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RESEARCH ARTICLE

Estimating Annual Flow Frequency Function Using HEC-HMS and GIS: A Case Study Mula River in Jhal Magsi, East Balochistan

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Abstract: Water is a basic necessity for life, and it is the most abundant natural resource on our planet. Its usefulness is vast and at times becomes hazardous when not properly managed. Balochistan is a region suffering from extreme events of flood and drought conditions. The study area, Jhal Magsi, located in central Balochistan, Pakistan, is one of the most vulnerable regions to flash flooding. The SRTM DEM for Jhal Magsi was used in HEC-GeoHMS, an ArcGIS extension for terrain pre-processing, basin processing, and catchment delineation. Hydrological models are used to simulate the impact of climate on water resources. Integrating Remote Sensing abilities and Geographic Information System techniques with the hydrological modeling approach is very useful to understand problems and enhance the methods of investigation for better decision making. Based on the results of the watershed delineation, this analysis identified the basin characteristics, estimated rainfall distributions. HEC-DSS is used to store and retrieve data to give input to HEC-HMS for flood frequency studies and AEP calculations. The tabular results consist of three tables. The frequency curve shows the percent chance of exceedance ordinates. The expected probability frequency curve is between a 5% and 10% chance of exceedance confidence limit of the observed values. Calibration and validation had been done, and statistical analysis as well. The graphical results show outliers to predict extreme events, which are expected once in the coming 50 years. The research will be helpful for hydrological modeling and future prediction in the data-sparse regions of Balochistan for damage reduction studies using HEC-RAS.

Keywords: GIS, Hydrology, Flash Flooding, HEC-GeoHMS, HEC-HMS

Introduction

Balochistan has been enduring devastating natural disasters like flooding, drought, wind hazards, and earthquakes due to climate change. North and East Balochistan are most vulnerable because of flash flooding. Eastern districts of Balochistan can be considered the food basket for many parts of the province. Some extreme events in the past in these areas have caused major agricultural, irrigational, social, and economic losses (Ashraf & Routray, 2015. In North Balochistan Zhob, Harnai, Loralai. face flash flooding, whereas in the central and southeast part of Khuzdar, Jhal Magsi, Gawader, Nasirabaad, Jaffrabad, and Turbat suffer both from western dispersions and monsoon as well (Ashraf & Routray, 2015; Rees, et al., 1990).

The investigation into the heavy rains has increased in all parts of Pakistan. A significant increase in the incidence of heavy rains has been observed at every doorstep in Northern Areas, Sindh, AJK, and Balochistan, except for 98% in Northern Areas and Balochistan. Each show has its claim one-of-a-kind

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highlights. The strategies utilized by other models include temperature, precipitation, soil properties, exposure, vegetation, physiological, and Hydrogeology parameters. These models can be utilized in exceptionally complex and huge bowls with their particular highlights. Geospatial software and data retrieval techniques are very much in use for hydrological models (Baumbach, 2015). Hydrological models are presently a day considered a vital and vital approach for water and environmental management (Sorooshian, 1991). Geographic information systems use altitude data and geometry algorithms to perform tasks faster. Watershed physical features and data management have been effectively explained. Geospatial products are designed to help create basin models (Hudgens & Maidment, 1999). ArcGIS is a highly applicable, efficient tool for extracting grid values related to their events, rotation, and distribution, which performs chemical and hydrological analysis on any grid (Baumbach, 2015). The combination of HEC-GeoHMS with GIS is now being practiced the world over for hydrological studies by extracting terrain characteristics, delineating the basin, and creating the HEC-HMS model (Knebl et al., 2005). Six components categorize the data in the project extension with ArcGIS: (1) Basin model, (2). Climate model (3). Control specifications (4). Time series data (5). Pair data (6). Grid data (Sorooshian, 1991).

HEC-HMS is software for hydrologic modeling, and other hydrologic models also generally have similar inputs but different formats, such as explanations about irrigation, land use or cover, soil type, and rainfall data (Interagency Advisory Committee on Water Data, 1982). It had better also have discharge measurement data for the calibration process. HEC-HMS is used for the better estimation of run-off from rainfall data of any Watershed (Yuan et al., 2019). In hydrology, the frequency analysis of a flood is a very active field that deals with the severity of events, discharges, phases, or volumes from its occurrence or the possibility of exceeding it (Federal Emergency Management Agency, 2007; Waananen & Crippen, 1977). As it is a topic of interest, various studies have been done previously using different techniques and different study methods or models, like some statistical techniques, and some Hydro engineering, which are GIS, HEC-SSP, HEC-HMS, HEC-RAS, etc. HEC-HMS was very focused on flow and approached it from an engineer's 'worst-case scenario' point of view. HMS does provide flexibility in regard to local hydrology, so you can tailor your model to fit your climate, local precipitation, and evaporation (Oleyiblo & Li, 2010; Yener et al., 2007). Ideally, HEC-HMS is widely used as it generally gives good simulations in rural and urban areas. So, if you have enough data on rainfall and flow rates, HEC-HMS can be useful; you will be able to calibrate the model with some known data.

An important difference between HEC-HMS and HEC-DSS is the use of a data storage system to achieve time sequence and Statistical data. This relates to similar data, which must ensure that temporal and statistical information are not stored in the HEC HMS dataset. The information is put away in a partitioned HEC DSS information record, which is recovered utilizing the HEC HMS display (U.S. Army Corps of Engineers, 2009; Halwatura & Najim, 2013). Long-term information arrangement (a long time and more) can be put away in HEC-DSS, and numerous demonstration runs can be scored at different times within the information arrangement. Information can moreover be obtained through other HEC models, such as the HEC-FDA, which analyzes the toll advantage of surge control and surge management alternatives. Although the HEC-DSS program bundle could be an awesome way to handle hydrologic information, there's no simple way to exchange information from a spreadsheet to a HEC-DSS record. The HECDS database enables the simple graphing of data that arises in exceeding expectations with minimal client organization (Halwatura & Najim, 2013).

Calibrating and validating the model with real-time data. Calculation of Annual Exceedance Probabilities (AEP) for different flood return periods. Develop flow functions for current conditions in unplanned water flow during and after the study (Zhang et al., 2014). Various reports were published by the Federal Flood Commission, WAPDA, and PMD. The physical and hydrological parameters can be taken from other sources, such as topographic maps and adherent symbolism, but the advanced height (DEM) has numerous preferences. These days, a few sensors can set the condition of something. It is found in several

DEM items and is inferred, which is exceptionally vital for hydrological applications. With the final proposal data of the dam, you'll be able to dispense with the hydrographical arrangement by planning the watershed. At the same time, an extensive number of hydrographic systems and watershed highlights can be characterized. The integration of other hydrological information, such as integration and bend number (CN), permits others to gauge hydrological parameters such as interim time, concentration-time, etc. Developing advances within the geographic data space moves forward frameworks GIS), effective devices permit control, capacity, examination, and display of neighborhood reference information. GIS also plays a key part in geographic data support (Goodchild et al., 1996). In addition to extricating information from GIS and presenting it into recreation models, GIS is more suited for hydrological modeling than coordinating reenactment models (Puech & Raclot, 2004). Flood rate investigation in urban watersheds has no record of yearly crest records related to arriving utilization alteration and urban stormwater framework development (Villarini et al., 2009).

Flood hydrographs for diverse arrival conditions have been obtained using the soil conservation benefit, bend hydrological model, and the motor wave model for directing accessible data inside the HEC-HMS program. Basic surge maps, as well as surge chance maps for diverse, arrive utilize scenarios with HEC-HMS and HEC-RAS, HEC-Geo-HMS and HE, created by joining with C-Geo-RAS, as well as GIS and inaccessible detecting. Speed, stages, and amounts are required for particular AEPs (also known as yearly probabilities) to meet the goals of surge recurrence studies. Stream and arrange recurrence bends are regularly utilized to calculate surge harm. Volumes are regularly utilized for the estimation of Flood control structures such as concentration lakes. Values may be required: current development, without-project conditions, and future development, without-project conditions.

A coordinate modeling approach is exceptionally successful for surge estimating, straightforward flooding, and surge risk mapping. Inferred surge and surge chance maps can be utilized as a viable instrument to diminish the harm within the flood-affected areas of the bowl (Hasan & Ahmad, 2006). Yearly greatest stream recurrence capacities assessed from the investigation of long records of the greatest maximum annual stream are the foremost solid recurrence capacities. Be that as it may, long-term record insights are once in a while accessible. In expansion, watershed conditions have changed. Calibrated watershed models with known recurrence of precipitation occasions are regularly utilized to create stream recurrence work and compare with other gauges. The calibration of the demonstration is regularly based on accessible verifiable occasions of comparable frequencies. The existing design structures are not a feasible procedure for dodging future surge catastrophes. Instep, arranging for major water and debris stream preoccupations is required for compelling surge control along the Mula and other sediment-rich and inclined waterways (Chen et al., 2011). The objectives of this study are to estimate watershed data management, delineation, pre-processing, physical features calculation, and initial parameterization.

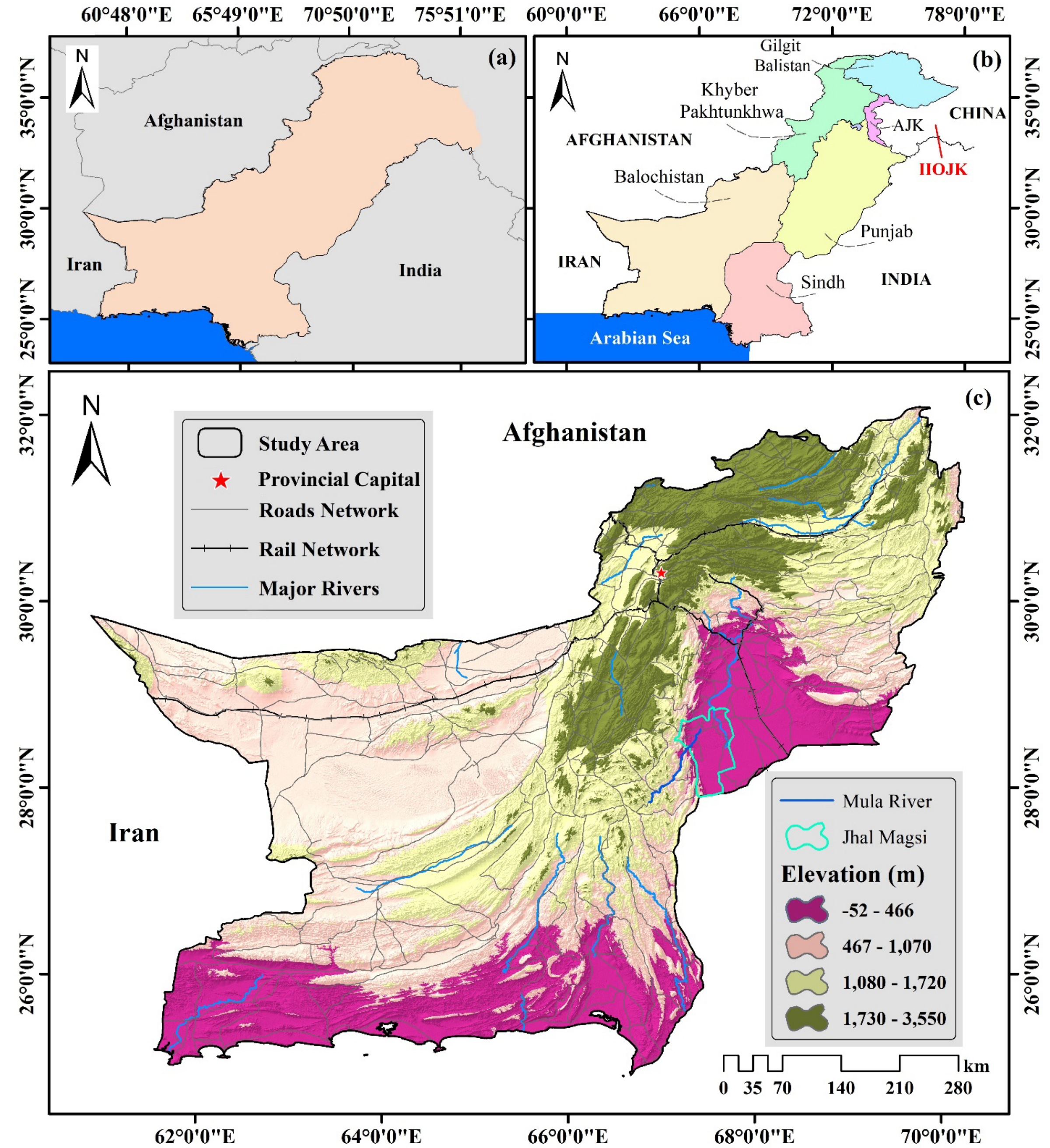
Methods and Materials

Study Area

Balochistan is the largest province of Pakistan, with an extent of 347,190 km^2 (43.6%) (Ullah et al., 2025). Quetta is the provincial capital of Balochistan and is located in a geographically significant area because of its distinct geography, climate, and socioeconomic dynamics (Mengal et al., 2025). There are many small and large river channels flowing all over the province, as shown in Figure 1. District Jhal Magsi covers an area of about 3,615 km^{2,} and the elevation of the district is 40 to 1,544 meters. Jhal Magsi district was established on 16 February 1992, and the Absolute location of the district is from 27°53'34" to 28°50'50" North latitudes and 67°09'34" to 67°48'13" East longitudes (Planning & Development Department & UNICEF, 2011). According to the 7th Population and Housing Census, the population of Jhal Magsi is 203,368 people (BPS, 2023). The Magsi tribe's hometown is Jhal Magsi. During the British Raj, it was a part of the Kalat state. The two largest tribes in the area are Jamoot and Baloch. The majority of the population speaks Balochi, Saraiki, and Sindhi (RSPN, 2018). The climate of the district is characterized by mild winters, with January having the lowest mean temperature (about 8°C), and scorching, dry summers, with June having the highest mean temperature (about 44°C). About 79.9% of the workforce in the district is employed in agriculture and livestock farming, which form the backbone of the area's economy. Sugarcane, cotton, tobacco, canola, sunflower, wheat, barley, rapeseed, and mustard are among the main crops. Additionally, fruits including watermelons, dates, guavas, citrus, and mangoes are grown. Cattle, buffalo, sheep, goats, camels, and poultry are the livestock of the district. Aseel poultry, Balochi sheep, Berberi goats, and Bhagnari cattle are among the native indigenous (Balochistan Almanac, 2025). Mula River flows from the district Jhal Magsi and is often encountered by flash flooding and flooding because of the Indus due to improper irrigation patterns. It has unlimited impacts on its surroundings in agricultural and economic ways.

Figure 1

(a) Pakistan Map, (b) National and Provincial Boundaries of Pakistan, and (c) Balochistan Map Showing Jhal Magsi, Mula River, Major Roads, Railway, Major Rivers, and Elevation



Similar to Pakistan, particularly in the province of Balochistan, there is no proper long record of any hazardous incidents, however, several urban flash flood hazard events have happened in various years (Ullah et al., 2024). The present study area was selected because flash flooding and drought conditions have badly affected this area, and other parts of Balochistan at the same time. The eastern part consists of Jaffrabad, Nasirabad, Jhal Magsi, etc. These areas are called the food basket for many parts of the region. These areas face heavy flooding because of the Indus River and heavy monsoon rainfall, which affects life and the economy a lot. Lack of flood management planning causes great disturbance to human life and land, as well as there is no proper pattern to store water for agricultural and domestic use (RSPN, 2018). Fewer Metrological and discharge gauge points, because of which no forecasting for floods and planning or security measures were taken.

Mula River

Mula River has a large catchment area composed of rocky, fractured formations, steep slopes, and bare rock surfaces with minimal vegetation, as shown with the dark blue color in Figure 1. Important towns located outside the catchment area are Kalat (in the north), Surab (in the west), Khuzdar (in the south), Gandava (in the east), and Jhal Magsi (in the south-east). Mula River has four major tributaries (Mula branch river, Angira nullah, Ledho nullah, and Main Mula river), which originate from different directions and areas. The river/nullah channels form a series of sand-bedded, wide valleys of flat/small channel slopes, narrow gorges with steeper channel slopes, gravel outwash beds of gorges, etc. i) The Mula branch river drains the central part of the watershed. It originates from the Kalat district and flows from north to south up to Kechari, where it joins the Main Mula river. The catchment area of the Mula River up to Kechari is 970 sq. miles (2512.3 sq. km), and the length of the mainstream is 80 miles (128.7 km) with a bed slope of 105 ft./mile (19.9 m/km). ii) Ledho nullah drains the eastern part of the watershed. It originates from the north and flows towards the southwest. The catchment area up to its confluence with the Main Mula river is 573 sq. miles (1484 sq. km). Length of Lehdo nullah 69 miles (111 km) with bed slope 110 ft./mile (20.8 m/km). iii) Angira nullah drains the western part of the watershed. It originates from the vicinity of Surab and flows in the southeast direction. Its catchment area is 611 sq. miles (1582.5 sq. km), length 55 miles (88.5 km), and nullah bed slope is 153 ft./mile (29 m/km). iv) Main Mula river drains the southern part of the watershed from the Khuzdar side in addition to the main tributaries of Mula river, Mula branch, Angira nullah, and Ledho nullah. The catchment area of the main Mula River between the dam site and Kechari is 736 sq. miles (1,906.2 sq. km). The total catchment of the Mula River at the proposed Naulong Dam site is 2890 sq. miles (7485 sq. km) (Hasan & Ahmad, 2006). Naulang Dam is located on the Mula River at about 1 km South at latitude 28°26'15" N and longitude 67°19'50" E. The dam site is about 30 km southwest of Gandava town in Tehsil and District Jhal Magsi of Balochistan Province (RSPN, 2018).

Datasets and Methodology

Through geospatial data, watershed delineation requires a Digital Elevation Model (DEM). SRTM DEM was obtained through online sources from the United States Geological Survey (USGS Earth Explorer), and the study area was extracted using a shapefile (.shp). The Pakistan district maps of Balochistan were acquired from the Spatial Decision Support System (SDSS), Lab. Frequency analysis needs river runoff or flow and meteorological data like precipitation and temperature. Metrological data in the present study from 1990 to 2016 were obtained from the Pakistan Meteorological Department (PMD) (Table 1). River discharge data from 2004 to 2015 were obtained from the Water and Power Development Authority (WAPDA). The obtained data was further processed in the Hydrological Construction Center (HEC) and a Geographic Information System (GIS) environment. Geospatial procedures depict streams and watersheds and build a hydrological exhibition structure for HEC-HMS (Sorooshian, 1991). HEC-GeoHMS is a public-domain extension for ArcGIS used for the preparation of GIS data for import into HEC-HMS and the generation of GIS data from HEC-HMS output. The detailed methodological framework followed for the present study is shown in Figure 2.

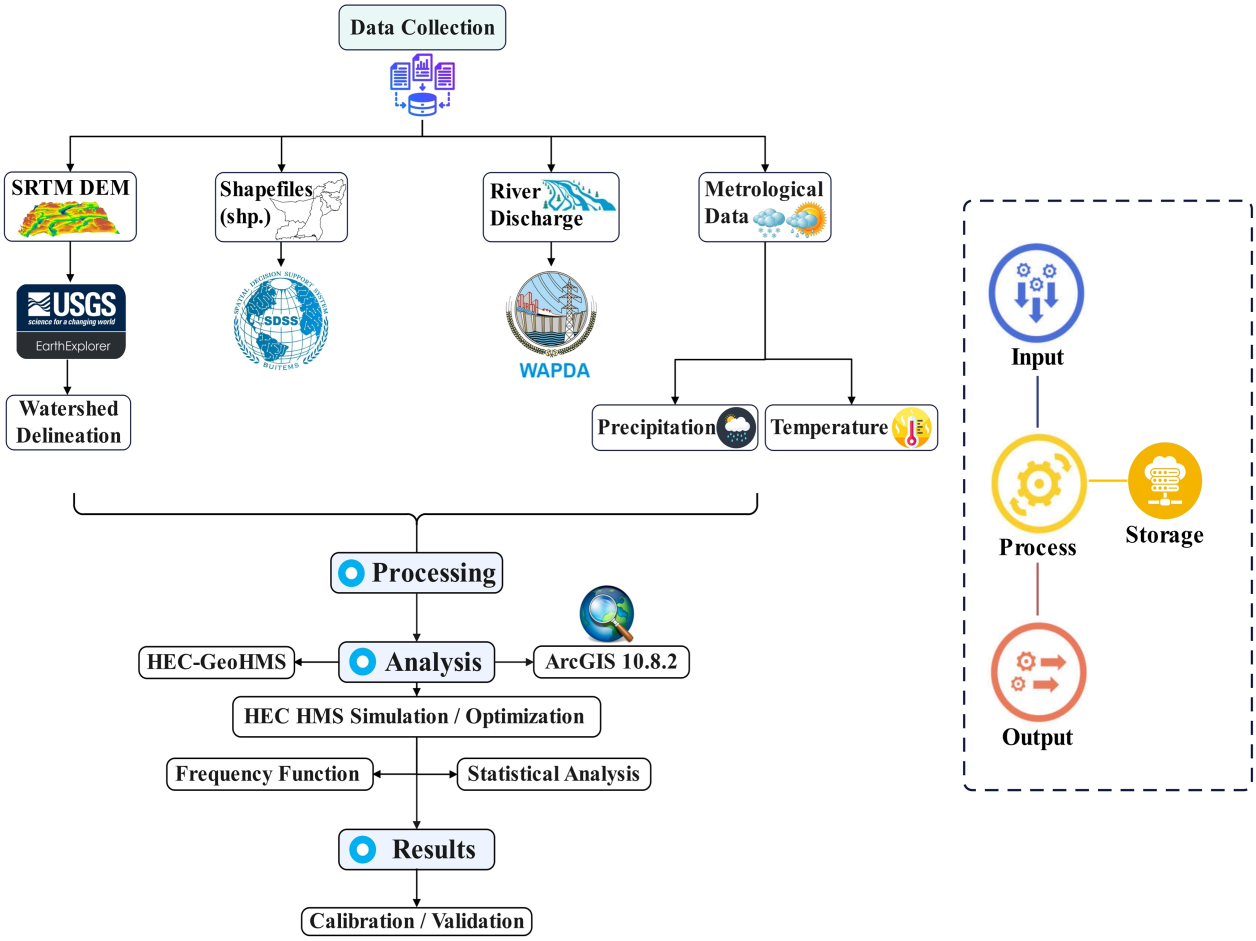
Table 1

Tableshows the used dataset, its source, and links.

Data	Source	Link
DEM (Digital Elevation Model)	USGS Earth Explorer	https://earthexplorer.usgs.gov/
Pakistan District Shapefile	SDSSL	https://ncgsa.org.pk/spatial-decision-support-system-lab-sdssl/
Metrological Data, e.g., temperature, precipitation	Pakistan Meteorological Department	http://www.pmd.gov.pk/
Discharge Data	WAPDA	http://www.wapda.gov.pk/

Figure 2

The Detailed Methodological Framework Followed for the Present Study



Data Management and Processing

Hydrologic Parameter Estimation

The calculation of the bend type (CN) and different accident parameters was supported by completely different soils and databases. The variety of bends will speak of the association of traditional respect for a sub-pool or a single cell for a mesh sub-pool (Baumbach, 2015). The watershed and channel properties, as well as the program format, are a square measure connected to HEC-GeoHMS to estimate the initial values of the concentration-time. Moreover, the properties of the bowl and channel will be used to calculate the CN Slack and the main kaleidoscopic parameters of the steering Muskingum-Cunge (Vittal et al., 2015).

HMS Model Support

HEC-GeoHMS produces a series of hydrological inputs that are a square measure used specifically in HEC-HMS. Estimation of hydrological indicators, giving tables of physical properties of waterways and sub-basins. While working with HEC-GeoHMS, the buyer will use alternative ArcGIS growth programs to generate additional parameters to perform abstraction operations and complete the hydrological demonstration. Volumes are needed to take into account the specified annual repetition of voltage spikes, high currents, stages, and chances of probability. Volumes are often used for the existence of management structures, such as holding pools. Values are also needed for: 1, current progress, non-project conditions; 2, future improvements, although the conditions do not apply. The terms show and the future are used to touch the conditions of the bowl, which existed later, against the background of the explosion and for a specific purpose. Some terms refer to the condition of bowls and channels, singly, if no activity is carried out. For ongoing improvement, the repeatability for non-design conditions can be improved by a measurable study of the perception of flow, scene, or volume. Physical properties of the Jhal Magsi bowl within the knowledge used at intervals in territorial reflection; territorial links can be used to estimate flow rates for current and future conditions of use. As a standard thumb rule, the annual combined repetition capacity, estimated from a measurable survey of long annual crest flow records, is the most powerful repetition work. In any case, broad data is recorded once during availability. Therefore, with a long history, catchment conditions could change altogether due to urbanization or alternative non-stationary forms, or notable cases could not occur among the number of records. Therefore, the exact operation of the flow rate cannot be fully determined from chronic data. A bowl with a demonstration sign of precipitation with known repetition is often used to repeat the flow and compare it with alternative predictions. Demonstration activity for the vast majority is supported by current proven cases at comparable frequencies.

Developing a Frequency Function

A rainwater steering show was created that displays the characteristics of the bowl and channels for the appropriate circumstance: current or future, unlimited. The current demonstration, which does not have an expanding area, shall be calibrated according to the observation, if available, or approved by territorial conditions or flow sensors. Collected precipitation data, performed a measured survey, and characterized the depth of identified recurrence for the bowl. Conclusions on the actual survey can be displayed as a fragment of repetition duration (IDF) or as a fragment of repetition of duration (DDF). Demonstration of the introduction of precipitation flow to calculate the most extreme flow, preparation, or volume. Distributed re-precipitation (AEP) to the highest flow, location, or volume uptake when a suspected storm is outlined above (Hudgens & Maidment, 1999).

- Repeating the process for a series of frequency events.
- Combining the results to get a complete frequency function.
- Whenever further adjustment of the frequency curve was required, sensitivity analysis was used to determine the most important parameters.

Decided on the best estimate of the backflow rate for this enterprise by comparing the results of this hydrological storm frequency model with other methods (e.g., flow statistics and regional regression equations, if available).

Computing Future Development Frequency Functions

Once this re-improvement work was received, the next step was to move forward with the long-term re-improvement work. Completion of development work was achieved with the help of a hydrological model. The hydrological show should be associated with re-bending, which is embraced. Repeat work is calculated by constantly changing the demonstration and using the same precipitation. Changes in the demonstration may result from changes in the use of profits or cases of companies that manage surges. Two basic ways to connect a hydrological show:

- Calibration of the peak flow of the hydrologic model to match the desired frequency.
- Assignment of a frequency of the hydrological model to the maximum flow according to the accepted frequency curve.

Changes in the reverse bending intervals through future units of advance area, calculated from the dynamic characteristics of the bowl and applying the constant precipitation display used for this state of improvement (Schendel & Thongwichian, 2015). The steps below depict an approach that requires fitting a breakthrough model to receive returned work using misfortune values as a standardization parameter. Use smart sensors for reference conditions, as well as to demonstrate parameters. Use the HEC-HMS show to calculate the flow crest for return cases. Compare the flow ridges calculated by HEC-HMS for this return case with the bending flow obtained at constant recoil. For example, compare the highest HEC-HMS flow with the best 0.01 AEP flow from the covered rework using AEP zero precipitation 01. Set the HEC-HMS display parameters as the best stream calculated by the HEC-HMS for this iteration. Rethink the standardization handle for multiple repetitions (0.50-0.002-AEP). Change the demo settings to repeat the end of the circumstance (send using an amendment or think). Use the first graduated accident estimate for each recurrence, except for precipitation supported by such a recurrence, to calculate the future performance of the flow recurrence (Gizaw & Gan, 2016).

Recurrence Interval

Actual methods were used to estimate the probability of a case of precipitation through the handle, known as the return investigation (Hudgens & Maidment, 1999). Repeated intermediate time relies on the probability that the situation will be reached before or exceeded in the same year.

Floods

Repeat intervals and 100-year bursts. To illustrate, there is in fifty percent probability that 60 inches of rain can fall in an extremely 24-hour period in a given year. It is alleged that the round-the-clock amount has a recurring period of fifty extended hours. First of all, using repetitive studies, the probability that a flow of fifteen thousand feet per minute (ft3 / s) will occur in an excessively given flow rate for any year is one in a hundred.

Subsequently, the largest flow in the sector of fifteen is said to have a recurring period of one hundred long periods. The unit of precipitation recurrence area supported each scale and timing of precipitation events, while the intervals of periods of the flow of streams are assumed because they were on the scale of the annual main flow. To perform a re-study to select repeated time intervals, you need 10 or an additional long period of knowledge. A lot of time is spent checking the information, the approach is higher - the hydrologist can rely a lot on the analysis of the waterway with a 30-year record compared to the study of the flow supported by a 10-year record. In case the probability that the counter records a square measure is pleasant and accessible for a very long time, for example, for a fairly long time, rework that corresponds to the data can also be the most important reliable strategy. In any case, it must contain the re-addition of a fast-recording time. Through coercive use, particularly when it provides knowledge of creation or exploitation when peace can also be a priority (Burnham, 1980; Hudgens & Maidment, 1999).

Validation

For calibration and validation, the data was observed from 2009-2010. HEC-DSS manages the data for processing in HEC-HMS and calibration and validation in Excel files. Information technology is easy to directly connect with the processing of simulating software.

Statistical Analysis

This step is very necessary for any research for accuracy assessment. The determination coefficient (R^2), the Nash-Sutcliffe (NSE) are described below. Used observed data for calibration and validation, data (2009 -

2010). Therefore, this study presents Nash-Sutcliffe (NSE) efficacy statistics, which determination coefficient (R^2), used for the analysis and performance of the models through calibration & validation of the flood frequency analysis of the HEC-HMS hydrological model. The different equations used to calculate NSE and R^2 are described below (Haan, 1977).

Nash-Sutcliffe (NSE)

The Nash-Sutcliffe (NSE) demonstration performance constant is used to estimate the demanding management of hydrological models. wherever Qo is traditional for the observed belts and Qm is a slender release. The discharge is observed at the moment Qot, t.

$$\mathbf{NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{obsi} - Q_{simi})^2}{\sum_{i=1}^{n}(Q_{obsi} - Q_{obs})^2}}$$

Coefficient of Determination R^2

The square R may be an actual degree, but the established relapse line is close to the data. this is additionally called the confidence constant or the confidence constant for various relapses. The definition of the R-squared is extremely basic, it is the rate of the variability of the response variable processed by the linear model (Haan, 1977).

R^2 = Explained variation / Total variation

R^2 is always between 0 and 100%:

$$\mathbf{R^2 = \left\{\frac{\sum_{i=1}^{n}(Q_{obsi} - Q_{obs})(Q_{obsi} - Q_{obs})}{[\sum_{i=1}^{n}(Q_{obsi} - Q_{obs})^2]^{0.5}[\sum_{i=1}^{n}(Q_{simi} - Q_{sim})^2]^{0.5}}\right\}^2}$$

Results and Discussion

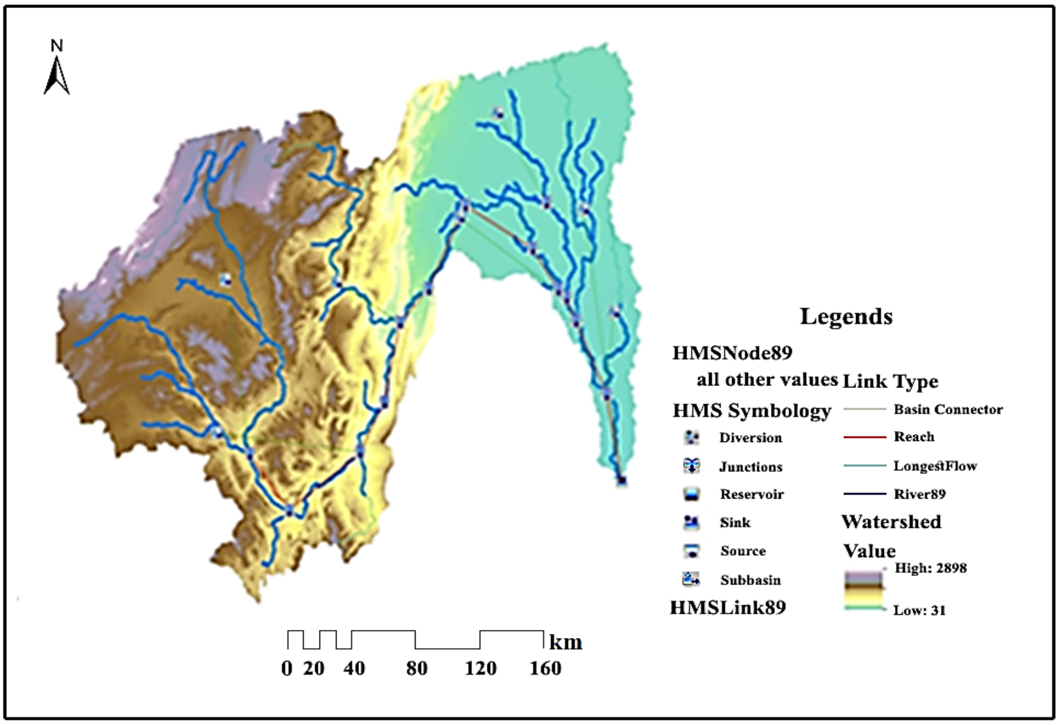
The spatial distributions of the estimated damages show high-intensity losses in agricultural lands (crops) along rivers and nullas. This region, which is part of very fertile land, produces a variety of summer crops and fruits. However, due to the lack of detailed data on crops, no further analysis can be performed to estimate the damage to crops. Many sections of roads, including main roads and many smaller roads, are affected by flooding. In this study, only the size of the flood has been mapped. However, by integrating detailed GIS data (properties, streets, crops, etc.), a detailed damage estimate can be developed down to the finest detail based on the precision of the GIS data (Hoffmann & Sander, 2007). Data for the floodplain are not available and are not available for the study area. Therefore, this mapped flood reaches of one of the historical floods can be used very effectively to establish general floodplain boundaries, which are generally produced based on specific flood models. These designated floodplains can help contain future development within their boundaries to prevent and minimize the loss of people and property.

Preprocessing and Watershed Delineation using HEC-GeoHMS

Geographic Information Frameworks (GIS) have opened various opportunities for hydrological demonstration of watersheds. HEC-GeoHMS was created as a geospatial geophysical toolkit for engineers and hydrologists with a forced encounter with GIS. A hydrological demonstration has advanced to talk to the sub-basin in more detail than the standard approach, wherever hydrological parameters have found a central role in large basins (Baumbach, 2015). Due to the availability of radar precipitation and spatial information, hydrological modeling using smaller sub-basin areas or a network system has provided many targeted bowl illustrations. HEC-GeoHMS is planned to satisfy the desires of each modeling approach (Figure 3).

Figure 3

The Map Shows the Elevation of the Watershed Delineated Area with its Reach, River Tributaries, and HMS Symbolog.



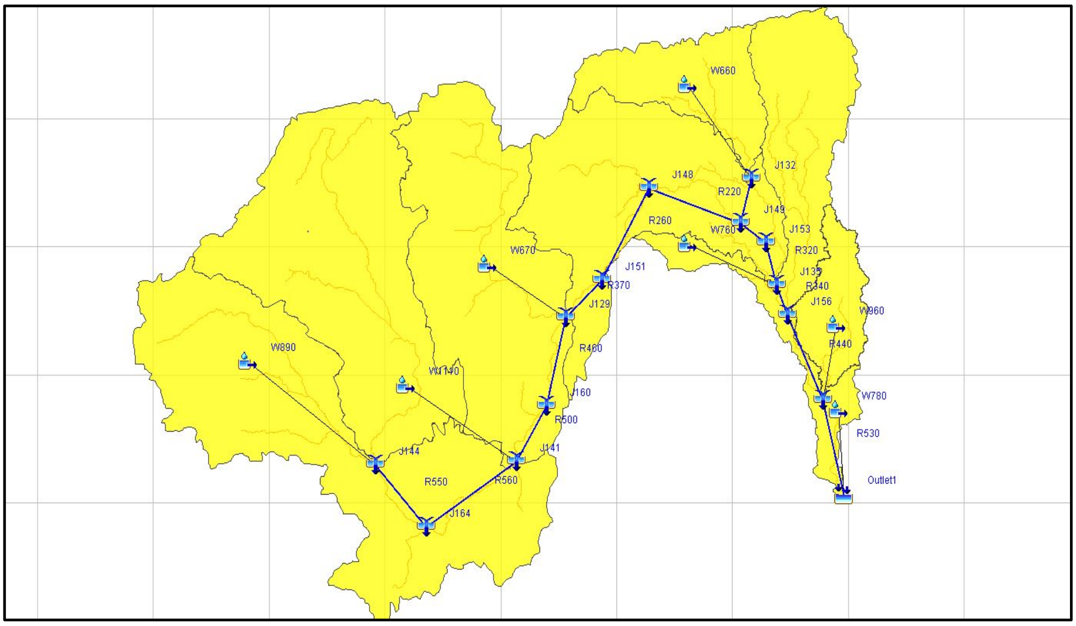
HEC-HMS Schematic

As a numerical demonstrator, HEC-HMS includes completely different ways of simulating the behavior of the bowl, channel, and water management structure, thus predicting flow, stage, and time. This study provides solutions to the study problems through equations and deals with the arrangement and adjustment of each method.

HEC-HMS map imported for ArcMap (HEC-GeoHMS). More attempts were made at optimization, calibration, verification, flood functions, and AEP calculations (Figure 4).

Figure 4

HEC-HMS Exported a Map From HEC-GeoHMS with its Sub-Basins. Tributaries and HMS Symbology



Model Parameters

Through the process of optimization, best-fit parameters were tested, which showed suitable results during the simulation. Table 2 shows the best-fit parameters for the study process and the ranges on which the best set. These are Loss SCS Curve number, Transformation Clark's Unit Hydrograph, Base Flow Constant Monthly, and Routing Muskingum (Yuan et al., 2019).

Table 2

Selected Models and Parameters during Optimization that Best Fit During Simulation

Model	Parameters	Min	Max	Best fit
Loss SCS Curve Number	Initial Abstraction	0mm	500mm	5mm
	Curve number	1	100	45 - 55
	Imperviousness	1%	100%	Current 15 – 25 Future 5%: 20 – 30 10%: 25 - 35
Transform Clark's Unit Hydrography	Time of Concentration	0.1hr	500 hours	100 – 150
	Storage of the coefficient	0hr3	150 hours	100 - 120
Base Flow Constant monthly	Months	0 m^3/s	10,0000 m^3/s	10 – 40 m^3/s
Routing Muskingum	K	0.1hours	150 hours	0.1 – 3
	X	0	0.5	

Calibration and Validation

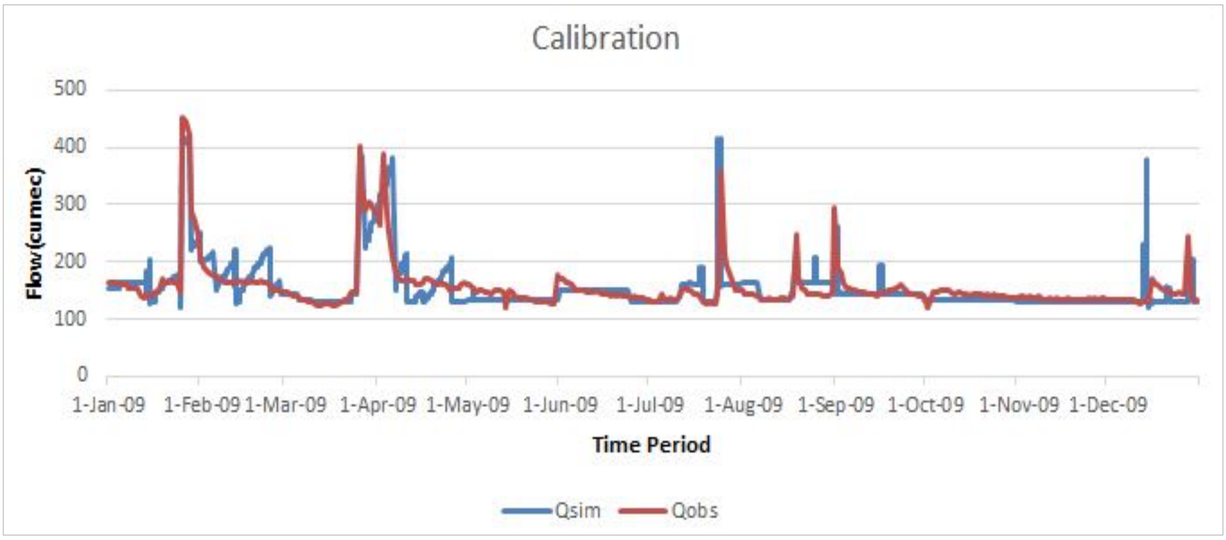
The HEC-HMS calibration and verification were performed between 2009 and 2010, respectively. Figure 5 shows the satisfactory results of the HEC-HMS model, but because of the lack of real-time data, there is a bit of disturbance in the last months of the year. The flow peaks are simulated well. Table 3 shows the statistical results of the calibration and validation periods. Simulated results are within the range of predefined NSE and R^2.

Calibration

Calibration is performed for the year 2009. It shows the clear differences and similarities between the simulated and observed flow (Figure 5).

Figure 5

Calibration between Observed And simulated Flow for the Year 2009

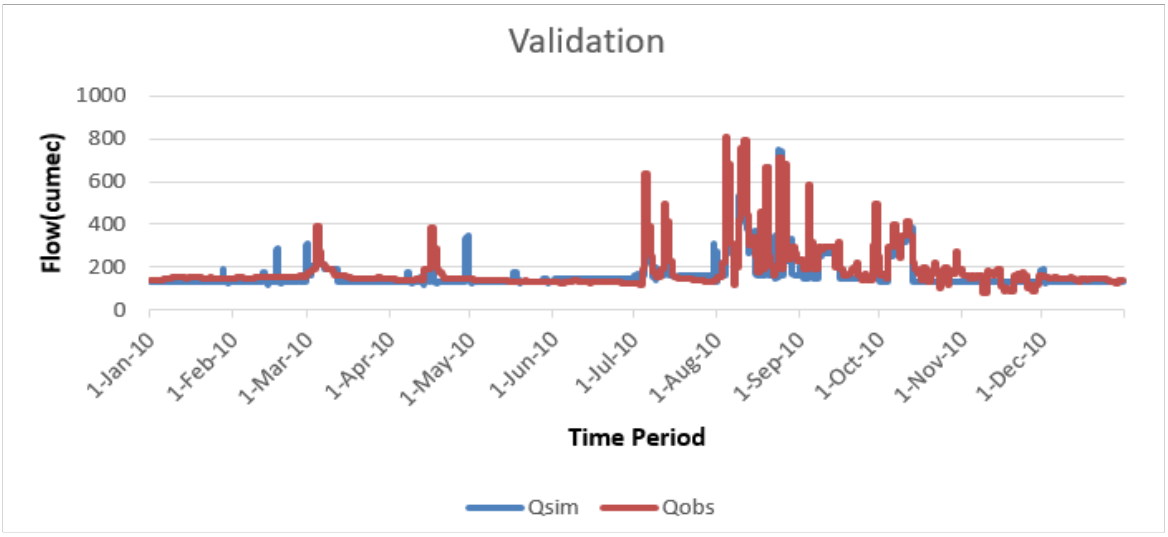


Validation

The validation for 2010 shows the graph of simulated and observed flow. There is some confusion in the graph due to the lack of data in the last months of the year (Figure 6).

Figure 6

Validation of the Model Between Simulated and Observed Flow for the Year 2010



Statistical Analysis

Statistical analysis is necessary for research to be done. Two analysis tools used for this study are NSE and R^2.

Table 3

Accuracy Assessment by Using Statistical Analysis Tools. Shows Calculated Values for Calibration and Validation

Statistical Analysis Tools	Calibration	Validation
NSE	0.6	0.5
$\mathbf{R^2}$	0.6	0.5

Flood Frequency Analysis

The magnitude of the discharge, with the possibility that the stage volume will occur or exceed. The resulting flood frequency functions provide the information you need to:

- Assessing the financial profits of the flood damage reduction project
- Sizing and plan of water control measures on the off chance that the level of overshoot or unwavering quality is indicated.
- Create reservoir criteria and report on the show's achievements.
- Establishment of floodplain management regulation.
- Make suitable regulations for local and land use.

Peak flows, phases, and volume are required for the specified AEP (also known as quarters) to achieve the targets (Guru & Jha, 2015). Stream recurrence and stage bends are frequently utilized for flood damage calculations. Volumes are regularly utilized to estimate surge control structures such as detention pools. Values may be required for current advancement conditions exterior the venture and future improvement for non-project conditions. Display and future are utilized to demonstrate current watershed conditions at run time and at a point, individually.

The current non-project show was calibrated based on the watched information, and after that, approved. For a chosen recurrence, the data was utilized from the DDF to characterize a precipitation hyetograph, at then the precipitation stream introduction shows how to calculate the most extreme stream. Then assigned the precipitation frequency (AEP) to the maximum flow following the described thunderstorm design assumption (Table 4). Similar steps were repeated, aimed at series frequency procedures (Waananen & Crippen, 1977). The outcomes are collectively provided for complete frequency studies.
Recurrence intervals and probabilities of occurrences

Table 4

Represents the Recurrence Interval After How Many Years with its AEP's and Percent Change

Recurrence interval, in years	Probability (AEP) of Occurrence in any given year	Percent Change of Occurrence in any given year
500	1 in 500 (0.002)	0.2
200	1 in 200 (0.005)	0.5
100	1 in 100 (0.01)	1
50	1 in 50 (0.02)	2
25	1 in 25 (0.04)	4
10	1 in 10 (0.1)	10
5	1 in 5 (0.2)	20
2	1 in 2 (0.5)	50

Some theoretical (repeated) cases of precipitation within the watershed were used to create work on the flow frequency. The case of 0.01 AEP, which is used to return bursts, is based mainly on the depth of local DDF capacities developed locally. HEC-HMS has eight predefined alternatives for reverse storms. Actual frequencies offer a satisfactory definition of return work. All eight recorded precipitation frequencies were used as the limiting connotation to demonstrate the watershed; during this method, eight quintiles were obtained for the inverse capacity.

Floods Recurrence Intervals

You may find yourself in a limited state when a truly monumental rainfall occurs. The storm manifested itself in a very 100-year surge, for example. The waterway of the Indus reached a peak of twenty feet. This means that the waterway returns to the preparation for the ridge (physique), which happens because it was a hundred times longer.

Table 5

This Table Shows the Current and Future Chances for the Recurrence of Floods with 5% and 10%

AEP's	CURRENT	FUTURE 5%	FUTURE 10%
0.5	95.5	115.5	109.3
0.2	210.8	250.2	251.6
0.1	261.5	306.1	308.8
0.04	410.9	462.7	464.5
0.02	526.5	574.5	576.6
0.01	644.5	699.6	700.9
0.004	710.4	768.7	770.2
0.0002	809.7	894.2	896.8

Agreeing with reliable data on actual rainfall and flow organization, the chance of the waterway returning to its original level in twenty feet per hundred years lasts a long time. The 100-year burst level is calculated based on past existing data, because a lot of data is coming in (Halbert et al., 2016), the amount of the 100-year burst may change (especially if the huge surge hits the current year) (Table 6).

Table 6

Shows The specified AEP's Concerning the Time

Duration	Depth (in) for Specified Annual Exceedance Probability							
	0.50	0.20	0.10	0.04	0.02	0.01	0.004	0.002
5min	0.13	0.20	0.25	0.32	0.38	0.44	0.49	0.58
10min	0.19	0.29	0.36	0.46	0.54	0.62	0.70	0.82
15min	0.23	0.35	0.43	0.55	0.64	0.73	0.82	0.96
30min	0.32	0.47	0.57	0.72	0.83	0.94	1.04	1.22
1 hours	0.45	0.64	0.77	0.94	1.07	1.21	1.33	1.53
2 hours	0.64	0.88	1.04	1.26	1.42	1.59	1.76	2.00
3 hours	0.77	1.04	1.23	1.47	1.66	1.85	2.03	2.31
6 hours	1.06	1.40	1.65	1.95	2.22	2.50	2.75	3.10
12 hours	1.43	1.91	2.25	2.67	3.00	3.30	3.60	4.00
24 hours	1.90	2.50	2.98	3.46	3.85	4.25	4.60	5.20
36 hours	2.25	3.02	3.54	4.15	4.60	5.09	5.53	6.24
2 days	2.25	3.40	3.95	4.65	5.15	5.70	6.20	7.00
3 days	3.00	4.07	4.65	5.50	6.20	6.80	7.50	8.40
5 days	3.61	4.91	5.76	6.85	7.63	8.42	9.20	10.29
10 days	4.73	6.44	7.54	8.96	9.97	11.01	11.95	13.46

Flow Frequency Curve for Mula River

Figure 7

Flow Frequency Curve between Current and Future for 5%

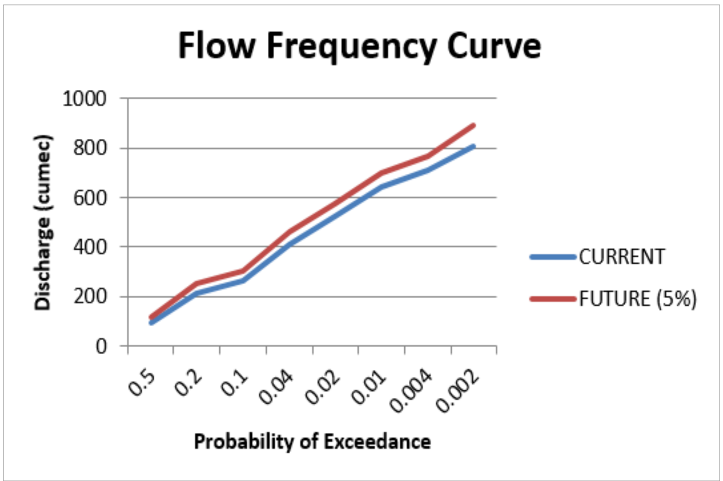
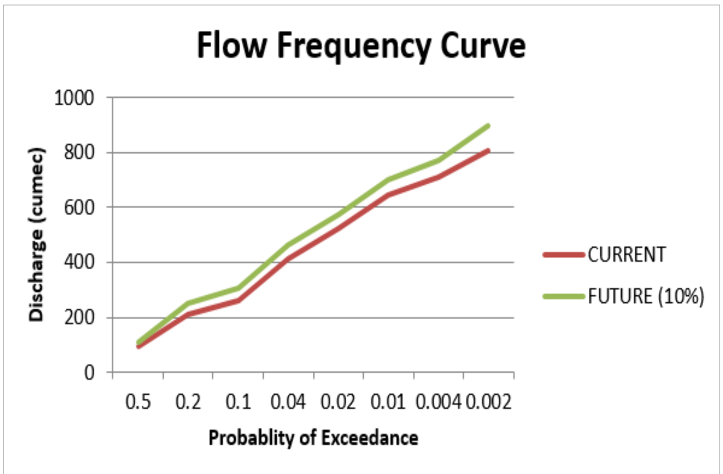


Figure 8

Flow Frequency Curve between Current and Future for 10%



Discussion

Because more information is gathered or when the bowl of a waterway changes to affect the flow of water within a waterway, researchers are overestimating the recurrence of floods. Dams and urban development are an illustration of several man-made changes in the watershed that affect the bursts. The re-potential of current and future improvement conditions to be used in the Jhal Magsi catchment. To calculate the increase in EAD, the expert needs current and future opportunities to replicate the flow of improvement. Using the associated existing precipitation flow rate, calibrating the current advance at bowl intervals, adverbial recurrence precipitation events with HEC-HMS intervals were used to calculate the flow rate. Eight repeated rainfall cases were used for adequate determination for this work. The work done on the flow rate at that time is compared to the power created using the strategies of choice. At that time, a leading assessment of the current improvement in the recurrence of work is covered. Thus, the precipitation flow demonstration was changed to display the bowl with further advancement. Different strategies can be used to calculate the flow rate recurrence without further improvement conditions.

You will probably limit yourself when there is a huge rainstorm. Storm, for illustration. This led to a 100-year surge. The Indus Waterway, a ridge for twenty feet to arrange. This indicates that the waterway has the highest level (height), as it happens once in a hundred for a long time. Supported rainfall data and flow organization are maintained, and the probability of the flow returning to the 20-foot organization is once in a hundred years. The 100-year burst level is measured using current chronic data; as additional data becomes available, the 100-year flood level may change (especially in the event of a major surge in the middle of the current year).

Uncertainty

Lack of metrological and discharge data did not allow a model to compute more efficiently because which last months of 2010 didn't show a good, simulated pattern. The impact of climate change on arrival is used by the venture in the overvoltage protection system, overvoltage protection, previous warning schemes, etc. It is also must think in a larger context that includes it.

Conclusion

The key objectives of this study are to use geospatial data to map common natural disasters for this flooded document and to provide planners and disaster management agencies with a quick view of ground conditions and the impact of disasters through forecasts. This information can also help them develop a rapid response plan and act quickly to take appropriate corrective action. It can help residents of flood-affected areas visualize and assess the amount of flood and property losses. This study also covers the characterization of the Jhal Magsi sub-basin, determining sub-basin indicators, intersections, access, and exit points to examine the effects of flash floods. On the other side of the investigation, the annual exceedance probability is calculated using the annual discharge data. Further, HEC-GeoHMS, used as a plugin with ArcGIS, a geospatial software, gave an efficient result of the basin's hydrological characteristics, like river length, sub-basin, and slope. HEC-DSS is used to manage the real-time data in statistical comparisons of metrological data. After that HEC-HMS flood frequency method was followed with the selection of some suitable parameters concerning the study area. Deposition measures of identified frequency are used to calculate the flow frequency function in HEC-HMS. Eight precipitation frequency measures were used to provide a necessary determination of purpose. The best predicted current enhancement condition frequency function is adopted. Subsequently, the precipitation flow pattern was changed to reflect the basin with future development. The resulting model predicts that in the next 500 years, there will be the possibility of a flood of greater magnitude or intensity that could cause more damage as urbanization increases. Flow rate modeling helps the water management department, such as the PDMA and NDMA departments, to implement control measures more efficiently. Geospatial data and tools are useful in determining the physical properties of the basin. Flash floods are a major problem in Balochistan. The meteorological department should have a measuring station in more prone areas like Jhal Magsi. This research can be useful in further scientific (hydrological), social, and economic studies, as it determines the most suitable outlet for the reservoir project. This study also predicted future floods; hence, future work can also be done with it, like HEC-RAS modeling, urbanization planning, and damage reduction. A full frequency function is required for flood damage analysis. Assessing flood damage requires expansion of the yearly highest flow frequency function for recent and upcoming changing situations. Two input data are required for the flood damage study: 1. Hydrological and hydraulic data, 2. Financial data: to total the hydrologic and water-powered information prerequisite, the most noteworthy stream must be restored to the height of the water surface. HEC-RAS calculates surface heights for a specific flow velocity.

This study can also be conducted to evaluate the financial benefits of a flood warning system to determine whether there is federal or state government interests. For this, the anticipated time coming from the framework with the HEC-HMS was assessed. The following step is to utilize the bend of the day to foresee hurt decrease choices. The expected warning time for this was estimated in one place. This process can be repeated for several sensitive areas throughout the basin. Impacts of climate change on arrive utilize planning, investment in surge assurance foundation, surge protection early warning systems, etc. It is also must think in a larger context. Flood damage reduction alternatives can also be calculated based on EAD (Expected Annual Damage).

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Availability of Data and Materials: Data and materials for the present study will be available upon request from the corresponding author (niamatullahza@gmail.com).
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References

Ashraf, M., & Routray, J. K. (2015). Spatio-temporal characteristics of precipitation and drought in Balochistan Province, Pakistan. *Natural Hazards, 77*(1), 229–254. https://doi.org/10.1007/s11069-015-1593-1

Balochistan Almanac. (2025). *Brief History Jhal Magsi District.* https://pakistanalmanac.com/balochistan-jhal-magsi/

Baumbach, T. (2015). *Watershed modeling using Arc Hydro Tools, GeoHMS, and HEC-HMS.* Geo, 2015. https://openprairie.sdstate.edu/cvlee_pubs/2/

Burnham, M. W. (1980). *Adoption of flood flow frequency estimates at ungaged locations (Training Document No. 11).* U.S. Army Corps of Engineers, Hydrologic Engineering Center. https://www.hec.usace.army.mil/publications/TrainingDocuments/TD-11.pdf

Chakraborty, S., & Biswas, S. (2021). Simulation of flow at an ungauged river site based on HEC-HMS model for a mountainous river basin. *Arabian Journal of Geosciences, 14*(20). https://doi.org/10.1007/s12517-021-08385-5

Chen Z., Lin B., Ding Z., Lian K., Kang L., Guo L., & Zhai W. (2011). Treatment of Pipkin type I fracture of femoral head associated with posterior dislocation of the hip. *Zhongguo xiu fu chong jian wai ke za zhi [Chinese journal of reparative and reconstructive surgery]*, *25*(5), 521–525.

Federal Emergency Management Agency. (2007). *Flood frequency analysis methods. In Guidelines and specifications for flood hazard mapping partners* (pp. D.4.3-1–D.4.3-20).

Gizaw, M. S., & Gan, T. Y. (2016). Regional flood frequency analysis using support vector regression under historical and future climate. *Journal of Hydrology, 538,* 387–398. https://doi.org/10.1016/j.jhydrol.2016.04.041

Goodchild, M. F., Kemp, K. K., Thériault, M., & Roche, Y. (1996). *Systèmes d'information géographique-notions de base* (No. BOOK). Université Laval, LATIG.

Guru, N., & Jha, R. (2015). Flood frequency analysis of Tel Basin of Mahanadi River System, India using annual maximum and POT flood data. *Aquatic Procedia, 4,* 427–434. https://doi.org/10.1016/j.aqpro.2015.02.057

Haan, C. T. (1977). *Statistical methods in hydrology.* Iowa State University Press.

Halbert, K., Nguyen, C. C., Payrastre, O., & Gaume, E. (2016). Reducing uncertainty in flood frequency analyses: A comparison of local and regional approaches involving information on extreme historical floods. *Journal of Hydrology, 541,* 90–98. https://doi.org/10.1016/j.jhydrol.2016.01.017

Halwatura, D., & Najim, M. M. M. (2013). Application of the HEC-HMS model for runoff simulation in a tropical catchment. *Environmental Modelling & Software, 46,* 155–162. https://doi.org/10.1016/j.envsoft.2013.03.006

Hasan, M. H., & Ahmad, S. (2006). *Water for Balochistan Policy Briefings* (Vol. 2, No. 1, pp. 1–9). from http://www.waterinfo.net.pk

Hoffmann, J., & Sander, P. (2007). Remote sensing and GIS in hydrogeology. *Hydrogeology Journal, 15*(1), 1–3. https://doi.org/10.1007/s10040-006-0140-2

Hudgens, B. T., & Maidment, D. R. (1999). *Geospatial data in water availability modeling* (Doctoral dissertation, Center for Research in Water Resources, University of Texas at Austin).

Interagency Advisory Committee on Water Data. (1982). *Guidelines for determining flood flow frequency (Bulletin 17B).* U.S. Geological Survey.

Knebl, M. R., Yang, Z. L., Hutchison, K., & Maidment, D. R. (2005).Regional scale flood modeling using NEXRAD rainfall, GIS, and HEC-HMS/RAS: A case study for the San Antonio River Basin summer 2002 storm event. *Journal of Environmental Management, 75*(4), 325–336. https://doi.org/10.1016/j.jenvman.2004.11.024

Mengal, S., Ullah, N., Rehman, T., & Ullah, S. (2025). Comparison between the problems of urbanization in Quetta City and Hub City: An urban geographical perspective. *ACADEMIA International Journal for Social Sciences, 4*(1), 375–391. https://doi.org/10.63056/ACAD.004.01.0079

Oleyiblo, J. O., & Li, Z. J. (2010). Application of HEC-HMS for flood forecasting in Misai and Wan'an catchments in China. *Water Science and Engineering, 3*(1), 14–22. https://doi.org/10.3882/j.issn.1674-2370.2010.01.002

Pakistan Bureau of Statistics (PBS). (2023). Balochistan Province 7th Population and Housing Census 2023. https://www.pbs.gov.pk

Planning & Development Department, Government of Balochistan, & United Nations Children's Fund (UNICEF). (2011). District Development Profile: Jhal Magsi 2010. Government of Balochistan. https://www.ndma.gov.pk/storage/publications/July2024/C39NbG43gJaAjSZ3Zaih.pdf

Precipitation and temperature regimes in upland Balochistan: Their influence on rain-fed crop production. *Agricultural and Forest Meteorology, 52,* 381–396. https://doi.org/10.1016/0168-1923(90)90094-M

Puech, C., & Raclot, D. (2004). *Expertise sur l'utilisation des données spatiales dans le domaine de l'hydrologie.* Cemagref—France.

Rees, D. J., Samiullah, A., Rehman, F., Kidd, C. H. R., & Keatinge, J. D. H. (1990). *Rural Support Programmes Network (RSPN). (2018). District Profile Jhal Magsi.*

Schendel, T., & Thongwichian, R. (2015). Flood frequency analysis: Confidence interval estimation by test inversion bootstrapping. *Advances in Water Resources, 83,* 1–9. https://doi.org/10.1016/j.advwatres.2015.05.004

Sorooshian, S. (1991). Parameter estimation, model identification, and model validation: conceptual-type models. In *Recent advances in the modeling of hydrologic systems* (pp. 443-467). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-011-3480-4_20

U.S. Army Corps of Engineers. (2009). *HEC-DSSVue: HEC Data Storage System Visual Utility Engine User's Manual (Version 2.0).* Hydrologic Engineering Center. https://www.hec.usace.army.mil/software/hec-dssvue/documentation/User%27sManual_2.0/HEC-DSSVue_20_Users_Manual.pdf

Ullah, N., Tariq, A., Qasim, S., Panezai, S., Uddin, M. G., Abdullah-Al-Wadud, M., & Ullah, S. (2024). Geospatial analysis and AHP for flood risk mapping in Quetta, Pakistan: A tool for disaster management and mitigation. *Applied Water Science, 14*(11), Article 236. https://doi.org/10.1007/s13201-024-02293-1

Ullah, S., Ullah, N., Tariq, A., Panezai, S., Tahir, P., & Khan, B. (2025). Spatial assessment of the availability of healthcare facilities at the district level in Balochistan using GIS: Identifying gaps and way forward. *Spatial Information Research, 33*(2), 8. https://doi.org/10.1007/s41324-025-00602-7

Villarini, G., Smith, J. A., Serinaldi, F., Bales, J., Bates, P. D., & Krajewski, W. F. (2009). Flood frequency analysis for nonstationary annual peak records in an urban drainage basin. *Advances in Water Resources, 32*(8), 1255–1266. https://doi.org/10.1016/j.advwatres.2009.05.003

Vittal, H., Singh, J., Kumar, P., & Karmakar, S. (2015). A framework for multivariate data-based at-site flood frequency analysis: Essentiality of the conjugal application of parametric and nonparametric approaches. *Journal of Hydrology, 525,* 658–675. https://doi.org/10.1016/j.jhydrol.2015.04.024

Waananen, A. O., & Crippen, J. R. (1977). *Magnitude and frequency of floods in California (Water-Resources Investigations Report 77-21).* U.S. Geological Survey. https://doi.org/10.3133/wri7721

Yener, M. K., Sorman, A. U., Sorman, A. A., Sensoy, A., & Gezgin, T. (2007). Modeling studies with HEC-HMS and runoff scenarios in Yuvacik Basin, Turkiye. *Int. Congr. River Basin Manage*, *4*(2007), 621-634.

Yuan, W., Liu, M., & Wan, F. (2019). Calculation of critical rainfall for small-watershed flash floods based on the HEC-HMS hydrological model. *Water Resources Management, 33*(7), 2555–2575. https://doi.org/10.1007/s11269-019-02257-0

Zhang, Q., Gu, X., Singh, V. P., & Xiao, M. (2014). Flood frequency analysis with consideration of hydrological alterations: Changing properties, causes and implications. *Journal of Hydrology, 519,* 803–813. https://doi.org/10.1016/j.jhydrol.2014.08.011