International Journal of Environment and Climate Change

Volume 14, Issue 11, Page 277-291, 2024; Article no.IJECC.125060
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Flood Vulnerability Assessment in Paradip Coastal Area Using Weighted Overlay Index

Yogeshwari Rohit [a*] and Nikita Bhuraria [a]

[a] School of Planning and Architecture, Bhopal, India.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijecc/2024/v14i114545

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/125060

Original Research Article

Received: 19/08/2024
Accepted: 21/10/2024
Published: 29/10/2024

ABSTRACT

Paradip, a prominent coastal city on India's eastern seaboard, presents a unique combination of environmental challenges and urban pressures. It has the largest tidal range among major regional tidal gauge stations, including Vishakhapatnam and Chennai. The city experiences an annual sea level rise of 2.33 mm, with projections indicating an increase of 0.183 feet by 2047 and 0.76 feet over the next century. The city's unique environmental and urban issues are exacerbated by its placement within the Mahanadi River's deltaic deposits, floodplains, and coastal marine deposits along the Bay of Bengal. The shoreline of Paradip is topographically uniform, with ground elevations ranging from 3.6 to 5.7 meters. According to India's Wind and Cyclone Hazard Map, Paradip is in the "Very High Damage Risk Zone," indicating the presence of significant wind speeds along the coast. The paper digs into these vulnerabilities and their possible influence on the coastal community, emphasizing the city's need to strike a balance between urban growth and ecological preservation. One of the main problems is flooding. Rainwater enters government buildings and

**Corresponding author: E-mail: yogeshwari271997@gmail.com;*

Cite as: *Rohit, Yogeshwari, and Nikita Bhuraria. 2024. "Flood Vulnerability Assessment in Paradip Coastal Area Using Weighted Overlay Index". International Journal of Environment and Climate Change 14 (11):277-91. https://doi.org/10.9734/ijecc/2024/v14i114545.*

impoverished areas because of encroachments on natural drainage systems. Dryland capable of residential, agricultural, and other economic activities is submerged by overflowing water which causes loss of life, property, and infrastructure. This study evaluates flood vulnerabilities in Paradip, a coastal city, using GIS and a weighted overlay index. By integrating satellite imagery, digital elevation models (DEM), and historical data on rainfall and soil types, we developed a detailed flood vulnerability map that categorises areas into high, moderate, and low risk. ArcGIS Pro 2.7.3 software and a weighted overlay index were utilized for the collection, processing, and display of spatial and attribute data. spatial analysis was the process used to produce the flood vulnerability map. The results provide essential insights for urban planning and flood mitigation strategies, with direct implications for improving disaster preparedness and climate resilience. The flood vulnerability map was then compared to the masterplan of Paradip which was proposed for 2030, to know the actual vulnerable area and to defy some major which were proposed by Paradip development authority. The study illustrates how remote sensing and GIS techniques can be effectively utilized to generate flood vulnerability data essential for informed decision-making.

Keywords: Community; environment; flood; urban issues; vulnerabilities.

1. INTRODUCTION

Floods are the most frequent natural disasters to impact society worldwide; it is estimated that over one-third of the planet's geographical area is susceptible to flooding, which affects over 82% of the world's population. (Argaz, 2019). These high-magnitude earthquakes have the potential to cause significant topographic modifications as well as massive geomorphic changes. India is a nation prone to natural disasters, with multiple natural disasters occurring yearly. Among them, India experiences its most frequent and severe natural calamities like floods. Researchers and the UN's sustainable development objectives indicate that between 1995 and 2015, floods were the worst natural hazard, affecting an estimated 2.3 billion people and accounting for 157,000 documented deaths globally. (Halder, 2023) The Brahmaputra River can go as deep as approximately 440 feet (135 meters), with an average depth of 100 feet (30 meters). Floodwaters can reach up to 3,500,000 cubic feet per second (100,000 m3/s), whereas the annual average discharge is roughly 700,000 cubic feet per second (19,000 m3/s). The average flow of the Ganga-Brahmaputra river delta is around 1,086,500 cubic feet per second (30,770 m3/s), which is the third biggest in the world. It also has the largest yearly load of suspended silt, weighing about 1.87 billion tons. The districts of Mymensingh and Jamalpur in the lower Brahmaputra River basin are primarily affected by flooding (Halder, 2023).

This project aims to evaluate and map flood risks in the coastal region of Paradip using advanced GIS techniques and a weighted overlay index to enhance risk management, disaster planning, and sustainable development in the coastal region of Paradip, an important location within Odisha. The goal is to create a comprehensive weighted overlay index that incorporates geographical layers like topography, past flood data, land use patterns, and sea level rise estimates. This index, which is customized to the particular geographic and meteorological characteristics of Paradip, attempts to offer a sophisticated perspective on the composite flood risk in the area. The second objective is to identify and prioritize high-risk areas in the Paradip coastal region after the Weighted Overlay Index has been created. This will provide a clear spatial representation of susceptibility levels for effective resource allocation and targeted intervention strategies. Expanding upon the vulnerability evaluation, the third purpose endeavors to suggest focused mitigation tactics, offering counsel to regional administrations and interested parties to augment flood resilience in Paradip. This project attempts to provide useful insights for evidence-based decision-making by utilizing cutting-edge GIS techniques, ultimately promoting resilience and sustainable development in response to the increasing flood threats in Paradip.

Topography plays a crucial role in determining an area's flood vulnerability, among other influencing factors. The study area's topography, which takes into account factors like land use, elevation, rainfall, and land cover, greatly affects how prone it is to flooding. Gently sloping low-lying locations are more vulnerable to flooding, whereas higher topography may be less susceptible. Alterations in natural drainage patterns due to land use changes, such as urbanization and deforestation, can exacerbate flood risks.

Authorities' mitigation initiatives are vital to controlling flood risks. This entails putting policies and infrastructure in place to manage and reroute water flow, like building levees, dams, and stormwater drainage systems. Flood damage is also mitigated by effective disaster response and preparedness plans. Activities around coasts are largely regulated by Coastal Regulation Zones (CRZ). CRZs seek to strike a balance between environmental conservation and development by defining permitted and restricted zones. To ensure sustainable coastal development and reduce flood vulnerabilities, the enforcement of these restrictions is crucially dependent on the Odisha Coastal Zone Management Authority.

The vegetation in the study region provides a natural barrier against flooding. Mangroves serve as a buffer, for example, lessening the force of storm surges and preserving coastal ecosystems. Flood dangers can be considerably reduced by maintaining and replanting vegetation in flood-prone locations. The identification and safeguarding of ecologically vulnerable regions is essential to reducing the risk of flooding. These places, which are frequently abundant in biodiversity, offer crucial ecosystem services and serve as organic barriers against severe weather. By putting conservation measures into place, these areas can remain resilient to flooding and retain their biological balance.

1.1 Study Area

Paradip is situated 210 nautical miles from Kolkata and 260 nautical miles from Visakhapatnam, the other two major ports in the eastern part of the country. Its latitude is 20o15' 55.44" N, and its longitude is 86o 40' 34.62" E. State Highway No. 12 and National Highway No. 5A provide excellent connections between Bhubaneswar and Cuttack with Paradip. It is situated roughly 94 kilometers (by road) from the Cuttack railway station and 125 kilometers (by road) from the Bhubaneswar Airport.

The port city of Paradip, located in the Odisha district of Jagatsinghpur on the country's east coast, is an intriguing example of how environmental dynamics and urban growth interact. Paradip, spanning 248 square kilometers, serves as a crucial hub for the region's economy and industry. Its transition from a mangrove-covered coastal region to an artificial deep-water port is symbolic of the intricate dance that occurs between the protection of the environment and the pursuit of economic progress. This study explores the distinctive environmental characteristics of Paradip, looking at how its location and climate have influenced the city's identity and presented difficulties for sustainable growth.

Fig. 1. Location of Paradip

Fig. 2. Paradip Port

Location: Paradip's prime location at the confluence of the Mahanadi River and the Bay of Bengal emphasizes the city's economic importance. Ideally positioned between the major metropolises of Visakhapatnam and Kolkata, Paradip is essential to trade and business between the states of Odisha, Jharkhand, Chhattisgarh, Madhya Pradesh, Uttar Pradesh, Bihar, and West Bengal. Because of the city's relative flatness and gentle slope towards the sea, a strong transportation network, including highways and railroads, has grown. To incorporate Paradip into the economic activity of its hinterlands, this link is essential.

Beyond its economic significance, Paradip's location has unique advantages and disadvantages. The city is protected from severe winds, choppy waves, and storms by the naturally occurring deep bay created by the meeting of the Mahanadi River and the Bay of Bengal. This protected site lowers the dangers associated with bad weather by guaranteeing safe ship docking and anchoring. The Mahanadi River, a notable part of the city's landscape, is essential to Paradip's environment because it serves as both an inland waterway and a source of water for home and industrial usage.

However, Paradip is vulnerable to environmental risks due to its unique location, which offers strategic and economic advantages. The city's location along the Bay of Bengal's deltaic deposits, floodplains, and coastal marine deposits makes it naturally vulnerable to flooding and cyclonic storms, especially during the southwest monsoon season. The urban and environmental fabric of Paradip is always in danger due to storm surges because of the flat geography, which has ground elevations ranging from 3.6 to 5.7 meters. Because of its location, Paradip Port is vulnerable to the effects of cyclones that originate in the Bay of Bengal. The 1999 super cyclone demonstrated the extraordinarily high wind speeds that may be experienced in this area, up to 248 km/h. Super Cyclone AMPHAN, an extraordinarily powerful cyclone with associated wind gusts of 200 to 210 km/h, is currently posing a threat to the port. Right now, AMPHAN is situated about 360 kilometers south of Paradip. The port should take the necessary safety measures to reduce potential dangers since bad weather is expected. (Das, 2011)

The region is humid and hot because it sits on India's eastern coast. The mean temperature of the year is between 35.96°C and 13.30°C, meaning that it does not change much. The range of the mean maximum temperature is 28.6°C to 35.8°C, and the range of the mean minimum temperature is 13.3°C to 22.5°C. Paradip receives roughly 1400 mm of rainfall annually, which is more than the 1180 mm national average but less than the 1489 mm state average. Seventy-five percent of the rainfall falls in Paradip between June and September. Because of the significant precipitation, Paradip experiences high humidity levels, ranging from an average of 80.1% in December to a maximum of 98.6% in July. The lowest humidity level is 44.4%. (Simulated historical climate & weather data for Paradip, 2023)

Wind – Wind: The wind raise for Paradip shows how many hours a year the wind blows in the designated direction. Example SW: The wind is blowing from the northeast (NE) to the southwest (SW). Particularly for sailing vessels, voyages from East to West are extremely challenging at Cape Horn, the southernmost landmass in South America, due to its distinctively strong west wind. (Simulated historical climate & weather data for Paradip, 2023).

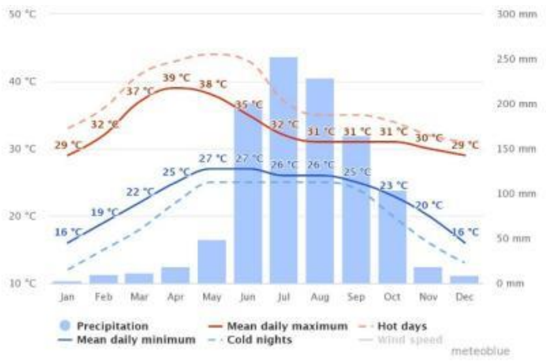


Fig. 3. Temperature

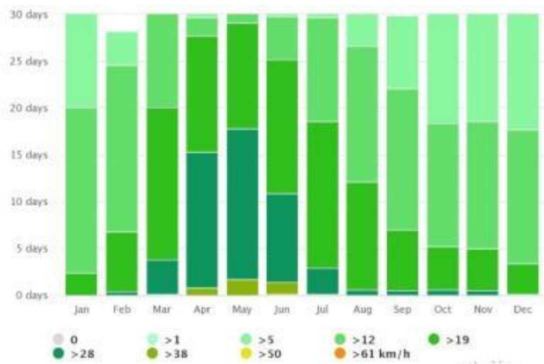


Fig. 4. Wind Speed

The days of the month when the wind reaches a particular speed are depicted in the Paradip figure. The Tibetan Plateau provides an intriguing illustration of this, as the monsoon produces consistent strong winds from December to April and calm winds from June to October.

Sea level - Every lunar day, Paradip has two high tides and two low tides that are roughly similar in magnitude. These tides are known as semi-diurnal. The lowest water level is +0.40 meters, while the highest is +3.50 meters. There are 2.58 meters for the mean high-water spring and 0.71 meters for the mean low-water spring. There are 2.02 meters of mean high water neaps and 1.32 meters of mean low water neaps. (Relative Sea Level Trend 500-106 Paradip, India, 2021)

2. COASTAL REGULATION ZONES

Paradip is a seaside city spanning 23 kilometers along the shore. 37.68 kilometers are all under coastal regulatory zones. Approximately 15.3% of the property is located in coastal control zones. The Odisha Forest and Environment Department, the Odisha Space Applications Center (the science and technology department), and the Odisha Coastal Regulation Zone (CRZ) notification 2019 have prepared these coastal zones.

The Coastal Regulation Zone (CRZ) is a key component in regulating coastal development and mitigating the effects of flooding. It also plays a significant role in preventing environmental deterioration. It promotes in ensuring the preservation of coastal resources in addition to protecting the delicate coastal habitats. To protect the coastal environment and promote sustainable development, India's Coastal Reserve Zone (CRZ) laws restrict industrial and human activity near beaches. The CRZ facilitates the general planning, coordination, and implementation of actions aimed at resolving environmental issues in coastal zones. By regulating activities including as construction, mining, and waste dumping, Coastal Regulation Zones (CRZs) help maintain the ecological balance and biodiversity of the coastal regions. It aims to create a balance between the coastal environment's priceless resources, economic development, and preservation (Joseph, June 2000).

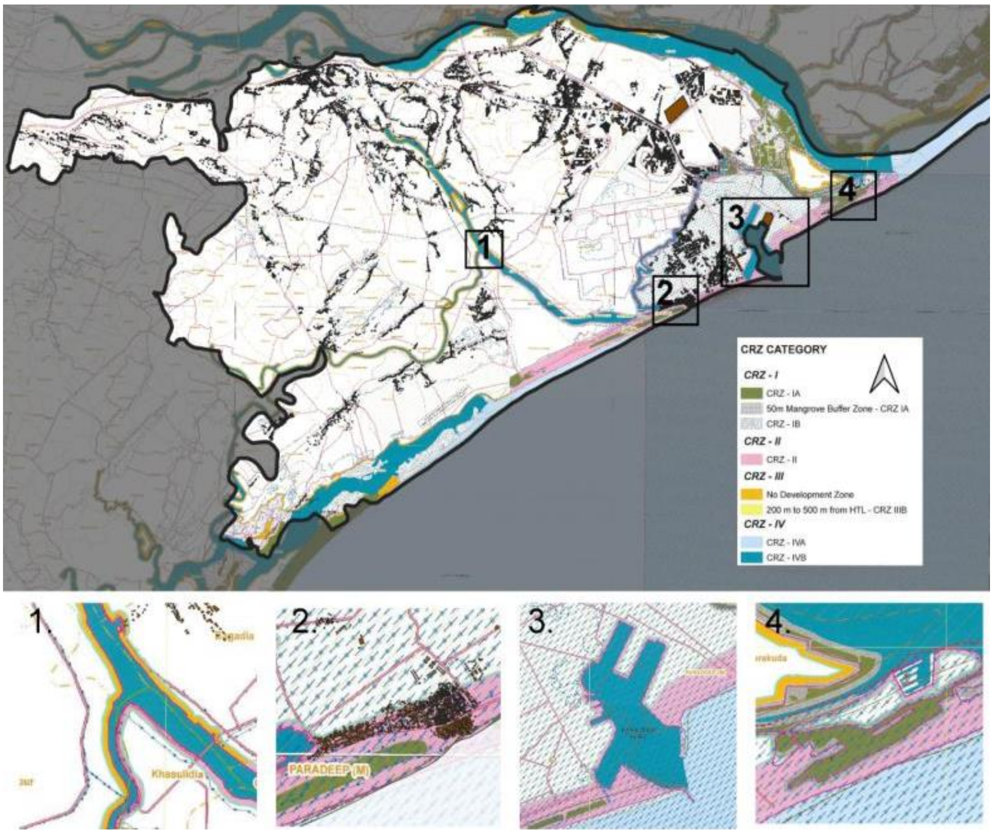


Fig. 5. Coastal Regulation Zone

India's Coastal Regulation Zone (CRZ) is a strategic framework that categorizes coastal zones in order to govern and regulate activities throughout the vast coastline of the nation. The most restrictive zone, designated as CRZ-I, includes national parks and other environmentally sensitive locations where new construction is prohibited. The strict ban is meant to protect these important ecosystems' virgin state. Furthermore, there is a sub-classification (Table 1) inside CRZ-I, which highlights the importance of conservation even more. The first sub-classification restates the outright ban on new construction, particularly in regions that are ecologically fragile like national parks. The second subclassification, which recognizes its ecological relevance and sensitivity, defines the area between low and high tide.

Buildings are allowed in CRZ-II, however, there are limitations. On the landward side of currently constructed roadways, construction is permitted to balance environmental preservation with developmental demands. While recognizing the importance of infrastructure development, this classification ensures moral land use practices.

CRZ-III, which is 200 meters from the high tide line is classified as a "No Development Zone." No building is allowed in this area to protect the coastal ecosystem from the damaging effects of human activity. To ensure a cautious and controlled approach to coastal development, some developments may be permitted within the 200–500 meter range with prior approval from the Ministry of Environment and Forests (MEF).

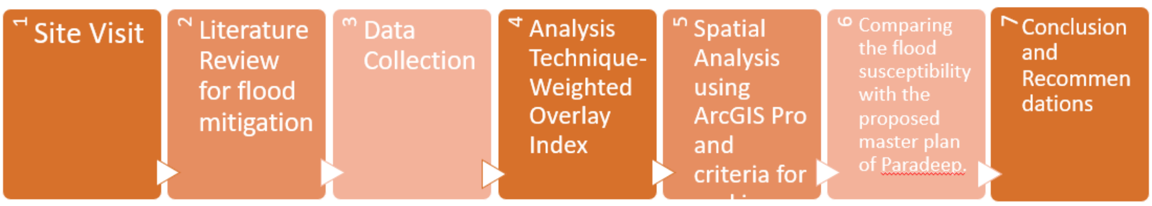
The watery region up to territorial boundaries is covered by CRZ-IV. This classification highlights the need to control activities in these seas in order to preserve biological balance and stop environmental degradation, while also acknowledging the dynamic nature of coastal ecosystems. (MINISTRY OF ENVIRONMENT, 2019)

Table 1. Coastal Regulation Zone

	Define	**Leg**	**Type**	**%**	**Area (Kmsq)**
CRZ- I	No new construction (Ecologically sensitive areas i.e. national parks)		CRZ-IA 50m Mangrove Buffer	**12** 8	**4.33** 3.09
	The area between Low & high Tide area.		CRZ - IB	14	5.2
CRZ- II	Permitted Buildings (landward side of existing road)		CRZ-II	23	8.57
CRZ- III	No Development Zone (200m area from the high tide line)		No development Zone	7	2.7
	200-500 m (developed by prior approval MEF		CRZ IIIB	-	-
CRZ- IV	Aquatic area up to territorial limits		CRZ- 1VA	7	2.79
			CRZ-IVB	29	11

Source- (MINISTRY OF ENVIRONMENT, 2019) & Odisha space application centre (centre, 2021)

3. METHODOLOGY AND APPROACH



The research team used a thorough methodology to investigate flood hazards in the coastal region of Paradip. To lay the groundwork for a foundational grasp of flood vulnerabilities, GIS methodologies, and environmental evaluations, the journey began with a thorough analysis of the current literature. After that, a thorough process of gathering data was initiated, which included compiling pertinent data and obtaining historical flood records, land use patterns, topographical data, and sea level rise estimates. Maintaining the reliability of the information required cooperation with environmental agencies and municipal authorities to obtain current and reliable data.

Throughout the whole research process, the engagement of multiple agencies remained essential. These partnerships made it easier to validate data and gave us a comprehensive understanding of Paradip's environmental dynamics. After obtaining the necessary data, the study moved on to the analytical stage, where sophisticated GIS methods were used to combine geographical layers and derive important conclusions. A detailed environmental assessment was conducted, accounting for topographical considerations, tidal range, and coastal characteristics to investigate the unique dynamics of Paradip. The purpose of this study was to find stresses and potential weak points unique to the surrounding area (Ouma, 2014).

After defining the problem, the study described the challenges associated with Paradip's flood vulnerabilities in light of the environmental dynamics discovered during the assessment phase. One of the main results was the development of a Flood Susceptibility Map, which gives stakeholders and decision-makers a useful tool and depicts areas that are in danger. To improve the accuracy of risk assessment, a Comprehensive Weighted Overlay Index was created by combining many spatial layers to quantitatively evaluate and rank flood vulnerabilities in the coastal region of Paradip (Ramakrishnan, January 2023).

The study's final step was to rate the issues that were found according to their seriousness, possible impact, and urgency for remediation. This approach took into account both immediate and long-term issues, giving rise to a sophisticated comprehension of the order of importance for intervention. The research's methodology, conclusions, and findings were ultimately produced in a thorough documentation. In light of the increasing flood vulnerabilities in Paradip, this documentation is an invaluable tool for future research projects, decision-making procedures, and the application of focused mitigation strategies. In the end, it will improve risk management, disaster planning, and sustainable development.

The collection of data is the main process in terms of digital mapping or GIS operation to conduct this study methodologically. This study makes use of both primary and secondary data. GPS-acquired Ground Control Points (GCPs) made up the majority of the data. The digital elevation model (DEM) data from the Shuttle Radar Topography Mission (SRTM), the Landsat 8 soil vector map, the Tropical Rainfall Measuring Mission (TRMM), and the area's administrative map were the secondary data used.

Flood vulnerability mapping: Using the ArcGIS Pro Software, six thematic-layer factors were developed in a GIS environment to identify the study area's flood-vulnerability zones (Ouma, 2014). The study's flood vulnerability factors (Kaoje, 17th May, 2017) were selected using a combination of in-depth research, resident consultation, and literature reviews. The distribution of rainfall, land cover and usage, elevation, slope, drainage density, and soil type are the contributing elements (Raufu, Application of Remote Sensing and Geographical Information System (GIS) in Flood Vulnerability Mapping: A Scenario of Akure South, Nigeria, 2023). The metropolis of Paradip was divided into four regions (high, moderate, and low) with differing levels of flood susceptibility to estimate the flood risk zones. The Analytical Hierarchical Process (AHP), which is based on multi-criteria decision-making, is used to classify the flood vulnerability aspects by giving them proportionate weights. AHP is a decision-making process that takes into account people's actual ability to make significant decisions. It permits the active involvement of decision-makers in fully comprehending all feasible possibilities before reaching a consensus or making a decision. The AHP implementation uses a pairwise comparison technique to ascertain the relative value of each step toward accomplishing the goal. Similarly, pairwise evaluations of the alternatives' performance against each criterion define their priorities, which in turn determines how the alternatives' rankings (i.e., the competing options under consideration) are established.

Using the four vulnerability levels as a framework for ranking, each vulnerability element in this study was ranked based on the decision maker's preference. To create criterion values for each evaluation unit, each element was weighted according to its expected impact on floods. The inverse ranking was applied to some of these criteria, with weights ranging from 1 (the least significant component) to 4 (the most significant element). The Weighted Linear Combination (WLC) method was used to superimpose all of the map layers, or the factors, in the final GIS spatial analysis for the flood vulnerability zone simulation.

4. RESULTS AND DISCUSSION

4.1 Flood Vulnerability Factors

Landuse land cover: The initial onset of flooding is significantly influenced by changes in land use and land cover, according to several specialists in flood hazard management. The primary reason for this is that this element takes into account the effects of current land use patterns and their varieties on soil stability and water infiltration (Dalia Farghaly, 2016). Satellite image from Landsat 8 was used to define the land cover classes in the research area. A minimum of eight and a maximum of twelve different classes could be identified by the use of the ISO cluster classifier in an unsupervised classification technique. To identify four distinct classes that significantly affect flood susceptibility, reclassification efforts were subsequently conducted. The four categories are made up of built-up areas, green cover, forests, and vacant grounds (Burayu, September 2023). The built-up regions were awarded a value of 4, indicating that they are more susceptible to flooding, whilst the areas with fewer settlements were assigned a reduced risk of flooding. The generated map of land cover factors is shown in Fig. 6.

Rainfall distribution: Heavy rains are a major contributing factor to floods, frequently overflowing natural waterways. When these systems are unable to control the excess water, widespread flooding usually results. Flood typically occur when a lot of rain falls and doesn't seep into the earth quickly enough to cause overflow to become surface runoff. The TRMM recordings in the research region provided the daily rainfall data for this particular investigation. An average daily rainfall assessment was calculated using a geographic information system (GIS) and the kriging technique. The result was merged into a rainfall data raster layer. The study area's southern sectors have the highest recorded rainfall amounts, which range from 50mm to 90mm. To streamline the study, the rainfall distribution raster was divided into four classes: 1 represented the lowest rainfall, and 4 represented the highest rainfall (Burayu, September 2023).

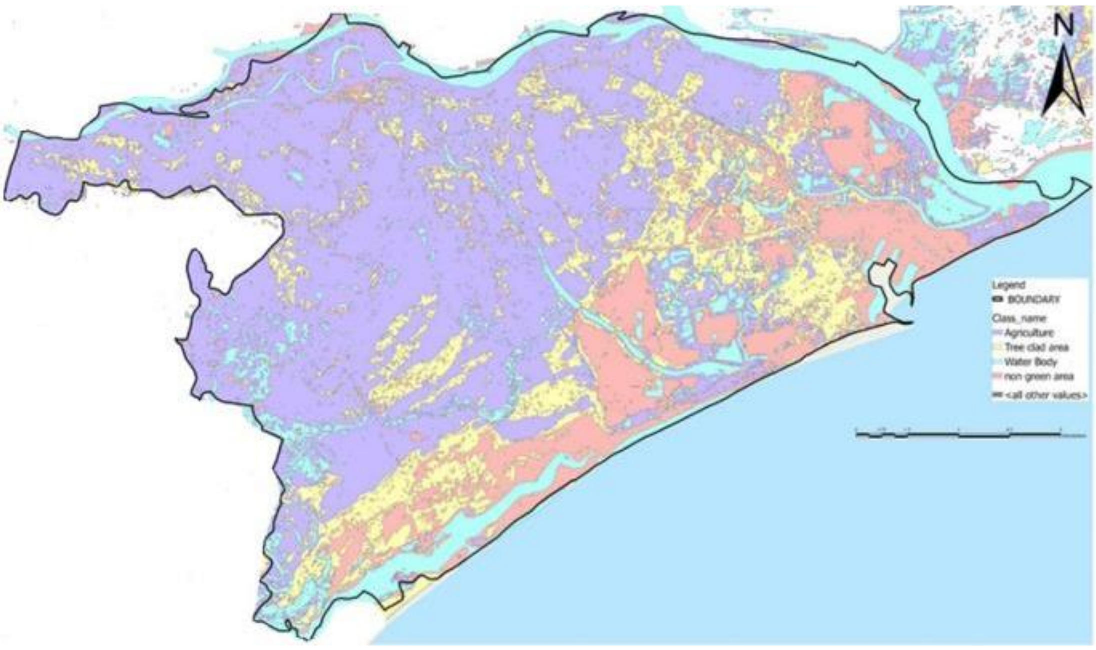


Fig. 6. LULC Map

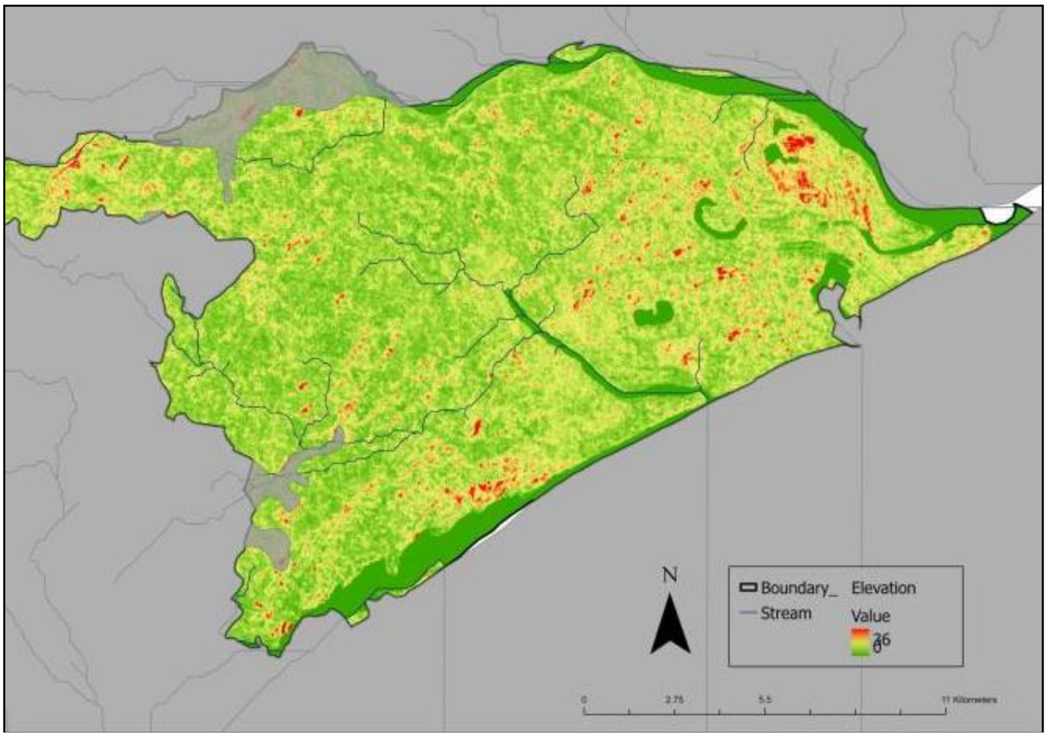


Fig. 7. Elevation Map

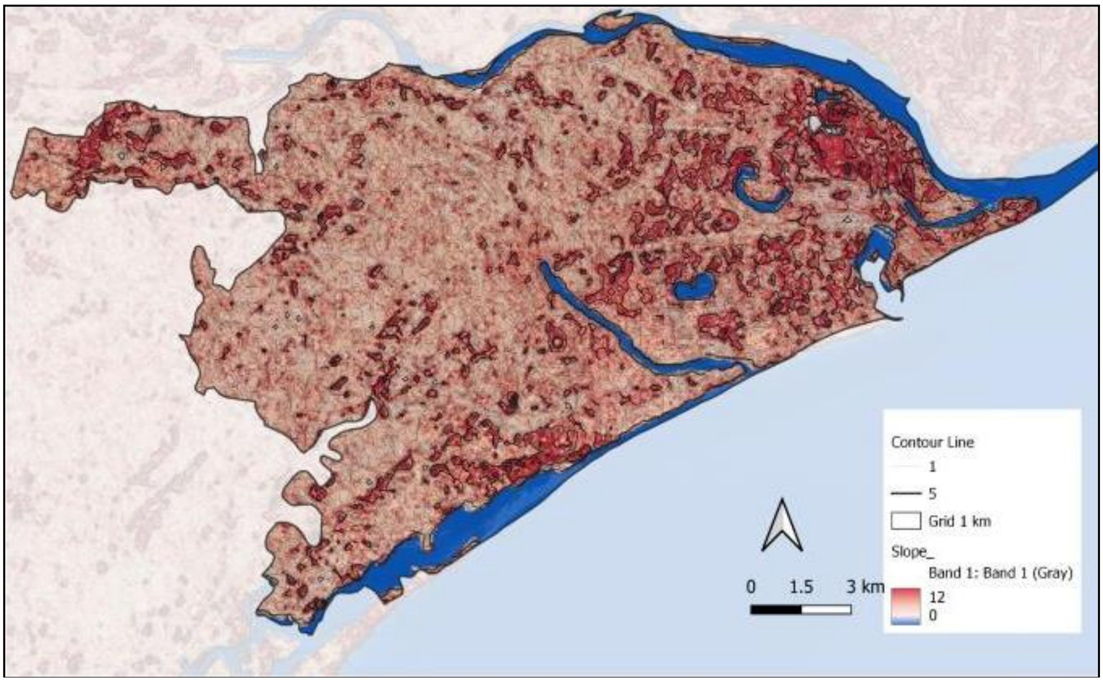


Fig. 8. Slope Map

Elevation and slope factor: The regions that are most vulnerable to floods are shaped by elevation and slope, which are crucial factors in determining flood vulnerability (Burayu, September 2023). Slope determines the velocity and duration of water movement, whereas elevation affects the direction and intensity of water flow. Floods usually happen when water moves quickly over smooth or level ground, while harder terrain takes longer to flood Steeper slopes are more likely to see surface runoff, but flat terrain is more likely to see waterlogging (Dalia Farghaly, 2016). The research area's SRTM DEM data provided the elevation and slope factor data, which were then divided into four different classes. Based on the features of its terrain, the class with the lowest value was ranked higher at 4, while the class with the highest value was ranked lower at 1, indicating that it was more vulnerable to surface runoff. The Fig. 7 show the reclassified slope and elevation maps.

Drainage density factor: There is an inverse link between infiltrate and drainage density. Increased runoff within basin areas, especially in geologically erodible zones, is indicated by a higher drainage density. This lowers the risk of flooded areas (Gemechu Shale Ogato, 2020). As a result, when drainage density levels rises, the drainage density rating decreases. After the SRTM DEM's data for the drainage density factor was recovered, the strata were divided into four different groups. The class that had the lowest drainage density rating was ranked higher, at 4, indicating that it was more susceptible to flooding. On the other hand, the class with the highest drainage density score received a lower rank—1, indicating that it was less vulnerable to flooding. This shows the reclassified drainage density map factor.

Soil factor: The structure and infiltration capacity of soil are critical factors influencing its ability to absorb water, and these characteristics vary with different soil types. When the soil's infiltration capacity decreases, surface runoff increases, making flooding more likely. In this study, a soil type map was created using data from the Nigeria Geological Survey, categorizing the different soil types in the area.

Four main soil classes were identified: gravelly sandy clay loam, stony sandy clay, stony sandy loam, and gravelly sandy clay. Each soil type has different water absorption abilities, affecting how much water infiltrates the ground versus how much runs off, contributing to flood risk. To assess this, the soil types were ranked based on their potential to generate flooding. The soil with the highest flood-generating potential was given a rank of 4, while the soil with the lowest flood potential was ranked one (Munyai, 2019).

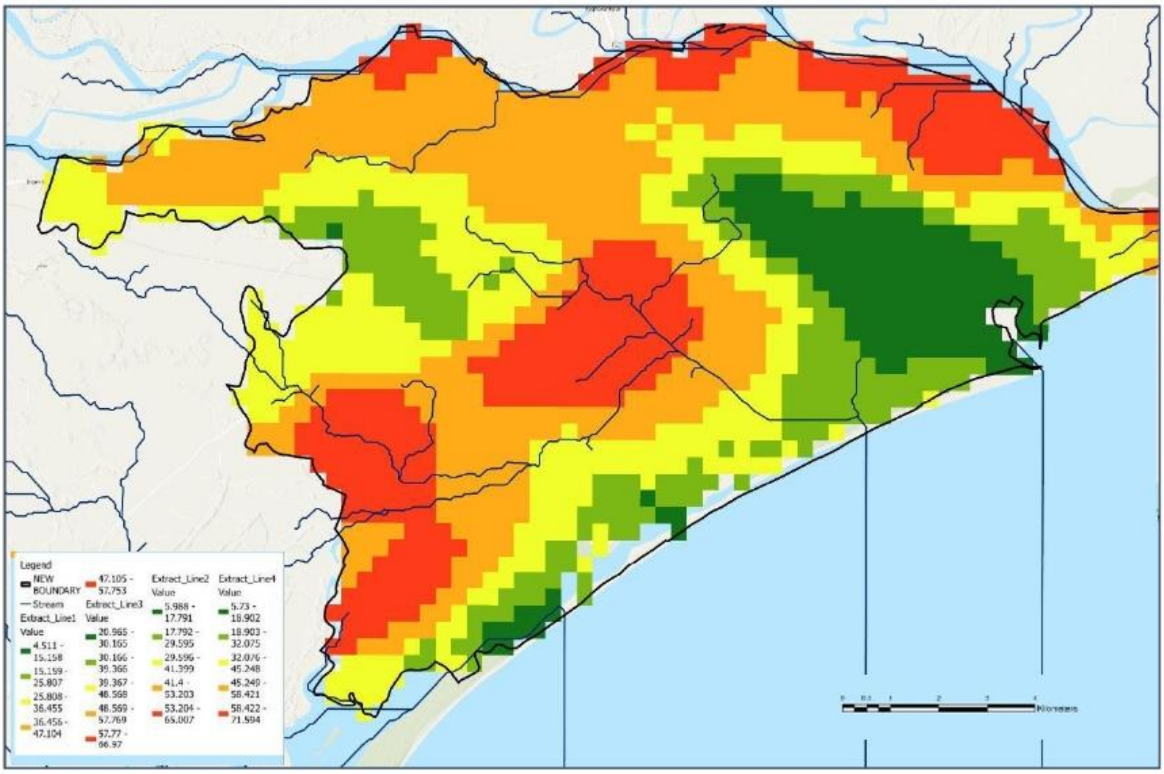


Fig. 9. Drainage Density Map

This ranking system helps determine which areas are more vulnerable to flooding, based on the soil's characteristics. Soils that drain poorly or have limited infiltration capacity (such as those with more clay) are more likely to cause flooding, while soils with better drainage (like sandy loams) are less likely to contribute to flood formation.

5. CRITERIA FOR RANKING

The results and ranking criteria were produced using multi-criteria ranking, as shown in the Table 2 below, where relatives weights of criteria, where R1 = LULC, R2 = RAINFALL, R3 = ELEVATION, R4 = SLOPE, R5 = DRAINAGE DENSITY, R6 = SOIL. Weight values are absolute numbers between 0 and 1 that represent the priorities (Sensing, September 2024). When using a weighted linear combination, the overall weights are assumed to add up to 1. When an element has a higher weight value, it impacts the overall research more. The rainfall component has the largest weights, as seen from the factor weights obtained for this study region, showing that it affects more floods in the area than the other elements.

Table 2. Summary of vulnerability weights and ranking

	R1	R2	R3	R4	R5	R6	Weights	Percent (%)
R1	0.20	0.20	0.20	0.20	0.20	0.20	0.20	**20**
R2	0.35	0.35	0.35	0.35	0.35	0.35	0.35	**35**
R3	0.11	0.11	0.11	0.11	0.11	0.11	0.11	**11**
R4	0.11	0.11	0.11	0.11	0.11	0.11	0.11	**11**
R5	0.15	0.15	0.15	0.15	0.15	0.15	0.15	**15**
R6	0.08	0.08	0.08	0.08	0.08	0.08	0.08	**8**
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**100**

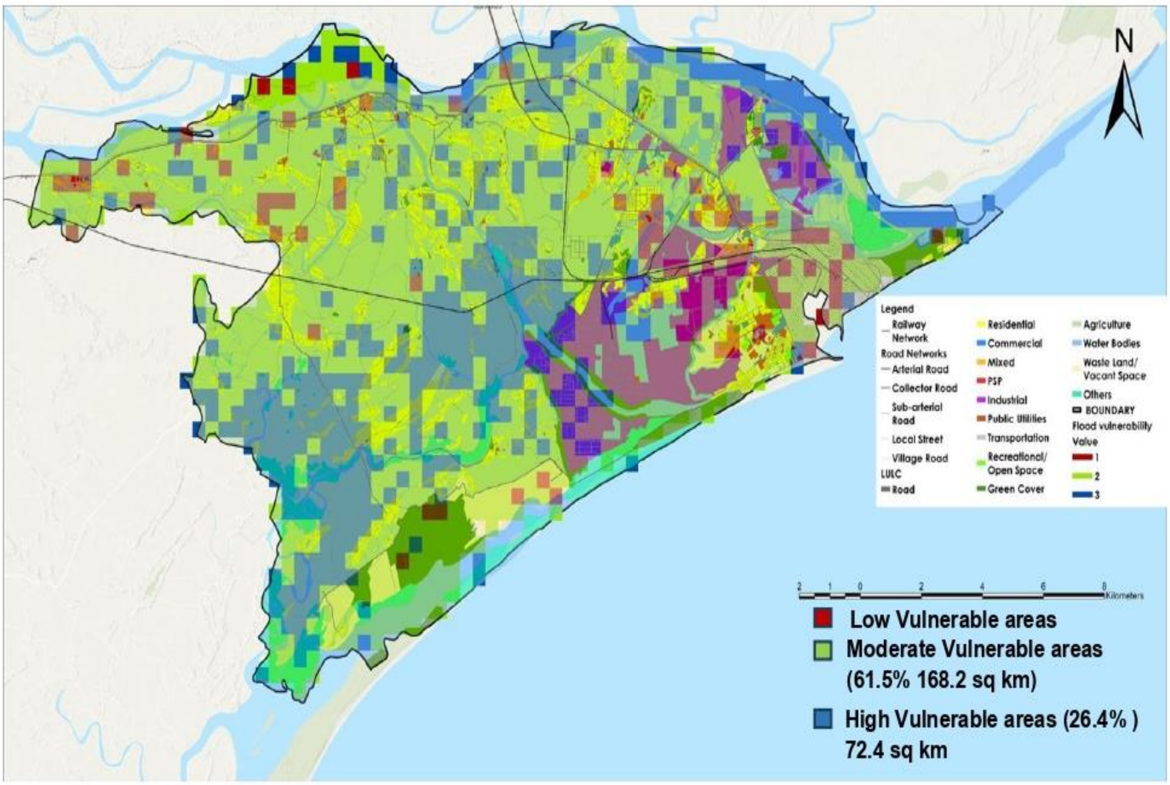


Fig. 10. Flood Susceptibility Map

Flood Vulnerability mapping for Paradip: In our research, we used a methodical approach in our research area to evaluate the characteristics that make a place vulnerable to flooding. A four-tier vulnerability scale was used to rate these elements according to their perceived importance, with weights ranging from 1 (least important) to 4 (most important). To model flood susceptibility zones, we combined different map layers in the last phases of spatial analysis using the weighted overlay index method. A thorough flood vulnerability map was produced by overlaying the classed layers in ArcGIS after a multi-criteria evaluation with weights given to each factor was completed (Kaoje, 17th May, 2017). Within the study area, the overlay analysis's conclusion identified four unique risk zones: flood zones with high, moderate, and low levels of vulnerability. The results indicate that the low vulnerability area occupied 12.1% (33.4 Sq km), a moderate vulnerability in 61.5% (168.2 Sq km), and high vulnerability in 26.4% of (72.4 Sq km).

Comparing the flood susceptibility map and the proposed master plan of Paradip (2030): In a comparative study of the Paradip Master Plan for 2030 and a flood susceptibility map (Swain, 2020), significant discrepancies were identified through overlay analysis, revealing critical vulnerabilities in the proposed development plan. The analysis found that 12.3% of the entire study region, which includes areas designated in the master plan for future development, falls within zones highly susceptible to flooding. This highlights potential challenges for long-term planning and development in the area (Swain, 2 December 2020).

Of this flood-prone portion, 3.22% of the total industrial area designated in the master plan is at risk of flooding. This raises concerns about the resilience and sustainability of industrial infrastructure, which could face significant operational disruptions or damage from flood events.

Similarly, 8.78% of the proposed residential zones are vulnerable, threatening the safety of communities living in these areas. This exposes a significant portion of the population to potential flood hazards, highlighting the need for more robust flood mitigation strategies or revisions to the residential planning areas.

In addition, 0.2% of areas earmarked for Public and Semi-Public (PSP) use—such as schools, hospitals, and other essential services—are also at risk. This could affect vital public infrastructure, which is critical during flood events for emergency response and recovery.

Demographic forecasts for 2031 indicate that 13 villages, comprising a population of 46,104 residents, will be directly affected by these flood-susceptible zones. The findings emphasize the urgent need for integrating flood risk management into future urban and regional planning for Paradip, with potential adjustments to land use and development zones to protect both infrastructure and the local population.

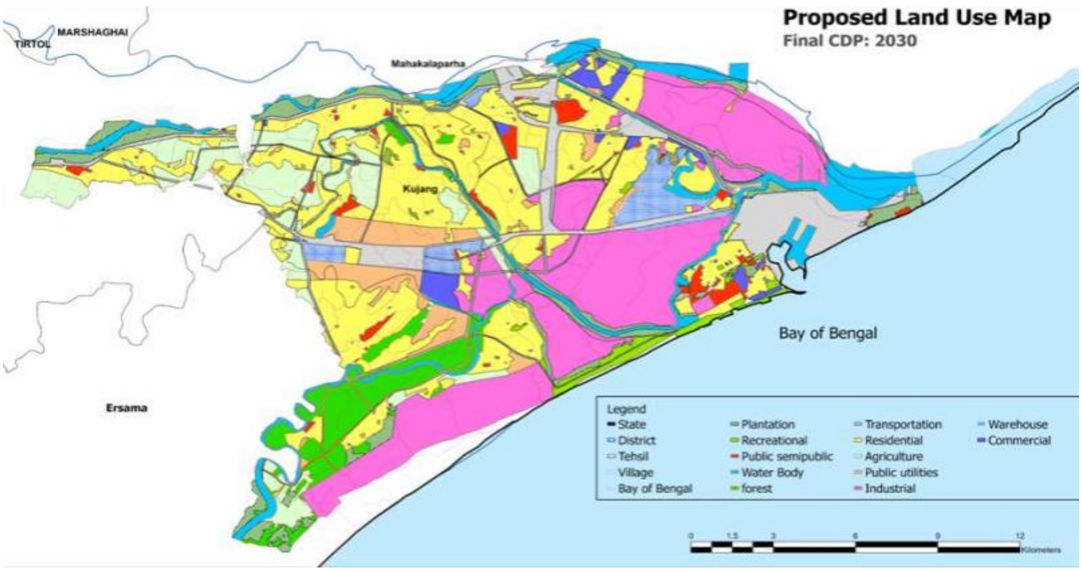


Fig. 11. Proposed Masterplan of Paradip 2030

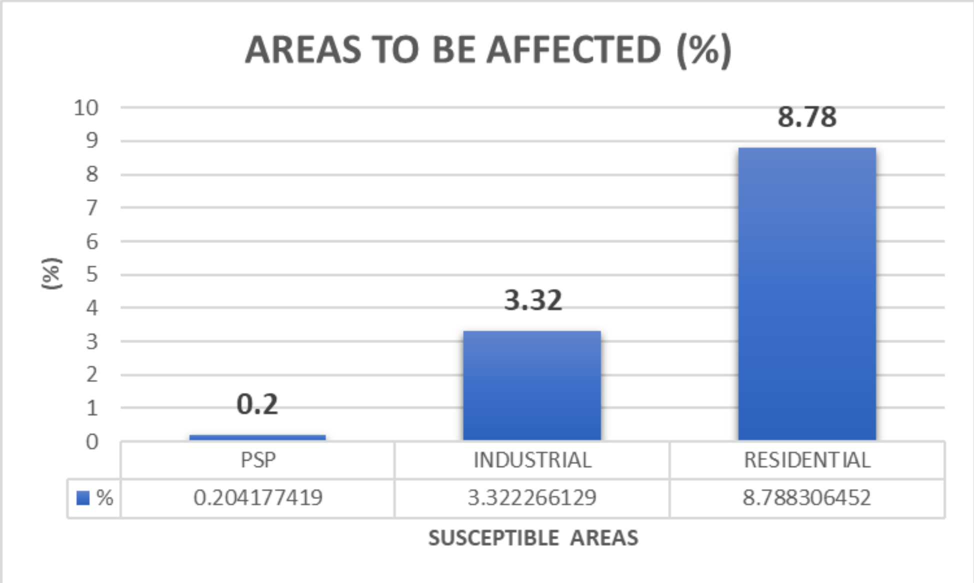


Fig. 12. Graphical presentation showing affected areas

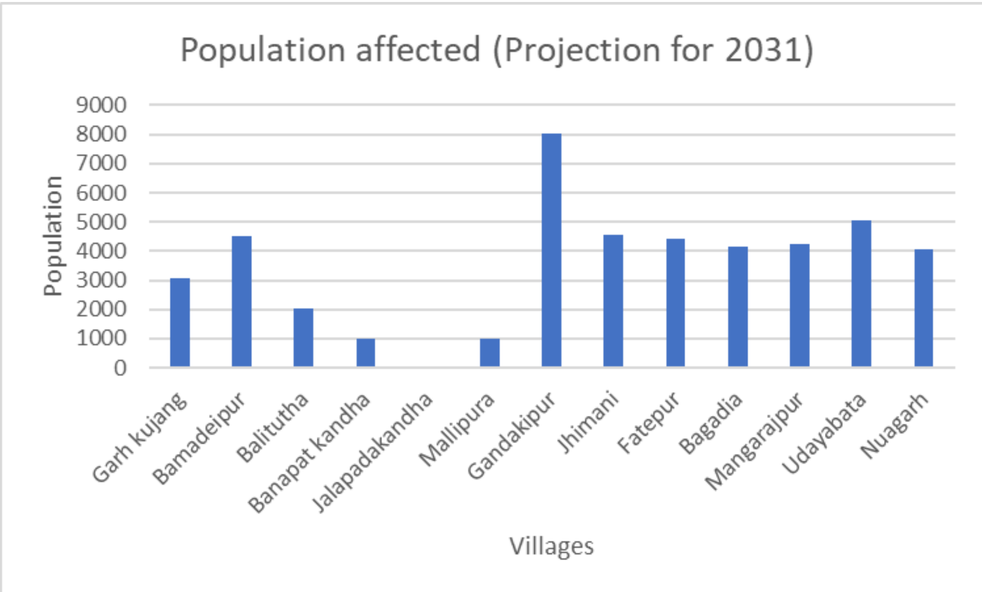


Fig. 13. Graphical presentation showing the affected population

6. CONCLUSIONS

In conclusion, by creating a thorough map of flood vulnerability shows the various levels of flood risk, our study effectively accomplished all three of its goals. This information is extremely beneficial in preventing the potential effects of flood catastrophes in the area and protecting the lives and property of the people living in Paradip. The results of the mapping of flood vulnerability clearly categorize the area, with 26.4% (72.4 Sq km) having high susceptibility, 61.5% (168.2 Sq km) having moderate vulnerability, and 12.1% (33.4 Sq km) showing low vulnerability. These discoveries must be addressed to protect the community's safety and well-being in flood-prone locations.

Several important things to ponder based on our analysis:

Locations Risked by Floods: The susceptibility map makes it evident which places are more likely to flood. Because of the possibility of flooding, it is best to avoid large-scale development initiatives in these areas. For planners, carriers, and emergency services, flood vulnerability maps are an invaluable tool that facilitates a thorough evaluation of flood risk. Planners in particular need to assess risks in light of potential outcomes to take appropriate measures to mitigate the problem. Given the discussion that came before it, using flood risk mapping as a key element of flood control strategies has a lot of potential to lower damages in regularly impacted places. Delineating likely inundated areas within a given catchment is made possible by the integration of flood frequency analysis with GIS. This study highlights how well GIS and remote sensing technologies work to categorize and identify regions in the study area that are at different risks of floods. The paper concludes with recommendations for resolving the flooding problem in the Paradip study region.

1. **Residential Zone:** The proposed master plan's allocation of residential buildings in flood-prone zones poses a significant risk to public safety. It is recommended that these areas be reassessed and relocated to safer zones. Where relocation is not feasible, flood-resistant building designs, elevated structures, and the incorporation of green infrastructure, such as permeable pavements and urban wetlands, should be implemented to mitigate flood impacts. Additionally, early warning systems and evacuation plans need to be integrated into the master plan for efficient emergency response during floods.
2. **Industrial Zone:** Establishing industrial zones in flood-prone areas could lead to severe environmental damage, infrastructure losses, and business disruptions. To prevent these risks, industrial development should be redirected to areas with lower flood vulnerability. In cases where industries must operate in flood-prone zones, stringent regulations should be enforced, including flood-proofing of facilities, the creation of retention ponds, and the construction of protective levees. Emergency containment plans for hazardous materials must be developed to avoid contamination during floods.
3. **Population Safety:** The planned development in flood-prone areas presents significant concerns for the safety and well-being of residents and workers. To minimize potential casualties and injuries, the master plan should prioritize the relocation of populations from high-risk zones. Disaster preparedness initiatives, such as community education programs on flood risks and safety protocols, should be introduced. Establishing safe shelters and ensuring proper access to healthcare and emergency services are also crucial components of a flood-resilient community.
4. **Infrastructure and Transport:** Key infrastructure, including roads, bridges, and utilities, should be designed with flood resilience in mind. Raising critical infrastructure above flood levels, implementing sustainable drainage systems, and ensuring that transport networks remain functional during flood events are essential for maintaining connectivity and access to essential services during emergencies.
5. **Flood Mitigation and Climate Resilience:** To build long-term resilience, the master plan should incorporate comprehensive flood mitigation strategies, such as the creation of buffer zones along rivers, afforestation programs to enhance natural water absorption, and the restoration of mangroves and wetlands to act as natural flood barriers. These measures, combined with investments in climate resilience, will help mitigate the impact of extreme weather events and reduce long-term risks to both urban and rural areas.

In conclusion, a critical review and revision of the proposed master plan for Paradip, based on the flood susceptibility map, are essential to reduce possible risks to the population, environment, and economy. Relocating residential and industrial areas as well as bringing flood mitigation and climate resilience plans into effect may be necessary for this.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Argaz, A. (2019). Flood hazard mapping using remote sensing and GIS tools: A case study of. *Journal of Materials and Environmental Sciences*, 171-181.

Farghaly, E. E. D. (2016). Towards sustainable land uses within the Elbe River biosphere reserve in Lower Saxony, Germany by means of TerraSAR-X images. *Journal of Geoscience and Environment Protection*.

Das, S. (2011). Examining the storm protection services of mangroves of Orissa during the 1999 cyclone. *Economic & Political Weekly*, 60-69.

Ogato, G. S. (2020). Geographic information system (GIS)-based multicriteria analysis of flooding hazard and risk in Ambo Town and its watershed, West. *Journal of Hydrology: Regional Studies*.

Halder, B. (2023). Large-scale flood hazard monitoring and impact assessment on landscape: Representative case study in India. *Sustainability*.

Ministry of Environment, F. A. (2019). *CRZ notification 2019*. Ministry of Environment, Forest and Climate Change, India.

Munyai, R. B. (2019). An assessment of flood vulnerability and adaptation: A case study of Hamutsha-Muungamunwe village, Makhado municipality. *Jamba*.

Ouma, Y. O. (2014). Urban flood vulnerability and risk mapping using integrated multi-parametric AHP and GIS: Methodological overview and case study assessment. *Water*.

Raufu, I. O. (2023). Application of remote sensing and geographical information system (GIS) in flood vulnerability mapping: A scenario of Akure South, Nigeria. *International Journal of Environment and Geoinformatics*, 90-100.

Raufu, I. O. (2023). Application of remote sensing and geographical information system (GIS) in flood vulnerability mapping: A scenario of Akure South, Nigeria. *International Journal of Environment and Geoinformatics*.

Relative sea level trend 500-106 Paradip, India. (2021). Retrieved from https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=500-106

Simulated historical climate & weather data for Paradip. (2023). Retrieved from https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/paradip_india_1260393

Joseph, K. (2000, June). The application of coastal regulation zones in coastal management: Appraisal of Indian experience. *Ocean & Coastal Management*, 515-526.

Kaoje, I. U. (2017, May 17). Urban flood vulnerability mapping of Lagos, Nigeria. *International Journal of Science and Technology*, 224-236.

Swain, K. C. (2020, December 2). Flood susceptibility mapping through the GIS-AHP. *International Journal of Geo-Information*.

Centre, O. S. (2021, June 1). CRZ zones.

Ramakrishnan, R. (2023, January). Coastal vulnerability map, Odisha, India: A satellite-based approach to develop two-dimensional vulnerability maps. *Regional Studies in Marine Science*.

Burayu, D. G. (2023, September). Identifying flood vulnerable and risk areas using the integration of analytical hierarchy process (AHP), GIS, and remote sensing: A case study of southern Oromia region. *Urban Climate*.

Sensing, J. O. (2024, September). Assessment of flood risk in the high rainfall coastal area of Cuddalore Taluk, Southeast India, using GIS-based analytic hierarchy process techniques. *Journal of the Indian Society of Remote Sensing*.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/125060