Flood hazard zone mapping of Warna river watershed

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Abstract:
Flooding is often regarded as the most severe environmental disaster in recent years. A visualisation of flood risks is required for disaster prevention and mitigation The goal of this study is to assess the hazards of flooding in the Warna dam's areas. This research work has adopted remote sensing and geographic information techniques. In order to lessen and control their impacts on both humans and the ecosystem, the risk of flooding is evaluated. Several variables contribute to flooding. Ten flood-controlling variables viz. rainfall, slope, flow accumulation, topographic wetness index, drainage density, stream power index, elevation, curvature, distance from the river, land use, and land cove are used to create a map of the upstream risk of flooding, and downstream area of Warna dam. Weighted overlay analysis tool in QGIS software is used for multi-criteria decision-making of several variables influencing flood. Weightage for different parameters affecting floods is based on the reference of literature regarding flood hazard mapping using QGIS and remote sensing technology. The flow structure has been extracted from the ASTER DEM using QGIS software, and a drainage density image has been generated. This flow density varies from 0.95 to 4.16 km/km2 in the middle and downstream regions of the study area, which are more likely to experience flooding. The eastern portions of the basin, which are downstream, have areas with exceptionally high inundation danger. Over 35% of the farmland and 30% of the populated areas are in flood-prone areas. 31.82 and 30.57 percent of the areas are impacted by the extremely high and moderate flood threat zones.

Keywords: *Elevation, DEM, watershed, slope, GIS, hazard, flood*

I. Introduction:

The Indian Ocean and southern Asia's seasonal winds, which blow from the southwest in the summer and the northeast in the winter, have an impact on the Tropical Monsoon rainfall area in India (Kripalani and Kumar 2004). Most frequently, rain starts to fall around the first week of June. The wettest month in Maharashtra is July, while August often sees a lot of rain. The monsoon starts to wane as September arrives from the state.

Environmental dangers and calamities have long been seen as the most harmful things that may happen to civilization and the human race. One of the biggest and most dangerous risks is flooding, which claims thousands of lives, harms the housing, infrastructure, fishing, and agriculture industries, and interferes with social and economic activity.

When a dam fails or there is a significant amount of rain for a prolonged period, it can cause flooding, which can put people's lives and property in danger. (Nyarko, 2014) A flood is defined as a "natural and persistent overflow of huge quantity of water" that results from strong and prolonged rainfall and ultimately exceeds the capacity of rivers, streams, and coastal regions as well as the absorption capacity of the earth (Leopold et al., 1964).

It is impossible to completely stop floods from happening. Engineering techniques for preventing flooding are costly. Furthermore, tampering with a river's hydrology may not necessarily have the desired effects.

The actual flooding process is the result of a complicated collection of controlling elements, where both nature and people play a part (Sapkale et al., 2022). The characteristics of the watershed, such as current global warming, excessive precipitation, siltation of streams brought on by forest destruction and eroding soil, inappropriate construction of dams, modifications to land use, like raised infrastructure building, farming, and populated areas on flood zones, are just a few of the factors that contribute to major floods.

The management of water resources and hydrology have benefited greatly from remote sensing (RS) during the past 20 years (Bastiaansen 1998). On the other hand, the Geographic Information System (GIS) has been extensively utilized to simulate surface water, notably flood and the damage that goes along with it (Boyle et al. 1998; Green and Cruise 1995; Werner 200). It is vital to perform in-depth research on the flood due to the many facets of its harm, including the obliteration of residential structures, agricultural fields and crops, urban infrastructure, the filling of dam reservoirs, and the shortening of their usable lives. A map of flood-prone areas was produced by Brivio et al. (2002) using the remote sensing data with a Geographic Information System (GIS).

Areas that are susceptible to a certain hazard are shown on maps of hazard zones. Since dams were built to mitigate flooding, floods frequently result from them (Lemperiere, 2017). Knowing and identifying flood-prone locations may be a useful tool in managing flood hazards in such a situation (Rahman & Saha, 2007). The creation of hazard zone maps has become somewhat simpler because of the availability of data from remote sensing at different solutions and the analysis of such data in geographic information systems (GIS). Even small watersheds have risk of flooding areas. They may be efficiently identified using GIS (Seejata et al., 2018).

As a result, the area's ASTER DEM was employed for the current investigation, on which Q-GIS created additional theme layers. The final map of the flood danger zone for the research region was created in Q-GIS using weighted overlay analysis, a popular Geographic information system approach for multi-criteria problems.

II. Study area:

The four districts that make up the study area are Sangali, Satara, Kolhapur, and Ratnagiri.

The research area is located along the Warna River between the latitudes of 16° 54'N and 17° 18.78'N and the longitudes of 73° 4.39'E and 74° 4.39'E. It is both upstream and downstream of the Warna dam. The research area is around 5.1 km long in total. The Warna River is surrounded by mountains on both sides. The region's height above sea level varies from 552 to 1107 meters. The research region is thought to have a tropical wet and dry climate, with 3000mm of precipitation on average each year. The yearly average temperature is 25.2°C. There are evergreen forests, wet and dry deciduous forests on the slopes of the hills that run east and create the Warna river catchment area, and forests with bushy and stunted tree growth on the hills to the north-east portion of the research area. The Warna River is classified as potentially flood-prone in this situation. The intensity of rainfall is greatest on the dam's upstream side, which is a mountainous location. It lowers as we travel downstream.

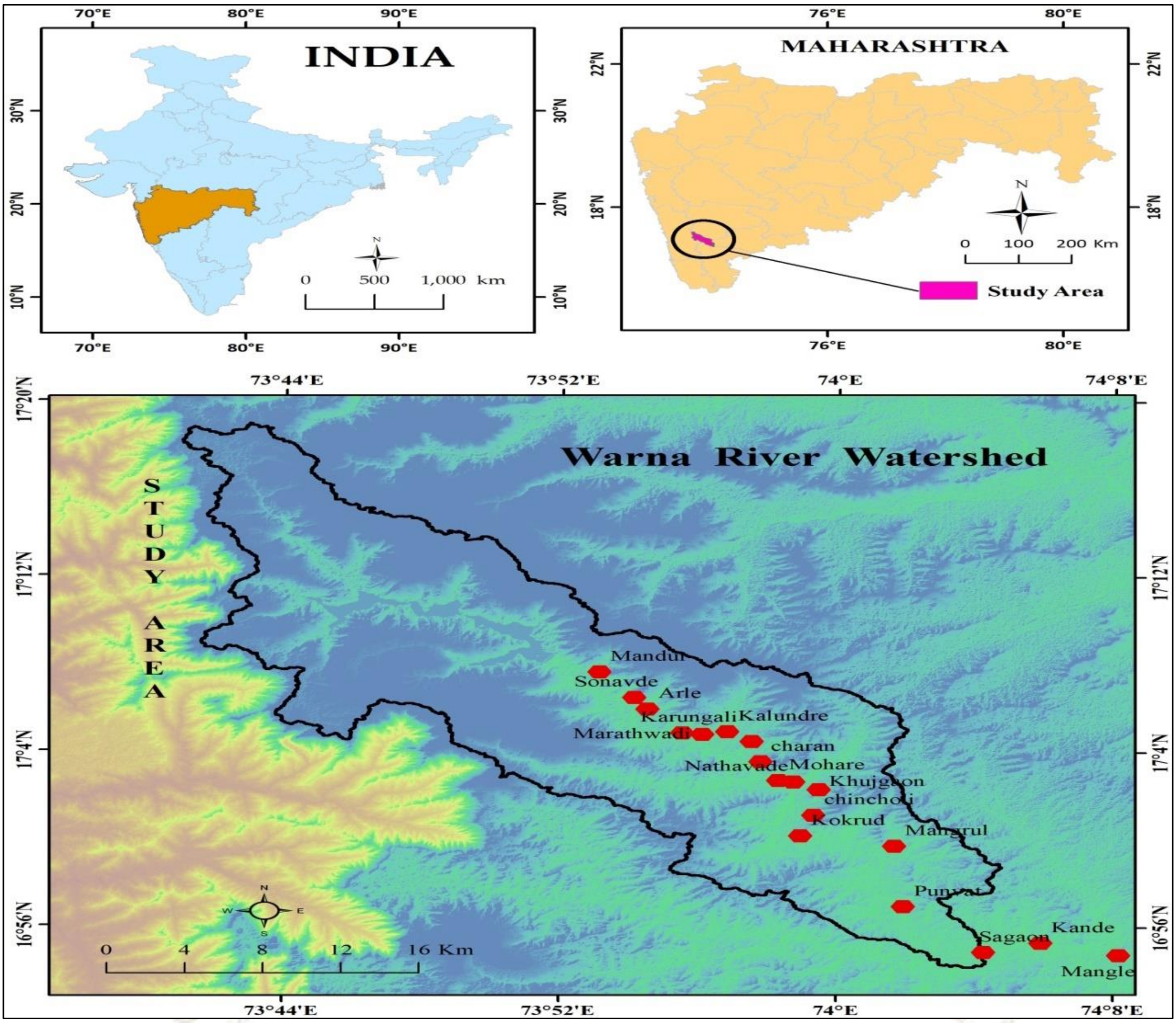


Figure no. 1: Illustration of field location

III. Methodology:

In this research work, the data is collected from different data sources.

1. Toposheets taken from the 'Survey Of India' website are used to create the base map.
2. Advance Spaceborne Thermal Emission and Reflection Radiometer, a Digital elevation model picture with a resolution of 30 m utilized to construct a base map and watershed for the region of interest.
3. Annual average rainfall for key locations within and outside the research region is obtained from the website of 'Indian Meteorological Department'.
4. A Landsat 9 picture with a resolution of 30 m is used to map land use and land cover.

In QGIS 10.8, eight spatial layers representing topographic or terrain parameters were produced from the DEM: elevation, slope, distance from the river, flow accumulation, drainage density, curvature, topographic wetness index, and stream power index.

The DEM's correctness was tested using the Survey of India's Topographical Map. of 47G 11,12,15,16 and 47 L 1,47 K 4, 47 H 13, 47 H 9 (1: 50,000).

The land use and land cover map was created using a Landsat 9 image from the website https://earthexplorer.usgs.gov.

1. Elevation: The most significant component of controlling flood is elevation (Mojaddadi et al., 2017;Das,2019). Flat lowland locations may flood more quickly than higher altitudes because water continually travels from higher terrain to lowe r areas.. (Das, 2019).With an ASTER DEM of 30 m resolution, elevation map is produced.
2. Slope: The slope map was created using a digital elevation model (DEM) taken from the research region's topographic map. The contour interval is 20 metres. The slope map was categorized as follows : (a) 0°–7.8°, (b) 7.9°–18°, (c) 19°–54°.
3. Distance from the river: Depending on how far a place is from the drainage system, a flood incident's size will vary. (Das,2019; Predick and Turner, 2007) Since the nearby places are inside the flow path, regions close to the drainage network frequently experience more flooding than those farther away. (Mahmoud and Gan, 2018; Das, 2019). Areas 90 meters or less from the system of drainage, according to Pradhan (2009), are susceptible to flooding. According to Samanta et al. (2016), places fewer than 100 meters away are particularly vulnerable to flooding, but locations more than 2000 meters away have a comparatively low risk of flooding. Regions which are 0.5, 1, 1.5 and 2 km away from the waterways are categorised as very high, high, medium, low flod sensitive.
4. Flow Accumulation: Water flowing down into the output raster's cells is built up as accumulated flow, and high accumulative flow values indicate areas of focused flow, which raises the danger of flooding (Kazakis et al.; 2015)
5. Drainage density: The highest drainage densities are correlated with the highest flood runoff rates, according to Kazakis et al., 2015. When paired with river energy, increased rainfall, and big river discharges alter the system for drainage of the river region. (Sapkale et al., 2022).

   Drainage Density = (Streams' entire length in km)/ (Entire area in km^2)
6. Toographic Wetness Index (TWI): It is a physical illustration of flood-prone zones and is an important part of a waterway basin. (Hong et al., 2018a). The TWI of a catchment can be used to identify flat terrain and hydrographic regions. (Papaioannou et al., 2015). TWI levels are often greater when located near floodplains. (Adam and David, 2011) TWI values are frequently higher if close to flooding areas.

   $$TWI = \ln\left(\frac{As}{Tan\beta}\right)$$

   Where As represents the uphill drainage area that empties a pour point and is the inclination at the point of pouring.
7. Stream Power Index:

   An important indication of sediment movement and stream channel erosion is the stream power index. (Hong et al. ; 2018). The computation of the stream power index is done using the provided equation (Moore et al., 1991):

   $$Stream\ power\ index = As\tan\beta$$

   where As denotes the catchment area and β reflects the slope grade

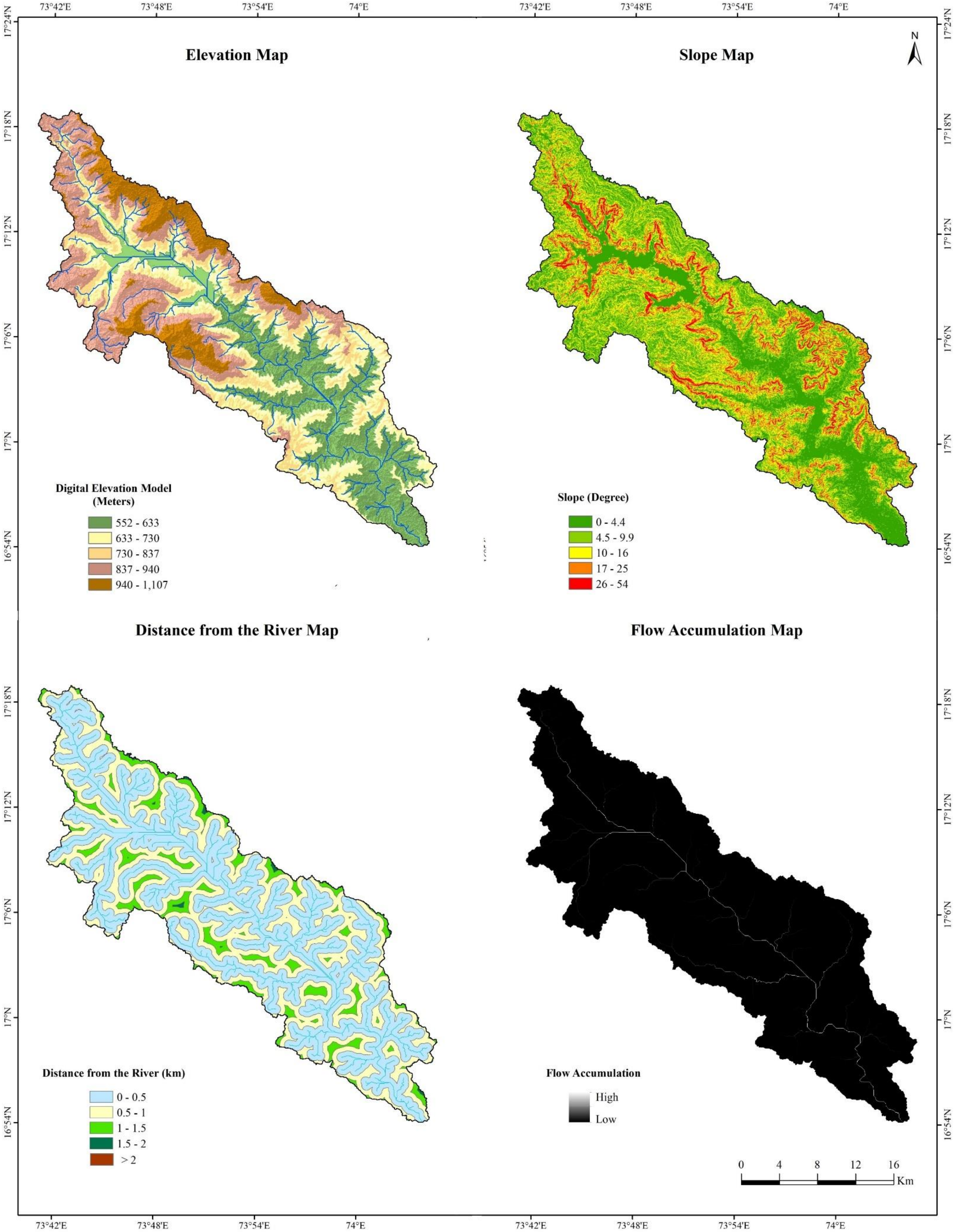


Figure 2: a) Elevation b) Distance from the river c)Slope d) Flow accumulation

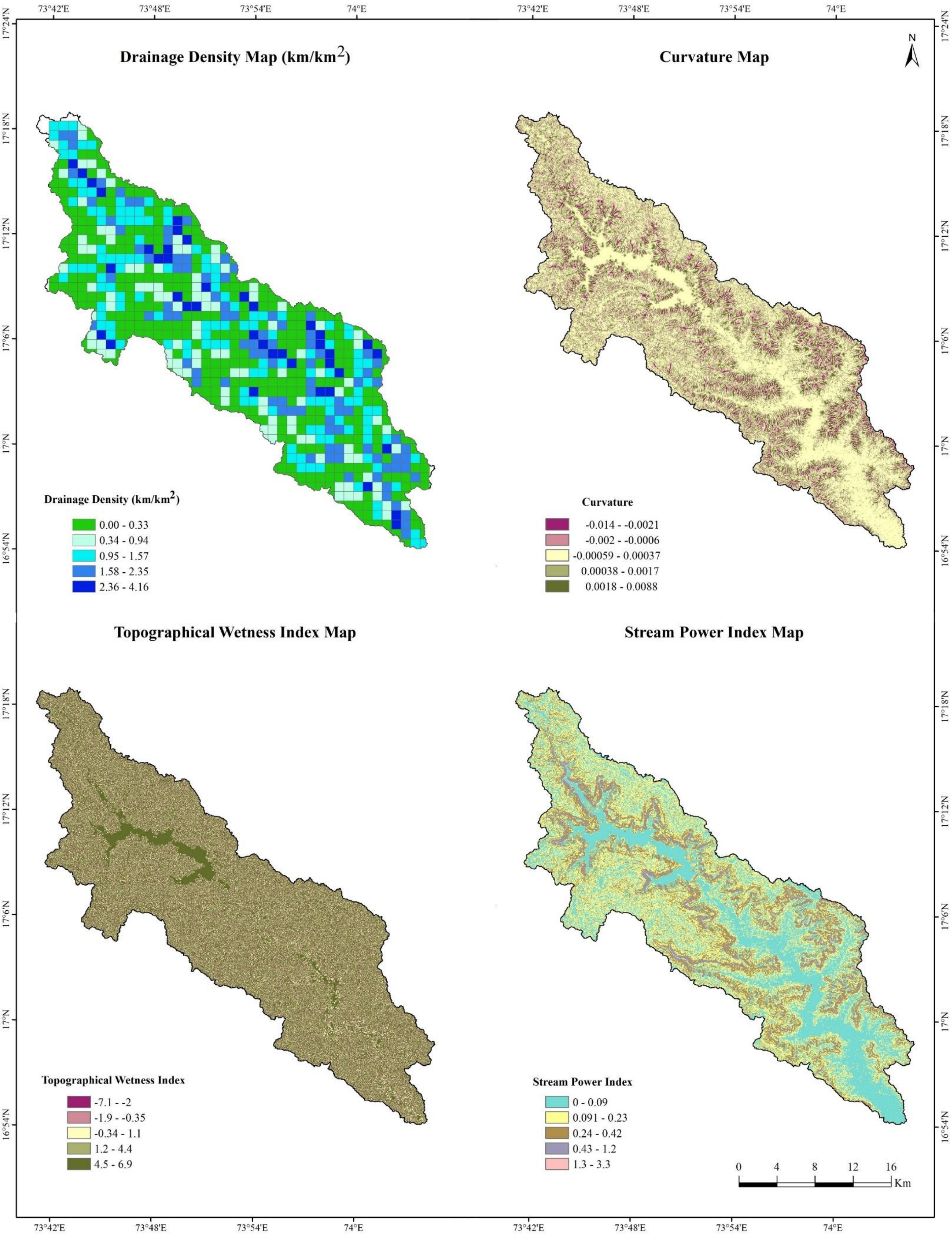


Figure 3 : a) Stream power index b) Curvature c) Topographic wetness index d) Drainage density

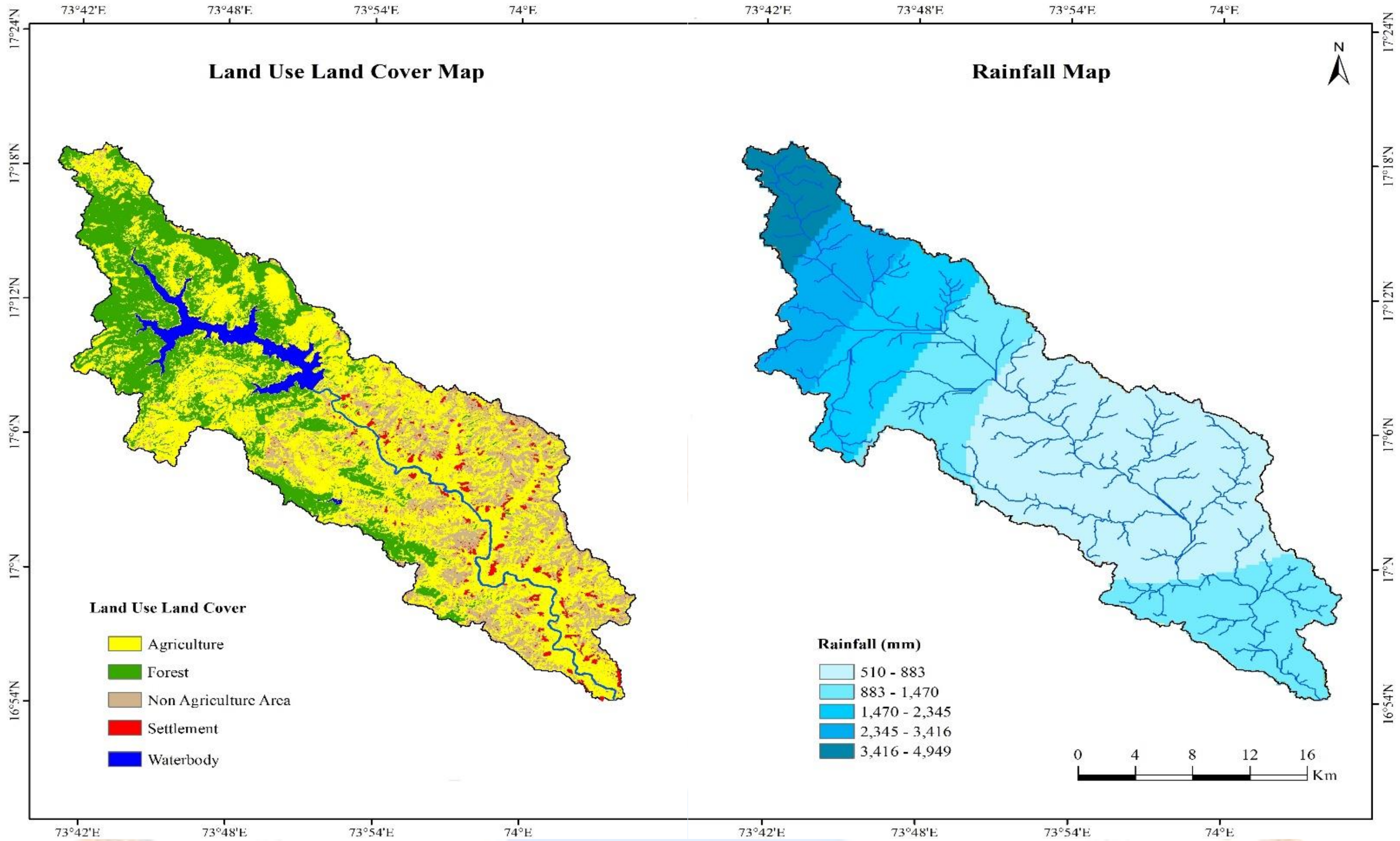


Figure 4 : a) Rainfall b) Land use and land cover

8. Curvature: Runoff and infiltration are highly dependent on topographic curvature in a given location. (Cao et al., 2016). A research conducted in 2000 by Hudson and Kesel discovered that flooding is considerably more likely when the curvature runs between 1.0 and 2.0. For the curvature map, five categories were developed. A curve could be convex, concave, or flat.
9. Land use: Land use alterations affect the hydrological patterns in drainage basins, that consequently affects the area's hydrological cycle. Changes in land use, according to Beckers et al. (2013), can increase a region's chance of flooding, and usage changes influence the hydrological behaviour of drainage basins, which consequently has an impact on the area's hydrological cycle. Changes in land use affect runoff and the movement of sediment, altering the chance of flooding. (Benito et al., 2010). The land use/land cover map was created using Landsat 9 imagery at a resolution of 30 m.
10. Rainfall: In all environmental situations, rain is the main cause ogf inundation. (Secongd et al.; 2007) Numrous studies have discovered a strong correlation among rainfall and the likelihood of flooding in certain areas. (Zhang and Smith ; 2003) The yearly mean precipitation of key areas within and surrounding the research region was gathered.

IV. Results

The highest altitudes in the watershed region are found in the north and some southern sections. The center region of the watershed has the least elevation. The highest altitude in the research region is 1107 meters above sea level, having a mean elevation of 800 meters. The largest slope value in the area is 54°, with a mean slope of around 10°. A significant portion of the Warna watershed is in an area with a substantial threat of flooding. The mean slope of the Warna watershed has been identified to be medium. The terrain rises somewhat to the north and south. A lower slope may be found in the basin's center. (Fig. 2. b) Flow accumulation was established using DEM. The portions of the watershed in the north, north-west, and south-east showed the highest drainage density is 4.16 km/km^2, with a mean density of 1.62 km/km^2 (Fig. 2.j).

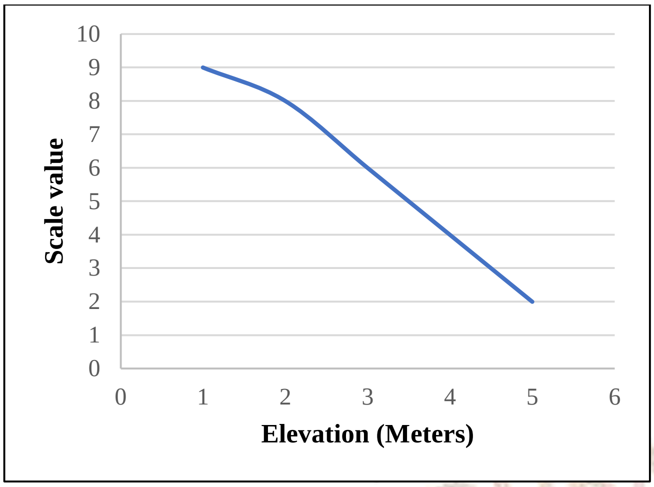
Weighed overlay analysis is done in QGIS. A particular zone was defined using the appropriateness scale. Depending on the scale number of the weighted overlay evaluation and the flood vulnerability, the danger of flooding ranges from extremely low to very high in some areas. There are regions with exceptionally high flood vulnerability along the watershed's extent and in the catchment's eastern part. An area with a high risk of flooding has an index greater than 8. Figure 4 depicts the region of every land use/land cover group which is located in the field of extremely high risk for flooding.

56.77% of farmlands and about 4.96% of the settlement region reside in high flood-prone areas. These flood-risk groups occupied an enormous area of farm lands. In the study region, residential and farms in the basin's downstream zone have been more susceptible to extreme floods. Unanticipated agricultural operations and cutting down forestry create flooding in the Warna river basin. The following settlements in the research regions were flooded: Mandur, Sonavde, Arale, Karanguli, Kalundre, Marathwadi, P. T. Varun, Charan, Mohare, Nathwad, Khujgaon, Chincholi, Kokrud, Mangrul, Punvat, and Sagaon. During heavy floods, river bank slides may cause major dangers to communities, agriculture, and floodplain regions.

Table no. 1 Weighted overlay analysis and scale values

Sr. No.	Parameters	Sub Classes	Scale Value
1	Elevation (Meters)	552-633	9
		633-730	8
		730-837	6
		837-940	4
		940-1107	2
2	Slope (Degrees)	0-7.8	8
		7.9-18	6
		19-54	4
3	TWI	-7.1 - -2	2
		-1.9 - -0.35	6
		-0.34 -1.1	7
		1.2-4.4	8
		4.5-6.9	9
4	Distance from River (Km)	0-0.5	9
		0.5-1	8
		1-1.5	6
		1.5-2	4
		>2	2
5	SPI	1.3- 3.3	9
		0.43-1.2	7
		0.24-0.42	5
		0.091-0.23	3
		0-0.09	2
6	Rainfall	3416- 4949	6
		2345 - 3416	5
		1470- 2345	4
		883- 1470	3
		510- 883	2
7	Drainage Density	2.36 -4.16	9
		1.58 -2.35	7
		0.95-1.57	5
		0.34 -0.94	3
		0.0 -0.33	2
8	Curvature	-0.014 - -0.0021	7
		-0.002- -0.0006	8
		-0.00059 - 0.00037	9
		0.00038 - 0.0017	5
		0.0018- 0.0088	3
9	Flow Accumulation	581,981.92 - 1,030,593	9
		355,655.62 - 581,981.92	8
		173,786.27 - 355,655.62	6
		48,498.49 - 173,786.27	4
		0 - 48,498.49	2
10	Land use	Agriculture	6
		Forest	5
		Non-Agriculture Area	3
		Settlement	8
		Waterbody	9

Places that are very susceptible to inundation have a combination of very low elevation, a low degree of slope, and a close location to the drainage network.


Scale value
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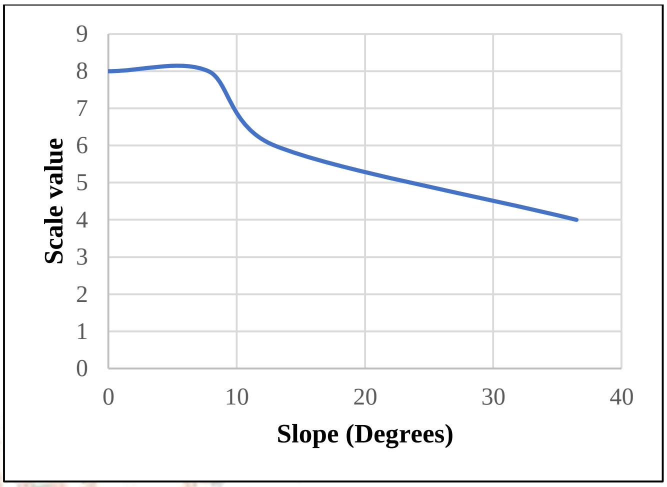
Elevation (Meters)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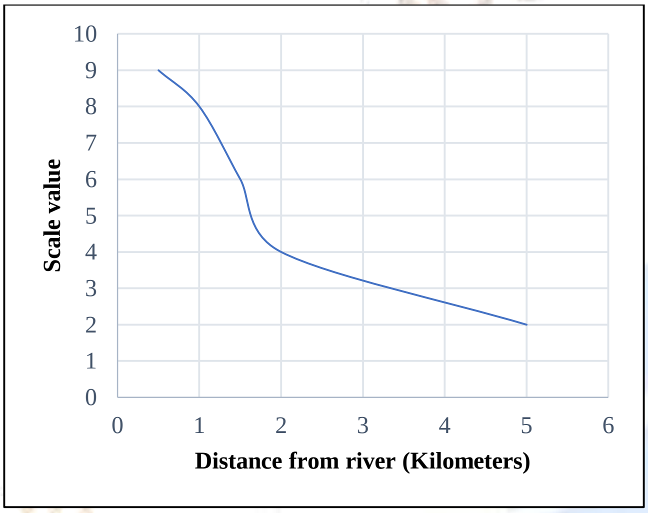
Slope (Degrees)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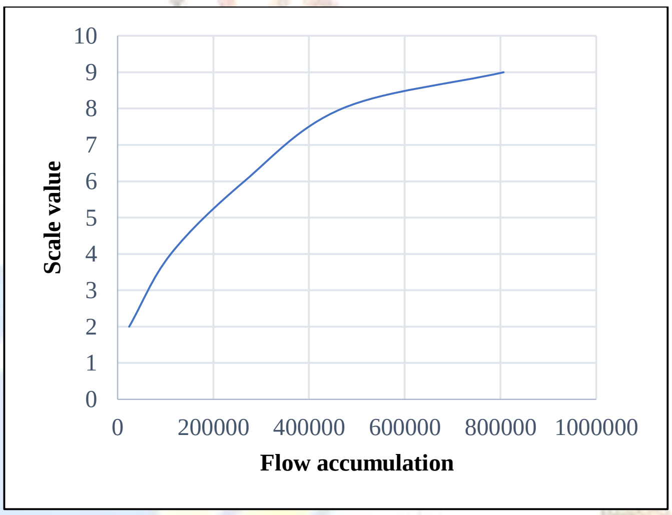
Distance from river (Kilometers)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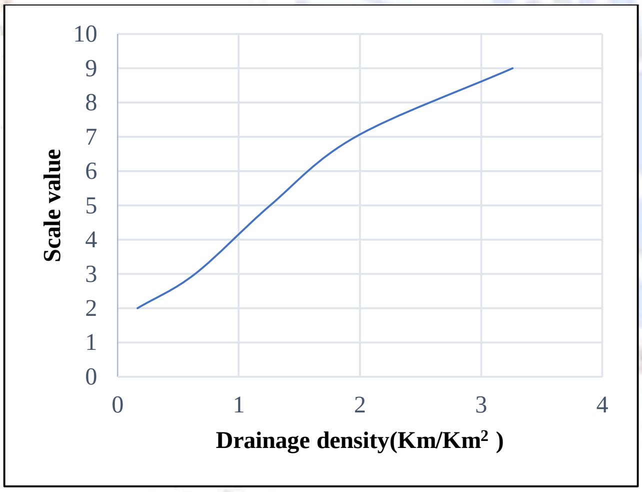
Flow accumulation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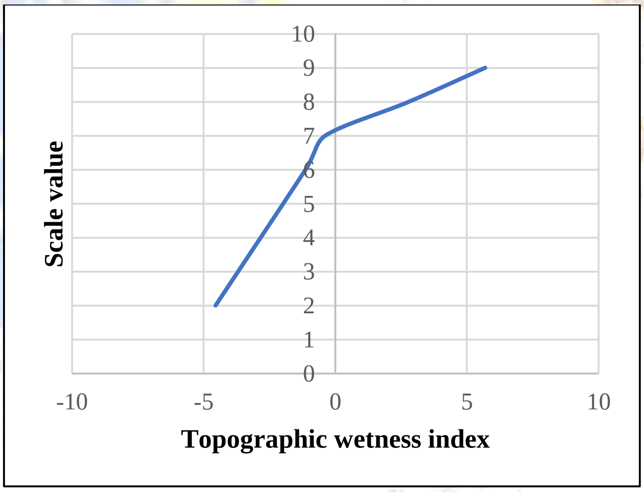
Drainage density(Km/Km²)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Topographic wetness index

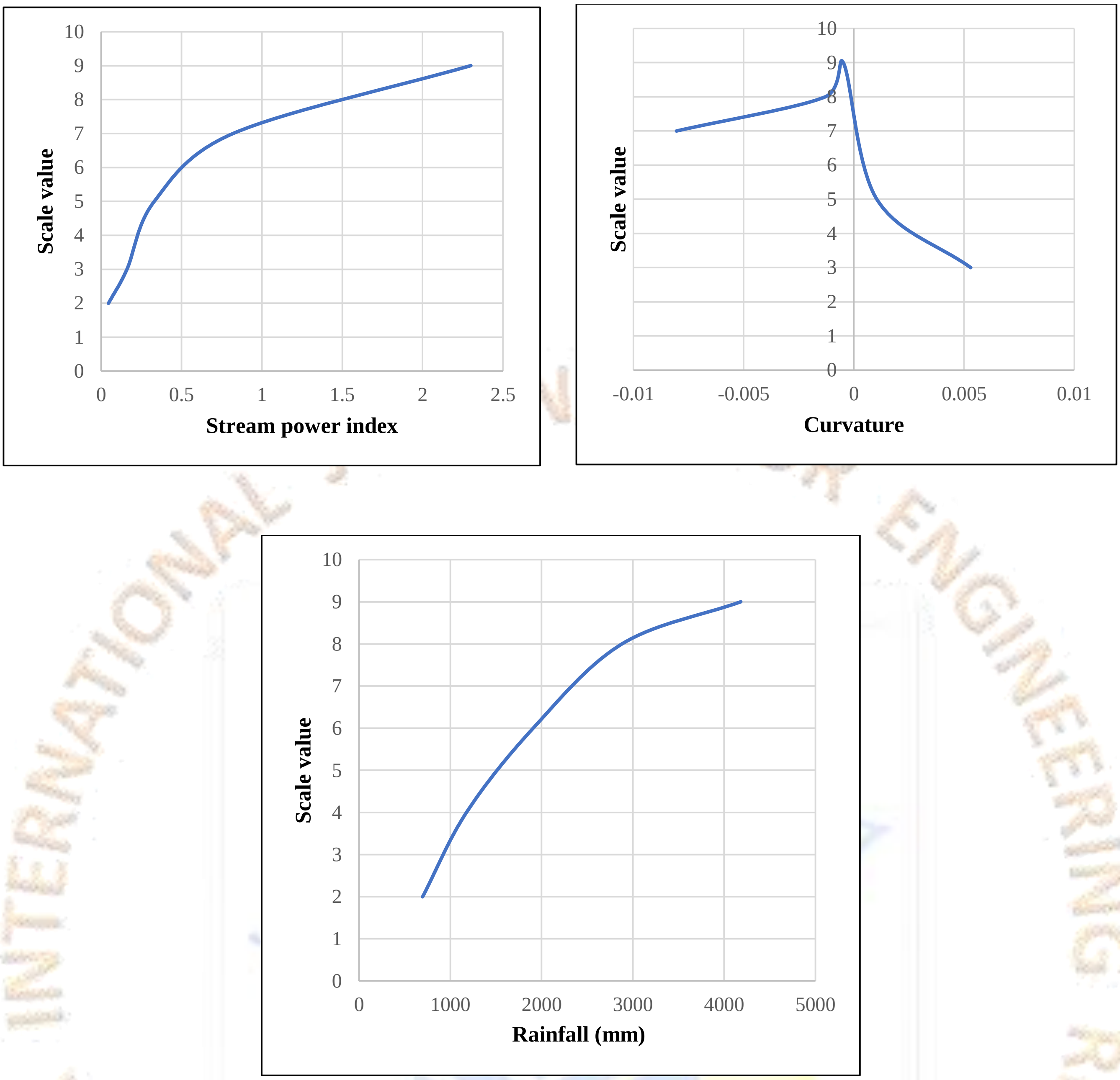

Figure 5 Graphs showing relation between scale value and flood parameters

Validation:
For validation, a list of flood affected villages in the warna basin is collected from the office of Assistant engineer grade 1, Warna Irrigation Sub-Division, Kodoli of Water resource department, Maharashtra. This research work also revealed the flood-affected villages which are found to be the same as that villages mentioned by the Warna irrigation sub-division, Kodoli of the Water resource department.

Table No.2 Affected Land use land cover areas in sq. km

Serial Number	Class Name	Area in Square kilometers
1	Agriculture	7.01
2	Forest	4.44
3	Non-Agriculture Area	13.8
4	Settlement	2.39
5	Waterbody	2.07

V. Conclusion:

Several catastrophic floods has grown substantially in the last decades which results in erosion of riverside. The likelihood of severe floods occurring more frequently is likely influenced by sedimentation, escalating flood stages, and the discharge from dam.; 1. Modifications in land use and land cover in the upstream region are a contributing factor to the catastrophic floods that occur in the central and downstream areas of the Warna river basin. 2. Elevation serves as one of the key elements regulating floods in the research region. Locations with a lower and milder slope have a higher danger of flooding in the basin's downstream portion.; 3. A calamity occurs close to the river's convergence zones, especially in the village of Sagaon in this research region, seriously damaging farmland, houses, roadways, electrical poles, and other infrastructure. 4. The rivers' highly sinuous meandering routes restrict the usual flow of water, slowing velocity and slowing down the flow of water, resulting in water stagnation. As a result, the meandering basins immediately overflow, flooding the meander belts and loops. (Singh, 2011)

Recognising the flood risk sensitivity associated with the Warna river watershed, as well as the current study findings and flood zone mapping, can help in minimising flood impacts during flood management. Numerous flood-affecting basin aspects were examined collaboratively to improve flood region mapping precision, providing a solid foundation for communities, local governments, and politicians to reduce the danger of floods. Furthermore, the outcomes-driven findings and proposed methodology provide unique techniques to mitigating the terrible flood which could be applied to similar flood research in other regions of India.

Flood vulnerability map given in this research may be used by engineers, lawmakers, urban planners, and government agencies to help prevent floods in the Warna watershed.

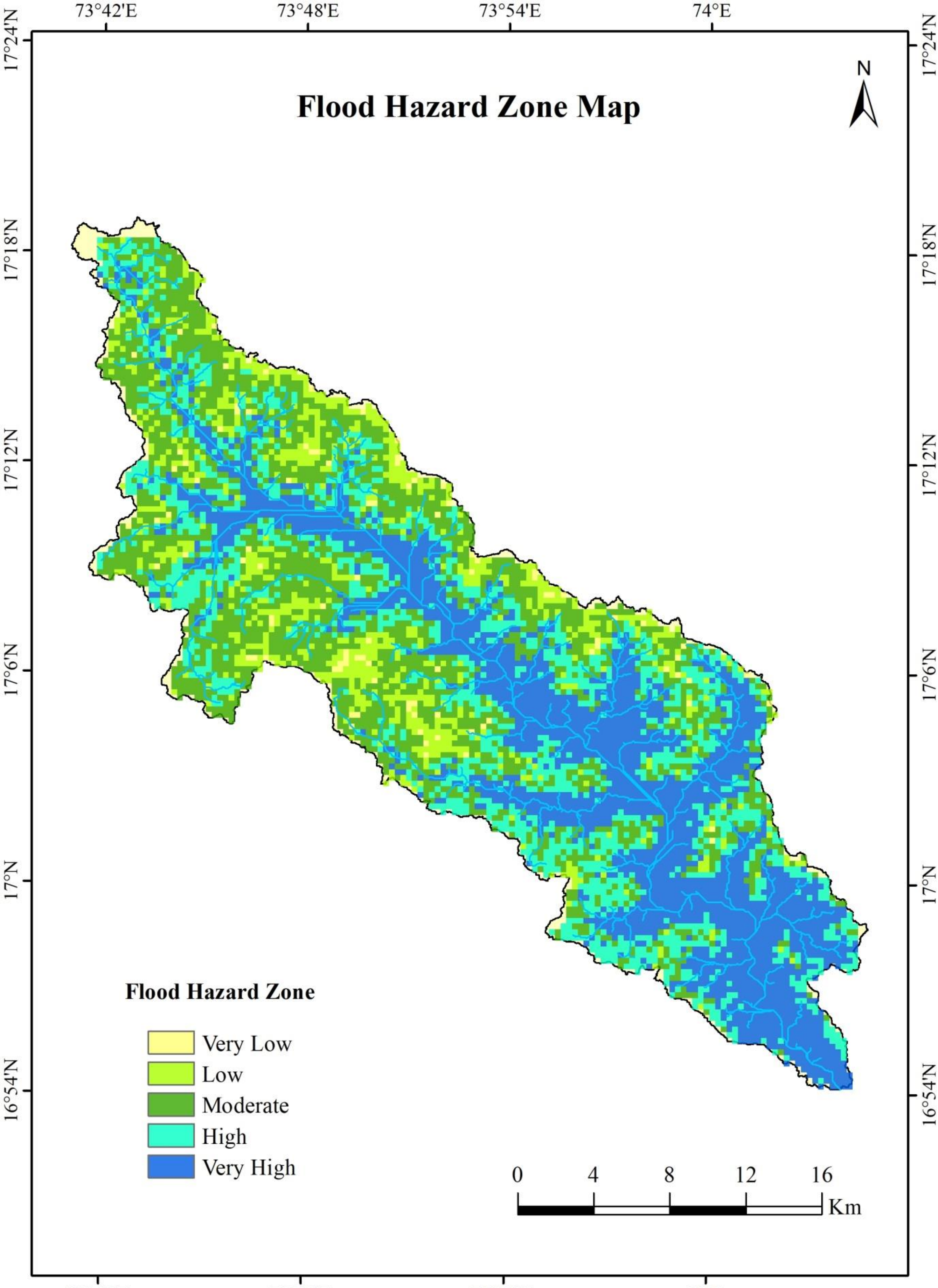

Figure 6: Flood hazard zone map`

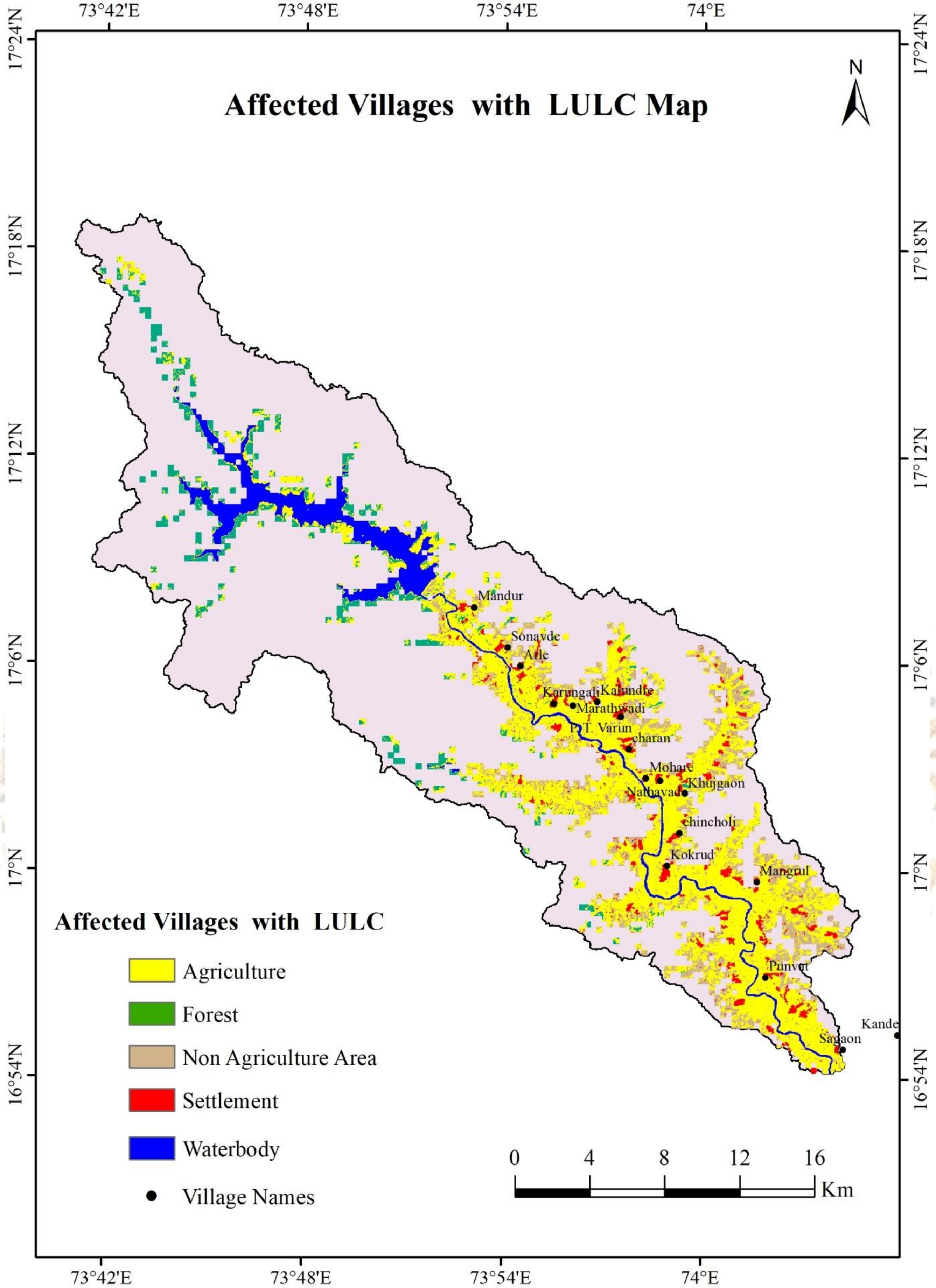

Figure 7: Affected villages with land use and land cover

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