International Journal for Research Publication and Seminar

ISSN: 2278-6848 | Vol. 16 | Issue 1 | Jan-Mar 2025 | Peer Reviewed & Refereed Refereed

Special Edition : SPARK 2025 : XXI National Conference on Emerging Technology Trends in Engineering & Project Competition

# Urban Flood Studies and Rainfall Trend Analysis: A Case Study of the Pili River, Nagpur

**Jayesh Churhe, Atharv Godshelwar, Roji Gondane, Nandesh Nimje, Mushfiya Aeman,**
**Dr. N. R. Dhamge**
jayeshchurhe1308@gmail.com, shubhgodshelwar9090@gmail.com, rojigondane30@gmail.com, nandeshnimje@gmail.com, mushfiya.sheikh53@gmail.com
9552670608, 7719805841, 9588469280, 7038633417, 8767420580
**Department of Civil Engineering, KDKCE, Nagpur**
**Department of Civil Engineering, Professor KDKCE, Nagpur**

## Abstract

Urban flooding is becoming a stand-alone challenge throughout the globe, particularly in fast urbanizing regions with low drainage infrastructure. This study, therefore, localizes itself to the urban flooding along the Pili River, Nagpur, India, to identify flood-prone areas and analyse the factors contributing to flood events. The assessment is derived from 25 years of rainfall data, and hydrological survey assessments and discharge estimations to quantify flooding in the region. The research identifies that urbanization, encroachment, and inefficient waste management enhance the risk of flooding. Various recommendations are proposed to improve flood resilience by upgrading flood infrastructures, sustainable planning, and enhanced flood management practice.

## Introduction

Floods are one of the most destructive types of natural disasters that affect lives, infrastructure, and economies. In urban environments, specifically defined by poor drainage and high surface runoff, flooding has become more likely to occur because of all the processes of rapid urbanization going on. For this reason, it is different from riverine flooding because urban flooding is more due to local elements such as surfaces that do not absorb water, poor stormwater management, and unruly urban growth. Nagpur, in Maharashtra State, India, witnesses urban flooding because of inadequate drainage infrastructure and heavy monsoonal rainfall. The Pili River crosses the north part of the city, acting as a key drainage channel, but suffers the problem of pollution, encroachment, and silt. During the peak rainy season, the river overflows and inundates the vicinity, and thus, properties and lives are grievously destroyed. This study tries to identify the flood-prone areas along the Pili River and analyze rainfall and hydrological data for practical approaches to mitigate floods. Figures 1 and 2 show floodwater from the Pili River on July 21, 2024, flowing onto the nearby roads and into people's homes.

Fig.1: Flood at Pili River

Fig.2: Floodwater entering people's homes

**Literature Review**

Urban flooding can be attributed to climate change, heightened rainfall intensity, and poor drainage infrastructure. Various studies examined numerous flood prediction and mapping techniques, inclusive of modern hydrological models and remote sensing applications. Advanced image processing techniques, like segmentation, achieve high precision in flood delineation with fewer computational resources.

**Hydrodynamic Simulation of Pili River for Riverbed Development Using HEC-RAS.**

Authors' Name: Siddhant Dash, Chetan Topre, Ritesh Vijay, and Rajesh Gupta.

Year of Publication: 2016.

Summary Review: The hydrodynamic modeling of the Pili River, located in Nagpur, Maharashtra, India, attempts to deal with the risk of floods due to the accumulation of people in and along the rivers as witnessed in urban settings. As the city of Nagpur is advancing to a smart city, most rivers have proved not enough in their geometric shape to withstand peak runoff arising from sustained rainfall, thus leading to spillage of water in the basin, the flow channel, or both. In this case scenario, flood risk realization, HEC-RAS, and ArcGIS have all been integrated to model scenarios of flood with flood return periods of 5, 10, 25, 50, and 100 years examined. It was found that the river system, after the operation of levee point construction and dredging the riverbed to the depth of 0.5 meters, was able to carry more flood flows, thus decreasing the chances of overtopping at important distances on the critical chainages. The study pointed out the fact that it is essential to carry out appropriate measures of river training and define the boundaries of riverbanks to avoid flooding in the case of storms. This work adds to existing knowledge and serves an important area of river management in a city, highlighting that proper infrastructure planning should go hand in hand with economic and social development.

**Flood Susceptibility Analysis Using Freely Available Data, GIS, And Frequency Ratio Model for Nagpur, India.**

Authors: Gaurkhede, N. T. Adane, V. S.

Year of Publication: 2022.

Summary Review: Gaurkhede and Adane's study assesses flood susceptibility in Nagpur, India, using GIS and a frequency ratio (FR) model, addressing data scarcity in developing regions. They analyzed ten flood-influencing parameters, including runoff, lithology, and rainfall, using freely available remote sensing data. The FR model, applied to historical flood data, identified surface runoff (FR 4.30) as the most significant factor, followed by lithology and landforms. The model achieved 80.90% accuracy and 81.58% validation, demonstrating its effectiveness. The research underscores the importance of flood susceptibility maps for urban planning, particularly in cities like Nagpur with poor drainage. It offers a cost-effective approach for resource-limited cities to assess flood risks. The authors suggest integrating the FR model with other methods like logistic regression or artificial neural networks to enhance accuracy. They also recommend using the model to design Sustainable Urban Drainage Systems (SuDS), helping manage Nagpur's pre-monsoon droughts and monsoon floods. This study provides a valuable tool for flood mitigation and sustainable urban development.

**Statistical Analysis of Rainfall Data: A Case Study of Georgetown, Guyana.**

Authors: Shanomae Oneka Eastman, Basheer Khan.

Year of Publication: 2022.

Summary Review: The study presents a statistical analysis of rainfall data from Georgetown, Guyana, covering 30 years to support water resource planning and engineering design. The analysis reveals an average annual rainfall of 2339.3 mm, with a bimodal distribution peaking in May, June, and July. Various probabilistic methods, including the Chegodayev technique, were employed to assess maximum rainfall, with the Chegodayev method providing the best fit for annual data. The study highlights significant variability in rainfall patterns, which can impact agriculture and infrastructure. Descriptive statistics indicate a skewness of 1.3, suggesting a rightward asymmetry in the data, while kurtosis values indicate a mesokurtic distribution. The findings emphasize the need for effective water management strategies and infrastructure design to mitigate the effects of erratic rainfall patterns on urban and agricultural systems. Overall, the analysis serves as a valuable resource for urban engineers and farmers in Georgetown.

**Flood Study of Wainganga River in Maharashtra Using GIS & Remote Sensing Techniques**

Author Name: Ravindra Bhagat, Devendra Bisen

Year of Publication: January 2013

The context of the research is the flood analysis of the Wainganga River in Maharashtra with the aim of identifying the flood-prone areas by using GIS and remote sensing technologies. Ravindra Bhagat and Devendra Bisen explain the fact that climatic changes lead to higher levels of flooding that in turn affect lives, properties, and the economy. In the research, the vulnerability areas are defined using geographical information about the rainfall data, land use, soil types, and drainage density of this basin, thus indicating that the Wainganga basin floods very frequently, every 5 to 7 years. Some of these are; the synthesis of various layers of data culminating in a flood impact map which is useful in the management of the rivers and as well as mitigating the effect of floods. The study proves that GIS is crucial in analyzing flood patterns and aid in the right planning and response to floods.

**Flood Detection in Urban Areas Using Satellite Imagery and Machine Learning**

Authors: Ahad Hasan Tanim, Callum Blake McRae, Hassan Tavakol-Davani, and Erfan Goharian

Year of Publication: 1 April 2021

The study focused on enhancing flood detection in urban areas using satellite imagery and machine learning techniques. The research utilized Sentinel-1 satellite data to identify inundation extents during flood events, specifically targeting the urban landscape of San Diego, California. Various machine learning models, including Random Forest, Support Vector Machine, and Maximum Likelihood Classifier, were employed to classify water and non-water pixels based on backscattering intensity. The study highlighted the effectiveness of an unsupervised classification method, which achieved high precision (0.85) and accuracy (0.87) in detecting flooded areas. The authors emphasized the importance of accurate flood mapping for improving transportation safety and infrastructure planning in flood-prone regions. The research was funded by the Office of the Assistant Secretary for Research and Technology, Department of Transportation, and all authors contributed to the analysis, writing, and project administration. The findings underscore the potential of integrating satellite data with machine learning to enhance urban flood management and response strategies.

**Study Area and Data**

Nagpur is located in the geographical center of India, with an elevation of 310 m above sea level, spanning an area of 217.56 km², with a recorded population of 2.549 million as per the 2011 census. The city receives an average annual rainfall of 1242 mm, has a daily water supply of 700 million liters, and produces an average of 550 million liters of sewage daily. Nagpur is divided into zones north, central, and south, each defined by the river drainage of Pili, Nag, and Pora, respectively, and is characterized by both natural and artificial lakes. Specifically, the Pili River is about 18 km long; it flows to the east through the northern part of Nagpur after originating from Gorewada Lake in the northwestern part of the city and merging into the Nag and Kanhan rivers.1 For this study, the focus is on a 5 km stretch downstream from Gorewada Lake in the Pili River catchment. The river is joined by three separate drains, which empty into it at 2.1 km, 2.4 km, and 3.9 km, respectively. The areas of interest in this study comprise four sub-watersheds, namely the Gorewada catchment and the three drainage areas contributing to the Pili River.

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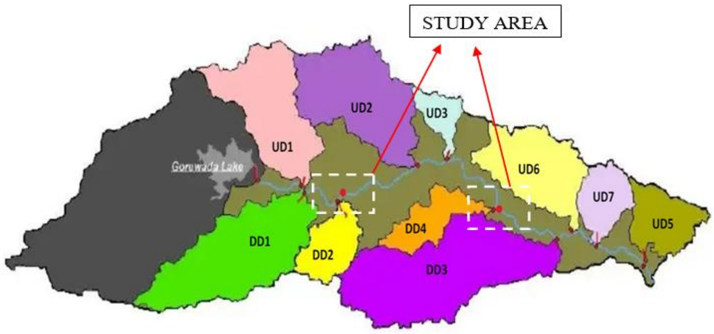



Fig.3**:** Catchment of Pili River and Study Area

**Data Collection**

**Rainfall Data:** From the Indian Meteorological Department, the rainfall records for the past 25 years (2000–2024) have been collected for analysis to find monthly rainfall patterns along with extreme rainfall events.

**Discharge Data:** The data has been collected from the Irrigation Department (Hydrology Division) in Nagpur.

**Field Surveys:** Field surveys were conducted at three sites (Yogi Arvind Nagar, Vanjara MIDC, and Zinga Bai Takli) to study the infrastructure, encroachments, and other water levels.

**Analysis Techniques**

**Rainfall Analysis:** Statistical tools were used to identify the rainfall trends, average optimal monthly rainfall, and extreme events. The mapping of flood-prone areas was done based on field observations and rainfall data to delineate vulnerable zones.

**Hydrological Analysis:** Cross-sectional measurements and flow calculations were used to ascertain the carrying capacity of the river and flag the overflow risks. The rational method was used to estimate peak discharge and assess how the river could accept runoff during extreme rainfall.

**Urban Flood at Pili River**

Urban flooding is a growing global challenge resulting from excessive rainfall runoff in densely populated areas, overpowering drainage systems. Contributing factors include expanded impervious surfaces (such as pavement and buildings), insufficient drainage infrastructure, and the creeping spread of development into natural floodplains. More frequent and intense rainfall events, which were worsened by climate change, throw more and more debris in the way. Urban floods develop suddenly, leading to extensive economic disruption and imminent danger to human life, unlike rural flooding. The property damage is only one part of the problem; it also affects vital infrastructure, transportation, and public health through the transmission of waterborne diseases. Integrated urban flood management requires co-designed strategies, from better drainage engineering, through green infrastructure application, to strict land use planning. Additionally, early warning systems and community preparedness can lessen the impact of these more frequent occurrences.

**Rainfall Trends Analysis**

The Rainfall statistics of Pili River at Nagpur show several deviations from the maximum to the minimum in normal values, which range from about 16 mm and 0.1 mm, respectively, within a span of 25 years from 2000 to 2024. Maximum actual rainfall by year has weak to strong variability, reaching a maximum of 167.8 mm in 2000 and 124.9 mm in 2014; the maximum actual rainfall is lower, nearly 49.49 mm in 2012 and 54.7 mm in 2022. Under the number of rainy days, they dipped and crested a few times, generally corresponding to rainfall status.

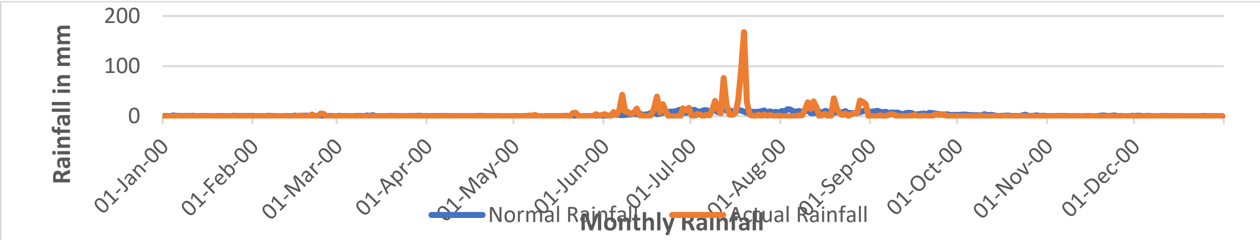



Fig. 4: Monthly rainfall for the year 2000

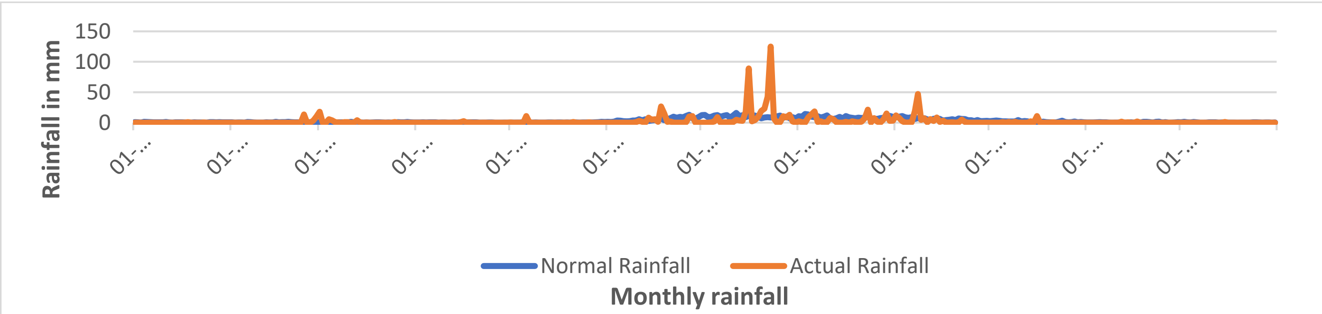



Fig.5: Monthly rainfall of the year 2014

For instance, there were 71 rainy days in 2000, 53 rainy days in 2024, and as many as 87 days in 2022. Average monthly rainfall from June through October is normally highly variable. It has been observed that the advantage of rainfall in July, and this goes as high as 16.99 mm in 2000 or as low as 21.4 mm in 2022. Extensions like August and September bring substantial rainfall, while lower average rain is observed in October. The maximum monthly precipitation occurrence persists in July- August at the very high end of the limits with a maximum of 167.8 mm for July 2000, whereas August 2022 recorded an all-high 96.7 mm. Whereas monthly minimum values have been stable due to low concentration, the range is often 0.01 and 1.34 mm applied as dry periods. The year 2022 both exemplified the maximums and has proved to be highly variable by illustrating years with superior rainfall and days.

**Estimation of flood by Rational Method**

The Rational method is a widely used technique for estimating peak discharge in small drainage areas, particularly in urban settings. Its core principle is that peak runoff is directly proportional to rainfall intensity, drainage area, and a runoff coefficient. The fundamental formula is:

$Q = 10 \times CiA$

Where,

Q: Peak discharge ($m^3/s$)

C: Runoff coefficient (dimensionless), representing the fraction of rainfall that becomes runoff

i: Rainfall intensity (mm/h or in/h), based on the design storm duration and return period

A: Drainage area (hectares or acres)

The Rational Formula is attributed to an Irish engineer, Thomas James Mulvaney, who introduced it in 1851. Mulvaney developed this method to address challenges in estimating peak runoff during storms for designing drainage systems and flood control measures. This method is most accurate for areas with relatively uniform land cover and slopes, and it's typically applied to catchments smaller than approximately 200 acres. A key assumption is that the peak flow occurs when the entire drainage area contributes runoff, requiring the rainfall duration to be equal to or greater than the time of concentration. The runoff coefficient (C) reflects the proportion of rainfall that becomes runoff, varying based on surface type and land use. Rainfall intensity (i) is determined from intensity-duration-frequency (IDF) curves, corresponding to the desired design storm. While simple and practical, the Rational method has limitations, including its inability to generate a complete hydrograph and its reduced accuracy in complex watersheds.

To estimate the actual discharge of the Pili River, we studied the research paper "Hydrodynamic Simulation of Pili River for Riverbed Development Using HEC-RAS."

$$Q = 10 \times C \times i \times A$$

$$= 10 \times 0.7 \times 74.9 \times 337.29$$

$\boldsymbol{Q} = \mathbf{49.122\ m^3/sec}$

The actual discharge of the Pili River is estimated as **49.122 m$^3$/sec.**

Also, theoretical discharge has been estimated by using Manning's Formula,

$$Q = \frac{Ax\, R^{\frac{2}{3}} x S^{\frac{1}{2}}}{N}$$

Where, Q is the discharge, A is the Cross-sectional area of Pili River, N is Manning's coefficient, R is Hydraulic radius, and S is the bed slope.

$$Q = \frac{Ax\, R^{\frac{2}{3}} x S^{\frac{1}{2}}}{N}$$

$$49.122 = \frac{18}{0.018} \times \left(\frac{18}{13}\right)^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

$$\boldsymbol{S} = \mathbf{1.563x10^{-3}} = \frac{\mathbf{1}}{\mathbf{640}}$$

$$Q = \frac{18}{0.018} \times \left(\frac{18}{13}\right)^{\frac{2}{3}} \times \left(\frac{1}{640}\right)^{\frac{1}{2}}$$

$\boldsymbol{Q} = \mathbf{49.11\ m^3/sec}$

The theoretical discharge of the Pili River is estimated as **49.11 m$^3$/sec.**

After comparing the actual discharge with the theoretical discharge, it has been observed that both discharges are nearly similar.

**Survey**

The survey was conducted in September 2024 for the urban flood study in the nearby Pili River, Nagpur, to understand the flood-prone areas, the hydrological parameters, and the impact of urbanization on flooding. The survey was conducted on three sites: 1) Yashodhara Nagar, Nagpur; 2) Vanjara MIDC; and 3) Zinga Bai Takli, which are shown in Figure 6 below.

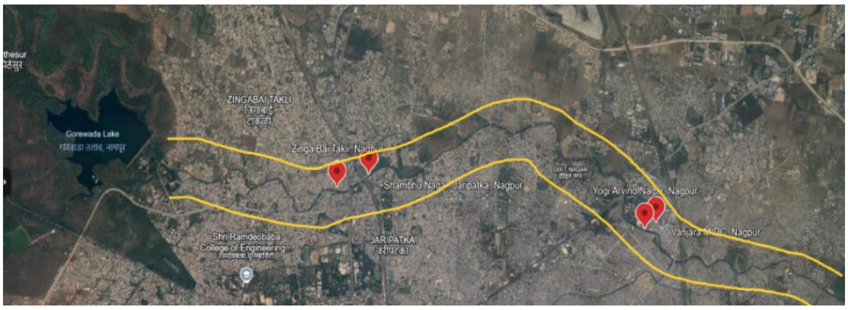


Fig. 6: Survey locations for Pili River

**Location 1:** Yashodhara Nagar, Nagpur.

**Date**: 01/09/2024

**Coordinates:** Lat. 21.184271 Long. 79.128393

**Time:** 12:18 pm


Fig. 7: Survey at Pili River, Yogi Arvind Nagar, Nagpur

Fig: 8: Survey at Yashodhara Nagar, Nagpur

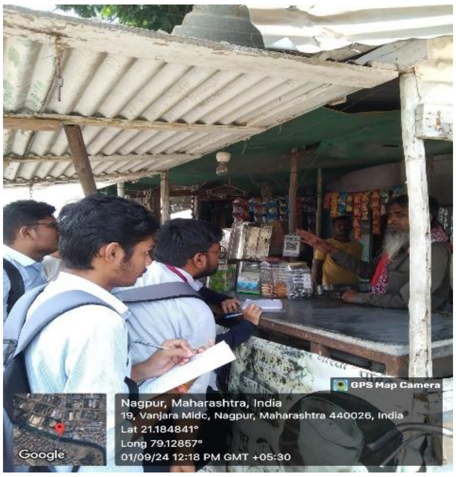
Yashodhara Nagar, Nagpur, it has been observed that significant urban encroachments and inadequate drainage infrastructure. The area, being a densely populated residential zone, suffers from frequent waterlogging due to poor stormwater management. Local people say that during the survey, floods occur up to 30cm above ground level. The flood area extends up to 1.5km if the rainfall exceeds 2 hours.

**Location 2:** Vanjara MIDC, Nagpur.

**Coordinate:** Lat. 21.184841, Long. 79.12857

**Time**: 12:31 pm

(a)




(b)

Fig. 9(a) & (b): Survey at Pili River, 19, Vanjara MIDC, Nagpur

It has been observed that Vanjara MIDC, Nagpur, is an industrial zone with high runoff during heavy rainfall. The survey identified storm drains that were insufficient to handle peak discharge. Local people say that in July 2024, the water level was up to 50 cm above ground level. The flood area extends up to 80-100 m.

**Location 3:** Adarsh Nagar, Zinga Bai Takli, Nagpur
**Coordinate:** Lat. 21.190178, Long. 79.076777
**Date:** 2:14 pm


(a)


(b)

Fig. 10(a)&(b): Survey at Pili River, Zinga Bai Takli, Nagpur

It has been observed that Zinga Bai Takli is a semi-urban area with mixed residential and commercial development. This location was particularly prone to flooding due to restricted flow capacity. Local people say that in August 2005, the water level was up to 100-200 cm above the ground level. The flood area extends up to 20 m. Notice is sent by the Municipal Corporation Nagpur when the flood occurred in the area for compensation allotment.

**Mitigation Measures**

Based on the study, the following mitigation measures are proposed:

**Flood Barriers and Retention Basins**

**Constructing Flood Barriers and Parapet walls:** Flood barriers and Parapet walls are built along the riverbanks to prevent the flooding of residential and commercial neighbourhoods.

**Retention and Detention Basins:** The development of retention basins helps reduce peak flood discharges after heavy rains.

**Reinforced Riverbanks:** Stabilize riverbanks with concrete linings, vegetation, or geotextiles to prevent erosion.

Fig. 11: Flood Barriers

**Levee Construction and Strengthening**

**Designing High-Strength Levees:** Construction of engineered levees with appropriate height and structural integrity to withstand extreme flood events.

**Periodic Inspections and Reinforcements:** Subjects' routine evaluation of existing levees to determine weak points and further reinforce those levees with advanced materials.

**Community-based Flood Protection:** Providing small-scale flood activities, such as sandbag walls, to protect specific properties from high-risk zones.

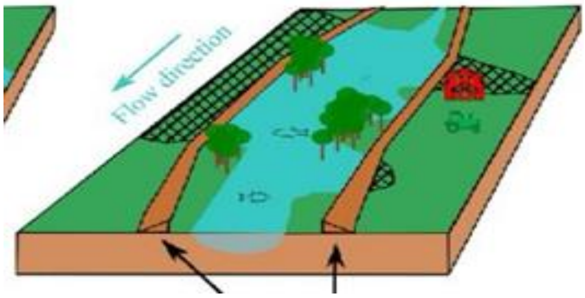


Fig. 12: Levee Construction

**Enhancement of Drainage Infrastructure**

**Enhancement of Drainage Infrastructure Regular Maintenance:** Periodical cleaning and desilting of drainage channels to prevent further clogging due to found sediment and solid waste over a long period.

**Capacity Expansion:** Improvement of drainage systems to allow for increased runoff from urban development and extreme rainfall events.

**Permeable Surfaces:** Also, through encouraging the use of porous pavements and green infrastructure in their designs, allowing natural infiltration of water into the ground, and, by doing so, reducing surface runoff.

**Advanced Early Warning System**

The AEWS, which uses 25 years of daily rain data, can accurately predict flood risks. It uses ML models, such as LSTMs and ARIMA, that analyze the behavior of rain and identify extreme weather events. It combines real-time data from IoT-based weather sensors and inputs predictions to U-Net and Res-Net models to segment flood chance and assess risk. If the thresholds are crossed, mobile alerts regarding the situation are automatically sent to appropriate authorities and residents via apps and SMS.

**Surface Elevation Adjustments and Terrain Modification**

**Raising Road Levels:** road improvement in flood-prone areas that serve to assist in reducing waterlogging and the same access during floods.

**Regarding Urban Landscapes:** Regulating land contours that create a gentle slope, allowing easy passage of water.

**Flood-Resistant Infrastructure Design:** This means providing lighting foundations and floodproofing measures in hospitals, power stations, and emergency shelters.

**Conclusion**

The study of urban flooding within the Pili River in Nagpur reveals increasing vulnerability due to several factors, such as inadequate drainage systems, rapid urban development, and encroachment. An analysis of rainfall data for 25 years confirms significant variations in rainfall trends with more frequent extreme events. The estimation of runoff by using the Rational Method and Manning's Formula reveals that the Pili River lacks sufficient capacity to deal with maximum monsoon runoff, leading to recurrent flooding. The field survey also reveals that areas of Yashodhara Nagar and Vanjara MIDC experience frequent flooding because of poor drainage infrastructure and impervious land surfaces.

To mitigate urban flooding, the study recommends several measures that include better drainage infrastructure, constructing flood barriers and parapet walls, reinforced riverbanks, and early warning systems. The implementation of sustainable urban planning methods using both green infrastructure and permeable surfaces will result in a substantial reduction of runoff. The essential components of flood mitigation include community-led preparedness and scheduled facility upkeep programs. New flood mitigation approaches must be developed for Nagpur because this research confirms infrastructure and lives require urgent protection.

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