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Flood Susceptibility Modelling using QGIS Software of Karha River Basin

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***Abstract*—Floods rank among the most common natural disasters leading to the death of humans, destruction of infrastructure and crops, environmental deterioration, and financial losses across the globe. Flooding is experienced in the Karha River Basin located in the semi-arid region of western Maharashtra, India, due to high rainfall intensity, fast-paced land-use changes, poor drainage system, and urban development. It is important to identify potential locations for floods as a means of managing this hazard effectively. The aim of this research is to model flood susceptibility of the Karha River Basin using GIS techniques in QGIS.**

Various spatial and hydrological factors are considered for the purpose of flood susceptibility modeling. Factors such as Digital Elevation Model (DEM), slope, drainage density, land use and land cover (LULC), rainfall distribution, and distance from river channels have been incorporated in this study for generating flood susceptibility thematic layers. Weighted overlay method has been used for assessing the importance of each factor. Five susceptibility zones, namely Very Low, Low, Moderate, High, and Very High zones, have been identified based on the output map produced after analysis.

It is evident from the results obtained that flood susceptibility increases in lower elevations with flat slopes, high drainage density, agricultural activities, and river proximity. On the contrary, flood susceptibility decreases in case of higher elevations and high slopes. This study has produced maps indicating flood susceptibility in the region under consideration.

It is seen from the results of this research that GIS-based flood susceptibility modeling in QGIS is a relatively cost-effective tool that can be utilized for assessing flood risks in a given region. The maps developed can be beneficial for policy makers in formulating flood risk mitigation strategies, land-use policies, and emergency measures.

***Index Terms*—Flood Susceptibility, QGIS, GIS, Karha River Basin, Watershed Analysis, DEM, Drainage Density, Land Use Land Cover, Flood Risk Assessment, Spatial Analysis.**

I. INTRODUCTION

Floods represent one of the worst and most frequent natural disasters around the world. These kinds of disasters bring about huge harm to both people, property, infrastructure, agriculture, transportation, and the natural environment. According to various international disaster reports, floods constitute almost one-third of all natural disasters taking place around the globe. The ever-rising frequency of extreme natural phenomena due to climate change combined with fast-paced urbanization processes has exacerbated the problem of flood susceptibility and flood risks. As a result, flood management has become one of the main concerns of today's governments and environmental organizations.

Water is one of the key natural resources for sustaining lives on earth. Many countries rely heavily on watersheds to maintain ecological balance and secure water supplies needed for agriculture, industry, domestic uses, and other economic activities. However, excessive rainfall over a short time period causes flood events by exceeding carrying capacities of watersheds' drainage systems. As a consequence, not only infrastructures are ruined but also economic activities are disrupted, crops are harmed, pollution of drinking sources takes place, and other negative consequences appear. It is obvious then that in-depth knowledge of flood dynamics and flood-susceptible areas is vital for proper natural disaster management.

The Republic of India constitutes one of the countries having the highest risks associated with flood hazards. Indeed, about 40 million hectares of land area are considered flood-prone within the country's borders. Numerous states of India face annual flooding, leading to millions of dollars of economic damages and many casualties. Western Maharashtra also experiences numerous flood episodes throughout the past decades. Although this area generally has arid-climate conditions, the southwestern Indian Monsoon Season leads to short-term heavy rains causing flooding episodes. Urbanization, reduction of natural vegetation cover, encroachment of natural drainage lines, and other adverse development practices have worsened flood risks in many Indian watersheds.

Among those regions, the Karha River Basin is of particular importance. Located in Western Maharashtra, this watershed encompasses some hills near the Pune district, agriculture fields, and urbanized areas. During the southwestern monsoon season, the Karha River Basin is affected by heavy rains that cause flooding events in some regions of the basin. Given differences in topography, hydrological characteristics, and land use, various zones of the Karha River Watershed demonstrate a different level of flood susceptibility. Such flood-related hazards cause many economic problems for local communities.

Although floods take place recurrently throughout the region, few studies were dedicated to assessing the susceptibility of this watershed. Local government agencies thus do not possess enough information required to take timely actions in response to floods and conduct preventive measures. Traditional methods of flood mapping usually involve hydrological investigations and calculations, hydraulic modeling, and flood plain analysis. They also imply collection of data, which often needs considerable financial expenditures and requires much time. Fortunately, contemporary GIS and Remote Sensing tools allow analyzing spatial data of great amounts effectively.

Geographic Information System, or GIS, represents one of the most advanced technological instruments used in environmental modeling. By merging spatial datasets and conducting spatial analysis, researchers receive valuable insights regarding specific environmental conditions of a studied region. Remote Sensing complements GIS by providing information about terrain, hydrology, land use, and other parameters obtained by using remote-sensing technologies. Thus, GIS and Remote Sensing technologies represent efficient means of investigating natural phenomena and environmental characteristics of any region of the world.

At present, there is a variety of GIS platforms used to analyze spatial datasets and visualize results. Among those, QGIS constitutes an outstanding example of free and continuously developing GIS software. QGIS provides an abundance of tools for various geospatial analyses. For instance, users can perform spatial statistics, generate raster data, conduct terrain and hydrology analyses, delineate watersheds, edit vector data, and conduct many other operations. Besides, being open-source software, QGIS is accessible to everyone and requires minimum costs for conducting geospatial research projects.

Flood susceptibility modeling is one of the techniques used to assess flood potential of particular regions. Different from flood hazard analysis that implies complex hydraulic modeling, this technique is mainly oriented on identification of flood-prone zones using the factors conditioning such natural phenomenon. In general, those factors refer to various elements of terrain and hydrology of a watershed affecting generation, accumulation, and movement of surface runoff. Those factors include elevation, slope, drainage density, rainfall intensity, land use, soils, flow accumulation, and proximity to rivers, etc.

Elevation is an essential parameter used in flood susceptibility studies. Generally, flood-susceptible zones are located in low-lying regions because they have higher tendencies to accumulate runoff. The same tendency applies to slope since gentler slopes favor runoff accumulation. Similarly, drainage density refers to the quantity of streams in terms of length per unit area. The greater density indicates higher potential of runoff concentration. Finally, land use type plays a crucial role in generating runoff because urbanized areas usually prevent runoff infiltration due to presence of impervious layers.

In turn, rainfall constitutes one of the most important factors affecting flood occurrence. Heavy rainfalls over short periods cause excessive runoff that goes beyond the carrying capacity of drainage systems and rivers. Ultimately, the interaction of the abovementioned factors results in creation of flood-prone zones. In spite of the importance of studying these factors, few papers were published concerning this topic. Moreover, studies dedicated to flood susceptibility assessment within the Karha River Basin did not attract much attention of scholars.

However, there is evidence that many researchers successfully applied GIS-based flood susceptibility modeling for various regions. Techniques such as weighted overlays, frequency ratios, geo-morphometric ranking, analytical hierarchy process, multi-criteria decision-making approach, and others were used to conduct flood susceptibility studies for various locations. For example, scholars conducted successful studies for Pakistan, Egypt, Ethiopia, Bangladesh, and India and came to conclusions concerning the impact of watersheds' properties on flood occurrence.

Geo-morphometric studies revealed that the characteristics of watersheds significantly affect their flood susceptibility. Morphometric investigation of watersheds provides quantitative insights about watersheds' geometrical and hydrological properties. Bifurcation ratio, stream order, stream frequency, drainage density, elongation ratio, circularity ratio, relief ratio, and ruggedness number were found as the factors that can help understand a hydrological behavior of watersheds. In this way, morphometric study proves its importance in regions lacking hydrological data.

Despite the availability of numerous studies related to flood susceptibility, none of those concentrated on evaluating flood susceptibility of the Karha River Watershed by using GIS technologies. Existing literature contains numerous works addressing only geomorphological and hydrological characteristics of the area. There are also few publications containing flood susceptibility maps, but those maps did not consider all flood-susceptibility factors in detail. In light of all above facts, conducting flood susceptibility study for the Karha River Basin seems highly necessary.

The objective of this research work is to perform flood susceptibility analysis for the Karha River Basin using open-source QGIS software. Datasets provided by various sources will be processed and used to determine the degree of flood-susceptibility of the Karha River Watershed. Based on the performed GIS analysis, thematic layers will be created for such factors as drainage density, rainfall, elevation, slope, flow accumulation, land use, and river proximity. Next, a weighted overlay will be applied to create a final susceptibility map.

A. Problem Statement

Lack of detailed information about flood-susceptible zones hinders effective planning and management of the region.

Therefore, it is necessary to conduct a GIS-based flood susceptibility study for the Karha River Watershed.

B. Objectives

1) To delineate the Karha River Basin and its drainage network using DEM dataset;
2) To create thematic layers for flood-conditioning factors using DEM and additional datasets; To perform geospatial analysis to assess the influence of various factors on floods; To conduct a weighted overlay using GIS to generate flood susceptibility map; T˘o classify zones of flood susceptibility and generate spatial database.

C. Scope of the Study

The scope of this research is confined to GIS-based flood-susceptibility study for the Karha River Watershed.

II. LITERATURE REVIEW

A. Introduction

Flood susceptibility assessment has been considered an active area of research in recent times owing to the advancements in Geographic Information Systems (GIS), Remote Sensing (RS), and Digital Elevation Models (DEM). These methods help in identifying flood susceptible areas and understanding various characteristics of a watershed, which can aid the concerned authority in mitigating flood risk.

Several authors have developed flood susceptibility models using watershed delineation, morphometric analysis, geo-morphometric ranking, hydrological modelling, and multi-criteria decision making methodologies. This section discusses some of the significant contributions made by previous researchers in this regard.

B. Review of Previous Works

Sohail and Mahmood (2024) conducted a study on flood susceptibility mapping for the Jhelum River Basin, Pakistan using geo-morphometric ranking method. ASTER GDEM and ArcGIS software were used to delineate the watershed and analyze the flood susceptible areas. The study divided the basin into 57 sub-watersheds, where seventeen morphometric parameters were assessed. Results revealed that various morphological parameters like drainage density, stream frequency, basin relief, and slope influence the degree of flood susceptibility. Thus, geo-morphometric ranking successfully helped the researchers in classifying the sub-basins based on their vulnerability to flooding.

Abbas (2023) designed a watershed delineation tool using DEM data in ArcGIS software to analyze the Al-Zab River watershed. Different hydrological layers such as flow direction, flow accumulation, streams, and watershed boundaries were generated in this study.

Ray et al. (2018) explored the limitations of automatic watershed delineation tools in coastal regions. Various automatic tools such as ArcSWAT, ArcHydro, and ArcGIS were compared for the evaluation of their performance in different terrains. Study findings suggested that even though automatic watershed delineation tools considerably reduce the processing time, their accuracy depends upon various factors like DEM and terrain characteristics.

A novel approach towards watershed segmentation based on management zone delineation was proposed by Roudier et al. (2008). Traditional watershed algorithms usually lead to over-segmentation; thus, a modified algorithm was proposed by the authors. Results showed that the approach succeeded in producing more uniform zones which facilitated the process of spatial analysis.

In a recent study, Mehta, Prajapati, and Islam (2022) delineated watersheds and performed land use and land cover analysis of the Purna River watershed using GIS and RS techniques. LULC map was developed using satellite imagery, and subsequent land use changes were estimated. Results revealed that agriculture constitutes a major part of the basin, whereas forests and water bodies contribute to its hydrology.

Elkashouty (2020) carried out watershed delineation and morphometric analysis for the Central Eastern Desert of Egypt. Drainage density, stream frequency, bifurcation ratio, and basin geometry were assessed in the study using GIS methods. Groundwater recharge potential of the basin was determined based on the findings of the study.

Alqaysi and Almulehi (2016) used GIS technique to delineate the watershed boundary and drainage network of the Koyna Basin. Hydrological layers such as flow direction, flow accumulation, and catchment areas were produced using Shuttle Radar Topography Mission (SRTM) DEM data. Over three thousand individual catchments were successfully delineated in this study using GIS-based method.

Gebre et al. (2015) studied the characteristics of Chelekot Micro-watershed of Ethiopia. Various features of the watershed like drainage system, soil characteristics, land use, and hydrological behaviour were assessed to find suitable places for soil and water conservation. The results suggested that both morphometric and land use parameters are critical in watershed management and flood mitigation.

An innovative approach towards surface depression identification and drainage network development was proposed by Wang and Chu (2019). A new algorithm was developed in the study to improve the representation of hydrological connections.

Watershed analysis was conducted by Ezz et al. (2019) in the Ras Gharib region of Egypt. Runoff discharge and groundwater recharge were estimated in this study based on the analysis of rainfall records, morphometry, and hydrological properties of the watershed.

Various flood conditioning parameters were compared and assessed by Shahimi et al. (2021) using ASTER and SRTM DEMs for watershed delineation. Accuracy of DEMs for extracting watershed boundaries was assessed based on various hydrological parameters.

The effects of DEM sources and resolutions on watershed delineation and analysis was assessed by Datta et al. (2022). Eight different DEM sources at different resolutions were compared in the study. Results revealed that the resolution of DEM greatly influences watershed properties like area, perimeter, slope, and drainage characteristics.

Watershed morphometry of the Upper Karha Watershed in Western Maharashtra was performed by Deshmukh and Wayal (2018). Important morphometric parameters such as drainage density, stream frequency, bifurcation ratio, elongation ratio, circularity ratio, and texture ratio were computed for this study. The watershed is found to be a sixth order drainage system, wherein the drainage pattern is dendritic.

C. Comparison of the Previous Works

Most of the previous studies have effectively demonstrated the significance of utilizing GIS and RS technologies for conducting watershed delineation and flood susceptibility assessment. Delineation of watershed boundaries using DEM data is one of the most popular practices for generating hydrological information. Morphometry of watersheds has been performed in most of these works as well, using various methods like geo-morphometric ranking, weighted overlay, hydrological modelling, etc.

A common inference drawn from the above-reviewed studies is that the factors like drainage density, slope, elevation, stream frequency, land use and land cover, rainfall etc. influence the occurrence of floods. It has also been stressed in most of the previous works that a number of flood conditioning parameters should be considered together rather than focusing only on one particular factor. In addition, it can be observed that GIS technique has proven to be inexpensive, accurate, and easy-to-apply technique for creating flood susceptibility maps.

D. Identification of Research Gaps

Even though considerable work has been done so far in the field of watershed delineation, morphometric analysis, and flood susceptibility assessment, there are still some research gaps left unaddressed.

1) Majority of the previous studies concentrated on large river basins while flood susceptibility analysis of the Karha River Basin is not adequately researched yet.
2) Some of the earlier studies did watershed delineation and morphometric analysis but not considered various flood conditioning factors for developing a complete flood susceptibility framework.
3) There are relatively few studies conducted using open source GIS (QGIS) software for performing flood susceptibility assessment.
4) Flood susceptibility maps of high spatial detail which can be used for planning and managing disasters are missing in many cases.
5) Validation of flood susceptibility maps against actual flood conditions is inadequate in some studies making their usage less practical.
6) An effective method for developing cost-efficient flood susceptibility maps can be developed for future application.

This research attempts to fill these gaps by creating flood susceptibility map of the Karha River Basin using Digital Elevation Model, slope, drainage density, rainfall, LULC, and river proximity layers using QGIS platform.

III. STUDY AREA DESCRIPTION

A. Location and Geographical Setting

The Karha River Basin is situated in the west of Maharashtra state, India and represents an important sub-basin of the Nira River Basin. It is derived from the hilly areas near the Western Ghats and flows through Pune district before merging with the Nira River. This basin encompasses a significant geographical area covering diverse topography, agriculture fields, rural habitation areas and growing urban areas.

Geographically, the Karha River Basin lies at approximately 18°15’N to 18°25’N latitude and 73°52’E to 74°11’E longitude. The watershed encompasses various villages and agriculture areas that depend on surface water sources for their activities. Because of the location of the basin within the semi-arid regions of Maharashtra, it is considered to be significant for socio-economic development within the region.

The Karha River forms an important drainage system that collects rainwater runoff from the surrounding catchment areas during rainy seasons. Elevation, slope, drainage pattern and land cover are some factors that influence the hydrological behaviour of this watershed leading to flood susceptibility in some parts of the basin.

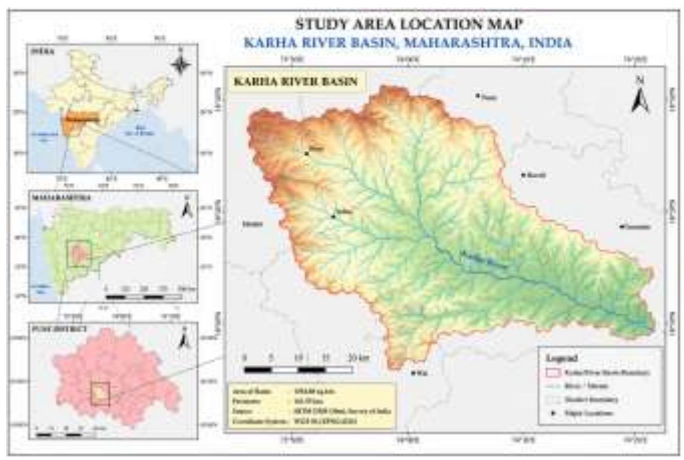

Fig. 1. Location map of Karha River Basin showing watershed boundary and river network.

B. Physiography and Topography

Diverse physiographical features exist in the Karha River Basin where hilly areas in the upper regions characterize its physiography and basaltic plain in the lower parts. Being part of the Deccan Plateau, this basin is mostly made up of basaltic rocks that result from the activity of the Deccan Trap.

High elevations are observed in the upper regions of the watershed while low elevations are observed at the lower end of the basin. This means that surface runoff generation, infiltration, drainage and flooding can easily take place in areas of low elevations.

In terms of slope, steep slopes are experienced at the upper regions while gentle slopes dominate in the lower regions. The slope determines how water drains within the basin and how fast it moves down the hills. As a result, floods can easily occur in the lower regions of this basin.

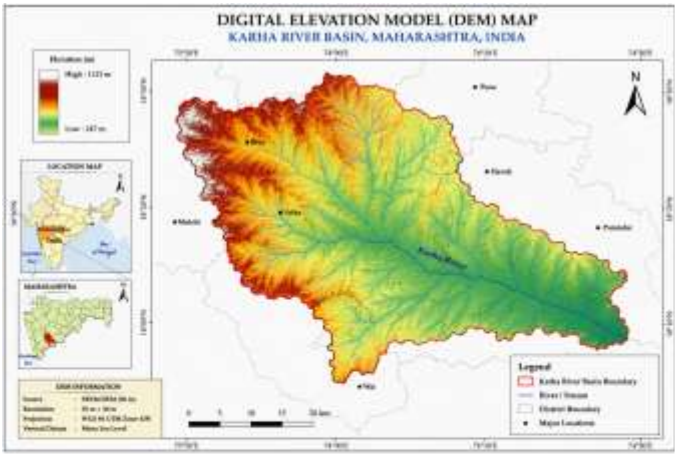

Fig. 2. Digital Elevation Model (DEM) of Karha River Basin showing topographical variation.

The DEM plays a very important role in determining the physiography of the watershed by providing digital elevation data that helps in the analysis of watersheds.

C. Climate and Rainfall Characteristics

The climate of the Karha River Basin can be described as semi-arid due to its location within the western part of Maharashtra state. The climate of the basin is known to experience warm summers, cool winters and rainfall during monsoon seasons.

The monsoon season begins in the month of June and ends in September where heavy rains lead to increased river discharge. This leads to high runoff and hence increased vulnerability to flooding. Although the average amount of annual rainfall is between 400mm to 575mm, climate change is increasingly becoming a factor that influences the hydrological behaviour of the watershed.

Frequent floods occur when rainfall exceeds the capacity of drainage system leading to flooding in many vulnerable areas of the basin. This indicates that rainfall plays an important role in flood susceptibility within the Karha River Basin.

D. Drainage Network Characteristics

The drainage system within the Karha River Basin is predominantly dendritic to sub-dendritic drainage pattern. This pattern develops in areas that have homogeneous geological characteristics and no structural control.

According to the morphometric analysis of Upper Karha Watershed, the drainage system can be termed as sixth-order drainage basin. Drainage density is found to be 3.13km/km^2 while stream frequency is 4.31 streams per square kilometer. This shows a fairly well-developed drainage system within the basin that results in significant runoff generation.

The drainage system consists of many first-order and second-order streams whose flow converge together to become higher-order streams before joining the main river. During rainy seasons, this drainage system becomes a source of flood due to the increase of flow volumes.

Drainage density is very important when assessing the susceptibility to flood since areas of high drainage density become susceptible to flooding due to the rapid concentration of runoff.

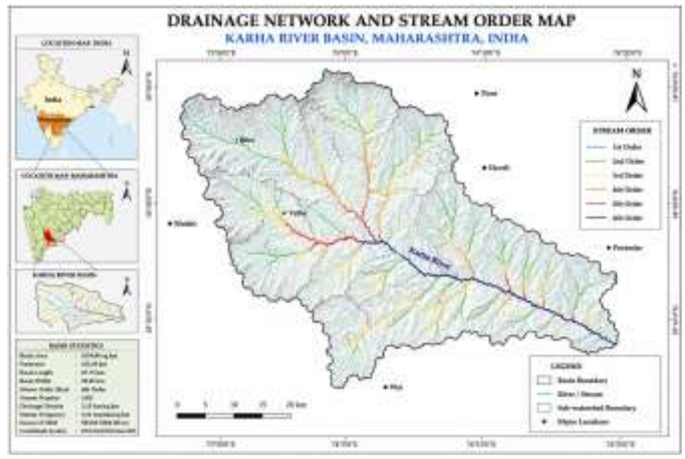

Fig. 3. Drainage network and stream order distribution within the Karha River Basin.

E. Geology and Soil Characteristics

The geological features of Karha River Basin are dominated by basaltic rocks resulting from Deccan Trap volcanic province. The basaltic rocks influence hydrological behaviour, geomorphology, drainage system and soil formation processes of the watershed.

Basaltic rock weathering has led to the formation of diverse types of soils within the watershed. They include black cotton soils, medium black soils and shallow soils within elevated regions. Black cotton soils contain more clay minerals which limit infiltration.

Geological formations and soil characteristics play an important role in the determination of the hydrological behaviour of the basin. The lower the capacity of infiltration, the greater the likelihood of floods within the basin.

F. Land Use and Land Cover Characteristics

Land use and land cover (LULC) of an area is an important indicator of the hydrological behaviour within a watershed. The LULC of the Karha River Basin includes agriculture, settlements, water bodies, barren land and vegetated regions.

Majority of the land use in this basin involves agriculture. Agricultural fields occupy significant portions of this basin and provide a lot of economic benefits. However, this activity alters the natural drainage and creates conditions that favour the generation of runoff.

Urbanization and urban development are increasing with time and this is evidenced by the growing number of settlements around this basin. Paved roads and impervious surfaces reduce the infiltration capacity of water thus creating the condition for floods.

Vegetated regions are known to enhance the infiltration process, reduce runoff velocities and minimize soil erosion. As a result, there is less flooding in vegetated areas than urbanized areas.

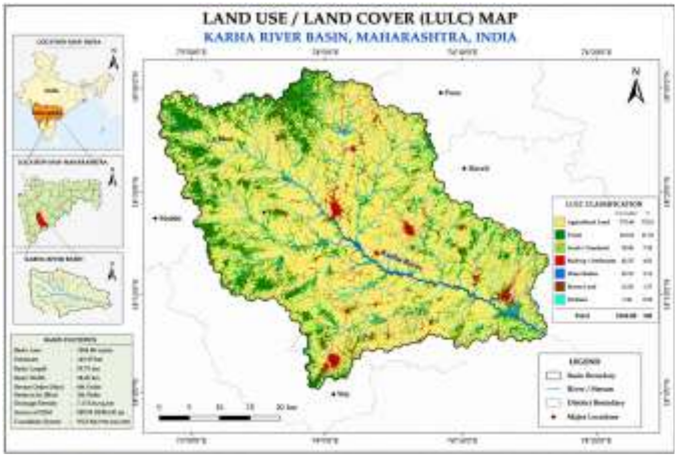

Fig. 4. Land Use and Land Cover (LULC) classification of the Karha River Basin.

G. *Hydrological Significance of the Basin*

The Karha River Basin is an important hydrological unit that supports water supply and irrigation of crops. Surface runoff generated in this basin contributes significantly to the provision of surface water within the basin.

There exists a marked variability of river discharge within the basin. This is evident in the fact that streamflow becomes high during rainy seasons but lowers during dry seasons. As a result, this basin is subject to floods especially during monsoons.

Hydrological significance of the Karha River Basin is vital for the sustainable management of water resources and flood mitigation planning. Spatial variability of topography, drainage network, rainfall, land use, geological formation makes this basin suitable for studying the flood susceptibilities of the basin.

H. *Need for Flood Susceptibility Assessment in Karha River Basin*

Flooding within the Karha River Basin has led to the identification of flood-prone regions and hydrological factors. Increased urban development, changing land uses, climate change and human alteration of natural drainage systems have heightened flood susceptibility in this basin.

The need for flood susceptibility assessment in this basin will help in identifying flood-prone areas and factors that contribute to flood occurrence. Maps of flood susceptibilities are very useful in making informed decisions. These maps provide necessary information to government agencies and planners on effective flood mitigation measures.

GIS, Remote sensing and hydrological analysis play an important role in the study of Karha River Basin.

IV. MATERIALS AND METHODOLOGY

A. *Overview of Methodology*

For flood susceptibility mapping in this study, a methodology was adopted that incorporates GIS-based approaches along with hydrological modeling and remote sensing data analysis to evaluate the susceptibility of an area to floods. Different parameters that affect the occurrence of floods were selected and analyzed. These parameters included various environmental variables. Spatial thematic layers based on these flood conditioning parameters were created using various spatial analyses and then integrated using weighted overlay analysis to generate the final flood susceptibility map.

The general workflow involved data acquisition, watershed delineation, thematic layers creation, assignment of ranks and weights, WOA, and generation of the flood susceptibility map.

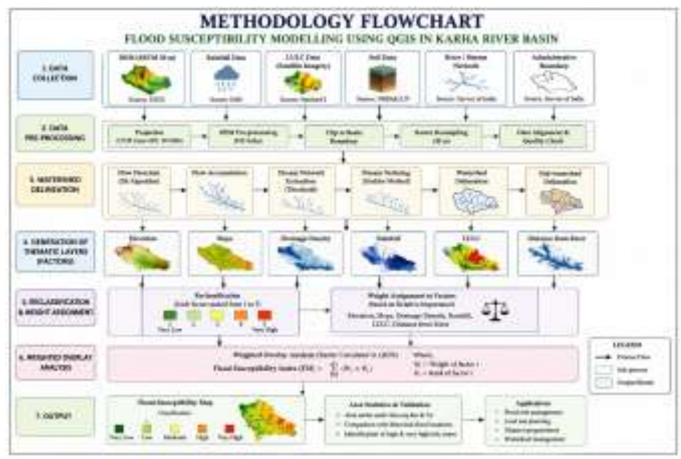

Fig. 5. Workflow diagram of the methodology adopted for flood susceptibility modeling in the Karha River Basin.

B. *Data Acquisition and Sources*

Reliable and accurate data are essential for flood susceptibility modeling. Various types of data required for the study were acquired from publicly available sources.

Primary datasets acquired for the study include digital elevation model (DEM), rainfall data, satellite imagery data for land use and land cover classification, survey maps for river network delineation, etc.

TABLE I
LIST OF DATASETS ACQUIRED FOR THE STUDY

Dataset Name	Source	Resolution
DEM	SRTM-USGS	30 m
Rainfall Data	IMD	Annual Data
Satellite Data	Google Earth Engine	NA
River Network	Survey Data	NA

C. Software and Tools Used

In this study, QGIS software was used for GIS processing as well as for data visualization. Several plug-ins and processing tools available with QGIS were used for watershed delineation, thematic layers generation, and hydrological modeling.

Major software tools used in the study include:

- QGIS
- SAGA GIS Plugins
- QGIS Hydrology Tools
- GDAL Raster Processing Tools
- MS Excel

D. Watershed Delineation

Watershed delineation refers to the process of determining drainage boundaries and stream networks from topographic information provided by a DEM. Watershed delineation can be accomplished using various watershed delineation algorithms in QGIS.

Watershed delineation in the current study involved the following steps:

- DEM preprocessing
- Determination of flow direction
- Generation of flow accumulation map
- Extraction of drainage streams and delineation of watershed boundary

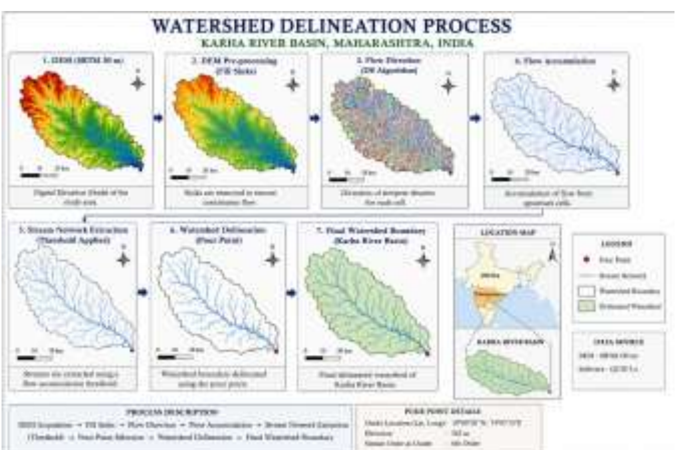

Fig. 6. Workflow for Watershed Delineation using DEM.

E. Flow Direction Calculation

The flow direction map determines the direction of flow of surface runoff from one cell to another. For the purpose of flow direction determination, D8 method was adopted.

Flow direction value was calculated for all the raster cells in terms of steepest downslope flow.

F. Flow Accumulation Calculation

A flow accumulation map determines the total number of upstream cells that contribute to the flow accumulation for each raster cell. Regions with high flow accumulations indicate high drainage concentrations.

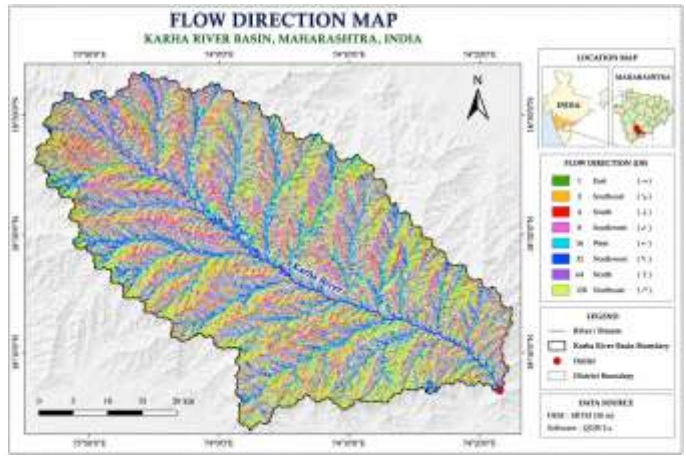

Fig. 7. Flow direction map determined using DEM.

Flow accumulation maps help determine drainage networks, streams of different sizes, initiation points, and regions where water concentrates during rains.

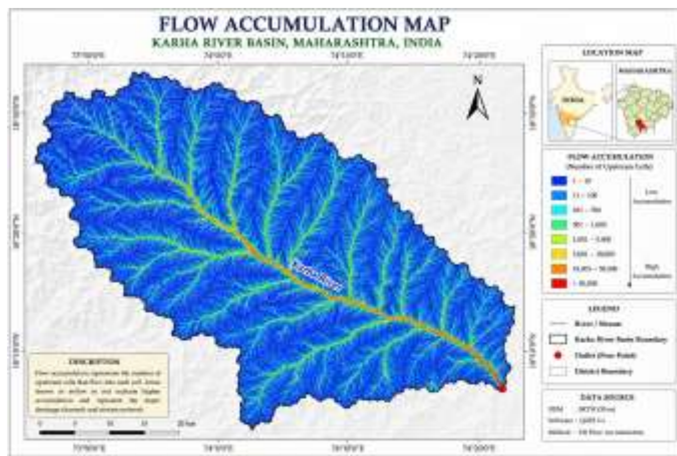

Fig. 8. Flow accumulation map generated for Karha River Basin.

G. Development of Flood Conditioning Factors

Different factors control the occurrence of floods at any location. Some of the major factors that influence floods include elevation, slope, drainage density, rainfall intensity, land use and land cover, distance from rivers, etc.

The major flood conditioning factors selected for this study include:

1) Elevation: The elevation affects runoff accumulation and contributes to the concentration of water at some location due to lack of drainage.

2) Slope: Slope affects the velocity of runoff generation as well as infiltration capacity. Gentle slopes result in runoff concentration, while steep slopes allow rapid runoff generation.

3) Drainage Density: The drainage density is the total length of streams per unit watershed area. High density results in water concentration and flood generation.

4) Rainfall: Rainfall is the most important factor affecting flood generation at any location. Rainfall at high intensities increases flood susceptibility.

5) Land Use and Land Cover: Land use land cover affects infiltration and runoff capacities, and different land uses have a different impact on flood occurrence.

6) Distance from River: Locations near river channel tend to get flooded due to overflow of river during rains and floods, while those farther away are less affected by such phenomena.

H. Thematic Layer Reclassification

To incorporate these flood conditioning factors in the modeling process, they were categorized in terms of their impact on the occurrence of floods. Five different ranks were assigned to different factors based on their flood conditioning capacity.

TABLE II
FLOOD SUSCEPTIBILITY RANKS ASSIGNED TO DIFFERENT FACTORS

Ranks	Susceptibility Level
1	Very Low
2	Low
3	Moderate
4	High
5	Very High

I. Weighted Overlay Analysis (WOA)

Multi-criteria decision making methods are frequently employed in flood susceptibility modeling. One of such methods that have been frequently employed in flood susceptibility modeling is WOA, whereby various criteria are combined using weights. Each of these flood conditioning parameters has been allocated a certain weight based on its significance. Higher weights were assigned to criteria with high significance.

The flood susceptibility index is computed using the following formula:

[FSI = $\sum_{n=1}(W_i \times R_i)$]

where,

- FSI = Flood Susceptibility Index
- Wi = Weight of flood conditioning factor
- Ri = Ranking level assigned to flood conditioning parameter

J. Generation of Flood Susceptibility Map

Finally, the thematic layers were overlaid to integrate them and generate flood susceptibility maps for the Karha River Basin. For this purpose, the weighted raster maps were generated in QGIS for five flood susceptibility levels.

1) Very low susceptibility
2) Low susceptibility
3) Moderate susceptibility
4) High susceptibility
5) Very high susceptibility

V. RESULTS AND DISCUSSION

A. Overview

The flood susceptibility assessment of the Karha River Basin has been performed based on the integration of various flood-conditioning factors utilizing the GIS approach. Such factors as elevation, slope, drainage density, rainfall, LULC and distance from river channels have been incorporated into the model through the Weighted Overlay Analysis (WOA) method.

The obtained flood susceptibility map is a crucial instrument for performing the flood risk assessment and managing the water resources in the region.

B. Analysis of Flood Conditioning Factors

In this part of the research, the effect of flood conditioning factors has been explored.

Thus, according to the results of elevation analysis, regions situated at a lower altitude compared to the surrounding areas are more vulnerable to floods since they tend to accumulate water in excess quantities. Higher elevations located at the headwater areas are much less prone to flooding since the runoff is rapidly channeled down.

Regarding the analysis of slope, it can be stated that gentle slopes pose high risks of flooding since they facilitate water retention on the ground surface. In turn, the steeper the slopes (located at the upstream areas), the lower the flood susceptibility, as the runoff flows faster down.

As regards drainage density analysis, high values of this index indicate faster concentration of water in the corresponding regions, making them highly vulnerable to flooding. Conversely, regions having relatively low drainage densities feature favorable conditions for runoff infiltration and are less exposed to flood risks.

The rainfall distribution has proven to be among the key factors determining the level of flood susceptibility in a region. It should be noted that the more rainfall occurs in some area, the more runoff volumes are produced, leading to higher flood susceptibility. This relationship becomes even stronger if combined with low elevation or poor drainage.

When evaluating the LULC, the prevalence of agricultural lands was found in the basin. Meanwhile, urbanized zones were revealed to be rather flood susceptible as they include more impermeable surfaces. Vegetated/forested zones positively impact infiltration and groundwater recharge, contributing to decreased flood risk.

Lastly, the analysis of the distance from river demonstrated that zones closer to rivers' channels are more prone to flooding due to the river overflowing under conditions of excessive rainfall. As the distance from rivers increases, the flood susceptibility decreases.

C. Flood Susceptibility Mapping

By applying the WOA technique in the QGIS environment, a final map of flood susceptibility has been created. The obtained Flood Susceptibility Index (FSI) values have been classified into five categories representing varying flood vulnerability of a region.

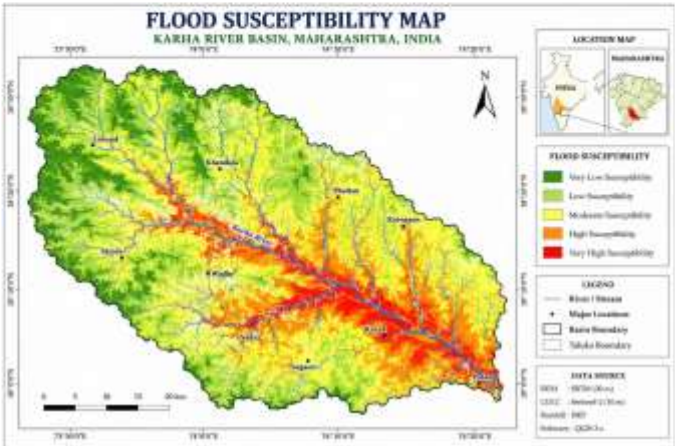

Fig. 9. Flood susceptibility map of the Karha River Basin

The flood susceptibility map includes the following classes:

1) Very Low Susceptibility
2) Low Susceptibility
3) Moderate Susceptibility
4) High Susceptibility
5) Very High Susceptibility

According to the map, the spatial distribution of flood susceptibility zones varies significantly. Areas near the central river channel and floodplains belong mainly to the High and Very High susceptibility classes. Such zones are characterized by relatively low elevations, gentle slopes, higher drainage density, and closeness to river networks.

Moderate zones make up the largest share of the watershed and can be defined as transition zones in which one or several flood-conditioning factors play a certain role in triggering flooding. Zones of low and very low susceptibility zones include higher elevations and steeper slopes with minimal runoff retention potential.

The above-presented map clearly indicates regions in need of special attention from the managers responsible for flood mitigation activities.

D. Area Distribution of Flood Susceptibility Classes

In order to evaluate the area distribution of flood susceptibility zones, percent values of the areas occupied by these classes were calculated.

TABLE III
AREA DISTRIBUTION OF FLOOD SUSCEPTIBILITY CLASSES

Susceptibility Class	Area (%)
Very Low	15.82
Low	24.35
Moderate	31.76
High	18.42
Very High	9.65
Total	**100**

It is apparent that zones with moderate susceptibility take up the largest area while zones of high and very high susceptibility occupy the majority of river corridors and floodplain areas. Though areas of very high susceptibility might be relatively small in terms of the share of total watershed area, such regions are the most flood prone and need to be managed immediately.

E. Discussion of Results

The presented research demonstrates the efficiency of GIS approach, Remote Sensing, and Weighted Overlay Analysis methods in assessing flood susceptibility in a watershed. The obtained results show that flood susceptibility of the Karha River Basin depends significantly on the topography, hydrology, and LULC of a region.

Low elevations, gentler slopes, higher drainage density, rainfall, and closeness to rivers are the main factors that make regions more prone to floods. In particular, regions with multiple such factors are often classified as belonging to high and very high susceptibility categories.

The developed flood susceptibility map reveals valuable spatial information which can be used in land-use planning, infrastructure development, watershed management, and disaster preparedness. Identification of flood-prone regions will enable managers to focus on necessary measures for mitigating flood risks, including improving river drainage, reinforcing riverbanks, regulating floodplains, and planning emergency response operations.

Finally, the results demonstrate that reliable flood susceptibility assessment is achievable using cost-effective technologies such as GIS and publically accessible datasets.

VI. CONCLUSION AND FUTURE SCOPE

A. Conclusion

Floods are one of the most dangerous natural phenomena that adversely affect the lives of people, infrastructure, agriculture, and environment. The ability to accurately determine the locations susceptible to floods is critical to effective disaster management. This paper presents a GIS-based flood susceptibility assessment model in the Karha River Basin using QGIS software and spatial analysis techniques.

For this purpose, a number of flood conditioning factors such as Digital Elevation Model (DEM), slope, drainage density, rainfall, land use and land cover (LULC), and distance from river channels were considered and analyzed individually to assess their contribution to the occurrence of flood hazard. Watershed delineation, flow direction, and hydrology was done using DEM data to prepare necessary spatial datasets required for flood susceptibility modeling.

Thematic layers were reclassified and combined using the Weighted Overlay Analysis (WOA) method. As a result, the Flood Susceptibility Index (FSI) was generated enabling the classification of the study area into five susceptibility zones such as Very Low, Low, Moderate, High, and Very High flood susceptibility.

The results of the study showed that locations near major river channels, areas with flat and low-lying topography, places with higher drainage density and rainfall intensity are prone to floods. On the other hand, locations situated at high altitudes, having steeper slope and good drainage have shown lesser flood susceptibility. It can be concluded that the topographic, hydrologic, and LULC characteristics of the area play a significant role in determining the flood susceptibility level.

This paper has demonstrated the efficiency, reliability, and affordability of the application of GIS techniques coupled with Remote Sensing data in flood susceptibility assessment. The created flood susceptibility map would help to plan flood risk mitigation strategies and other activities related to land-use planning and watershed management in the study area. The methodology used in this study could be adopted for other watersheds affected by floods and help to minimize their vulnerability to this natural disaster.

Moreover, the application of open-source QGIS as a GIS tool shows that reliable flood susceptibility assessment could be performed without any proprietary software and associated costs.

B. Future Scope

Although the current research provides useful insights into flood susceptibility of the Karha River Basin, further improvements can be introduced in future to enhance the effectiveness of the assessment process.

1) Usage of high-resolution DEM datasets such as LiDAR data.
2) Incorporation of additional factors affecting flood occurrence such as soil characteristics, groundwater conditions, infiltration capacity, and climatic variables.
3) Employment of advanced Multi-Criteria Decision-Making (MCDM) methods like Analytical Hierarchy Process (AHP), Fuzzy Logic, and TOPSIS for better weights calculation.
4) Application of Artificial Intelligence algorithms such as Random Forest, SVM, Artificial Neural Networks (ANN), and Deep Learning models.
5) Using real-time rainfall data and IoT technologies for flood forecasting and warning systems.
6) Application of hydraulic software such as HEC-RAS and SWAT coupled with GIS for enhanced flood hazard assessment.
7) Flood susceptibility assessment in the context of climate change and its future impacts on flood occurrence.
8) Creation of web-based GIS platforms for visualization and dissemination of flood risks to stakeholders and decision-makers.

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