

URBAN FLOOD DYNAMICS IN KOLKATA: EVALUATING FLOOD MAGNITUDE AND INTENSITY WITHIN THE KMC AREA

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Abstract

Urban flooding has ended up a major challenge in lots of main cities around the world and Kolkata isn't an exception. The metropolis's particular topography, coupled with rapid urbanization and negative drainage makes it especially liable to flooding. The objective of this study is to evaluate the importance and severity of city flooding in Kolkata with special attention to the jurisdiction of the Municipal Corporation. The predominant objective of this study is to better recognize flood dynamics by implementing advanced flood modelling. This study further did a comparative analysis of exclusive areas of the town. This study further offers a strategy for implementing powerful flood management by figuring out the main reasons for urban flooding. The approach uses hydraulic and GIS-based models to map flood situations below extraordinary eventualities. Data resources consist of ancient rainfall data as well as maps, and data on municipal drainage structures. The essential findings of the flood models screen great variation in the magnitude and intensity of flooding at special places in Kolkata. Research reveals areas of excessive flood threat. This also identifies crucial elements contributing to this risk which consists of insufficient drainage as well as excessive population density and low-lying geographical features. On the other hand, comparative evaluation performed on different flood control structures suggests exceptional efficiencies. Insights from this study are critical for city planners and makers of the policy. Targeted and effective flood control strategies may be developed with the help of expertise in the dynamics of urban flooding in Kolkata. The findings further emphasize the significance of improving drainage as well as implementing complete city planning and finally promoting community-based initiatives to improve the resilience of the flood. This study contributes to the improvement of broader city flood management. This study also provides valuable steering for other towns that are dealing with similar challenges. The suggestions supplied can form the basis for destiny efforts to lessen city flooding and defend vulnerable communities.

Keywords:

Urban flooding, Kolkata, Flood dynamics, Flood magnitude, Flood intensity, Municipal Corporation, Flood models, Comparative analysis, Flood management strategies, Urban planning, Drainage infrastructure, Hydrological models, GIS-based flood mapping, Community-based initiatives, Flood resilience.

Introduction

Urban flooding is a global issue which is exacerbated by weather change as well as rapid urbanization and insufficient infrastructure. Cities internationally face an expanded risk of flooding because of heavy rainfall and impervious regions. Kolkata is particularly vulnerable in low-mendacity regions specific to the Hooghly River (Mukherjee and Bardhan 2021). Rapid city development, as well as outdated culverts, and poor flood control strategies, contribute to the frequency and severity of floods. Managing urban flooding in Kolkata needs intensive expertise in its dynamics. There is also a need for the implementation of powerful mitigation techniques to shield citizens and infrastructure.

The geographical region of Kolkata influences the risk of flood extensively (Shackleton et al. 2023). The metropolis is situated on the banks of the Hooghly River and there are numerous low-mendacity areas. This obviously has a tendency to build up water. In addition, speedy

urbanization has exacerbated this vulnerability. Expanding impervious systems which is inclusive of roads and buildings as well as reduces natural drainage, and increases runoff. Poor drainage structures struggle to cope with a growing demand resulting in flood threats. Urban enlargement has destroyed the natural drainage system by encroaching on natural waterways and wetlands. These elements combine to present a complicated mission that requires integrated urban planning and infrastructure improvements to decrease flooding.

Studying flood dynamics in Kolkata is vital as the city is tremendously prone to flooding. This further poses intense risks to inhabitants and infrastructure. Understanding flood patterns and their reasons helps to enable the development of effective techniques as well as beautify urban resilience and make certain sustainable development (Cui et al. 2021). This permits the identity of high-risk areas as well as reporting on infrastructure improvements and further helps to guide the planning policies of the urban. Furthermore, insights received from such studies can improve emergency reaction and preparedness as well as reduce the socio-monetary effect of flooding. Finally, a comprehensive understanding of flood dynamics is needed to safeguard Kolkata's destiny amidst the challenges of growing urbanization and climate change challenges.

This study makes a speciality of assessing the significance and intensity of city flooding in Kolkata which is mainly in the jurisdiction of the Municipal Corporation. The study aims to feel elements especially downstream of urban flooding by the usage of superior flood modelling and comparative analysis. The most important objectives are to become aware of the main reasons for flooding as well as determine the effectiveness of current flood control structures and further suggest recommendations for enhancing flood control. The study seeks to provide actionable insights to city planners and the makers of the policy. This is done to assist them broaden targeted interventions to decrease flood risks and shield metropolis residents and infrastructure from future flooding.

Aim and Objectives of the Study

Aim: Assess the magnitude and severity of urban flooding through flood models and comparative analysis of the urban corporation in Kolkata.

Objectives:

- Analyse environmental as well as infrastructural, social and financial variables and become aware of the essential reasons for city flooding in Kolkata.
- Use and test flood models to simulate specific flood conditions and ensure accuracy and reliability.
- Evaluate the effectiveness of present day flood management techniques implemented by the municipality.
- Propose suggestions specializing in repairing Kolkata's resilience and decreasing the hazard of unlucky floods.

Literature Review

Overview of Existing Research on Urban Flood Dynamics:

The serious problem that has an impact on cities worldwide is urban flooding. The megacities such as Kolkata have become increasingly vulnerable to this problem (Mangal et al. 2024). This is because these cities have climate changes, which intensifies the rainfall, riverine flooding, and sea-level rise. The paper presents the importance of using climate resilience in urban planning. This has been done to reduce future flood risks. In the same way, there are studies that have analyzed the impact of extreme rainfall events in India's major cities. According to (Kumar et al. 2021), the serious damage that urban flooding causes to infrastructure and people. The important aspect that has been recognized as exacerbating the

vulnerability to floods is the considerable human and infrastructure costs, which are associated with urban flooding. Additionally, De et al. (2022), have highlighted that, how poor urban planning and the insufficient drainage infrastructure is prone to frequent and severe flooding. It results in many economic and social disruptions.

Discussion of Hydrological Models and GIS-Based Flood Mapping:

The two of the most important tools used in the analysis and management of urban flood risks are Hydrological modeling and flood mapping, which is based on a Geographic Information System (GIS). According to Almawas and Azmi (2022), these technologies aid in the thorough evaluation of flood hazards, exposures, and vulnerabilities. This further helps in planning and decision-making. They analyzed the current flood pathways and pinpointed the metropolitan areas that were at risk by examining optical and radar satellite pictures. Through the provision of insights for disaster preparedness and response, their research illustrates how GIS can successfully capture and predict the spatial dynamics of urban floods.

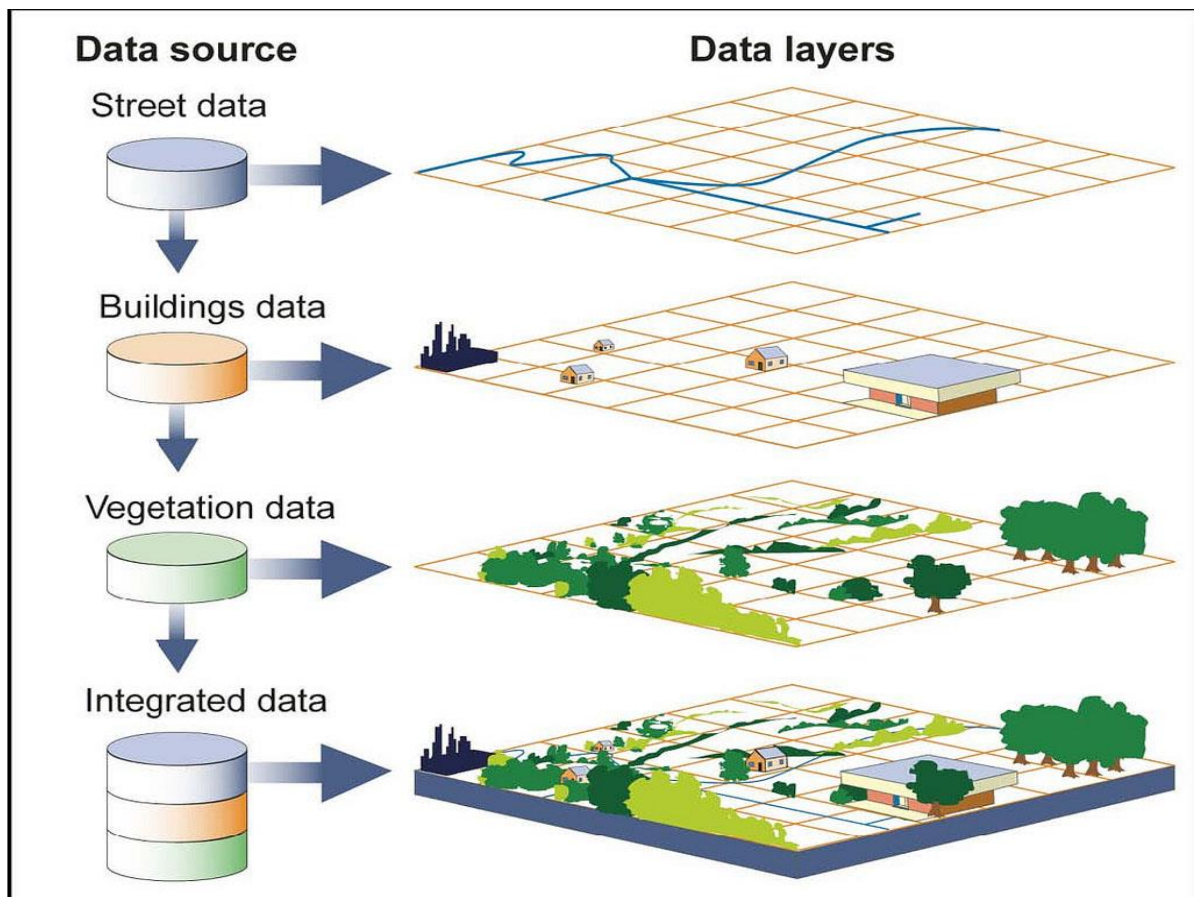


Fig 1: Geographic Information System (GIS)

(Source: <https://education.nationalgeographic.org/resource/geographic-information-system-gis/>)

Moreover, the studies have combined the hydrological models with GIS (Liew et al. 2021). This is to create the flood damage estimates and risk maps for Segamat Town in Malaysia. They produced precise results like damage curves and flood risk maps. This has been done by combining with the assessments of exposure and susceptibility with flood hazard analysis. The urban planners and emergency responders could identify the high-risk regions and prioritize flood reduction initiatives. Kolkata can use these helpful tools to manage floods

better. The Hydrological models and GIS mapping can simulate the flood scenarios in the city. They will show how urban growth affects the flood risks. These tools also help the design of targeted interventions to improve flood resilience. They visualize and measure the complex interactions between city structures and floodwaters.

Impact of Urbanization on Flood Risks:

According to Feng et al. (2021), urbanization significantly influences flood risks by altering natural water flow patterns. It also increases the space runoffs. The expansion of impermeable surfaces reduces the capacity of the land to absorb water. The roads and buildings are examples of these impermeable services. The flooding events grow more common and flood peak levels are rising. As per the studies of De et al. (2023), it is evident that how urbanization affected flood sizes in Bodrum, Turkey. The study have clarified the increasing danger of floods which is closely correlated with the development of the impermeable services. According to the results, controlling urban expansion is important for lessening its effects on flood dynamics. The drainage systems of the city have been strained which is the result of the rapid urbanization of Kolkata. According to Thakur and Blonde (2021), the poor drainage and sewer systems are the main causes of frequent flooding in Kolkata during the rainy season. The low-lying areas, which is especially the informal settlements, are highly vulnerable. This flooding causes economic losses and hampers the daily life of the communities.

Case Studies of Flood Management Practices in Other Cities:

The study of flood management in other cities offers a useful lesson that Kolkata can use to deal with flood challenges. There are several cities that have implemented these approaches. This is to lessen the likelihood of flooding and increase the resilience of their cities. The two examples of the structural measures that make up the approach taken by the city of Bangkok, Thailand, are the retention basins and floodwalls. The flood anticipating and local area-based readiness programs are two non-primary measures. It is obvious that the methods in which these initiatives have been integrated have made it simpler for the city to manage flood risks (Nachtnebel and Nandalal 2021). Furthermore, So Paulo, a city in Brazil, has embraced the stormwater management approach. This focuses on improving the quality of the water and preventing floods. The studies indicate that flood-proofing measures, river restoration projects, and stricter land use regulations were implemented in the flood protection strategy of So Paulo (Millington 2021). These initiatives have increased the adaptability and adaptability of the city's metropolitan regions.

Applicability of These Practices to Kolkata:

The city of Kolkata will be to tackle flood problems by studying global flood management practices. The experience of mixed flood management methods in Bangkok, will benefit Kolkata from combining the structural measures, which include enhancing the drainage infrastructure and constructing retention basins. On the other side the non-structural measures, which include community-based flood preparedness and early warning systems. The mix of both of these will help to enhance the ability of the city to respond and recover from the flood problems. Moreover, the land use and the urban planning of São Paulo emphasize the land-use regulations and flood-proofing measures, which act as valuable insights for Kolkata. The implementation of strict controls will help Kolkata to valuable insights for Kolkata. Additionally, the use of remote sensing and GIS as explained in Egypt could help Kolkata to a great extent in managing the flood. These technologies will help in precise mapping and monitoring of flood risks. Also, it will provide more targeted and

effective interventions. The community engagement and education will help Kolkata to engage the local communities in flood risk management, which is evident from the cases of Bangkok and São Paulo. This makes it crucial for building resilience. Furthermore, educating the residents about the flood risks will help to better cope with and recover from floods.

Methodology of the Study

Research Design and Approach

This study uses a quantitative research design developed by secondary information analysis. Secondary data includes historical data on rainfall and present maps and surveys of urban flooding in Kolkata (Pandey and Pandey 2021). The method collects and stores information from those sources for locating flood mitigation and making sure effectiveness of flood management measures. This study intends to expand comprehensive information on the importance and severity of city flooding in Kolkata Municipal Corporation. This is done through the usage of secondary data.

Data Collection Methods

The method of data collection for this study is basically inside the collection of secondary data on particular rainfall in Kolkata and within the shape of mapping and drainage. Rainfall data is collected from ancient climate data and gives a concept of its balance over time. On the other hand, information on water types is acquired from geological surveys and satellites which help to offer data on elevation in addition to mountains and natural drainage within the city (Verma et al. 2024). Information on drainage systems including the ability and circumstance of current drainage systems is accumulated from urban reviews and urban planning files. It additionally permits the identity of major reasons for urban flooding.

Selection and implementation of flood models

The flood model selected for this study is nicely acceptable to the city environment and might accommodate the particular geographic and infrastructural characteristics of Kolkata. Hydrologic Engineering Centre's River Analysis System (HEC-RAS) and Storm Water Management Model (SWMM) and others were taken into consideration due to their robustness in simulating flood conditions (Dubey and Kothari 2022). These models are compared to historic rainfall data as well as maps, and applicable drainage data and as compared to past floods to make certain accuracy during the method. These models help expect where flooding will occur as well as identify high-risk regions, and examine the effectiveness of existing management of flood strategies.

Criteria for comparative analysis

The benchmarking standards in this study consist of numerous key standards for evaluating the performance of flood models and management techniques (Newman and Gough 2020). These parameters consist of the accuracy of flood value forecasts based on historic flood events. The potential to simulate rainfall of varying intensity and length and the sensitivity of the models to changes in soil situations and drainage styles. In addition, the study considers the convenience of use as well as the requirements of the data, and the data efficiency of the model. The effectiveness of flood management is evaluated via metrics including flood frequency along with the duration and effect on inclined areas. This comprehensive evaluation ensures sturdy and reliable flood management solutions are provided in Kolkata.

Steps to Ensure Reliability and Validity of Findings

The studies follow a qualitative approach to ensure the reliability and validity of the findings. First, multiple data assets such as historical rainfall data as well as maps, and drainage system information are move-referenced for accuracy. Selected flood models are compared via the nicely documented past floods in Kolkata. Sensitivity analyzes are finished to assess version responses to numerous enter parameters. Peer evaluation and expert advice are blanketed to validate the technique and outcomes (Dzwigol 2022). In addition, the study makes use of numerical validation techniques to compare version output with flood observations. Together, those steps increase the accuracy as well as reliability and generalizability of study findings.

Data Analysis

Analysis of Key Factors Contributing to Urban Flooding

Environmental Factors:

The location and weather of Kolkata make it floods flood-prone area. From the geographical view the city is low lying and it is very close to the River Hooghly. So, for this reason, even a little rain can cause for the water to build up in the entire city. The elevation range of Kolkata is sea level to just a few meters above, this geographical position of the city makes flooding easy (Bose et al. 2023). In Kolkata, during the monsoon season, even a small range of rain can fell a big affect on the city. The entire drainage systems of the city are completely overflowed in the situation of heavy and long-lasting rainfalls. Climate change makes the situation even worse for the residents of Kolkata. Kolkata struggle a lot to manage the situation of floods and keep the city from getting waterlogged.

Infrastructural Factors:

The drainage system of the city is old and it is unable to manage the situation of heavy rains. There are many areas located in Kolkata which are still used colonial-era systems. These areas haven't been developed according to modern needs till now. On the other hand, in the different parts of the city, the growth of urban residents is fast which have blocked natural waterways and wetlands (Paul 2020). As a result, the water flow of the entire city is disrupted makes the situation too much tough to manage rainwater. The development of urban areas has added more concrete and asphalt surfaces in the city. For this reason the excessive water does not soaked into the ground. This significant issue increases the risk of flooding in Kolkata.

Socio-Economic Factors:

The main socio economic factor that contributed in the issue of urban flooding is high population density. There are many areas in Kolkata which have crowded neighborhoods and little open space. In these areas it is very difficult to implement effective flood control system (Mukherjee et al. 2021). The issue of unplanned land use and the construction of informal settlements in flood-prone areas increase the vulnerability of urban flooding in Kolkata. Inadequate maintenance of drainage systems and delays in flood management projects make the situation worse for the people of Kolkata during the rainy season. Effective flood prevention efforts are missing in the city due to a lack of coordination among government agencies and limited financial resources.

Assessment of Existing Flood Management Strategies:

Infrastructural Strategies

Building new drains and pumping stations to improve drainage system are the appropriate solution for Kolkata to mitigate the issue of Urban Flooding. The city needs to upgrade their old colonial-era infrastructure also. These upgrades are sometimes insufficient to prevent the

issue of urban flooding. Blockages and poor maintenance of drainage system reduce the effectiveness of the system (Ghosh 2024). Embankments and floodwalls have been developed along the Hooghly River and its tributaries to protect low-lying areas from flooding. This infrastructures will helps to protect the city from urban flooding but they are often breached during extreme weather and regular maintenance and reinforcement sharpen the ability of these infrastructures.

Policy Measures

Land use regulations are the policies that control the use of land as well as prevent buildings that are situated in various flood-prone areas. The aspect of illegal encroachments is very common. On the other hand, urban planning sometimes lacks the assessment of comprehensive flood risks. This respective approach contributes to vulnerable developments. On the other hand, the early warning system has also been set up. It has improved the preparedness and the response. These specific systems are in need of better coverage and accuracy. It is to provide effective alerts in time.

Community-Based Initiatives

Various public awareness campaigns are ongoing. These are to educate the residents about the risks of the flood that may occur and how to respond in the situation of flood. On the other hand, it is also true that a continuous effort is needed within these campaigns to build resilience for the longer term. Local involvement in flood management like monitoring drains and clean-up drives offered positive results. More amount of support is needed to prepare the communities for dealing with the aspects of the flood.

Comprehensive Understanding of Flood Dynamics in Kolkata

The natural and human-made factors both are responsible for the flood issues of Kolkata. This is why it is really crucial to keep focus on the geography, climate, infrastructure, and socio-economic conditions of Kolkata.

Geographical and Climatic Factors: Kolkata is situated in the Low-lying Ganges delta near the Hooghly River (Datta et al. 2021). This specific aspect makes it naturally flood-prone. The elevation of Kolkata is just a few meters above sea level (Majumdar 2021). This is why even a small amount of rain can cause water accumulation. The monsoon season that brings heavy and prolonged rainfall increases the risk of flood in Kolkata.

Infrastructural Challenges: The drainage system of Kolkata is very ancient (Mukherjee and Bardhan 2021). It is not capable of managing heavy rainfall. There are many areas in Kolkata that still utilize the drainage system of the colonial era (Paul 2020). It has not been upgraded to keep up with the urban growth. The drains get overwhelmed during heavy rain. This aspect leads to floods in the city. The blocked natural waterways and drainage channels make it more difficult to manage the excess amount of water.

Socio-Economic Factors: The higher level of population density and unplanned development also contribute to the problems of flood in Kolkata (Mithun et al. 2021). Controlling floods becomes difficult because of the crowded neighbourhoods that have very small open spaces. The informal settlements in the areas that are prone to flooding enhance the risks for vulnerable people. The poor practices of using land and illegal buildings ignore the issues of flood and hinder the natural drainage system.

Flood Modeling and Management Strategies:

There are various advanced tools like GIS-based hydrological models that helps in the process of managing the floods in Kolkata. These respective models simulate the scenarios of the flood. They also help in identifying high-risk areas and evaluating the management of various strategies. On the other hand, there are some gaps that remain in the management of floods.

Comprehensive Approach:

A complete approach for managing floods in Kolkata should be implemented. It is to upgrade the infrastructure, regulations of land use, and advanced models of floods. It is important to continually monitor the adaptive management. It can help in gaining long-term resilience. Engaging the community in the process and maximizing awareness about the risk of flood can help in reducing the negative impacts.

Implementation

```
✓ [1] #warnings library for dont showing warning messages
import warnings
warnings.filterwarnings('ignore')
```

```
[ ] #import the common libraries
import numpy as np
import pandas as pd
import seaborn as snb
import os
from matplotlib import pyplot as plt
```

```
▶ #import statmodel for ordinary least squares i.e. ols and linear regression
import statsmodels.api as sm
from statsmodels.formula.api import ols
```

```
[ ] #for dataset splitting
from sklearn.model_selection import train_test_split
```

```
[ ] #Import some regressors
from sklearn.ensemble import StackingRegressor
from sklearn.linear_model import LinearRegression
from sklearn.ensemble import RandomForestRegressor
from sklearn.linear_model import (
    SGDRegressor,
    BayesianRidge,
)
```

Histogram Analysis

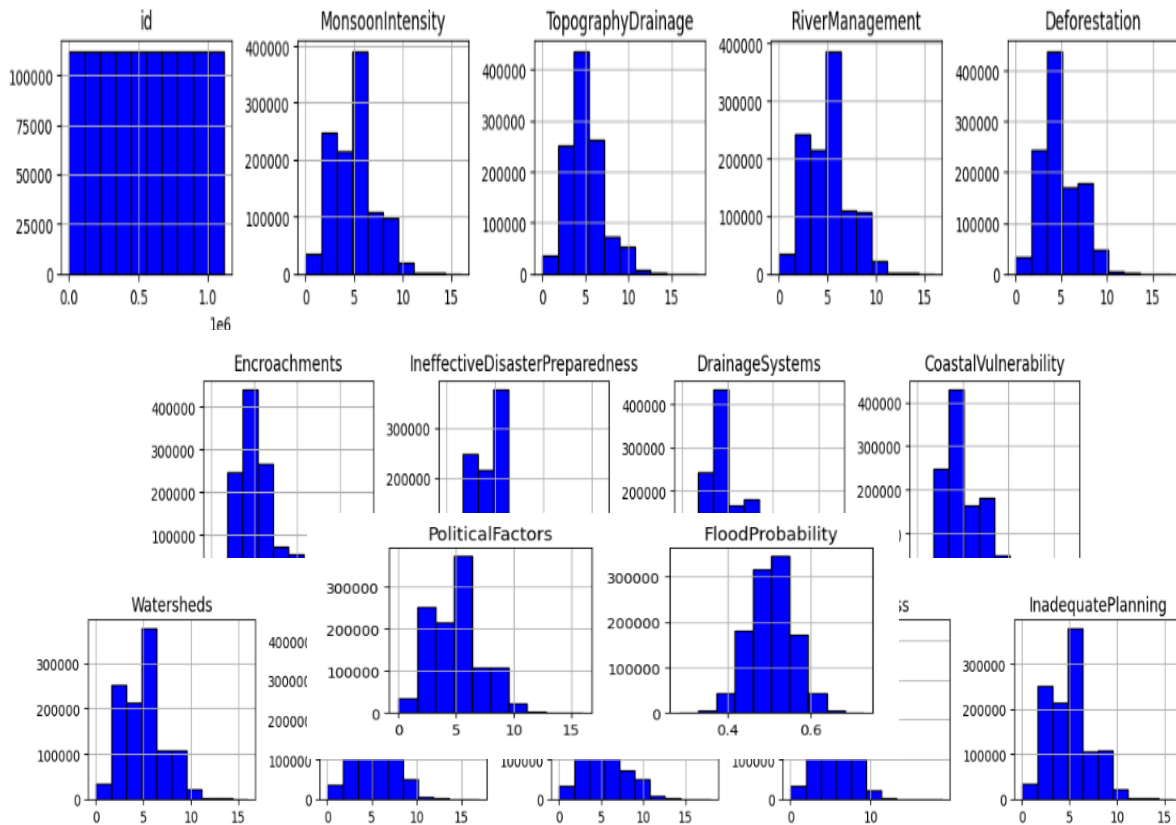


Fig 2: Histogram Analysis

The histograms display the elements related to flooding in Kolkata which related to flooding as well as useless disaster preparedness, insufficient drainage structures, and coastal weak spots. Flooding and shallow drainage cause flooding to be exacerbated whilst negative catastrophe preparedness and coastal vulnerability exacerbate its results. Although uncommon, earthquakes pose additional dangers. Addressing those troubles in a complete way is crucial for powerful flood management in Kolkata. On the other hand, this histogram shows the watersheds, political factors, and flood probability are showing in this histogram. This is very crucial for flood management in Kolkata.

Scatter Plot

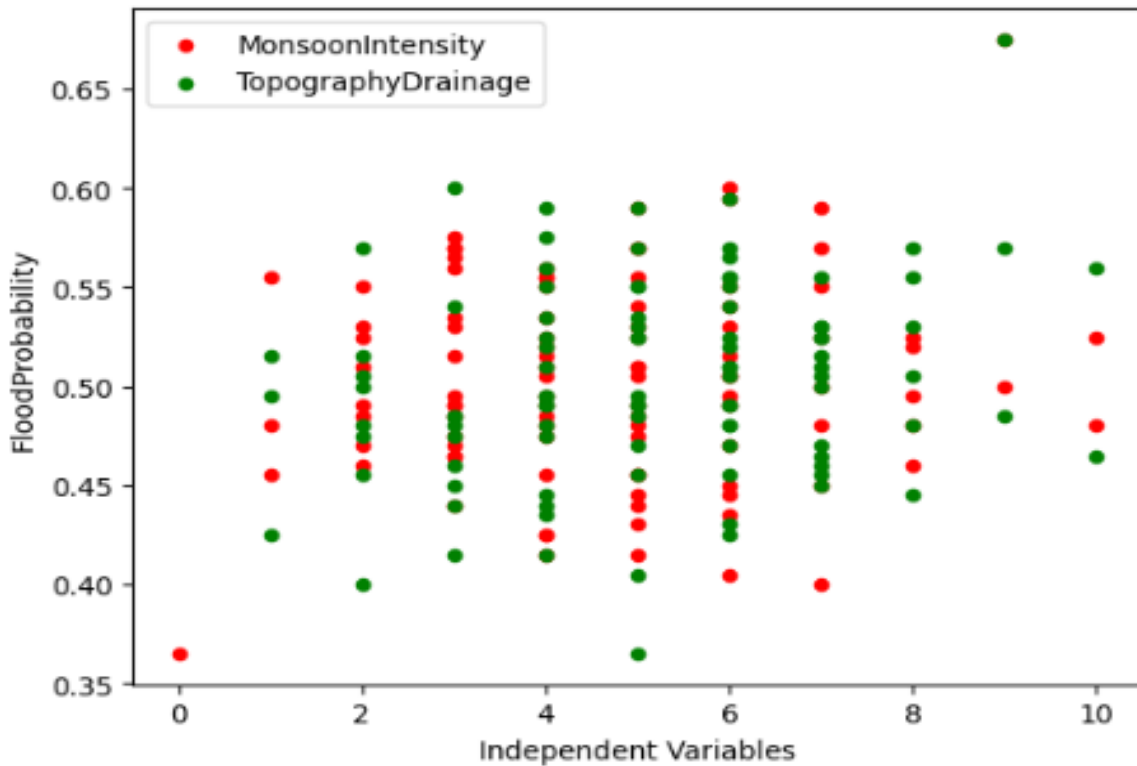


Fig 3: Scatter Plot Analysis

The x-axis is classified as "monsoon intensity," and probably shows the amount of rainfall at some point during the monsoon season. On the other hand, The y-axis is categorized as "flood opportunity". Each data factor represents a place and indicates the chance of flooding in that area given the rainfall intensity. For instance, the information point inside the upper proper corner of the landscape might constitute an area with high rainfall runoff and a high possibility of flooding whilst the facts factor in the decreased left corner might constitute an area with low rainfall depth and flood as it is able to be much less. The bottom axis "0 2 4 6 8 10" likely represents the fall monsoon units. The better the number, the extra intense the precipitation. The text "0.35, 0.40 0.45..." close to the left nook in all likelihood represents the opportunity for flooding. The higher the range, the higher the threat of flooding.

Note that that is only a fashionable court. There are different factors that have an effect on flood possibility along with topography and drainage. The textual content above the plot mentions those elements, but it is not always clear how they're brought to the data.

Multiple Linear Regression Method (OLS)

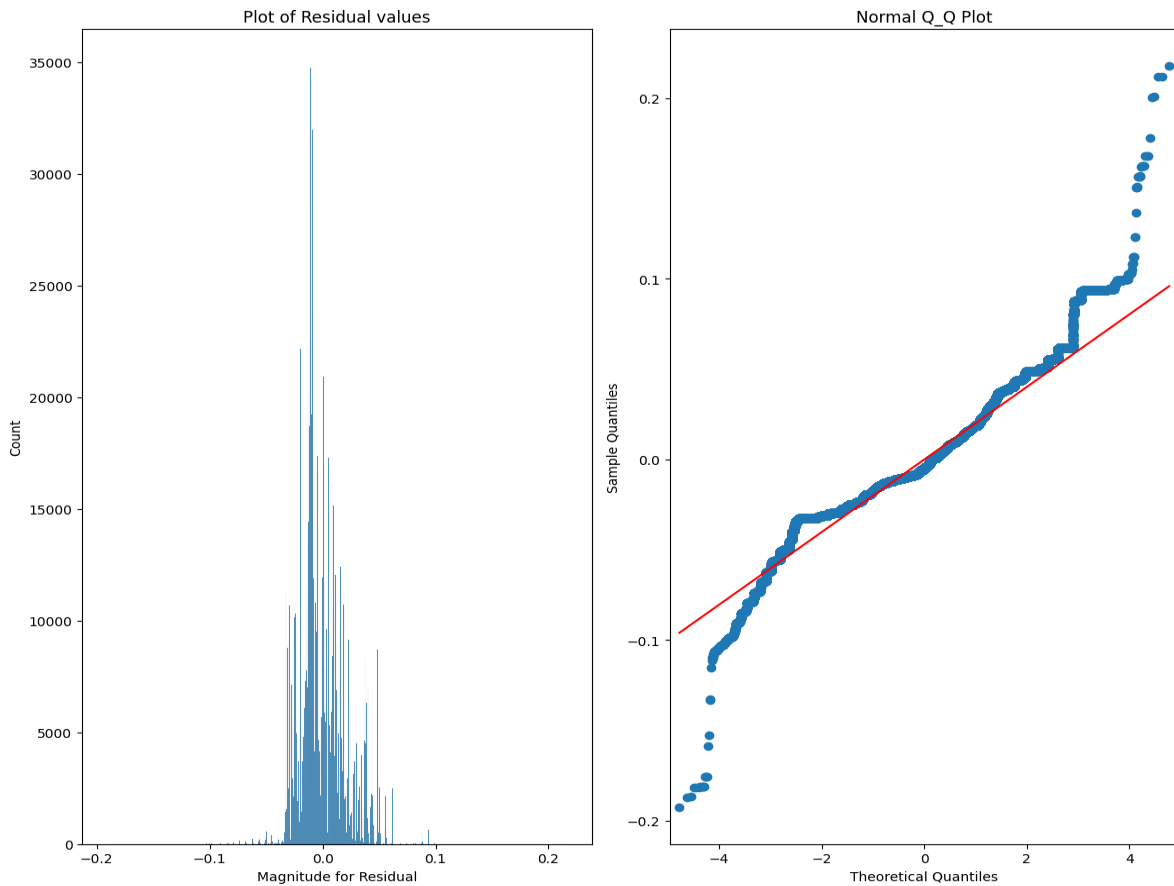


Fig 4: Multiple Linear Regression Method (OLS)

The left plot is a histogram of the residual distribution, which is ideally symmetric around zero. The correct plot is a normal Q-Q plot that compares set residuals to quantiles of an ordinary distribution. They talk not unusual floor collectively. Symmetry and mild curvature propose approximate normality with minor deviations. Consider it together with other tests of goodness.

In this technical, it was shown that some statistics on the dataset, exploratory data analysis for showing the relationship demonstration among the variables, correlation table for finding the highest correlation among the variables, OLS method and its r^2 score value and finally stacked model applied on data preprocessing dataset and its r^2 score value. Also it was seen that STacked model is effective than OLS method after data preprocessing. R^2 score for stacked model (0.8644) > R^2 score for OLS (0.845).

Conclusion and Recommendations

The survey reveals good-sized variability within the importance and depth of flooding across Kolkata, with more extreme flooding in some regions because of an aggregate of heavy rainfall as well as low soil and bad drainage. The models effectively identified high-risk regions and the spatial distribution of flood water in exceptional sorts of rainfall. The flood models efficaciously recognized excessive-risk areas. This also examined the spatial distribution of flood waters in special rainfall styles.

The findings highlight the pressing need for comprehensive city flood management in Kolkata. The town's cutting-edge infrastructure is unable to indicate the increasing risk of flooding as well as requires immediate and long-time period interventions. Effective flood control requires an integrated technique that mixes infrastructure upgrades with policy adjustments and community engagement. City planners and the makers of the policy have to prioritize flood resilience to protect town citizens and monetary sports from the unfavorable consequences of flooding.

Recommendations for Infrastructure Upgrades, Policy Measures, and Community Initiatives

Infrastructure Upgrades:

- Upgrade and extend existing drains to increase capacity and performance.
- Implement inexperienced infrastructure solutions such as tired sidewalks as well as green roofs and rain gardens to beautify natural drainage.
- Restore and guard natural waterways and wetlands to improve the city's natural drainage system.

Policy Measures:

- Stricter legal guidelines on land use and improvement could be introduced to save encroachment on water-susceptible regions.
- Design and put in force complete city flood control plans including early warning structures and emergency control.
- Flood risk tests need to be included inside the city making plans technique to make sure that new developments can resist flooding.

Community Initiatives:

- Increasing public cognizance of flood chance and community participation in flood preparedness and response sports is advocated.
- Develop a plan primarily based on neighbourhood tracking and remediation for neighbourhood drains and watersheds.
- Encourage partnerships among authorities agencies, NGOs and nearby groups to increase flood manipulate.

Importance of Integrating Advanced Flood Modeling Techniques into Urban Planning

It is miles essential to contain complete flood modelling strategies in urban planning for powerful flood management in Kolkata. These models offer valuable insights into flood risk and enable planners to make informed choices about land use, infrastructure improvement and emergency preparedness. Integrating flood modelling into the planning procedure enables the municipality to directly manage flood risk. This also helps to optimize useful resource allocation and design resilient structures. This strategic technique helps to mitigate the impact of flooding. This technique additionally ensures sustainable city improvement, improving the overall safety and well-being of Kolkata residents.

Limitations and Future Scope

Discussion of Study Limitations

This study has several barriers along with data boundaries and ability biases in flood models. Incomplete or previous rainfall and soil data can have an effect on model accuracy.

Furthermore, flood models are incomplete in capturing the complexity of urban flooding due to inherent simplifications and assumptions.

Areas for Future Research

Future studies need to examine the effect of weather exchange on city flooding. This takes into account estimates of rainfall intensity and frequency. Advanced flood modelling that consists of real-time records and device mastering algorithms can increase forecast accuracy. The socio-financial impacts of flooding and powerful mitigation techniques as well as warrant future studies.

Need for Continuous Monitoring and Adaptive Management

Continuous monitoring of rainfall as well as drainage situations and urban development is critical for well-timed and powerful flood control. Implementing adaptive management techniques advanced with the converting environment will ensure lengthy-term flood resilience in Kolkata. Regularly updating flood management plans and resource assessments will help to control rising flood risks as well as safeguard the future of the city.

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