Assignment 2: Report

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26 September 2024

1 Introduction

Flooding is a natural disaster that occurs when an overflow of water inundates land that is typically dry. This phenomenon can result from various factors, including heavy rainfall, rapid snowmelt, river overflow, storm surges, or the failure of infrastructure like dams. Floods can have devastating effects on communities, leading to loss of life, destruction of property, and long-term economic disruptions. They can also cause significant environmental damage, affecting ecosystems and water quality.

Given the increasing frequency and intensity of flooding events due to climate change and urbanization, it is crucial to model these occurrences to understand their potential impacts better. Flood modeling involves the use of mathematical and computational tools to simulate flooding scenarios, helping to predict flood behavior in specific areas. By analyzing different variables such as rainfall patterns, land use, topography, and hydrological responses, flood models provide valuable insights into flood risks. This information is essential for effective flood management strategies, enabling governments and organizations to design appropriate mitigation measures, allocate resources, and implement emergency response plans. In essence, accurate flood modeling not only aids in protecting lives and property but also enhances community resilience against future flooding events.

2 Region of interest

For this assignment, we have chosen the city of Hyderabad as our area of interest. Hyderabad is characterized by a tropical wet and dry climate, which features hot summers, moderate monsoons, and mild winters. The monsoon season, occurring from June to September, plays a critical role in the region's hydrology, as it brings significant rainfall that can lead to flooding, particularly in urbanized areas where impervious surfaces exacerbate runoff. The combination of rapid urbanization, insufficient drainage systems, and heavy rainfall during the monsoon poses a heightened risk of flooding in Hyderabad, making it essential to study and model these events. By understanding the flood dynamics specific to this city, we can better assess potential impacts and develop effective management strategies to mitigate flood risks.

3 Factors Affecting Flooding

Flooding is influenced by a complex interplay of various factors that can be categorized into hydrological, topological, meteorological, and socio-economic factors. Understanding these factors is crucial for effective flood modeling and risk assessment.

3.1 Hydrological Factors

- **Runoff**: Runoff refers to the water flow that occurs when excess rainwater or melted snow flows over the ground. Factors affecting runoff include land cover, soil saturation, and topography. Increased runoff can significantly contribute to flooding, especially in urbanized areas where impervious surfaces prevent water absorption.

- **Groundwater Levels**: High groundwater levels can reduce the soil's capacity to absorb additional rainfall, contributing to surface runoff and increased flood risk.
- **Soil Organic Carbon Content**: This factor affects soil permeability and water retention capacity. Soils rich in organic matter tend to absorb more water, potentially mitigating flood impacts.

3.2 Topological Factors

- **Digital Elevation Model (DEM)**: DEMs provide crucial information on the terrain, helping to identify low-lying areas that are more susceptible to flooding.
- **Land Use/Land Cover (LULC)**: Different land uses, such as urban areas, agricultural lands, and forests, influence how rainfall is absorbed or redirected. Urbanization typically increases impervious surfaces, leading to higher runoff.

3.3 Meteorological Factors

- **Rainfall**: As noted under hydrological factors, rainfall is a primary meteorological factor influencing flooding. Variability in rainfall patterns can significantly impact flood risk.

3.4 Socio-Economic Factors

- **Human Settlement and Built-Up Areas**: The density and distribution of human settlements affect drainage patterns and can exacerbate flooding, especially in areas with inadequate infrastructure.
- **Poverty**: Socio-economic conditions, particularly poverty, play a role in flood vulnerability. Communities with limited resources may lack effective flood management systems and may be less able to recover from flood events.

For this assignment, we have chosen the following specific factors to analyze in relation to flooding in Hyderabad:

- **Hydrological Factors**: Rainfall, Groundwater Levels, Soil Organic Carbon Content
- **Topological Factors**: Digital Elevation Model (DEM), Land Use/Land Cover (LULC).
- **Meteorological Factors**: Rainfall (noted as also under hydrological)
- **Socio-Economic Factors**: Human Settlement and Built-Up Areas, Poverty

4 Hydrological factors

4.1 Runoff quantity

To estimate the runoff associated with flooding in Hyderabad, we utilized the Rational Method, which relates the volume of runoff to the characteristics of rainfall and the land surface. The formula used is:

$$Q = C \cdot I \cdot A$$

where Q represents the peak discharge, C is the runoff coefficient, I is the rainfall intensity, and A is the area under consideration.

We estimated the runoff coefficient C based on the Normalized Difference Vegetation Index (NDVI) values, which provide information about vegetation cover in the area. Areas with high NDVI values reflect substantial vegetation cover, which enhances soil infiltration capabilities and reduces surface runoff. Conversely, low NDVI values indicate less vegetation, leading to increased runoff and a higher risk of flooding. By analyzing NDVI data, we can determine how different land use and vegetation patterns influence hydrological processes in the region.

This approach allows for a more accurate assessment of flood risk based on land cover characteristics, informing effective flood management and mitigation strategies.

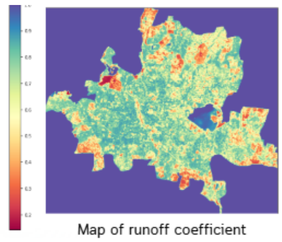


Figure 1: Map of Runoff Coefficient Based on NDVI

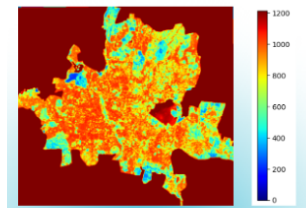


Figure 2: Map of Runoff Values (Q)

4.2 Groundwater Levels

Groundwater levels play a crucial role in flood modeling, as they significantly affect the soil's ability to absorb additional rainfall. The amount of water the soil can take in is directly impacted by existing groundwater levels, influencing both flood severity and duration. Understanding and monitoring groundwater levels helps in predicting areas at higher risk of flooding due to limited infiltration capacity.

When groundwater levels are high, the soil is often near saturation, meaning it cannot absorb much more water. This leads to increased surface runoff, which contributes to more intense and prolonged flooding. Conversely, areas with lower groundwater levels allow for more infiltration, potentially reducing surface runoff and mitigating flood impacts.

For our analysis of groundwater levels across Hyderabad, we followed these steps:

- **Data Collection**: Groundwater level data was collected from various stations, including both telemetric and manual monitoring stations across Hyderabad.
- **Data Visualization**: Groundwater levels at different stations were plotted to visualize spatial distribution across the city.
- **Interpolation Method**: We applied Inverse Distance Weighting (IDW) interpolation to create a continuous groundwater level map for Hyderabad. This helped in identifying spatial variations in groundwater saturation levels.

Findings:

- **Central and Northwestern Regions**: These regions have higher groundwater levels, indicating that the soil is closer to saturation. This implies:
  - Higher surface runoff due to reduced infiltration capacity.
  - Increased flood risk and severity in these areas during heavy rainfall events.

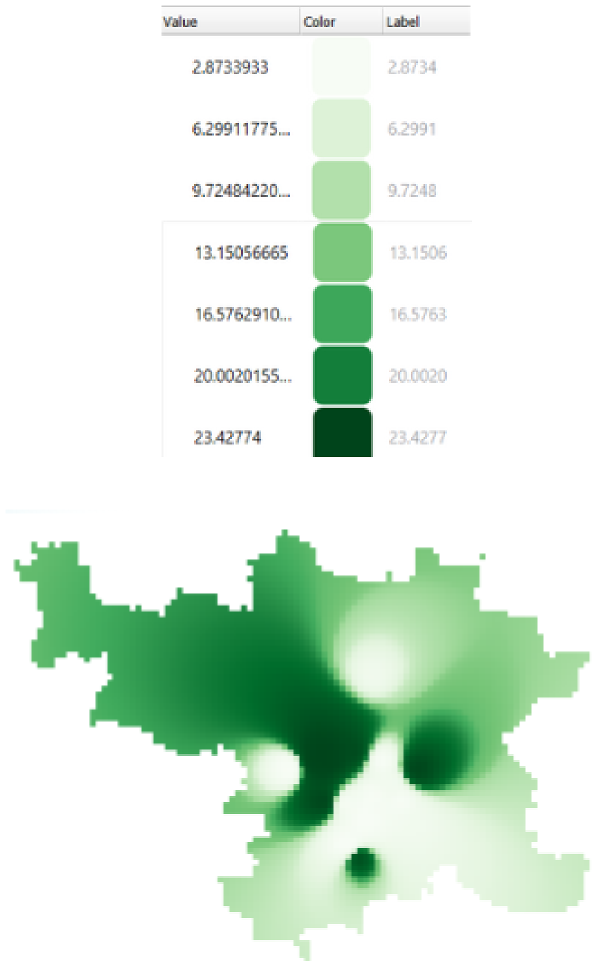


Figure 3: Interpolated map of groundwater levels

4.3 Soil organic carbon content

Soil Organic Carbon Content is a crucial factor in flood risk assessment due to its significant role in soil permeability and water retention. Soils rich in organic carbon generally exhibit higher water absorption capacities, which can mitigate flood impacts by reducing surface runoff. Conversely, areas with lower organic carbon are less able to retain water, leading to faster runoff and higher flood susceptibility, especially in urban settings with impervious surfaces.

In this study, we used data from **OpenLandMap** to evaluate the Soil Organic Carbon Content across Hyderabad. We specifically analyzed the layer depicting **organic carbon stock at 0-10 cm depth (kg/m^2)**, clipping it to match the Hyderabad municipal boundary. This produced a grayscale map where darker areas represent lower organic carbon levels, while lighter areas indicate higher content. This spatial distribution allows us to pinpoint regions more likely to experience rapid water runoff and thus higher flood risk. We then changed the colour palette of the grayscale map to get a better visualized output.

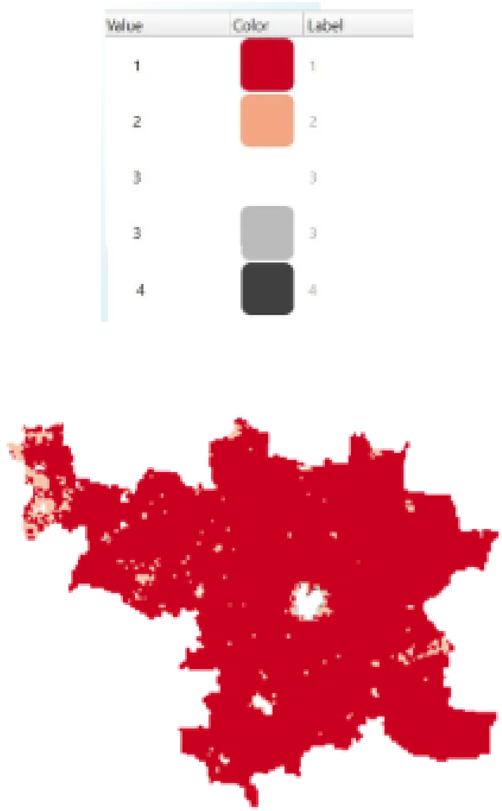


Figure 4: Map of Soil Organic Carbon Content for Hyderabad

In the above output, areas in red colour have lesser organic content and are hence more dry implying they are more flood prone, and areas in black have the most organic content implying they are least flood prone.

Flood-proneness was interpreted by categorizing areas with low organic carbon as more susceptible due to limited water retention.

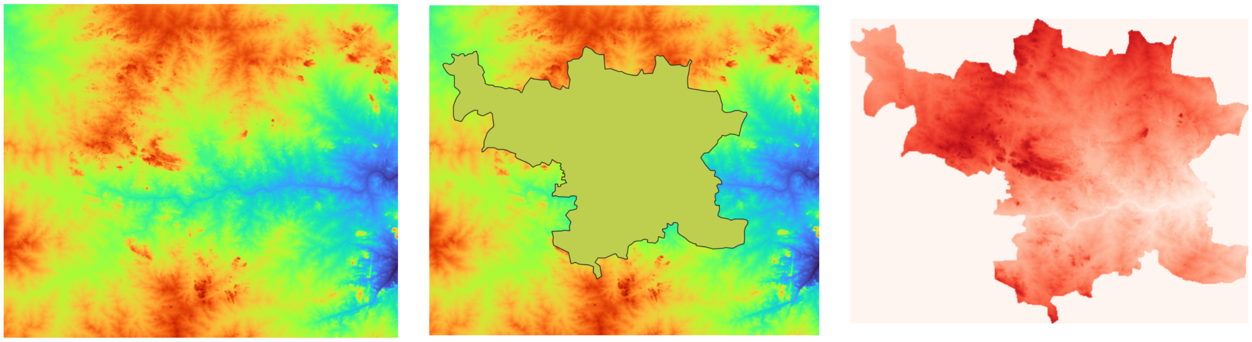
Thus, integrating Soil Organic Carbon Content with other factors like Land Use and Groundwater provides a comprehensive understanding of how soil properties influence flood-proneness. These findings highlight the need to consider soil organic content in urban flood risk assessments.

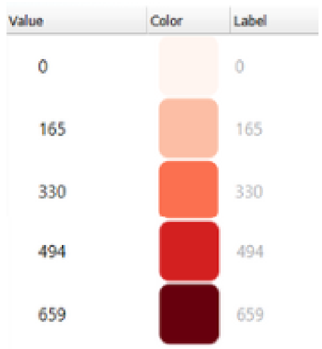
5 Topological Factors

5.1 Digital Elevation Maps

Digital Elevation Models (DEMs) are essential in flood modeling because they offer high-resolution terrain elevation data, which plays a crucial role in understanding water flow dynamics and flood behavior. DEMs help in determining flow paths and drainage patterns, identifying low-lying and flood-prone areas, and calculating slopes and gradients. These factors directly influence how water accumulates and moves across a landscape during a flood event.

In this study, we used a DEM file covering Hyderabad and surrounding regions. We overlaid this DEM with a shapefile of Hyderabad to delineate and clip the DEM specifically for the Hyderabad area. The resulting DEM shows a detailed elevation map of Hyderabad, where darker regions indicate higher elevations and lighter areas represent lower-lying regions more susceptible to flooding. This processed DEM enables a clearer understanding of Hyderabad's topography, aiding in the identification of potential flood-prone zones.





5.2 Land use Land cover- LULC

Land Use and Land Cover (LULC) analysis is crucial in flood modeling, as it provides insight into different land types and their flood susceptibility. For this study, we used Hyderabad's LULC data, categorized into water bodies (included flooded vegation or vegetation near the water bodies),urban areas,agricultural land, barren land and vegetation (in the order of weight assigned regarding flood proneness from 1-5). These categories were reclassified based on their flood proneness, considering factors like impermeability and runoff potential.

The LULC data was processed in the following steps:

1. **Data Collection and Clipping**: We obtained LULC data for Hyderabad from ESRI Sentinel 2 Land Cover Explorer, which was then clipped to the municipal boundary for focused analysis.

2. **Reclassification**: Each land cover type was assigned a flood-proneness score from 1 to 5, where higher values represent greater flood susceptibility. For instance, water bodies and areas near water bodies and urban areas were assigned higher values due to their impermeability and lack of water absorption capacity, while vegetation areas were assigned lower values due to their higher permeability and water retention.

3. **Raster Calculator and Visualization**: After reclassification, we used the raster calculator to apply these scores, generating a raster that highlights flood-prone areas. Darker regions indicate higher flood risk, emphasizing urban and water body-dense areas.

The reclassification weights were supported by research that indicates increased runoff in urban and water-dense areas due to reduced infiltration. Studies like "Estimation of Flood Land Use/Land Cover Mapping by Regional Modelling" (Mousavi, 2023) confirm that LULC types such as urban areas and water bodies heighten flood risk due to runoff and impervious surfaces. By incorporating these weighted values, our LULC analysis helps identify critical flood-prone zones in Hyderabad, supporting targeted flood mitigation efforts.

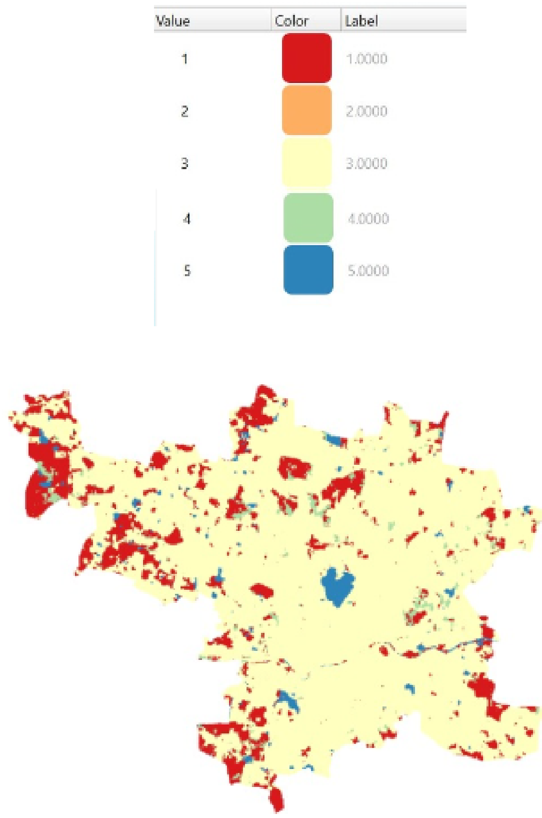


Figure 5: Reclassified LULC map showing flood-prone areas in Hyderabad

In the above output - Blue corresponds to higher flood prone areas. then it lowers to yellow which are lesser prone to flood and red corresponds to least flood prone areas.

6 Meteorological factors

6.1 Rainfall

To accurately assess the rainfall distribution across Hyderabad, we collected rainfall data from various weather stations situated throughout the city. The rainfall data points from these stations were plotted on a map based on their geographic coordinates. This allowed us to visualize the spatial distribution of rainfall across the region.

To better understand and generalize the rainfall patterns across areas without direct measurements, we applied the **Inverse Distance Weighting (IDW) interpolation** method. IDW is a spatial interpolation technique that estimates rainfall values for unmeasured locations based on the values from nearby stations, with closer points given higher weight than farther points. This method provides a smooth, continuous rainfall distribution map, offering insights into spatial rainfall trends.

Steps in Rainfall Data Collection and Analysis:

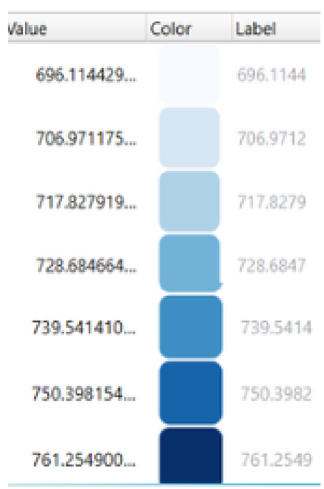
1. **Data Collection**: Rainfall data was obtained from multiple weather stations across Hyderabad, with each station's readings providing localized rainfall information.

2. **Mapping**: Each station was plotted on a geographic map using its coordinates, establishing a visual distribution of rainfall data points.

3. **Interpolation Using IDW**: The IDW method was employed to interpolate rainfall values across unmeasured locations, creating a continuous surface that represents estimated rainfall values citywide.

Findings: From the interpolated rainfall map, we identified distinct regional patterns in rainfall distribution:

- **Central and Northeastern Regions**: These areas consistently exhibit higher rainfall levels throughout the year, indicating they are more prone to substantial precipitation compared to other parts of the city.
- **Spatial Rainfall Variability**: The IDW interpolation highlights differences in rainfall intensity, which is critical for understanding localized flood risks and managing water resources in Hyderabad.



Value	Color	Label
696.114429...		696.1144
706.971175...		706.9712
717.827919...		717.8279
728.684664...		728.6847
739.541410...		739.5414
750.398154...		750.3982
761.254900...		761.2549

7 Socio-economic factors

7.1 Human settlements and built up areas

The Global Human Settlement Layer (GHSL) dataset provides a spatial representation of human development by detailing the distribution, density, and growth of built-up areas globally. For our analysis, we focused on the GHSL data for Hyderabad, which includes information on human settlement density within the city boundaries. The dataset illustrates various levels of urban density, ranging from high-density areas with substantial infrastructural buildup to sparse regions representing undeveloped land or green spaces. In our flood assessment model, this socio-economic layer is crucial because urbanized and densely populated areas are particularly vulnerable to flooding due to the extensive presence of **impermeable surfaces, such as concrete and asphalt**, which inhibit water infiltration and increase surface runoff.

In the clipped Hyderabad GHSL data, we interpreted high-density built-up regions (displayed in darker colors) as areas with intense human activities and infrastructure. These regions are more likely to experience increased runoff and reduced water absorption, exacerbating flood risk, especially during heavy rainfall events. Conversely, darker regions indicate less developed or open areas, which may allow for greater infiltration and subsequently lower flood risk.

To integrate this data into our flood susceptibility model, we classified the GHSL values according to settlement density. High-density areas received a higher weight in flood susceptibility calculations, as these regions are more prone to flooding. The reclassification process used a color ramp ranging from light pink to violet, with the darker shades representing more densely populated or built-up zones.

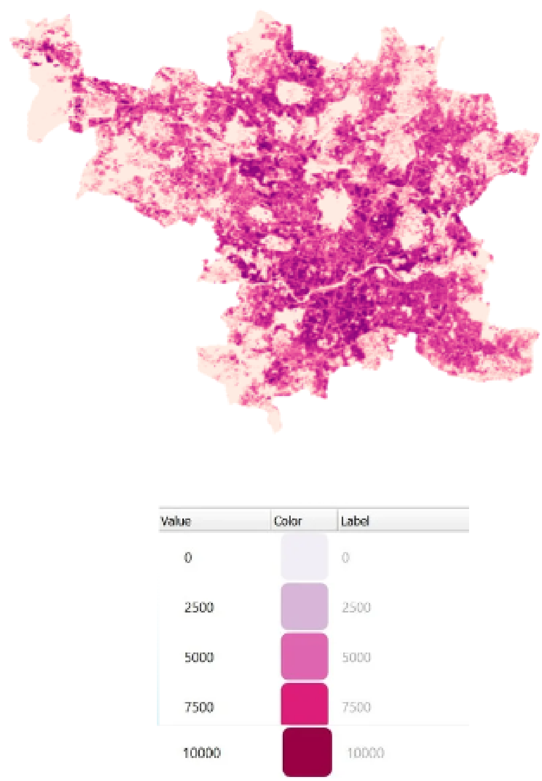


Figure 6: Clipped Hyderabad GHSL map showing human settlement density

In the above output, very light pink indicates less human settlement and it gets darker in colour (darker pink) as increases, with highest human settlement and built up area shown in violet.

This socio-economic factor highlights how urban expansion and settlement density affect flood risks, emphasizing the importance of considering human development in flood management strategies. GHSL data enables city planners and policymakers to identify high-risk zones where flood mitigation measures, like improved drainage systems, may be necessary to safeguard urban infrastructure and reduce vulnerability in densely populated areas.

7.2 Poverty

Poverty was incorporated as a socio-economic factor in flood risk assessment to highlight its indirect impact on flood vulnerability. Although poverty does not directly cause flooding, communities with limited resources face higher risks of severe impacts from flood events. Poorer populations often lack robust infrastructure, insurance coverage, or access to emergency services, which leaves them more vulnerable during floods and extends recovery time.

The poverty data for Hyderabad was sourced from a CSV file provided by the Ministry of Housing and Urban Poverty Alleviation. The data includes the percentage of the population below the poverty line across different regions. We interpolated this data spatially using the **Inverse Distance Weighting (IDW)** method, creating a continuous poverty distribution map. This map visually represents poverty concentration, where darker areas indicate higher poverty levels. By overlaying this map with other flood-prone indicators, we could identify regions with both high flood susceptibility and high poverty, prioritizing these for targeted flood management measures.

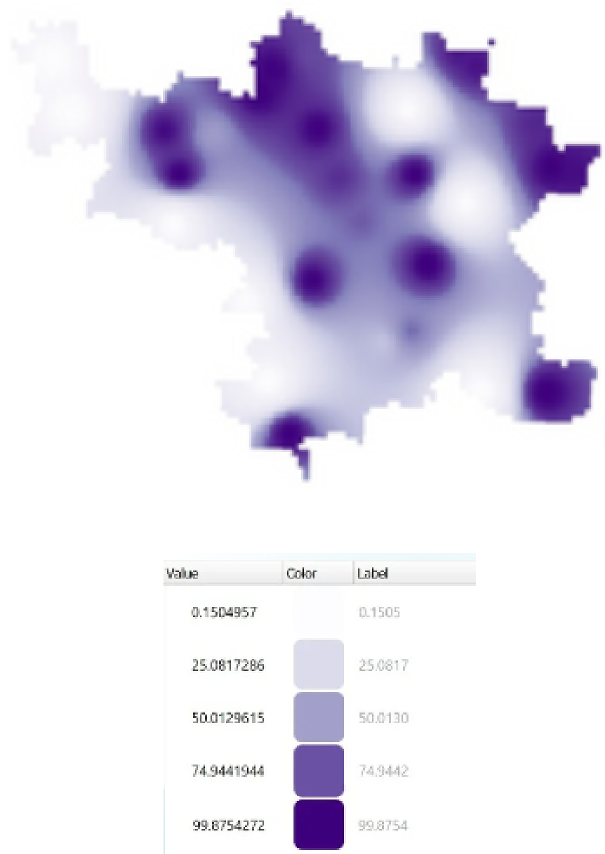


Figure 7: Spatial Distribution of Poverty in Hyderabad, showing higher vulnerability in darker areas

By integrating poverty data, we ensure a comprehensive flood risk model that considers the socio-economic aspects of flood resilience, underscoring the need for socio-economic support in flood-prone, impoverished areas.

8 Results

8.1 Raster calculator

The Raster Calculator tool in QGIS was used to combine the spatial layers of selected flood-related factors, allowing us to create a weighted flood proneness map for Hyderabad. By assigning specific weights to each factor based on its influence on flood susceptibility, we achieved a composite representation of flood risk across the study area.

**Flood Proneness = ("new_rain_idwclipped@1"×0.25) +
("new_gw_idwclipped@1"×0.10)+
("dem_clipped@1"×0.15)+("Poverty clipped@1"×0.05)+
("Raster Soil@1"×0.15)+ ("Red - Raster calculator@1"×0.20)+
("Hyderabad settlement output@1"×0.10)**

Figure 8: Formula for assigning Weights

8.1.1 Settings and Parameters

To ensure consistency and relevance in the spatial output, the following settings were applied:

- **Extent:** The geographical extent of Hyderabad was set with the following boundaries:
  - North (Top boundary): 18.692675002
  - South (Bottom boundary): 15.961112132
  - West (Left boundary): 76.487814944
  - East (Right boundary): 80.618693352

  These boundaries were specified in the Raster Calculator with:
  - **X Min:** West boundary
  - **X Max:** East boundary
  - **Y Min:** South boundary
  - **Y Max:** North boundary
- **Resolution:** Set at 75x100 meters to maintain consistency across all layers.

8.1.2 Formula and Weights

The formula used in the Raster Calculator integrated each factor's layer with a weight reflective of its contribution to flood susceptibility. The formula applied was:

Each factor weight was assigned based on extensive literature analysis:

- **Rainfall (25%):** Rainfall intensity is a primary driver of flood susceptibility, contributing directly to runoff and water accumulation. Several studies prioritize rainfall as a major factor:
  - *Satellite Remote Sensing and GIS-Based Multi-Criteria Analysis for Flood Hazard Mapping* - Francesca Franci.
  - *Flood Hazard Mapping Using Fuzzy Logic, Analytical Hierarchy Process, and Multi-Source Geospatial Datasets* - Saeid Parsian, pg 4.
  - *Incorporating Probabilistic Approach into Local Multi-Criteria Decision Analysis for Flood Susceptibility Assessment* - Zhongqian Tang.
  - *Disaggregation of the Copernicus Land Use/Land Cover (LULC) and Population Density Data to Fit Mesoscale Flood Risk Assessment Requirements in Partially Urbanized Catchments in Croatia* - Bojana Horvat.
  - *Flood Vulnerability Assessment Using an Integrated Approach of Multi-Criteria Decision-Making Model and Geospatial Techniques* - K. S. Vignesh, pg 770.
- **DEM (Elevation) (15%):** Elevation influences flood pathways, with lower elevations being more susceptible to water accumulation. Relevant studies include:

- *Satellite Remote Sensing and GIS-Based Multi-Criteria Analysis for Flood Hazard Mapping* - Francesca Franci.
- *Assessment of Flood Hazard Areas at a Regional Scale Using an Index-Based Approach and Analytical Hierarchy Process: Application in Rhodope–Evros Region, Greece* - Nerantzis Kazakis.
- *Estimation of Flood Land Use/Land Cover Mapping by Regional Modelling of Flood Hazard at Sub-Basin Level Case Study: Marand Basin* - Seid Mohamad Mousavi.

- **LULC (20%):** Land Use/Land Cover impacts flood susceptibility as urbanized areas increase runoff. Supporting studies:
  - *Disaggregation of the Copernicus Land Use/Land Cover (LULC) and Population Density Data to Fit Mesoscale Flood Risk Assessment Requirements in Partially Urbanized Catchments in Croatia* - Bojana Horvat.
  - *Satellite Remote Sensing and GIS-Based Multi-Criteria Analysis for Flood Hazard Mapping* - Francesca Franci.
  - *Estimation of Flood Land Use/Land Cover Mapping by Regional Modelling of Flood Hazard at Sub-Basin Level Case Study: Marand Basin* - Seid Mohamad Mousavi.
- **Groundwater (10%):** Groundwater levels affect soil saturation and can exacerbate flooding in areas with high water tables. Referenced study:
  - *Satellite Remote Sensing and GIS-Based Multi-Criteria Analysis for Flood Hazard Mapping* - Francesca Franci.
- **Soil Organic Carbon Content (15%):** Soil type and organic content influence water absorption, where higher organic content improves retention. Relevant studies:
  - *Incorporating Probabilistic Approach into Local Multi-Criteria Decision Analysis for Flood Susceptibility Assessment* - Zhongqian Tang.
  - *Assessment of Flood Hazard Areas at a Regional Scale Using an Index-Based Approach and Analytical Hierarchy Process: Application in Rhodope–Evros Region, Greece* - Nerantzis Kazakis.
  - *Satellite Remote Sensing and GIS-Based Multi-Criteria Analysis for Flood Hazard Mapping* - Francesca Franci.
  - *Estimation of Flood Land Use/Land Cover Mapping by Regional Modelling of Flood Hazard at Sub-Basin Level Case Study: Marand Basin* - Seid Mohamad Mousavi.
- **Human Settlement and Built-Up Area (10%):** Urban areas increase runoff due to impervious surfaces, raising flood risk. Supporting studies:
  - *Assessment of Flood Hazard Areas at a Regional Scale Using an Index-Based Approach and Analytical Hierarchy Process: Application in Rhodope–Evros Region, Greece* - Nerantzis Kazakis.
  - *Disaggregation of the Copernicus Land Use/Land Cover (LULC) and Population Density Data to Fit Mesoscale Flood Risk Assessment Requirements in Partially Urbanized Catchments in Croatia* - Bojana Horvat.
- **Poverty (5%):** Though it doesn't directly affect flood susceptibility, poverty influences vulnerability as impoverished communities often lack flood mitigation resources. Referenced study:
  - *Predicting Flood Insurance Claims with Hydrologic and Socioeconomic Demographics via Machine Learning: Exploring the Roles of Topography, Minority Populations, and Political Dissimilarity* - James Knighton.
  - *Disaggregation of the Copernicus Land Use/Land Cover (LULC) and Population Density Data to Fit Mesoscale Flood Risk Assessment Requirements in Partially Urbanized Catchments in Croatia* - Bojana Horvat.

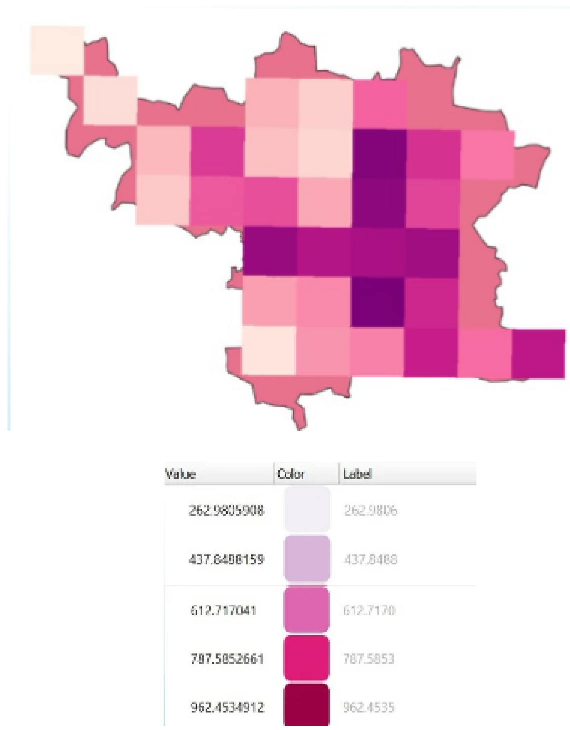


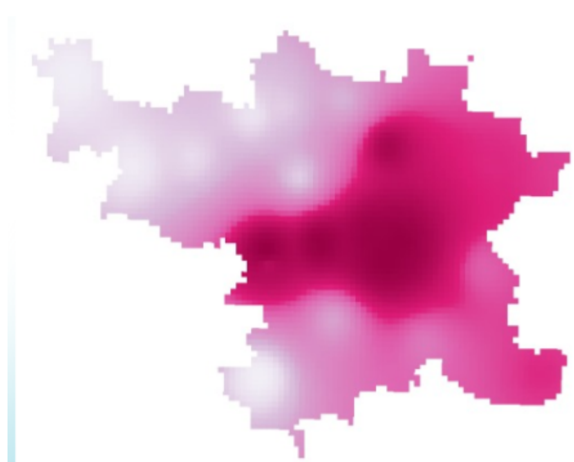
Figure 9: Output of the Raster calculator overlayed on hyderabad shapefile

The above output shows the areas which are more flood prone in dark colours (highest flood prone area shown in purple).Lighter colours indicate that the area is less flood prone.

By combining these weighted layers, we generated a flood-proneness map that offers insights into the areas at highest risk in Hyderabad. The weighting choices reflect both environmental and socio-economic factors, providing a holistic perspective on flood susceptibility.

8.2 Interpolation and final output

After conducting initial raster calculations, we refined the spatial representation of values across Hyderabad by applying the Inverse Distance Weighting (IDW) interpolation method. This method allowed us to create a continuous, smoothly varying surface that estimates values over unsampled areas based on surrounding data points. To ensure coherence and accuracy, we adjusted the resolution to align with other spatial data layers and optimized the raster cell size, resulting in a more detailed and visually accurate map.



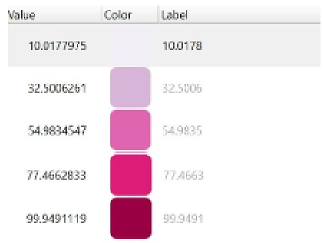


Figure 10: Interpolated map of final values

9 Conclusion

The interpolated map reveals that the central and northeastern regions of Hyderabad are particularly vulnerable to flooding. These areas consistently show higher values, indicating factors such as reduced infiltration capacity or topographical characteristics that increase flood risk during heavy rainfall. This pattern aligns with the individual factor maps—such as rainfall intensity, land cover, and soil composition—which also highlight these regions as areas of concern. The consistency of results across multiple factors strengthens the reliability of our model, suggesting that central and northeastern Hyderabad should be prioritized for flood risk mitigation and urban planning. These findings provide valuable spatial insights for decision-makers, supporting targeted resource allocation and preventative measures in flood-prone areas.

References

[1] Francesca Franci, "Satellite remote sensing and GIS-based multi-criteria analysis for flood hazard mapping." *Geomatics, Natural Hazards and Risk*, 2019.

[2] Saeid Parsian, "Flood Hazard Mapping Using Fuzzy Logic, Analytical Hierarchy Process, and Multi-Source Geospatial Datasets," *Environmental Earth Sciences*, 2019, p. 4.

[3] Zhongqian Tang, "Incorporating probabilistic approach into local multi-criteria decision analysis for flood susceptibility assessment," *Journal of Flood Risk Management*, 2020.

[4] Bojana Horvat, "Disaggregation of the Copernicus Land Use/Land Cover (LULC) and Population Density Data to Fit Mesoscale Flood Risk Assessment Requirements in Partially Urbanized Catchments in Croatia," 2018.

[5] K. S. Vignesh, "Flood vulnerability assessment using an integrated approach of multi-criteria decision-making model and geospatial techniques," *Environmental Monitoring and Assessment*, New Research Paper 2, 2022, p. 770.

[6] Nerantzis Kazakis, "Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope–Evros region, Greece," 2017.

[7] Seid Mohamad Mousavi, "Estimation of flood land use/land cover mapping by regional modelling of flood hazard at sub-basin level case study: Marand basin," *Geomatics, Natural Hazards and Risk*, 2019.

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[9] S. H. Pourali, "Topography Wetness Index Application in Flood-Risk-Based Land Use Planning," *Applied Spatial Analysis*, 2014.