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Flash Flood Risk Assessment using Geospatial Technique – A Case Study of Bangalore Districts, Karnataka

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Abstract:

Flash flooding has become a serious problem in several cities worldwide, including Bangalore, India. This study thoroughly evaluates the flash flood risk in the Bangalore district using cutting-edge geospatial methodologies. The study explores the complex interactions between variables that lead to flash floods by combining remote sensing, geographic information systems (GIS), and the weighted overlay method. Meteorological data and digital elevation models (DEMs) were gathered and analyzed. To identify flood-prone areas, some of the important variables like elevation, slope, drainage network, rainfall patterns, and land use/land cover were examined. Flood inundation scenarios under various rainfall intensities from 1958 to 2023 was used. The results of this study provide valuable insights into the spatial distribution of flood risk in Bangalore district. The identified flood-prone areas will be usefull for urban planning, disaster management, and decision-making processes. By implementing effective mitigation measures, such as improved drainage systems, floodplain management, and early warning systems, it is possible to reduce the impact of future flood events and enhance the resilience of the city and mitigating the impacts of future flood events.

Keywords: Remote Sensing, GIS, Digital elevation Model, flood management, Weighted Overlay Analysis.

Introduction:

Globally, urban flash floods have become more intense and frequent due to rapid urbanisation, climate variability, and inadequate drainage infrastructure. According to Marchi et al. (2010), flash floods are characterised by their abrupt onset, brief duration, and high peak discharge, which can seriously harm people, property, and the urban environment. In contrast to riverine floods, flash floods are caused by heavy rainfall and by land-surface characteristics, such as slope, imperviousness, drainage density, and land-use changes.

Unplanned growth, the degradation of natural drainage systems, and the encroachment into floodplains have made cities worldwide more vulnerable to flash flooding (UNDRR, 2022). Numerous studies have demonstrated that climate change has made heavy rainfall events more severe, increasing the risk of flooding in cities across wealthy and developing nations (IPCC, 2021). Flood risk assessment is now a crucial component of catastrophe risk reduction.

India's cities are particularly susceptible to flash floods due to the country's increasing urbanisation and inadequate stormwater drainage systems. Due to excessive rainfall and insufficient drainage infrastructure, the main metropolitan agglomerations of Bengaluru, Hyderabad, Chennai, and Mumbai have frequently experienced urban floods (Gupta & Nair, 2012; Mishra et al., 2018). Due to increased imperviousness, decreased lake area, and disruption of natural drainage linkages, Bengaluru has seen frequent flash floods in recent years (Sundaresan et al., 2015).

Hydrological and hydraulic modelling, which are computationally and data-intensive, are used in conventional flood risk assessment techniques. However, long-term rainfall variability and geographical analysis receive less attention in the present literature on urban flood risk assessment, which tends to focus on a few factors, short-term rainfall data, and local-scale research. Additionally, most studies are unsuitable for urban planning and policymaking because they are not pertinent to the district or regional levels. For the accurate identification of flood-prone locations, comprehensive frameworks for flood risk assessment that integrate long-term hydrometeorological data with geospatial analysis are necessary.

In this context, by superimposing several parameters that affect flood occurrence, the current study aims to assess the risk of flash floods using geospatial analysis. Effective flood control measures and urban development are anticipated to benefit from the research study's findings.

Objectives:

1. To analyze the factors contributing to flash flood risk using GIS-based overlay analysis.
2. To assess and identify vulnerable regions prone to flash flooding.
3. To generate a flash flood risk zonation map for Bangalore Urban and Rural districts, Karnataka

Literature Review:

The rising vulnerability of urban areas under rapid urbanisation and climate variability has drawn more attention to flash flood risk assessment. Hydrological modelling, statistical analysis, and geospatial approaches have been used in numerous studies to identify flood-prone areas and support disaster management planning. The capacity of GIS-based flood risk assessment to incorporate many flood-influencing parameters has led to its widespread adoption worldwide. By combining topographic, hydrological, and land-use data, Pradhan (2009) demonstrated the effectiveness of GIS and multi-criteria decision analysis (MCDA) in mapping flood susceptibility. In a similar vein, Tehrany et al. (2013) highlighted the significance of drainage density, slope, and land cover in flood occurrence by using weighted overlay and analytic hierarchy process (AHP) techniques to identify flood-prone locations. These studies demonstrated that GIS-based overlay analysis is a dependable method for zonating flood risk, especially in areas with little data.

Urban flood risk assessment in developing nations has been the topic of various studies in recent years. Rahmati et al. (2016) highlighted the importance of long-term rainfall variability in flood risk estimation by integrating rainfall, elevation, land use, and proximity to rivers using GIS-based MCDA to create flood susceptibility maps. Research by Kazakis et al. (2015) further demonstrated that the accuracy of mapping flood risk in urban settings is increased when topographical parameters and land surface characteristics are combined. Because major cities in India frequently experience flooding, urban flooding has been studied in great detail. According to Gupta and Nair (2012), the main causes of urban floods in India include unplanned urban growth, the loss of natural drainage systems, and insufficient stormwater infrastructure. According to Mishra et al., (2018) analysis of extreme rainfall patterns, flash floods are becoming more likely as high-intensity rainfall events occur more frequently over Indian cities. By combining rainfall, land use, slope, and drainage factors, studies carried out in cities like Mumbai, Chennai, and Hyderabad have effectively employed GIS-based techniques to identify flood-prone areas (Patel et al., 2017; Sinha et al., 2020).

Prior research has focused on the effects of urbanisation and lake encroachment on flood risk in Bengaluru. According to Sundaresan et al. (2015), increased impervious surfaces and decreased lake interconnectivity have drastically changed natural flow patterns, leading to more frequent flash flood events. To evaluate flood-prone areas in Bengaluru, Ramachandra et al. (2016) used geospatial analysis, emphasising the impacts of drainage disruption and land-use changes. Nevertheless, much of this research focused on specific areas or lacked sufficient temporal rainfall data. Despite tremendous progress, current research has certain shortcomings. Extreme rainfall variability may not be adequately captured by short-term rainfall statistics, which are commonly used in flood risk assessments. Furthermore, many studies either focus solely on urban cores or fail to incorporate peri-urban and urban areas into a single framework. Furthermore, district-scale flash flood risk zonation using long-term rainfall data and several conditioning factors receives little attention.

Study Area:

The bustling city of Bangalore, often called Bengaluru, is situated in the southeast of the Indian state of Karnataka. It covers an area of around 4,494 square kilometers (Urban with 2,196 sq km and Rural with 2,298 sq km) and is located at latitude 12.8° North to 13.5° North and longitude 77.0° East to
78.2° East. It is one of the most populated cities in India, home to more than 12 million people. The vibrant city of Bangalore, the capital of Karnataka, is well-known for its quick urbanization and technological development. The city, which is located on the Deccan Plateau, draws visitors from all over the nation because of its lovely temperature. Bangalore has become a significant IT hub due to its advantageous location and climate, earning the moniker "India's Silicon Valley." The city's global nature is influenced by its diversified population, lively culture, and plenty of educational opportunities. However, problems like pollution, traffic jams, and strained infrastructure have also been brought on by fast urbanization, therefore it's critical to manage urban problems and guarantee sustainable growth.

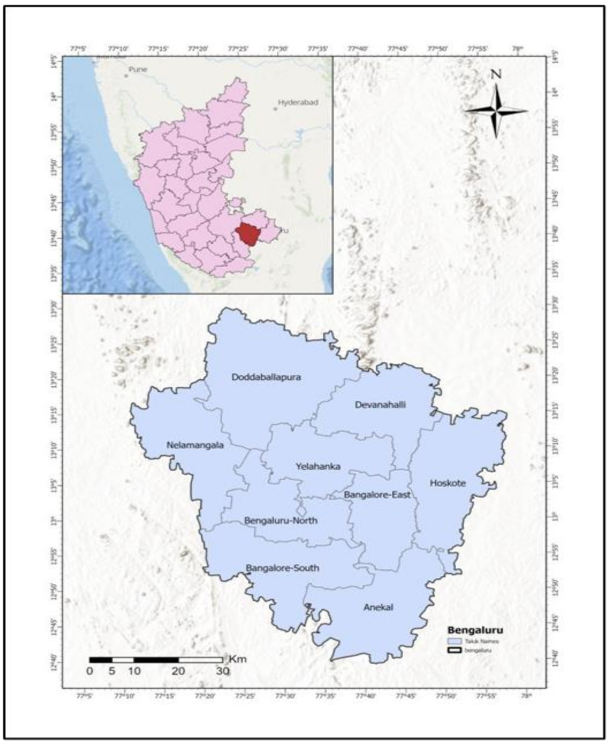

Fig 1: Study Area

Materials And Methodology:

1. Data Collection: Collection of data is one of the crucial step. For a thorough weighted overlay analysis, a robust dataset that accurately captures the variables that affect flood risk is necessary. The layers that are used for this paper are Land Use and Land Cover (LULC), Digital Elevation Model (DEM), Rainfall, Highway, Soil. The Land use and land cover was collected from ESRI portal specifically Sentinel-2 dataset with 10m resolution of 2023. The TerraClimate portal was used to collect NetCDF (Network Common Data Form) format for the historical rainfall dataset from 1958 to 2023 with 4km spatial resolution. The DEM was acquired from United States Geological Survey (USGS) Earth Explorer portal specifically from Shuttle Radar Topography Mission (SRTM) 1 arc-second global dataset that provides 30m high-resolution elevation data for the Earth's land surface. This layer offers vital details regarding the research area's topography, such as aspect, slope, and elevation. Surface runoff and drainage patterns are influenced by the DEM, which forms the basis of the study. Geospatial analytic methods were used to create a slope map from the DEM. The rate of surface runoff is significantly influenced by slope, with steeper slopes causing faster water flow and more erosion. Areas vulnerable to rapid water collection and possible flooding are identified with the aid of the slope map. The Soil was collected from the Food and Agriculture Organization (FAO) of 1km spatial resolution in the year 2023. The highway dataset was collected from the DIVA GIS portal.

Sl No	Parameters	Dataset	Spatial Resolution	Source	Time series
1	Land Use Land Cover [LULC]	Sentinel - 2	10m	ESRI	2023
2	Rainfall	Climatic Research Unit Time Series [CRU TS 4.0]	4 km	Terra Climate	1958 - 2023
3	Digital Elevation Model [DEM]	Shuttle Radar Topography Mission (SRTM) 1 arc-second global	30 m	United States Geological Survey (USGS) Earth Explorer	2014
4	Soil	FAOSTAT	1 km	Food and Agricultural Organisation (FAO)	2023
5	Road (Highway)	Bing Maps	5 m	OpenStreetMap (OSM)	2023

2. Data preprocessing: Following the acquisition of the required data layers, data processing and weighted overlay analysis preparation are the next steps. Usually, this procedure involves data preprocessing to guarantee consistency and compatibility, preprocessing may be necessary for the obtained data layers, including DEM, rainfall, LULC, and soil maps. Tasks like georeferencing, clipping, and resampling to a similar coordinate system and spatial resolution may be required for this. Then Reclassification is done to assign relative weights and standardise the values of several levels. This entails turning continuous data into categorical data, where distinct ranges stand for varying degrees of danger or suitability. The slope map, for instance, might be recategorised into "low," "moderate," and "high" slope classes. The weight assignment is followed by relative importance of each stratum in raising the risk of flooding determines its weight. Usually, these weights are allocated on a range of 1 to 10, where more important aspects are awarded larger weights. For example, slope and rainfall may be given greater weights than soil type. Finally a weighted sum technique is used to merge the weighted layers. This entails adding up the weighted values for every layer at every cell position after multiplying the value of each cell in a layer by its associated weight. The end product is a raster map that shows the total danger of flooding, with larger values denoting riskier places.

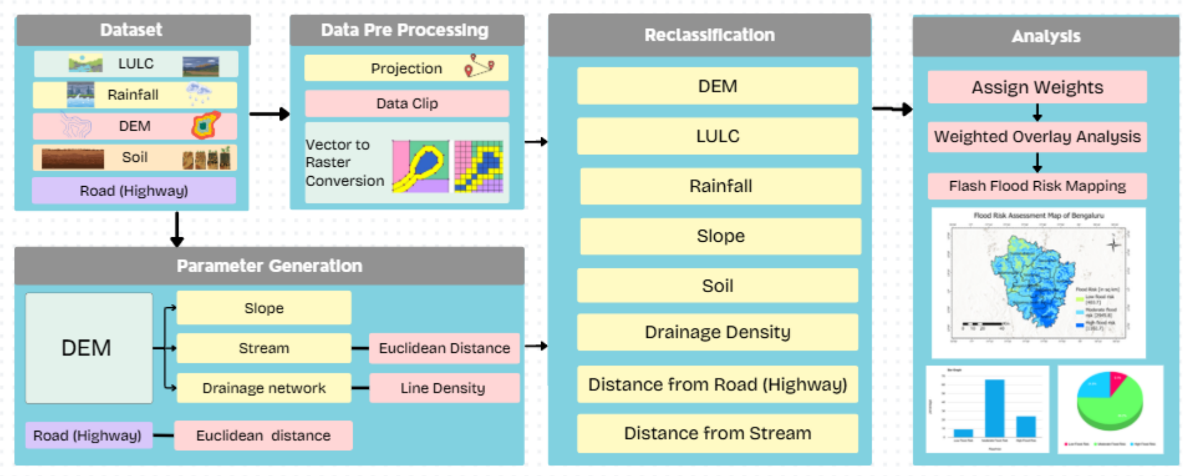

Fig 2: Methodology

3. Flash Flood Risk Parameter

Elevation: A 3D representation of the Earth's surface that includes vital details regarding aspect, slope, and elevation is called a Digital Elevation Model (DEM). Understanding the topography of a region is crucial for understanding a variety of environmental processes, such as hydrological modeling, land use planning, and natural hazard assessment. This can be achieved by examining DEM data. DEM data is important when assessing the danger of flooding in urban areas. We can identify areas that are more vulnerable to floods by looking for low-lying elevations, steep slopes, and drainage patterns. The possible effects of rainfall on various regions of the research area can also be evaluated by using DEM data to compute flow accumulation and define drainage basins. In the end, DEM data is a key component of the weighted overlay analysis, helping to accurately determine the danger of flooding.

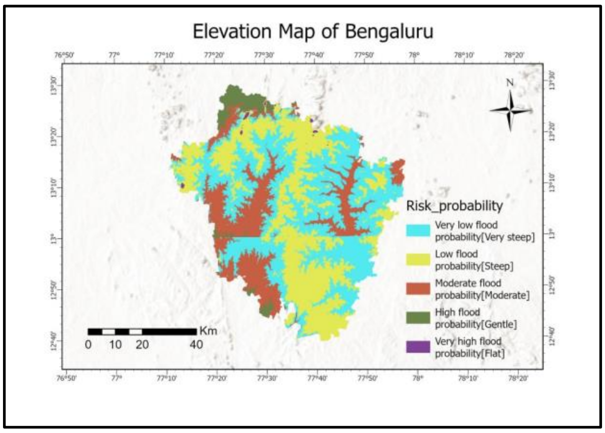

Fig 3: Elevation / DEM map of Bengaluru

The elevation map of Bangalore uses a color-coded legend to highlight locations with different flood probabilities. The map shows the various levels of flood danger. The scattered tiny patches, in the northwest and some central regions, is a very high flood probability indicating flat region is witnessed in purple. In the southern area, high flood probability is denoted in green colour indicating gentle slope. A brown colour indicates flood with a moderate probability(moderate slope) spreads widely over the map, especially branching out in the center and south. The yellow indicates low flood probability with steep slope that lowers danger and is widespread in most places. Much of the map has a very low flood probability (blue) that is very steep, particularly in the eastern, southern, and central regions.

LULC: Maps of land use and cover (LULC) are crucial resources for comprehending how different forms of land cover are distributed spatially within a given area. They offer important information about the landscape's makeup, encompassing water bodies, forests, urban areas, agricultural lands, and other land cover groups.Applications such as urban planning, environmental monitoring, disaster management, and climate change research all heavily rely on LULC maps. They aid in locating regions vulnerable to erosion, flooding, and other natural disasters. Policymakers and planners can decide on land use management, infrastructure development, and conservation initiatives using knowledge of the land cover characteristics. LULC maps can also be used to track land cover changes over time, which makes it possible to evaluate trends in urbanization, deforestation, and other human-caused environmental effects.

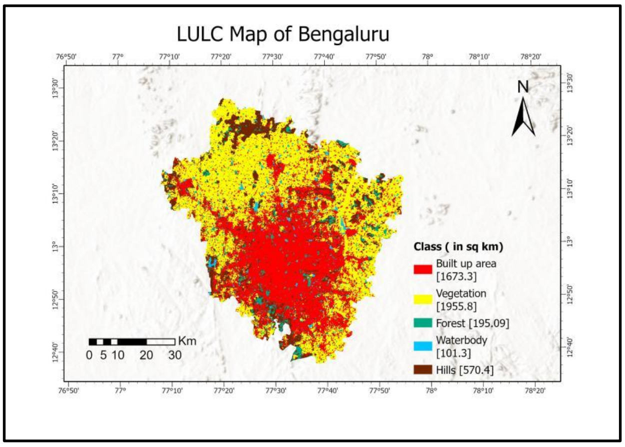

Fig 4: LULC Map of Bengaluru

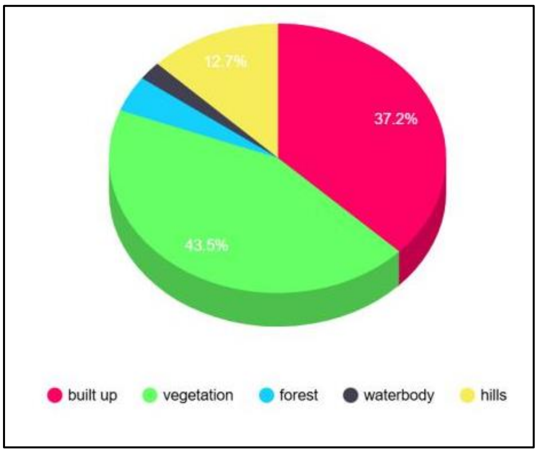

Fig 5: Pie Chart of LULC

The spatial distribution of land cover types and its consequences for flood risk assessment are highlighted in Bengaluru's LULC (Land Use Land Cover) Map. The territory is divided into five classes on the map: "Waterbodies" (blue), "Vegetation" (yellow), "Cropland" (green), "Barren land" (brown), and "Built-up area" (red). Built-up areas predominate in the centre and southern regions, indicating extensive urbanisation. This raises the danger of flooding by decreasing natural infiltration and increasing surface runoff. Although they seem to be limited in scope, the scattered blue waterbodies offer some natural drainage. Large areas of cropland and vegetation surrounding urbanised areas are essential for mitigating floods because they improve infiltration and decrease runoff. However, flooding problems can get worse as urban areas spread into natural settings. In order to balance growth and environmental management and lessen flood susceptibility by preserving flora and waterbodies, urban planners need to have this map.

Rainfall: One important determinant of flood danger is rainfall. Patterns of precipitation, intensity, and duration can be found by examining historical rainfall data. This data aids in forecasting probable future occurrences and comprehending the frequency and intensity of previous flood episodes.The effect of climate change on precipitation patterns, which may affect the frequency and severity of extreme rainfall events, can also be evaluated using rainfall data. Areas with higher rainfall intensity and frequency can be identified as being more vulnerable to flooding by integrating rainfall data into the weighted overlay analysis. This data is useful for creating early warning systems and efficient flood mitigation plans.

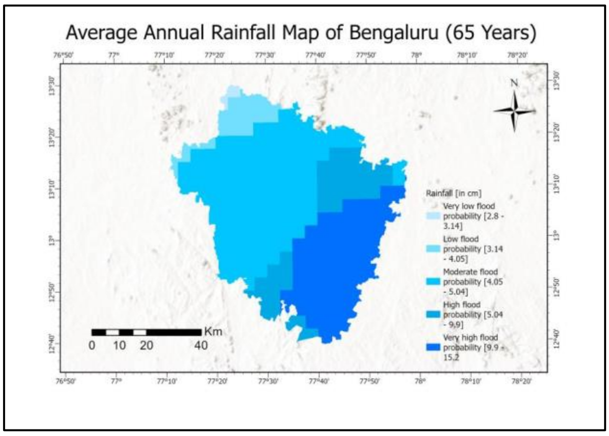

Fig 6 : Rainfall Map of Bengaluru

Flood risk probabilities are depicted on the above map according to the spatial distribution of rainfall. Different levels of flood danger are shown by the different colour-coded zones on the map. Locations shown in pink indicate "high flood probability," and these are primarily found in the central and southern areas, which are anticipated to have the most rainfall. Green areas around these indicate "very high flood probability," pointing to areas that are susceptible to flooding as a result of moderate to heavy rainfall. Mostly found in Bengaluru's northern and outer regions, blue areas denote "moderate flood probability," while purple zones indicate "low flood probability." Finally, "very low flood probability," which is present in the far northern and northeastern regions and is probably caused by less rainfall, is reflected in brown regions. By identifying flood-prone locations, this rainfall map facilitates effective water management planning and disaster preparedness throughout the region.

Slope: Slope, a fundamental concept in geography, gauges the steepness of a terrain. It calculates the elevation change rate over a given distance. Slope is an important factor in flood risk assessment because it affects how water moves across a landscape. Rapid runoff is made possible by steeper slopes, which raises the risk of erosion and flash floods. On the other hand, softer slopes minimize the chance of floods by allowing for slower infiltration and less runoff. Researchers and students can identify flood-prone locations and put in place suitable mitigation measures, such as building retention ponds or replanting, by examining slope data.

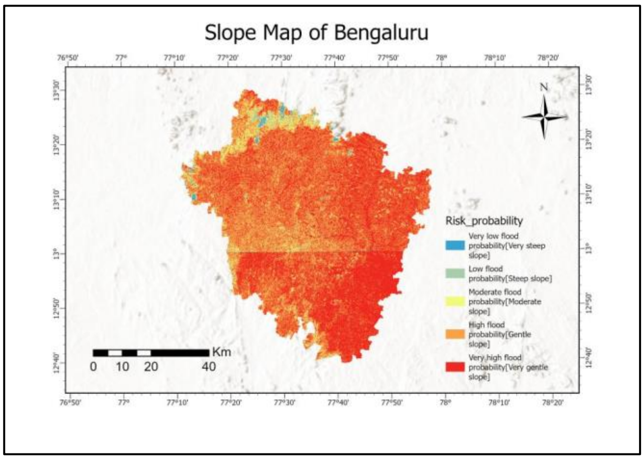

Fig 7 : Slope Map of Bengaluru

Based on topographical slope data, the Bengaluru Slope Map offers an evaluation of the risk of flooding. The map's colour-coding corresponds to the different flood risk that estimates in the area. The map's "red" areas, which show "very high flood probability," predominate, particularly in the southern and central regions, indicating low-lying or level terrain that is vulnerable to flooding. Scattered sparsely, "yellow" and "orange" sections indicate "moderate flood probability" and "high flood probability," respectively. In the northern regions, where higher elevations or steeper slopes probably allow natural drainage, the "green" (low flood probability) and "blue" (very low flood probability) zones are mostly located. Urban planners and disaster management officials may use this map as a vital tool to pinpoint locations that are at risk and put mitigation plans in place appropriately.

Soil: Often called the Earth's skin, soil is a complex mixture of organic materials, water, air, and mineral particles. It is an important part of our world, supporting life via key processes including carbon sequestration, water filtering, and nutrient cycling. Over thousands of years, rocks weather, and organic matter breaks down to create soil, which has a layered structure with unique horizons. The texture, structure, and chemical makeup of soil all affect how well it supports plant development, controls water movement, and preserves the health of ecosystems. In forestry, agriculture, and environmental preservation, soil is essential. We can preserve this priceless resource for the next generations by realizing its significance and implementing sustainable practices.

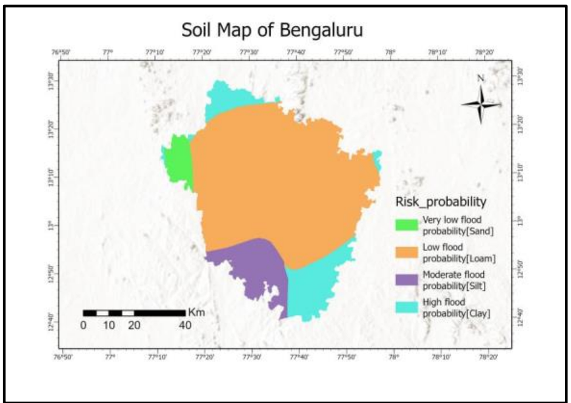

Fig 8 : Soil Map of Bengaluru

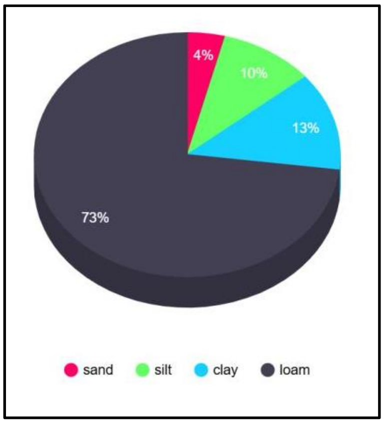

Fig 9: Pie Chart of Soil

The aforementioned map shows the likelihood of flooding in various city locations using a colour-coded approach. Areas with a high probability denotes clay that is shown in blue. They are mostly found in Bengaluru's eastern and southern regions. Moderate Flood Probability Areas denotes silt which include a large area of the city, especially in the southwest, are indicated by a heavier shade of purple. The northern and eastern regions of Bengaluru are home to the majority of the low flood probability areas that denotes loam which are shown in orange. The northwest portion of the city is home to the majority of Very Low Flood Probability Areas that denotes sand which are shown by a pale shade of green.

Drainage Density: The number and spacing of drainage channels within a given region are measured by drainage density, a critical hydrological metric. It is computed by dividing the drainage basin area by the total length of all stream channels. A more fragmented landscape with a higher propensity for erosion and quick runoff is indicated by a higher drainage density. On the other hand, flatter topography with slower runoff and higher infiltration rates is suggested by a lower drainage density. Drainage density is essential to comprehending a catchment's hydrological response in the context of urban flash flood risk assessment. Rapid runoff and flooding are more likely to occur in areas with high drainage densities, particularly during periods of heavy rainfall. Targeted flood mitigation measures can be implemented by identifying areas with increased flood susceptibility by integrating drainage density into the weighted overlay analysis. Furthermore, drainage density can aid in stormwater management system and drainage network design optimization.

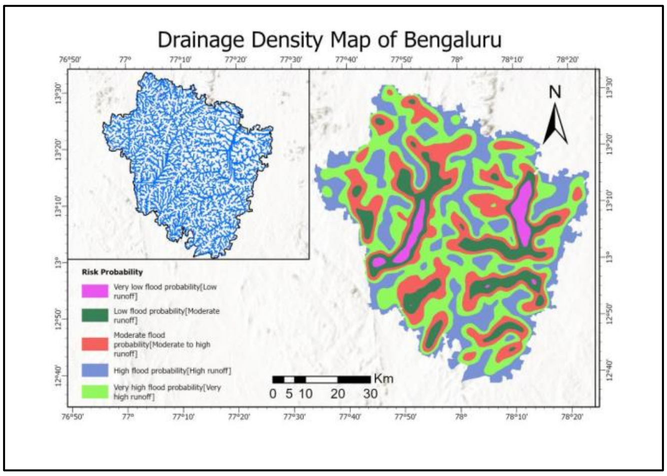

Fig 10: Drainage Density Map of Bengaluru

The Drainage Density Map of Bengaluru, seen in the above image, shows regions with different flood hazards according to drainage patterns. A color-coded legend on the map indicates the likelihood of flooding high flood probability (blue) is widely dispersed over the map, encompassing a sizable chunk of Bengaluru, indicating extensive drainage systems that are vulnerable to floods. Extremely high flood probability (green) indicates places at high danger of flooding and is found in sporadic patches, primarily in the central and southern regions. Moderate flood probability (orange) is mostly found in high-risk locations, but also scattered throughout the map. Smaller regions with a low flood probability (purple) are usually found in places with lower drainage densities. Extremely low flood probability (pink) is shown in remote areas, this indicates the least chance of flooding.

Distance from Stream: When determining flood danger, distance from streams is an important consideration. Because of increased surface runoff, bank erosion, and inundation, areas near water bodies are more vulnerable to flooding. We can determine regions with a higher risk of flooding by adding a distance-to-stream layer to the weighted overlay analysis. Informed land-use planning and focused mitigation strategies are made possible by this layer's assistance in defining floodplains and low-lying, flood-prone areas.

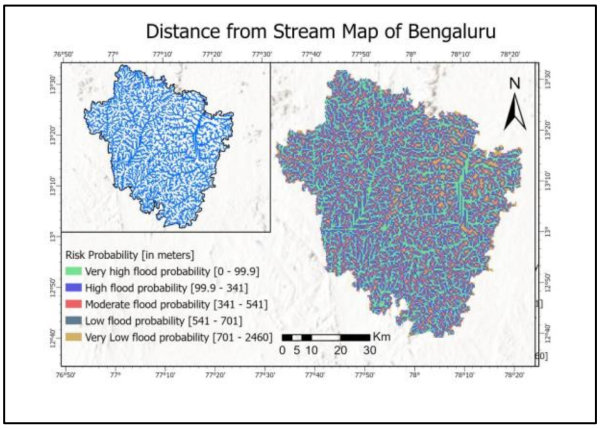

Fig 11 : Distance from Stream Map of Bengaluru

The "Distance from Stream Map of Bengaluru" map displays the spatial distribution of flood risk probabilities in the Bengaluru region according to closeness to streams. Five degrees of flood risk likelihood are distinguished by their respective colours, that is,very high flood probability (green) are the locations with the highest risk of flooding, which are those that are very near to streams. Flood probability high (blue) are areas close to streams that are at high danger of flooding. Zones with a moderate risk of flooding are indicated by a light blue flood probability. Areas farther from streams that are less likely to flood are designated as having a low flood probability (dark blue). Very low flood probability (yellow) are the areas with little danger of flooding that are far from streams. High and extremely high flood probability zones are clearly visible on the map, indicating that flood danger is concentrated closer to stream networks. The flood danger steadily decreases as one gets farther away from these streams, moving into low and extremely low possibilities.

Distance from Road: Urban development and flood danger can be greatly impacted by a location's proximity to major roadways. We may evaluate the possible influence of roadways on flood patterns by adding a "distance from highway" layer to the weighted overlay analysis. In some places, highways can obstruct water movement, causing localized flooding. They can also affect the intensity of development and patterns of land use, which can further affect the danger of flooding. We can determine whether places may be more vulnerable to floods because of their close proximity to transportation infrastructure by examining the spatial link between metropolitan areas and highways.

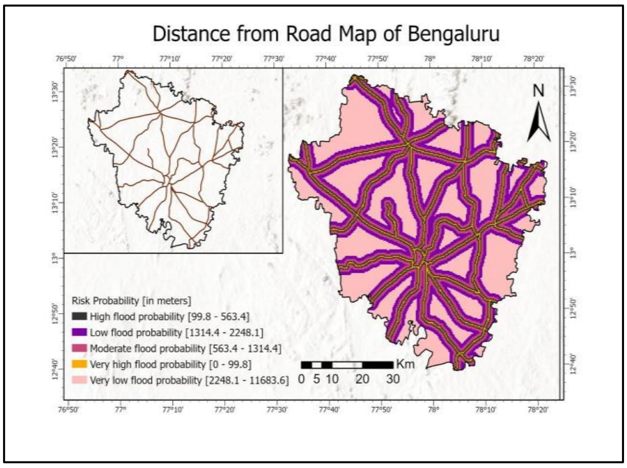

Fig 12 : Distance from Road Map of Bengaluru

Based on the Bengaluru region's proximity to road networks, the "Distance from Road Map of Bengaluru" map shows the spatial distribution of flood risk probability. Each of the five categories into which the flood risk zones are separated is represented by a distinct color. very high flood probability (dark blue) shows impermeable surfaces and inadequate drainage; areas immediately adjacent to roadways are at the worst danger of flooding. High flood probability (green) areas are areas with a high risk of flooding next to roadways. Intermediate zones with a moderate chance of flooding are designated as having a moderate flood probability (red). Low flood probability (cyan) are places with a lower risk of flooding that are those that are furthest from roadways. Very low flood probability (pink) areas with the lowest risk of flooding are those that are the farthest from the road system. Because surface runoff, decreased infiltration, and inadequate drainage systems can cause water to accumulate in these places, the map shows that flood risk is concentrated around the road network. Road corridors are the primary location of the very high and high flood probability zones, but the danger of flooding gradually declines with increasing distance from roadways.

1. Weighted Table :

Sl No	Parameters	Weightage
1	Rainfall	25 %
2	Distance from Stream	20 %
3	Drainage density	15 %
4	Elevation	15 %
5	Slope	10 %
6	LULC	10 %
7	Distance from road	3 %
8	Soil	2 %

Results And Discussion:

1. Interpretation of Flood Risk Zonation Results:

The flood risk assessment categorizes the study area into three classes: **low**, **moderate**, and **high flood risk** zones. The results indicate that **moderate flood risk dominates the region**, covering approximately **66.2% (≈ 2945.8 km²)** of the total area. High flood risk zones account for **24.8% (≈ 1102.7 km²)**, while low flood risk areas constitute only **9.1% (≈ 403.7 km²)**. The predominance of moderate flood risk zones suggests that a large portion of the Bengaluru Urban and Rural districts experiences conditions conducive to surface runoff accumulation but not persistent inundation. These areas typically exhibit **moderate slopes, mixed land use patterns, and partially developed drainage systems**, making them susceptible to flash flooding during high-intensity rainfall events.

High flood risk zones are primarily concentrated in **densely urbanized areas and low-lying regions**, particularly in parts of Bengaluru East, South, Anekal, and downstream catchments. These areas are characterized by **high impervious surface coverage, reduced infiltration capacity, disrupted natural drainage networks, and proximity to streams**, which significantly increase runoff generation and flood susceptibility. In contrast, low flood risk zones are limited in extent and are mainly observed in areas with **higher elevation, lower drainage density, permeable land cover, and comparatively natural surface conditions**, allowing effective runoff dispersion.

2. Discussion: Factors Influencing Flood Risk Patterns:

The spatial distribution of flood risk zones clearly reflects the combined influence of urbanization, drainage characteristics, topography, and rainfall variability. Rapid urban expansion in Bengaluru has led to extensive conversion of permeable surfaces into built-up areas, significantly reducing infiltration and increasing surface runoff. This phenomenon explains the widespread presence of moderate-to-high flood risk zones across urban and peri-urban regions. Drainage-related factors play a critical role in shaping flood risk patterns. Areas with high drainage density and proximity to stream networks exhibit elevated flood susceptibility due to the rapid concentration of runoff. Additionally, encroachment and blockage of natural drainage channels have reduced the capacity of stormwater systems to carry stormwater, exacerbating flash flooding during extreme rainfall events.

The results are consistent with earlier studies conducted in Bengaluru and other Indian cities. Sundaresan et al. (2015) and Ramachandra et al. (2016) reported that loss of lake interconnectivity and disruption of natural drainage corridors significantly increased urban flood vulnerability in Bengaluru. Similarly, Gupta and Nair (2012) emphasized that inadequate stormwater infrastructure and unplanned urban growth are key drivers of urban flooding in Indian cities. The dominance of moderate flood risk zones observed in this study aligns with findings by Pradhan (2009) and Rahmati et al. (2016), who highlighted the transitional nature of flood susceptibility in rapidly urbanizing regions.

Furthermore, the concentration of high flood risk zones in downstream and low-lying urban areas reflects the cumulative impact of upstream runoff contributions and altered hydrological responses due to land-use changes. This pattern has also been observed in studies conducted in cities such as Chennai and Hyderabad, where urban expansion intensified flash flood severity (Mishra et al., 2018). Overall, the results underscore that urbanization without adequate drainage planning, combined with increasing rainfall intensity, has transformed large parts of the Bengaluru region into flood-prone zones. The generated flood risk zonation map thus provides valuable insights for urban planners, disaster management authorities, and policymakers to prioritize mitigation measures and promote climate-resilient urban development.

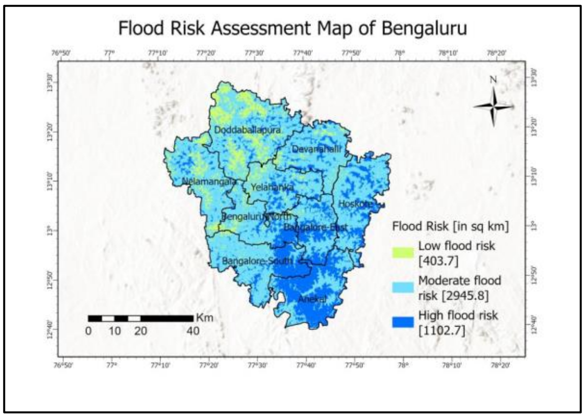

Fig 13 : Map showing Flood Risk Probability in Bengaluru

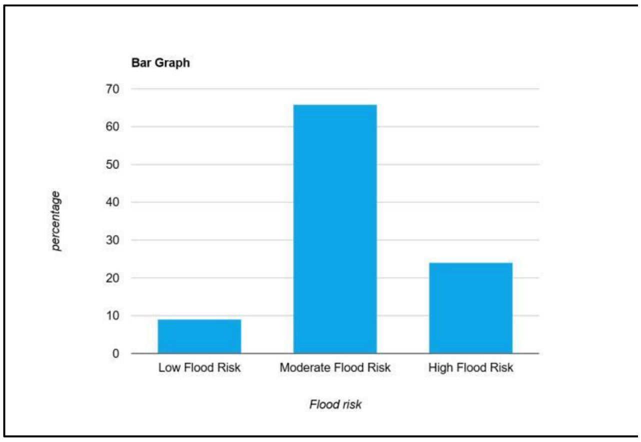

Fig 14 : Bar graph of Flood risk of Bengaluru in %

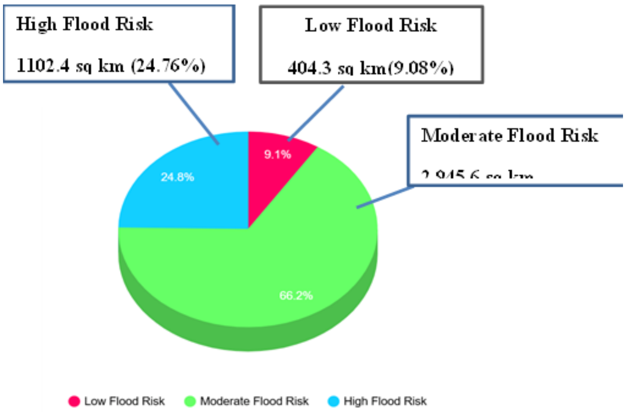

Fig 15 : Pie chart showing flood risk in sq km and percentage of Bengaluru

Mitigation Measures:

- Better Drainage and Stormwater Management: By modernizing and maintaining urban drainage systems, we can make sure they can withstand monsoon-season high rains.
- Early Warning and Communication Systems: By putting in place early warning and real-time flood monitoring systems that combine flood forecasts and meteorological data.
- Enhance River and Stormwater Infrastructure: To avoid overflow and floods, better management of rivers like the Vrishabhavathi, Arkavathi, and Kundalahalli, as well as stormwater drains, is necessary.
- Flood-Resilient Infrastructure Design: This involves implementing flood-proof designs for utilities, roads, and buildings in order to promote flood-resilient infrastructure.
- Cooperation Between Authorities and Partners: To guarantee an integrated approach to flood control, encourage improved cooperation between national, state, and municipal authorities as well as business sector partners.

Conclusion:

Bangalore's high flood risk zones have been successfully identified by the weighted overlay analysis. A thorough evaluation of the city's susceptibility to flooding has been made possible by the integration of several elements, including topography, land use, soil type, drainage density, rainfall intensity, and proximity to highways. The findings show that because of their low-lying topography, large impervious surfaces, and close proximity to water bodies, places like Bangalore East, Bangalore South, Hoskote, Anekal, Doddaballapura, and Nelamangala are more vulnerable to flooding. Strategies for catastrophe management and urban development may benefit greatly from these insights. The city may greatly lessen its susceptibility to floods by giving priority to these high-risk locations for focused interventions, such as enhanced drainage systems, stormwater management, and green infrastructure. Furthermore, by using the study to guide land use planning decisions, future development can steer clear of flood-prone areas and encourage sustainable behaviors.

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