Implementing GIS and Analytical Hierarchy Process for Cyclone Shelter Mapping of Vijayawada, Andra Pradesh: A Weighted Overlay Approach

Krishna Reddy M.[1]*, Bhavani B.[2], Bhogayya Naidu G.[3], Samarthi Praveen[4], Ravi Kumar Kallakunta[5] and Ravi Degala[6]

1. Department of Electronics and Communication Engineering, G. Pullaiah College of Engineering and Technology, Kurnool, Andhra Pradesh, INDIA
2. Department of Civil Engineering, Institute of Aeronautical Engineering, Dundigal, Hyderabad, Telangana, INDIA
3. Department of Civil Engineering, Vignana Bharathi Institute of Technology, Hyderabad, Telangana, INDIA
4. Department of Civil Engineering, CVR College of Engineering, Hyderabad, Telangana, INDIA
5. Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Guntur, Andhra Pradesh, INDIA
6. Department of Mechanical Engineering, Chaitanya Bharathi Institute of Technology (A), Gandipet, Hyderabad, Telangana, INDIA

*krishnareddymaddikeras@gmail.com

Abstract

Vijayawada, a rapidly expanding urban hub in Andhra Pradesh, has seen significant population growth, rising from 2,104,000 in 2021 to 2,291,000 in 2024. This growth has increased the city's vulnerability to cyclonic events, as evidenced by the severe impacts of recent cyclones like Phethai (2018), Hudhud (2014) and Michaung (2023). These events have caused widespread flooding, power outages and infrastructure damage. To bolster cyclone preparedness, this study utilizes a Geographic Information System (GIS) integrated with the Analytical Hierarchy Process (AHP) to determine optimal locations for Cyclone Shelters in Vijayawada. The analysis incorporates nine critical parameters: elevation, slope, roughness, Hillshade, proximity to roads and rivers, land use land cover, aspect and wind characteristics (speed and direction). Each parameter was re-scaled into five suitability classes and weighted accordingly, with distance from roads (15%), proximity to water bodies (14%) and elevation (13%) receiving the highest weights. Additionally, a Windrose diagram was developed using WRPLOT software, analyzing wind speed and direction data collected at 50-meter intervals from January 1, 2022, to July 31, 2024. This wind pattern analysis, with speeds classified into six classes and calms recorded at 1.52%, provided crucial insights for Shelter placement. The site suitability assessment for cyclone shelters in Vijayawada has been conducted, categorizing the land into five classes: not suitable, less suitable, moderately suitable, suitable and highly suitable.

The resulting suitability map is a critical resource for disaster management, aiming at bolstering Vijayawada's resilience to future cyclones and safeguarding its rapidly growing population. This study underscores the value of integrating GIS-based Analytic Hierarchy Process (AHP) techniques with wind pattern analysis to enhance disaster preparedness and optimize shelter placement, ensuring a strategic and effective response to potential cyclone threats.

**** Author for Correspondence***

Keywords: Cyclone preparedness, GIS-AHP, Windrose diagram, Site suitability mapping and Disaster management.

Introduction

Cyclones are among the most devastating natural disasters, posing significant threats to life, property and infrastructure, particularly in urban centers and coastal regions. Effective cyclone preparedness is crucial in mitigating the impact of these storms and one critical aspect is the strategic placement of shelters. The use of Geographic Information Systems (GIS) and the Analytical Hierarchy Process (AHP) has emerged as a powerful approach to enhancing cyclone preparedness through site suitability mapping for shelters. GIS provides a robust platform for integrating various spatial datasets such as topography, land use, population density and historical cyclone tracks. By analyzing these factors, GIS helps identify areas most vulnerable to cyclone impacts and those best suited for shelter placement.

The AHP, on the other hand, is a multi-criteria decision-making tool that assists in prioritizing these factors based on their relative importance. By conducting pairwise comparisons of criteria such as elevation, proximity to population centers and accessibility, AHP generates weighted values that reflect the significance of each criterion[23]. The weighted overlay technique in GIS allows these AHP generated weights to be applied across spatial datasets, resulting in a composite suitability map. This map highlights optimal locations for cyclone shelters, balancing factors like safety, accessibility and population needs[8].

The integration of GIS and AHP in this context not only enhances the accuracy and reliability of shelter site selection but also empowers disaster management agencies to make informed decisions, ultimately improving the resilience of communities against cyclonic events[17].

Vijayawada, known as the business capital of Andhra Pradesh, has seen significant urban growth in recent years. With a population increase from 2,104,000 in 2021 to 2,291,000 in 2024, the city's rapid expansion underscores its

https://doi.org/10.25303/187da01013

economic vitality but also highlights its vulnerability to natural disasters, particularly cyclones. The impact of recent cyclonic events such as Cyclone Phethai (2018) and Cyclone Michaung (2023), has exposed the need for improved disaster preparedness. Effective cyclone shelter mapping is critical in ensuring the safety of Vijayawada's residents, particularly in densely populated and low-lying areas.

The steady population growth in Vijayawada, driven by urbanization and economic development, has increased the city's exposure to cyclonic events. Historical data reveals that Vijayawada has been affected by several significant cyclones including cyclones Phethai, Hudhud, Neelam and Michaung, all of which caused considerable damage through flooding, infrastructure destruction and power outages. As the city continues to grow, the risks associated with cyclones become more pronounced, necessitating proactive measures to enhance disaster resilience. The increasing frequency and severity of cyclones in Vijayawada, combined with its growing population, underscores the urgent need for effective disaster preparedness strategies[16].

Cyclone shelters play a crucial role in safeguarding lives during such events, but their effectiveness depends on optimal placement[9]. Given the complex topography and urban layout of Vijayawada, a systematic approach to shelter mapping is required to ensure that shelters are located in areas that maximize accessibility and safety[2]. This study aims to address this need by employing a GIS and AHP to identify the most suitable locations for cyclone shelters.

The primary objective of this study is to develop a GIS-AHP based methodology for mapping cyclone shelters in Vijayawada. This involves the integration of several critical parameters including elevation, slope, roughness, hillshade, proximity to roads and rivers, land use, aspect and wind characteristics (direction and speed) into a comprehensive suitability analysis. The detailed methodology used in the current study is shown in fig. 1. The ultimate goal is to produce a detailed shelter suitability map that can guide policymakers in making informed decisions about shelter placement, thereby enhancing the Vijayawada's overall disaster preparedness and resilience.

Study area

Vijayawada, formerly known as Bezawada, is located in the Krishna District of Andhra Pradesh, India, at coordinates 16.50° N latitude and 80.64° E longitude. The geographical location map of the Vijayawada is shown in figure 2 with the network of roads, rail and rivers. Spanning 61.88 square kilometers, it stands as the second-largest city in the State and is widely regarded as its business capital. Vijayawada is a key part of the Andhra Pradesh capital region and serves as the administrative hub for the NTR district. The city is situated along the banks of the Krishna River, framed by the Indrakeeladri Hills of the Eastern Ghats. This geographic setting not only enhances its scenic beauty but also significantly influences its climate and its exposure to natural hazards, particularly cyclones.

In addition to its economic importance, Vijayawada holds a prominent place in the cultural and religious landscape of Andhra Pradesh. The city is home to the Kanaka Durga temple, a major Hindu pilgrimage site located atop Indrakeeladri hill. The Krishna River, flowing through the city, plays a central role in various religious practices including the Pushkaram festival, which attracts thousands of devotees. Vijayawada's rich historical legacy includes landmarks such as the Mogalrajapuram and Akkana Madanna caves, which date back to the Vishnukundina dynasty, as well as the Malleswara temple, which features inscriptions from the Eastern Chalukyas. These cultural assets underscore the city's status as a key center for education and heritage in the region.

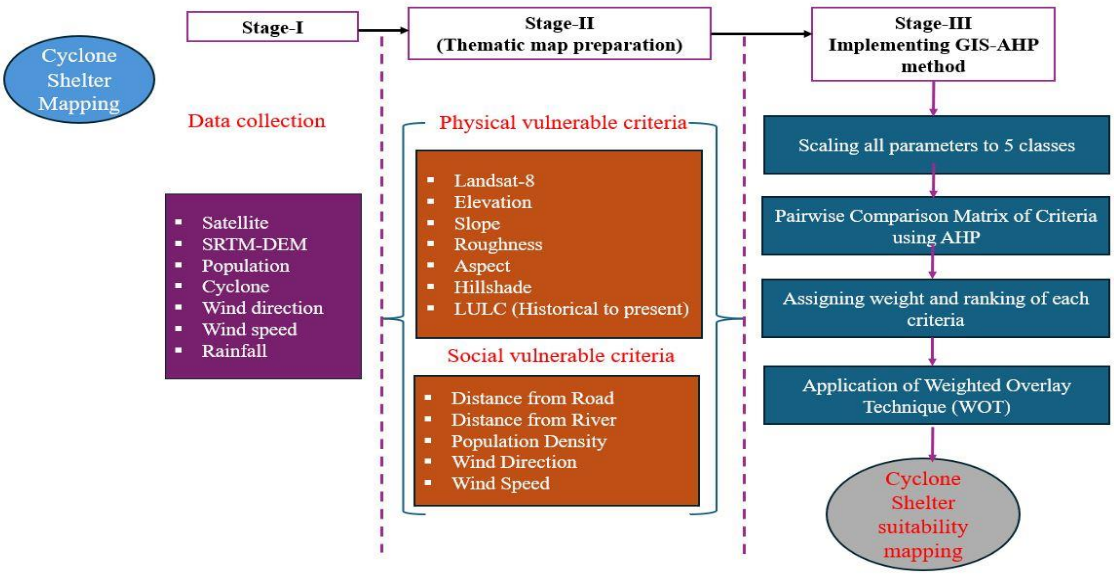

Fig. 1: Methodology used to develop the Cyclone Shelter site suitability mapping of Vijayawada

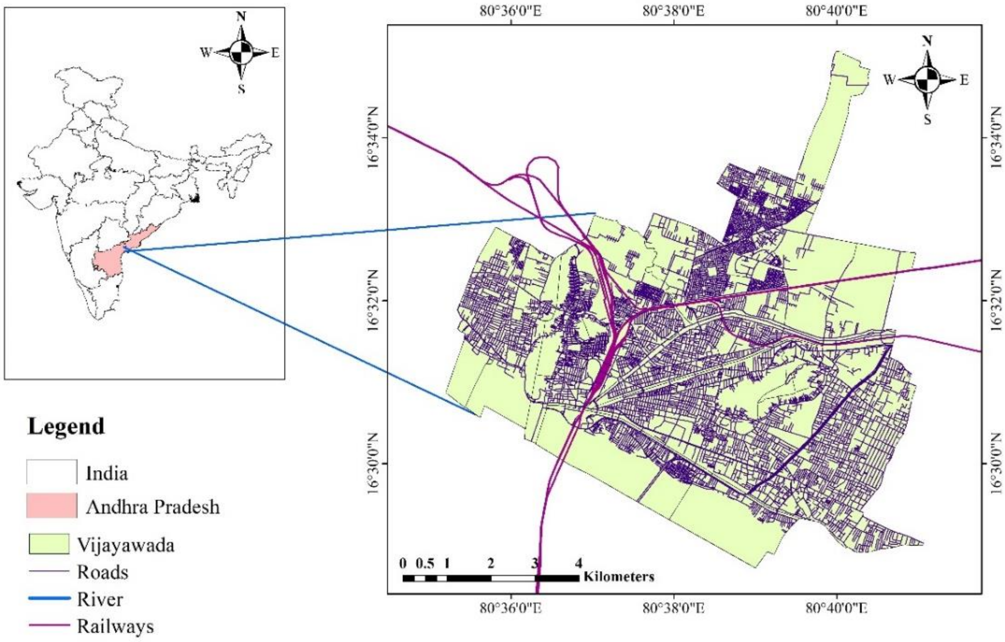

Fig. 2: Geographical location map of the Vijayawada with road, rail and river network

Fig. 3: Field and aerial photographs of different localities of Vijayawada during the 2024 floods

The climate of Vijayawada is classified as tropical wet and dry, characterized by significant temperature variations throughout the year. The city experiences an annual mean temperature ranging from 23.4°C to 34°C, with the hottest months being May, when temperatures often exceed 40°C. In contrast, the coldest months are December and January. The highest recorded temperature in Vijayawada was 48.8°C in May 2002, highlighting the city's vulnerability to extreme heatwaves. The city receives its annual rainfall from both the South-west and North-east monsoons, with an average precipitation of 977.9 mm. Monsoon rains often lead to flooding, especially in low-lying areas, a growing concern given the city's increasing population density and urban stretch. Vijayawada's low elevation, at just 11 meters above sea level, makes it particularly susceptible to flooding during cyclonic events.

The city is intersected by three major canals Eluru, Bandar and Ryves that originate from the Prakasam Barrage reservoir on the Krishna River. These canals are vital for the city's irrigation and water supply but also pose a risk during heavy rains, contributing to waterlogging and flood scenarios. In recent years, Vijayawada has been recognized as one of the fastest growing urban centers in India, with significant economic and population expansion projected to continue. According to Oxford Economics, it ranks among the top 10 fastest-growing cities globally, with expectations of a substantial increase in GDP by 2025. However, this rapid growth presents challenges, particularly regarding infrastructure and disaster preparedness.

The city's expanding urban footprint, coupled with its geographic and climatic conditions, heightens its vulnerability to natural disasters, especially cyclones. Consequently, there is an urgent need for effective disaster management strategies including the careful planning and placement of cyclone shelters, to safeguard the city's residents[14,15]. Vijayawada's unique combination of complex geography, deep cultural heritage and rapid urbanization makes it a critical area for disaster preparedness. Its exposure to cyclones, along with its economic and cultural significance, highlights the necessity of developing

https://doi.org/10.25303/187da01013

comprehensive strategies for cyclone shelter mapping and disaster management to ensure the safety and resilience of its growing population.

Cyclone History of Vijayawada: Vijayawada and its surrounding regions have been historically vulnerable to cyclonic events, with several significant cyclones impacting the area over the years. These events have varied in intensity and have caused widespread damage, emphasizing the need for effective disaster preparedness strategies. One of the notable cyclones was Cyclone Laila (2010) which brought heavy rainfall and strong winds, resulting in extensive flooding and landslides. The cyclone caused significant damage to homes, roads and agricultural fields, disrupting the lives of many residents. Cyclone Neelam (2012) followed, causing similar destruction with heavy rains leading to severe waterlogging and property damage. In 2014, Cyclone Hudhud primarily impacted Visakhapatnam but also brought heavy rainfall and strong winds to Vijayawada, leading to flooding in certain areas and disruptions in transportation and power supply.

Cyclone Phethai (2018) further highlighted the region's vulnerability, causing extensive damage to infrastructure, power lines and crops due to the heavy rainfall and strong winds it brought. Most recently, Cyclone Michaung (2023) underscored the ongoing threat of cyclones in the area. With wind speeds reaching up to 100 km/h, the cyclone caused severe flooding, particularly in low-lying areas (Fig. 3). The cyclone led to the evacuation of residents, cancellation of over 144 trains and widespread disruption. To analyze the wind patterns associated with these events, a Windrose diagram was developed using WRPLOT software, based on data collected at 50-meter intervals between January 1, 2022 and July 31, 2024. The wind speeds were classified into six classes: ≥ 11.10, 8.80-11.10, 5.70-8.80, 3.36-5.70, 2.10-3.36 and 0.50-2.10 m/s, with calms recorded at 1.52%. This analysis, as shown in figure 4, provides crucial insights into wind direction and speed, further informing the development of effective cyclone shelter mapping and disaster management strategies for the region.

Cyclone preparedness mapping through GIS-AHP integrated approach: Effective cyclone preparedness is crucial for mitigating the impacts of cyclonic events, particularly in vulnerable urban areas. GIS and AHP are powerful tools that have been increasingly adopted to enhance disaster preparedness and response strategies. GIS technology provides a robust platform for the integration and analysis of spatial data, enabling comprehensive assessment and visualization of risk factors associated with cyclones[10,11]. By mapping various data layers such as elevation, land use, infrastructure and population density, GIS facilitates the identification of high-risk zones and optimizes the placement of cyclone shelters[27]. This spatial analysis is essential for understanding the geographical distribution of hazards and ensuring that resources are allocated effectively to protect at-risk populations.

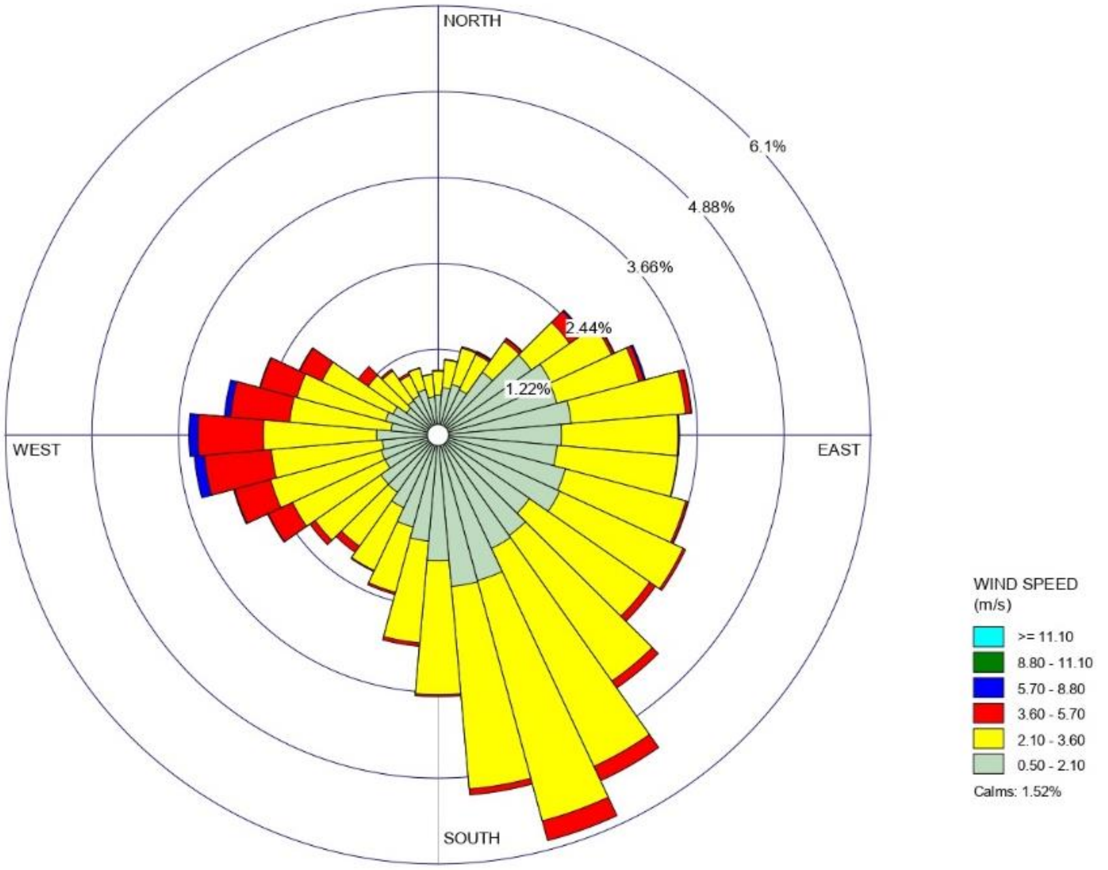

Fig. 4: Windrose diagram showing the wind direction and speed (m/s) of Vijayawada

Material ad Methods

AHP complements GIS by offering a structured decision-making framework that helps prioritize multiple criteria. This method involves decomposing complex decisions into simpler, hierarchical components and assigning weights to different criteria based on their importance[21]. In the context of cyclone preparedness, AHP can be used to evaluate factors such as proximity to flood-prone areas, accessibility of shelter locations and the robustness of existing infrastructure[4,6]. By integrating these criteria, AHP helps to determine the optimal locations for cyclone shelters, ensuring that they are placed where they will provide the greatest benefit and protection.

The integration of GIS and AHP has been demonstrated to significantly enhance cyclone preparedness strategies. Faizan et al[8] applied GIS and AHP to identify optimal cyclone shelter locations in coastal cities, highlighting the effectiveness of combining spatial analysis with multi-criteria decision-making. Their study considered factors such as land elevation, land use and proximity to critical infrastructure which are vital for ensuring the shelters' accessibility and resilience. Similarly, Allafta and Opp[3] utilized GIS-based multi-criteria analysis for flood risk management, illustrating how spatial data combined with decision-making frameworks can improve infrastructure planning and disaster response. Their research emphasized the importance of incorporating environmental and infrastructural data to develop robust risk management strategies[2,3,22].

Overall, the use of GIS and AHP in cyclone preparedness provides a sophisticated approach to disaster management. These tools enable a thorough analysis of spatial and environmental factors, facilitating the strategic placement of cyclone shelters and enhancing overall disaster resilience[1]. By leveraging GIS for spatial data analysis and AHP for prioritizing criteria, communities can develop more effective and responsive strategies to manage the impacts of cyclonic events[7].

Results and Discussion

In the current study of cyclone shelter mapping for Vijayawada, several key thematic maps including elevation, slope, aspect, hillshade and land use land cover (LULC) play crucial roles in identifying optimal sites for cyclone shelters. Each of these themes provides essential information that contributes to the overall suitability analysis, ensuring that shelters are placed in locations that maximize safety and accessibility. Elevation is a critical factor in cyclone shelter mapping as it directly influences flood risk, particularly in coastal or riverine areas. In Vijayawada, where the maximum elevation reaches 447 meters and minimum is just 11 meters, areas with higher elevation are generally preferred for shelter placement to avoid the risks associated with flooding during cyclonic events. Elevated areas reduce the likelihood of water inundation and provide a safer refuge for affected populations. In this study, the elevation map helps in identifying areas that are naturally safer from flooding. Slope is another important factor, with a maximum slope of 49.1 degrees in the study area. Steeper slopes are generally unsuitable for shelter placement due to the risks of landslides and structural instability during heavy rainfall and strong winds associated with cyclones[5]. Gentle slopes are preferred as they provide stable ground for constructing shelters, ensuring both the safety of the shelter and ease of access for evacuees. The slope map aids in excluding steep, high-risk areas from consideration in shelter site selection. The spatial distribution of elevation and slope of Vijayawada is shown in figure 5.

Aspect, which indicates the direction of the slope, is significant in cyclone shelter mapping due to its influence on wind exposure and solar radiation. With the maximum aspect value reaching 359 degrees in Vijayawada, understanding the orientation of the slope helps in assessing the potential wind load and thermal comfort of the shelter locations. Shelters placed on slopes facing away from the predominant wind direction during a cyclone are less likely to experience direct wind impacts, enhancing their resilience. The aspect map (Fig. 7) assists in identifying these safer orientations for shelter placement. Hillshade, with a maximum value of 255, is used to model the terrain and understand the effects of sunlight and shadows on the landscape. While it is primarily a visualization tool, Hillshade is useful in understanding how terrain features like hills and valleys might affect wind flow and shelter exposure during a cyclone. Areas that are heavily shaded or have complex terrain might experience turbulent wind patterns, making them less ideal for shelter placement. The hillshade map (Fig. 7) contributes to a more nuanced understanding of terrain impacts on shelter suitability.

The LULC maps prepared for the years 1985, 1995, 2005 and 2023 and shown in figure 8, provide insights into how the land in Vijayawada has been utilized and transformed over time. The main land use categories identified as cropland, built-up land, shrubland, fallow land, plantations and water bodies each have different implications for shelter mapping. Built-up areas are often preferred for shelters due to their proximity to population centers, but these areas must also be assessed for vulnerability to flooding and other hazards[13]. Conversely, water bodies and areas prone to flooding are unsuitable for shelter placement. The LULC analysis is crucial for understanding how land use changes might affect the suitability of shelter sites over time.

Population forecasting and density map: The population of Vijayawada has experienced consistent growth over the years, reflecting its emerging status as a major urban center in India. To forecast its future population growth, the Incremental Increase Method was applied. The mathematical expression of this method is given by eq. 1:

$$P_n = P + n.X + \{n(n+1)/2\} \times Y \quad (1)$$

where P_n = Population after n^{th} decade, X = average increase and Y = incremental increase. This method, which is a modification of the arithmetical increase method, is particularly suitable for towns experiencing an increasing rate of growth[19]. It factors in both the average population increase per decade and the incremental growth rate, offering a more nuanced projection for medium-sized cities like Vijayawada.

Based on historical data, the population grew from 2,104,000 in 2021 to 2,291,000 in 2024. Using this method, the average increase in population (X) and the incremental increase (Y) were calculated to predict future growth. The population is projected to continue rising steadily, reaching approximately 2,469,000 by 2027 and 3,006,166 by 2038. By 2050, the population is expected to reach around 3,385,166 (Fig. 6). This method provides a more accurate projection by accounting for both the growing population and the increasing rate of growth, thus offering a comprehensive forecast for the city's urban development trajectory[12].

Proximity to major roads and hospitals mapping: The city of Vijayawada boasts a well-established road network, spanning a total length of 1,264.24 km. This includes 1,230.00 km of municipal roads, 22.74 km managed by the Roads and Buildings (R&B) department and 11.50 km of National Highways. The city's main arterial roads, M.G. Road and Eluru Road, serve as vital lifelines, facilitating smooth traffic flow.

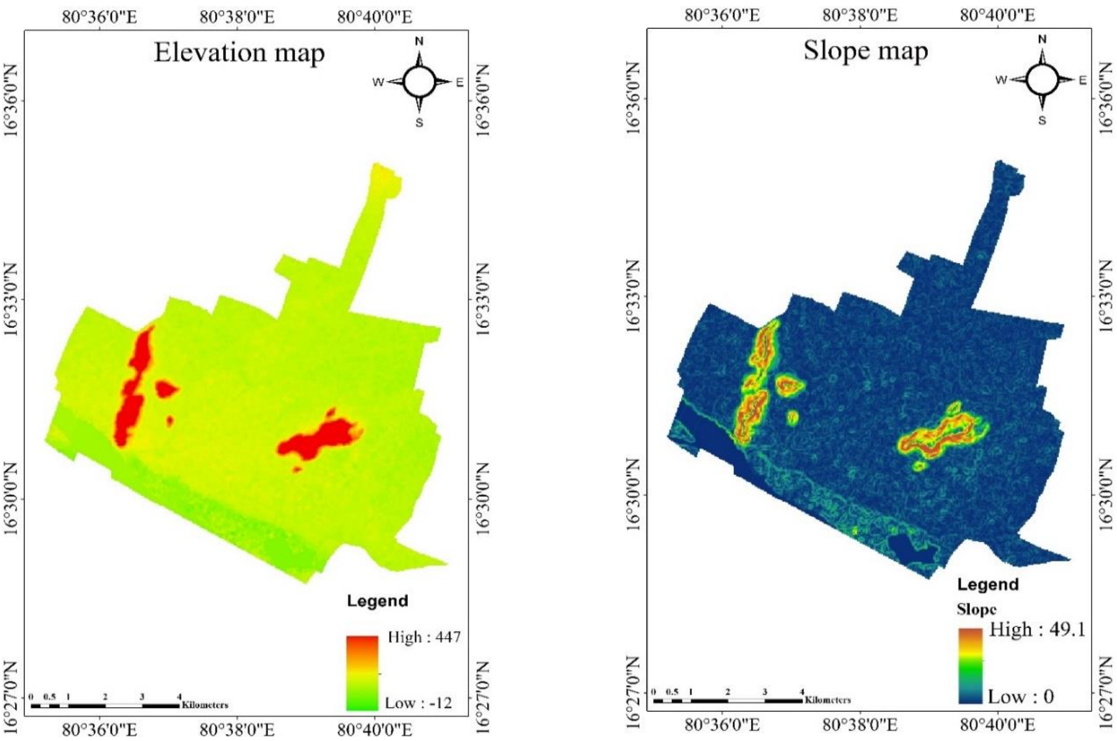

Fig. 5: Spatial distribution of elevation and slope of the Vijayawada

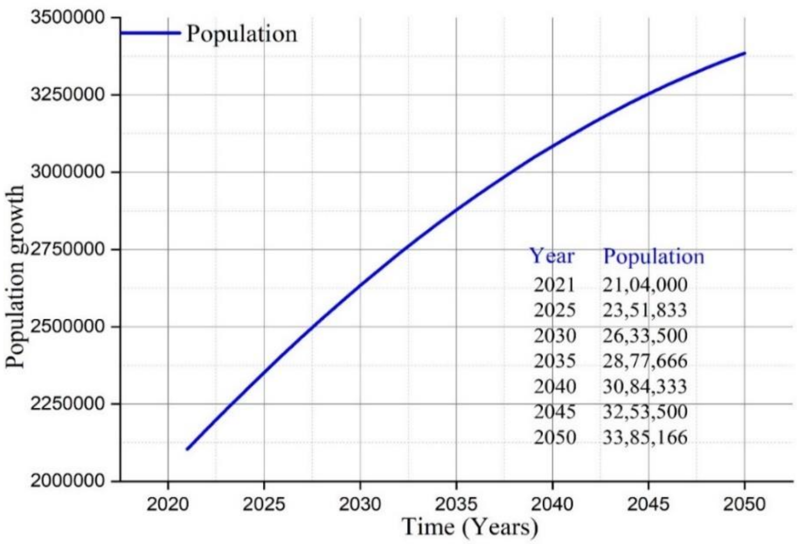

Fig. 6: Population trend analysis of Vijayawada till the year 2050

Benz Circle, one of the busiest junctions, handles an average of 57,000 vehicles daily and serves as the intersection for two major national highways, NH 16 and NH 65. In addition to its road infrastructure, Vijayawada is traversed by three canals originating from the Prakasam barrage reservoir such as Eluru, Bandar and Ryves further contributing to the city's complex urban landscape. A detailed proximity analysis was conducted, focusing on healthcare accessibility. A comprehensive list of 73 major and minor hospitals across Vijayawada was used for mapping with their precise latitudes and longitudes recorded mapping (Table 1). This data, along with the proximity of roads, rivers and other critical infrastructure, was used to develop a distance-to-hospitals map and Euclidean distance[26]. This mapping exercise provides crucial insights for urban planning and emergency response, highlighting the accessibility of healthcare services in relation to Vijayawada's road network and waterways.

Table 1
List of hospitals with their location details

S.N.	Name and specialization of the Hospital	Latitude	Longitude
1	Vijetha Health Care and Research Centre (P) Ltd.	17.35	78.57
2	Amma Hospital	16.52	80.61
3	Charithasri Hospitals Ltd.	16.51	80.63
4	Global Multispeciality Hospital	16.51	80.65
5	Meenakshi Eye Hospital	16.51	80.65
6	M.J Naidu Superspeciality Hospital	16.51	80.64
7	Andhra Hospitals (Vijayawada) Pvt. Ltd.	16.51	80.63
8	S.K. Super Speciality Laser Eye Hospital	16.51	80.65
9	Help Hospital Pvt. Limited	16.52	80.65
10	Sridevi Eye Hospital	16.52	80.64
11	Vijayawada Multispeciality Hospital (A Unit of Durgab)	16.51	80.64
12	Aswinee Nursing Home	16.52	80.64
13	Sandhya Hi-Tech Vision Care Centre	16.51	80.65
14	Dr. NTR Gastro Care Pvt. Ltd.	16.51	80.65
15	City Cancer Centre	17.42	78.49
16	Purna Heart Institute	16.51	80.64
17	Vijay Orthopaedic and Accident Care	16.51	80.63
18	Singari Ent Hospital and Research Centre	16.51	80.65
19	Arun Kidney Centre	16.51	80.65
20	Giridhar Ent Hospital	16.51	80.65
21	Sai Swetha Mother and Child Hospital	16.51	80.65
22	Heart Care Centre	16.51	80.65
23	Sumanth Hospitals	16.51	80.64
24	Vignesh Hospitals	16.51	80.63
25	Latha Super Speciality Hospital	16.51	80.64
26	Lifeline Trimurthy Hospital	16.52	80.64
27	Anu Hospitals	16.51	80.65
28	Metro Super Speciality Hospital	16.51	80.63
29	Kamala Orthopaedic Nursing Home	16.51	80.64
30	Peoples Clinic	16.51	80.65
31	Vijaya Super Speciality Hospital	16.51	80.64
32	Vasan Eye Care Hospital Vijayawada	16.51	80.63
33	Sunrise Hospitals (Unit of Ns Health Care Services Pvt.)	16.51	80.64
34	Sateesh Gastro and Liver Centre	16.51	80.63
35	Mother & Child Hospital & Family Hospital	16.51	80.64
36	Sankara Eye Hospital (A Unit of Kanchi Kama Kothi Me)	16.51	80.63
37	Krishna Gastro and Liver Centre and Safe Hospital	16.51	80.64
38	Sathish Urology and Andrology Centre	16.51	80.63
39	Gaayathri City Eye Hospital	16.51	80.64
40	Nori Mother and Child Hospital	16.52	80.63
41	HCG Curie City Cancer Centre (A Unit of Healthcare Glo)	16.52	80.67
42	Nagarjuna Hospitals Ltd.	16.49	80.68
43	Time Hospitals Private Limited	16.49	80.68

44	Liberty Hospital	16.49	80.67
45	Dr. Ramesh Cardiac and Multispeciality Hospital (P) Lt	16.51	80.66
46	Lakshmi Eye & Maternity and Laparoscopy Hospital	16.50	80.66
47	Vennela Mother and Child Hospital	16.50	80.66
48	Sentini Hospitals Pvt. Ltd.	16.51	80.67
49	Aayush NRI LEPL Healthcare Pvt. Ltd.	16.52	80.68
50	Rainbow Children's Hospital - Vijayawada	16.51	80.64
51	Chaitanya Eye Hospital	16.50	80.65
52	Pinnamaneni Care Hospital	16.50	80.65
53	Rich Hospital	16.51	80.63
54	Usha Cardiac Centre Limited	16.51	80.65
55	SVR Neuro Hospital	16.50	80.64
56	Maxivision Eye Hospitals Pvt. Ltd.	16.50	80.64
57	Royal Hospitals	16.51	80.64
58	Trust Hospital	16.50	80.66
59	Sri Venkateswara Nursing Home	16.55	80.63
60	Praveen Cardiac Centre	16.51	80.65
61	Krishna Institute of Medical Sciences Ltd., Vijayawada	16.50	80.65
62	Positive Pulse Hospitals	16.50	80.66
63	Suraksha Hospital	16.51	80.65
64	Prashanth Hospital	16.50	80.64
65	K.K Hospital	16.51	80.64
66	Ravi's American Cancer Care	16.50	80.65
67	Srikara Hospitals (A Unit of Venkateshwara Ortho Heal)	16.50	80.65
68	Capital Hospitals (A Unit of Capital Tree Health Care Pvt. Ltd.)	16.48	80.70
69	Kamineni Health Care Pvt. Ltd.	16.50	80.70
70	Andhra Hospitals (Bhavanipuram) Pvt. Ltd.	16.54	80.58
71	Dr. Pinnamaneni Siddhartha Institute of Medical Science	16.50	80.65
72	Ravi Mother and Child Hospital	16.51	80.65
73	Vennela Nethralayam-Vinukonda	16.06	79.74

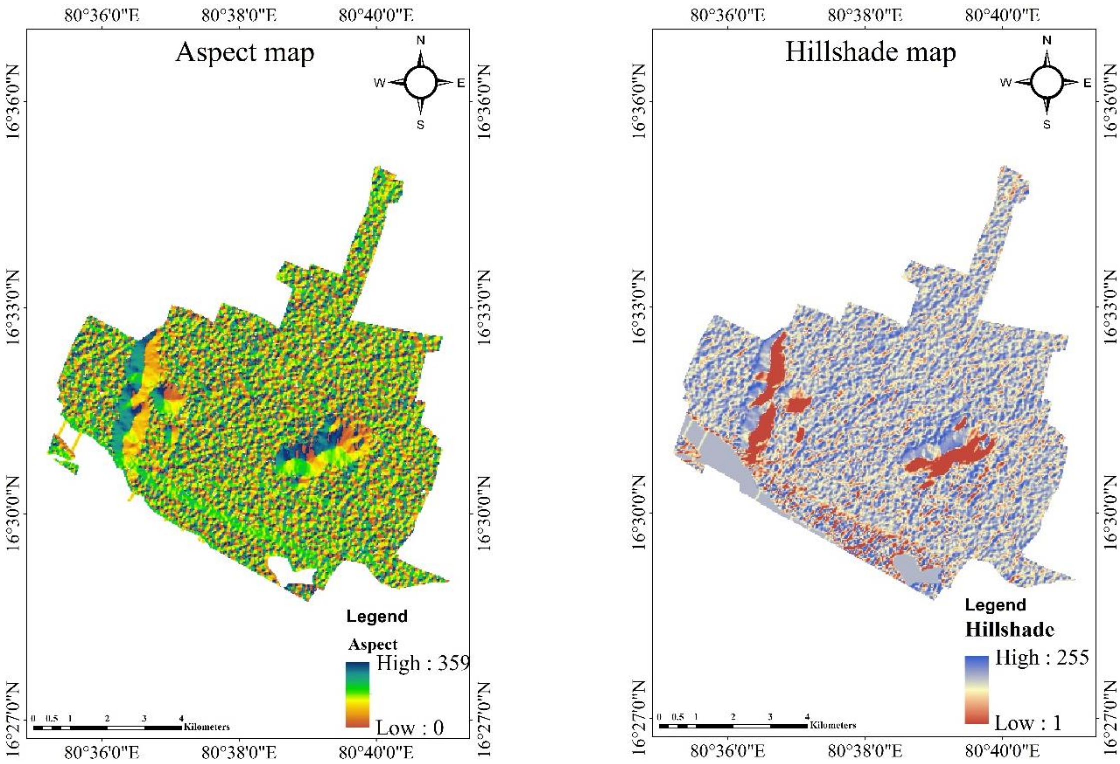

Fig. 7: Spatial distribution of Aspect and Hillshade mapping of Vijayawada

Implementation of Weighted Overlay Techniques: After preparing and analyzing these thematic maps, each theme was re-scaled into five classes to standardize the data and to allow for comparison. The GIS-based weighted overlay technique was then implemented, where each theme was assigned a weight according to its importance in cyclone shelter suitability[28]. This approach ensures that the final shelter suitability map reflects a balanced consideration of all factors, providing a comprehensive and reliable guide for shelter placement in Vijayawada. The integration of these themes through weighted overlay not only enhances the accuracy of the site selection process but also supports effective disaster management planning, ensuring that shelters are optimally located to protect vulnerable populations during cyclonic events.

Implementing AHP techniques within a GIS framework provides a powerful approach for cyclone shelter mapping, especially in regions like Vijayawada where multiple environmental factors must be considered. AHP serves as a structured decision-making tool that assigns relative weights to various spatial data layers based on their significance in determining the suitability of sites for cyclone shelters. This method involves pairwise comparisons of factors such as elevation, slope, aspect, hillshade and land use land cover (LULC), resulting in a hierarchical structure that reflects the impact of each factor on shelter suitability.

$$A = \begin{bmatrix} a11 & a12 \ldots\ldots & a1n \\ a21 & a22 \ldots\ldots & a2n \\ an1 & an2 \ldots\ldots & ann \end{bmatrix}, a_{ii} = 1, a_{ij} = \frac{1}{a_{ij}}, a_{ij} \neq 0 \quad (2)$$

In the AHP process, the importance of each factor is evaluated relative to others, with criteria organized hierarchically and rated on a scale from 1 to 9, indicating varying degrees of importance[18]. This comparative approach allows for the creation of a weighted matrix where each criterion is assigned a weight based on its relative influence on the decision-making process. Despite the inherent subjectivity in assigning these weights, the AHP method is recognized for its robustness and reliability, making it an ideal approach for regional studies like cyclone shelter mapping[20]. Once the weights are determined, the GIS-based weighted overlay technique (WOT) is used to integrate the spatial layers. All input layers are re-classified, rasterized and re-sampled to ensure consistency in pixel size and labeling. The weighted overlay analysis is then performed using the equation:

$$RI = \sum W_i R_j \quad (3)$$

In this equation, "W" represents the weight assigned to each layer, "R" is the rank assigned to each theme within a layer, "i" denotes the number of layers and "j" represents the number of themes within each layer. For cyclone shelter mapping, layers such as elevation, slope, aspect, hillshade and LULC are analyzed, with higher weights assigned to factors that significantly influence shelter suitability[24]. The resulting suitability map categorizes areas into different classes, with higher values indicating locations that are more suitable for shelter placement.

$$RI = W1 \times R1 + W2 \times R2 + W3 \times R3 + W4 \times R4 + W5 \times R5 + W6 \times R6 + W7 \times R7 + W8 \times R8 + W9 \times R9 \quad (4)$$

By integrating AHP-derived weights with GIS-based WOT, this methodology offers a comprehensive understanding of the region's suitability for cyclone shelters. The process allows for the systematic evaluation of multiple environmental and spatial factors, ensuring that the selected sites are both safe and accessible[25]. This approach not only enhances the accuracy of shelter mapping but also supports effective disaster preparedness, ultimately contributing to the safety and resilience of communities in cyclone-prone regions like Vijayawada. The assigned weights and ranking of each parameter with suitability class is summarized in table 2 and map showing the site suitability for cyclone shelter of Vijayawada is shown in figure 9.

Conclusion

This study presents a comprehensive approach to cyclone shelter site selection in Vijayawada by integrating GIS and AHP methodologies. Given the city's rapid urban expansion and increased vulnerability to cyclonic events, the analysis plays a vital role in disaster preparedness. By evaluating nine critical parameters such as proximity to roads, rivers, elevation and wind characteristics, this study creates a robust, data-driven suitability map for optimal cyclone shelter placement. Among the factors considered, distance from roads was the most influential, contributing 15% to the overall suitability. This emphasizes the crucial need for accessibility, ensuring that cyclone shelters are easily reachable during emergencies, especially when evacuation and rescue operations are time sensitive.

Proximity to water bodies, with a 14% influence, further highlighted the importance of avoiding flood-prone areas, as shelters near rivers or canals were deemed less suitable due to the heightened risk of inundation during heavy rains and storm surges. Elevation, with a 13% weight, was pivotal in identifying locations that are less exposed to wind and flooding, favoring higher ground for safer shelter placement. Population density and distance from the seashore, contributing 13% and 11% respectively, also factored the decision-making process. Areas with higher population densities were prioritized to ensure that shelters are placed where the greatest number of people can access them, while sites farther from the coast offered more protection from the direct impact of cyclones.

Parameters such as slope (10%), hillshade (10%) and land use land cover (9%) also played significant roles, further refining the suitability analysis by considering the physical landscape and land-use patterns. In addition to spatial factors, wind pattern analysis was integrated into the study using a Windrose diagram developed from wind speed and direction data collected between January 2022 and July 2024.

The analysis categorized wind speeds into six classes, with a notable observation that lower wind speeds predominated while calms were recorded at 1.52%.

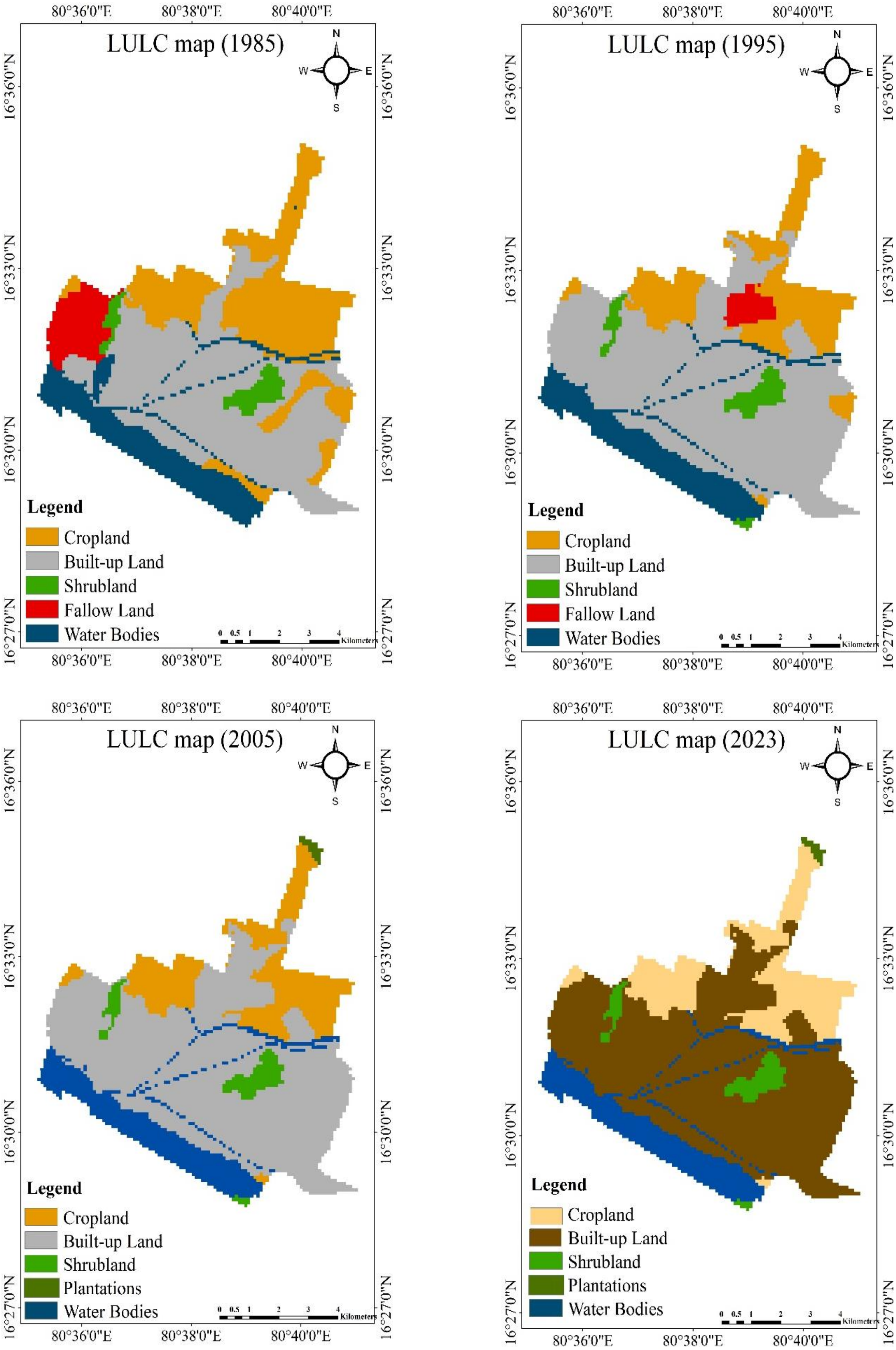

Fig. 8: Land Use Land Cover mapping of Vijayawada for four different decades showing the variation in the fields

Table 2
Rating and weightage of each variable used for mapping the Cyclone Shelter mapping over the Vijayawada

Parameter	Rescale	Suitability class	Ratings	% of influence
Distance from Road	1	Highly suitable	5	15
	2	suitable	4	
	3	Moderately suitable	3	
	4	Less suitable	2	
	5	Not suitable	1	
Elevation	1	Not suitable	5	13
	2	Less suitable	4	
	3	Moderately suitable	3	
	4	suitable	2	
	5	Highly suitable	1	
Slope	1	Less suitable	2	10
	2	Highly suitable	5	
	3	suitable	4	
	4	Moderately suitable	3	
	5	Not suitable	1	
Aspect	1	Highly suitable	1	5
	2	suitable	2	
	3	Moderately suitable	3	
	4	Less suitable	4	
	5	Not suitable	5	
Waterbody/river	1	Not suitable	1	14
	2	Less suitable	2	
	3	Moderately suitable	3	
	4	suitable	4	
	5	Highly suitable	5	
Hillshade	1	Very High	5	10
	2	High	4	
	3	Moderate	3	
	4	Low	2	
	5	Very Low	1	
Population density	1	Not suitable	1	13
	2	Less suitable	2	
	3	Moderately suitable	3	
	4	suitable	4	
	5	High suitable	5	
Distance from the seashore	1	Not suitable	1	11
	2	Less suitable	2	
	3	Moderately suitable	3	
	4	suitable	4	
	5	High suitable	5	
Land Use Land Cover	1	Moderately suitable	3	9
	2	suitable	2	
	3	Highly suitable	5	
	4	Less suitable	4	
	5	Not suitable	1	

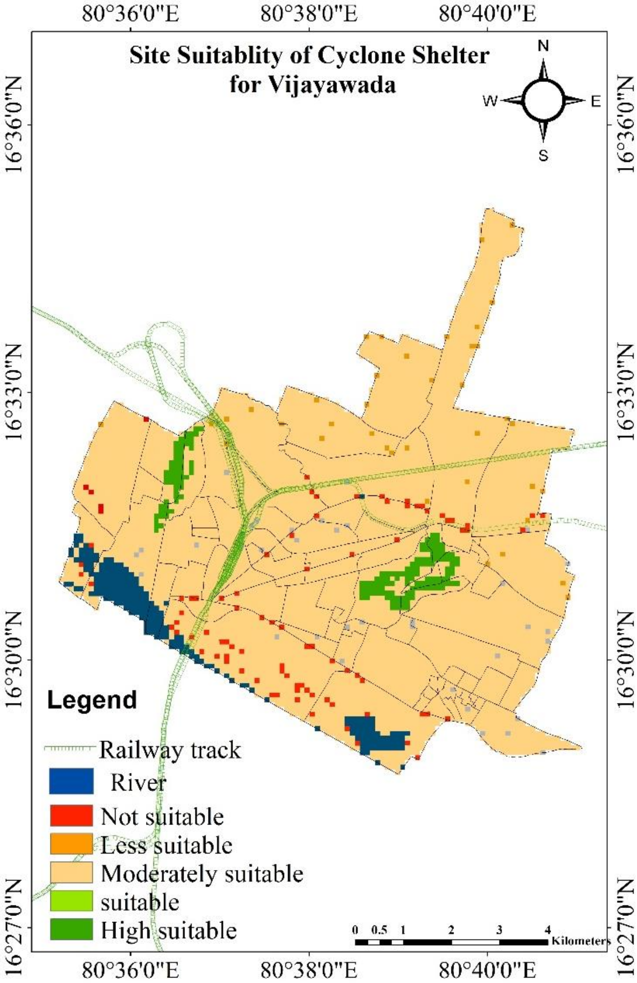

Fig. 9: Site suitability of Cyclone Shelter for Vijayawada, Andhra Pradesh, India

This information was critical in identifying areas less vulnerable to high wind exposure, guiding the strategic placement of shelters in safer zones. Overall, the study demonstrates the effectiveness of using GIS-AHP techniques combined with wind pattern analysis to develop a data-driven, strategic cyclone shelter suitability map. This map serves as a valuable resource for enhancing disaster management and resilience in Vijayawada, ensuring that shelters are optimally placed to protect its growing population. The methodology can be adapted and applied to other cyclone-prone regions, offering a scalable solution to enhance disaster preparedness and to reduce the risk to vulnerable communities.

References

1. Akash S.H., Sarkar S.K., Bindajam A.A., Kumari R., Talukdar S. and Mallick J., Assessment of coastal vulnerability using integrated fuzzy analytical hierarchy process and geospatial technology for effective coastal management, *Environmental Science and Pollution Research*, **3(1)**, 1-18 **(2023)**

2. Ali S.A., Khatun R., Ahmad A. and Ahmad S.N., Assessment of cyclone vulnerability, hazard evaluation and mitigation capacity for analyzing cyclone risk using GIS technique: A study on Sundarban biosphere reserve, India, *Earth Systems and Environment*, **4(2)**, 71-92 **(2020)**

3. Allafta H. and Opp C., GIS-based multi-criteria analysis for flood prone areas mapping in the trans-boundary Shatt Al-Arab basin, Iraq-Iran, *Geomatics, Natural Hazards and Risk*, **12(1)**, 2087-2116 **(2021)**

4. Botlagunta M., Botlagunta M.D., Myneni M.B., Lakshmi D., Nayyar A., Gullapalli J.S. and Shah M.A., Classification and diagnostic prediction of breast cancer metastasis on clinical data using machine learning algorithms, *Scientific Reports*, **13(1)**, 485-492 **(2023)**

5. Chaudhury S., Krishna A.N., Gupta S., Sankaran K.S., Khan S., Sau K., Raghuvanshi A. and Sammy F., [Retracted] Effective Image Processing and Segmentation-Based Machine Learning Techniques for Diagnosis of Breast Cancer, *Computational and Mathematical Methods in Medicine*, **2022(1)**, 6841334 **(2022)**

6. Das T., Talukdar S., Shahfahad Baig M.R.I., Hang H.T., Siddiqui A.M. and Rahman A., Assessing vulnerability to cyclones in coastal Odisha using fuzzy logic integrated AHP: towards effective risk management, *Spatial Information Research*, **32(3)**, 277-295 **(2024)**

7. Devi M.D., Juliet A.V., Hariprasad K., Ganesh V., Ali H.E., Algarni H. and Yahia I.S., Improved UV Photodetection of Terbium-doped NiO thin films prepared by cost-effective nebulizer spray technique, *Materials Science in Semiconductor Processing*, **127(1)**, 105673 **(2021)**

8. Faizan M.O., Hudait M., Sengupta K. and Chowdhury B.R., Flood susceptibility mapping using MCDM-AHP approach and geospatial techniques-a study of Hyderabad District, Telangana, India, *International Journal of Hydrology Science and Technology*, **16(2)**, 204-221 **(2023)**

9. Hoque M.A.A., Phinn S., Roelfsema C. and Childs I., Assessing tropical cyclone risks using geospatial techniques, *Applied Geography*, **98(4)**, 22-33 **(2018)**

10. Hoque M.A.A., Pradhan B., Ahmed N., Ahmed B. and Alamri A.M., Cyclone vulnerability assessment of the western coast of Bangladesh, *Geomatics, Natural Hazards and Risk*, **12(1)**, 198-221 **(2021)**

11. Hossain K.T. and Rahman M.H., Delineating the service area of cyclone shelter and vulnerable households using network analyst tool: a case study on Southkhali Union of Bagerhat District, Bangladesh, *Journal of the Asiatic Society of Bangladesh, Science*, **44(2)**, 137-148 **(2018)**

12. Lee Y.H., Keum H.J., Han K.Y. and Hong W.H., A hierarchical flood shelter location model for walking evacuation planning, *Environmental Hazards*, **20(4)**, 432-455 **(2021)**

13. Malagavelli V., Angadi S., Prasad J.S.R. and Joshi S., Influence of metakaolin in concrete as partial replacement of cement, *Int J Civil Eng Technol*, **9(7)**, 105-111 **(2018)**

14. Mitra R., Saha P. and Das J., Assessment of the performance of GIS-based analytical hierarchical process (AHP) approach for flood modelling in Uttar Dinajpur district of West Bengal, India, *Geomatics, Natural Hazards and Risk*, **13(1)**, 2183-2226 **(2022)**

15. Naveen Kumar R., Suresh Goud J., Srilatha P., Manjunatha P.T., Rani S.P., Kumar R. and Suresha S., Cattaneo–Christov heat flux model for nanofluid flow over a curved stretching sheet: An application of Stefan blowing, *Heat Transfer*, **51(6)**, 4977-4991 **(2022)**

16. Nijaguna G.S., Manjunath D.R., Abouhawwash M., Askar S.S., Basha D.K. and Sengupta J., Deep learning-based improved WCM technique for soil moisture retrieval with satellite images, *Remote Sensing*, **15(8)**, 2005-09 **(2023)**

17. Poompavai V. and Ramalingam M., Geospatial analysis for coastal risk assessment to cyclones, *Journal of the Indian Society of Remote Sensing*, **41(3)**, 157-176 **(2013)**

18. Rajakumari S., Minnu A. and Sarunjith K.J., Determination of vulnerable zones along Brahmapur coast, Odisha using AHP and GIS with validation against multiple cyclones, *Environmental Monitoring and Assessment*, **194(4)**, 278 **(2022)**

19. Rani B.M.S., Majety V.D., Pittala C.S., Vijay V., Sandeep K.S. and Kiran S., Road Identification Through Efficient Edge Segmentation Based on Morphological Operations, *Traitement du Signal*, **38(5)**, 1503-1508 **(2021)**

20. Reddy P.V., Reddy B.V. and Rao P.S., A numerical study on tube hydroforming process to optimize the process parameters by Taguchi method, Materials Today: Proceedings, **5(11)**, 25376-25381 **(2018)**

21. Saaty T.L., Decision making for leaders: the analytic hierarchy process for decisions in a complex world, RWS publications **(2001)**

22. Saranya A., Sivakumar V., Satheeshkumar S. and Logeshkumaran A., 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*, Doi: 10.1007/s12524-024-01998-9 **(2024)**

23. Sarker S. and Adnan M.S.G., Evaluating multi-hazard risk associated with tropical cyclones using the fuzzy analytic hierarchy process model, *Natural Hazards Research*, **4(1)**, 97-109 **(2024)**

24. Sen S., Nayak N.C., Mohanty W.K. and Keshri C.K., Vulnerability and risk perceptions of hydrometeorological disasters: A study of a coastal district of Odisha, India, *Geo Journal*, **88(1)**, 711-731 **(2023)**

25. Sherly M.A., Karmakar S., Parthasarathy D., Chan T. and Rau C., Disaster vulnerability mapping for a densely populated coastal urban area: an application to Mumbai, India, *Annals of the Association of American Geographers*, **105(6)**, 1198-1220 **(2015)**

26. Subramanian M., Lv N.P. and Ve S., Hyperparameter optimization for transfer learning of VGG16 for disease identification in corn leaves using Bayesian optimization, *Big Data*, **10(3)**, 215-229 **(2022)**

27. Tomaszewski B., Judex M., Szarzynski J., Radestock C. and Wirkus L., Geographic information systems for disaster response: A review, *Journal of Homeland Security and Emergency Management*, **12(3)**, 571-602 **(2015)**

28. Vijay V., Reddy C.S.K., Pittala C.S., Vallabhuni R.R., Saritha M., Lavanya M., Venkateswarlu S.C. and Sreevani M., ECG performance validation using operational transconductance amplifier with bias current, *International Journal of System Assurance Engineering and Management*, **12(2)**, 1173-1179 **(2021)**.

(Received 20th September 2024, accepted 19th October 2024)