFWS. As a consequence of this, the utilization of HEC-HMS as well as the accuracy of calibration and validation play extremely important roles in the process of developing EFWS for urban regions.

(HEC-GeoHMS) 10.3 used to establish the model's fundamental parameters prior to using HEC-HMS. The HEC-GeoHMS is a geospatial hydrology toolbox that has been developed specifically for engineers and hydrologists who do not have a background in GIS. ArcGIS and its extension, Spatial Analyst, are utilized by the HEC-GeoHMS in order to generate a wide variety of hydrologic modelling inputs. Study flow chart has been provided in the Figure 5 below.

These inputs are used by the Hydrologic Modeling System, which is part of the Hydrologic Engineering Center. ArcGIS and the Spatial Analyst extension are both available from the Environmental Systems Research Institute, Inc. (ESRI). HEC-GeoHMS analyses digital topography data and translates watershed boundaries and drainage paths into a hydrologic data structure that depicts the drainage network. Users of the application may do geographical analysis, identify sub basins and streams, describe watershed features, and visualize spatial information.

By using HEC-HMS, one may determine the amount of runoff that is collected, stored, penetrated, evaporated, or flowed, and then one can deduct the amount of precipitation that occurred from that total. The terms "interception" and "surface storage" are intended to refer to the same thing: the storage of water at the surface by vegetation such as grass or localized depressions in the ground, parking lot cracks and crevices, or an area where there are no roofs to prevent water from moving as overland flow. Specifically, these terms refer to the surface storage of water. The HEC-HMS software and documentation refer to interceptions, infiltration, storage, evaporation, and transpiration as a whole as losses. Because their files are interchangeable, HEC-HIMS and HEC-GeoHMS may be utilized together immediately.

The unit hydrograph, which is a well-established empirical model of the connection between direct runoff and surplus precipitation, is employed by HEC-HMS in order to simulate direct runoff. This model has been used rather frequently throughout its history. Sherman described it as "the basin outflow resulting from one unit of direct runoff created evenly across the drainage zone at a uniform rainfall rate over a certain period of rainfall duration" in his original suggestion, which was made in 1932. HEC-HMS models are used to compute each component of runoff separately. Models such as direct runoff, loss, routing, and base flow are examples of these types of models.

7.Conclusion

Flooding occurrences caused by large storms are common, causing major difficulties such as loss of property and lives. Hydrologic modelling is a method that is frequently utilized for the purpose of gaining an understanding of the processes of rainfall runoff that take place in gauged and ungauged catchments respectively.

Floods have been reported as one of the major disasters in Pakistan that has exposed all the provinces at risk especially during 2022 floods. Furthermore, flood damages have been assessed based upon the data provided by National Disaster Management Authority Pakistan. The application of GIS and hydrological modeling for flood prediction and assessment can play an important role to build the local early warning system. In addition to this, redesigning of hydraulic structures considering weather extremes is crucial to void flood damage.

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