A Geo-Spatial approach for the assessment of coastal submergence vulnerability by climate change: A case study from Bapatla District, A.P. State, India

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Abstract

The Indian Meteorological Department's (IMD) Cyclone e-Atlas was examined for historical storm data and predicted routes. Based on this report, it was identified that the Bapatla region is one of the most vulnerable areas to frequent cyclones and storm surges on the East Coast of India. The ArcMap 10.8.1 software was used to generate slope, drainage and base maps in the study area. The generated maps were applied to develop the Digital Elevation Model (DEM). The 610 villages and towns studied for coastal inundation encompass an area of about 176.49 sq. km. The DEM identified that most of the Bapatla District seaside village settlements are at high risk from coastal submergence.

440 villages, comprising of 151.45 sq. km, are unaffected by coastal submergence, making up 72% of the studied area. 170 settlements, with an area of approximately 25 sq. km, are most vulnerable to coastal submergence, accounting for 27% of the studied area. This area is extremely susceptible to major hydro-met catastrophes.

Keywords: Digital Elevation Model, Natural Disasters, GIS, Cyclone, Vulnerability.

Introduction

The evolution and reactions of coastal areas located at the frontier are influenced by several factors including interactions along the coastline and the complex interplay between human and naturally-induced pressures[6]. Most of the damage from climate change is expected to be felt in low-lying coastal areas because of the acceleration of sea level rise (SLR) and the severity of extreme weather and climate events such as heavy precipitation, floods and storm surge[10,11]. Every year, India suffers devastating losses due to cyclones, one of the many natural disasters that strike the country. Worldwide, tropical weather systems with winds of at least 34 knots are referred to as tropical cyclones (TCs), also called "cyclones" (62 kmph). These are the most extreme weather phenomena in the tropics and intense low-pressure zones in the linked Earth-atmosphere system cause them. The most apparent effect of sea level rise (SLR) due to storms, tsunamis, or even global sea level change is the permanent inundation of coastal areas, which will significantly affect the coastal zone's ecosystem and economy[9]. Long-term flooding shifts coastlines and destroys coastal ecosystems and infrastructure. Inundation can also intensify coastal flooding by exposing more land to the impact of storm waves and it can amplify coastal erosion by transporting deposited sediments further offshore.

Coastal areas are already vulnerable to the adverse effects of salinity intrusion and rising sea levels; subsequent rises in sea level would only exacerbate the problems these people face in their everyday lives and ability to make a living[15,18]. Remote sensing technology has been widely used to map the coastline and update maps frequently. It has also been used to monitor and assess changes in coastal habitats[3]. The devastating effects of storm surges from tropical cyclones have recently been a serious concern for coastal communities. A full risk modeling assessment is necessary to back up the storm surge mitigation measures[2]. Current and projected storm surge wave heights can be obtained with the help of a GIS-based risk model.

Human activities and infrastructure in coastal areas are constantly at risk from environmental factors, climate change and extreme weather events like storm surges. Even if there are many studies to analyze these events, the use of GIS-based technologies is restricted; coastal inundation is considered one of the most deadly and damaging natural disasters[22]. The average annual rate of sea level rise along the East Indian coast is 1.353%, while on the West Coast, it is only 0.372 %. The Government of India produced a report titled "Assessment of Climate Change over the Indian Region," acknowledging climate change as one of the country's most critical challenges[13]. Cyclones cause widespread flooding, which results in significant crop losses and other problems[12].

India's population residing in East Coast is extremely susceptible to major hydro-met catastrophes and Andhra Pradesh is one of the states considered to be at risk from these tropical storms and related disasters[19]. The State of Andhra Pradesh has taken a severe beating from powerful cyclones like Daye, Titli, Fani, Jawad, Amphan, Gulab etc. Andhra Pradesh’s entire coast is not equally at risk from storm surges. The area most vulnerable to storm surges is between Nizampatnam in Guntur district and Machilipatnam in Krishna district. The recently formed Bapatla district, established on 4th April 2022, is also part of this vulnerable coastal stretch[5].

There is an immediate need to strengthen research on the vulnerability and adaptation of inhabitants in natural disaster-threatened areas, as natural catastrophes brought on by climate change have significantly impacted the sustainability of residents' livelihoods. As a result, it will be crucial to protect the shore and its inhabitants in the future with the help of a solid framework for risk analysis and mitigation techniques.

Study Area

The present study is focused on the newly formed district of Andhra Pradesh State i.e. Bapatla district, which has a coastline of about 95 km and comes under the highly vulnerable coastal stretch of Andhra coast. The study was carried out for an area of 25km buffer from the coastline (Fig. 1). The global location of Bapatla district is between 79o 51' 12″to 80o 54' 46″N latitude and 15o 36' 23″to 16o 16' 19″ of E longitude. Bapatla, Chirala and Repalle are the district's three revenue divisions and each has its own sub-collector. The Bapatla revenue division consists of 6 mandals, while the Chirala revenue division has 10 and the Repalle revenue division has 9 mandals. Each mandal contains various village and town settlements.

Material and Methods

Digital Elevation Model (DEM) data can be used to create a map of the area that will be inundated due to rising sea levels[17]. As a first step, the imagery of the study area was acquired from Google Earth, a free software for satellite imagery acquisition. The satellite imagery of the study area is a Landsat/Copernicus imagery that was captured on the 14th of December 2015. The satellite image shows a detailed Bird's eye view of the study area, which is highly useful for precise observation and analysis. With the help of ArcMap 10.8.1 software and a district boundary map from the local administrative department, a buffer of 25 km was prepared. The buffer was used to identify the settlements within a 25 km boundary from the coast. Then, in Google Earth, the settlements were digitized.

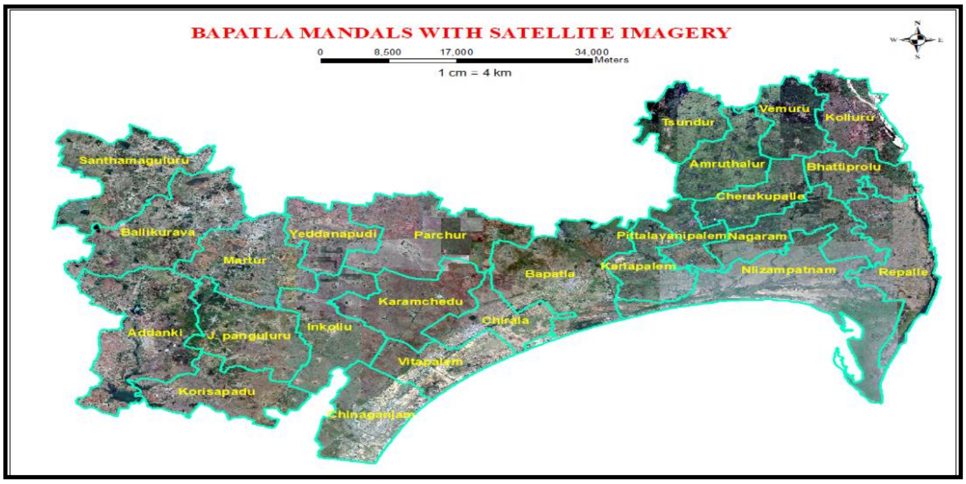

Fig. 1: Map showing the Mandals of Bapatla District.

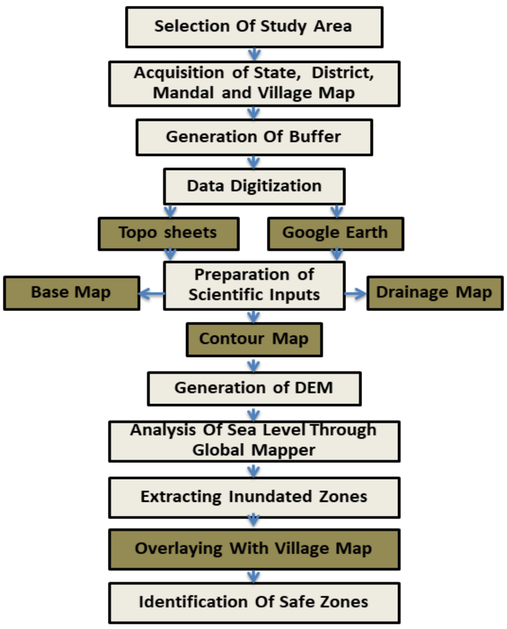

Fig. 2: Schematic diagram of the methodology

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The data that was required to prepare different kinds of maps (Base, location, drainage maps, etc.) for the study area was collected from other Topo sheets and Google Earth Pro. The data was analyzed and interpreted in Google Earth Pro, ArcMap 10.8.1 and Global Mapper. Digitizing surface features, making drainage, contour and surface maps, analyzing the maps and more are all part of the process for this study.

However, the preparation of contours and the generation of DEM are the most crucial procedures. To determine which locations will be inundated in the event of a rapid increase in sea levels, this study relies on a detailed examination of the digital elevation model (DEM). The flow chart of the methodology that we followed is described in fig. 2.

Preparation of Base Map: Multiple features, raster, or web layers can be combined to create a single base map. To put a map in context, a base map must be laid down first. Topo sheets and satellite images were used to compile the base map. The base map was drawn up with major built-up canals, roads, railroads etc. Different inputs were also digitized from Google Earth Pro and then processed in ArcMap 10.8.1. The satellite imagery from landsat/Copernicus was used to prepare the drainage map of the study area. The map shows various rivers and streams that flow across the district. All of the major rivers and streams were scanned using a variety of topo sheets and Google Earth. Together, GIS data and drainage maps provide crucial assistance in the strategic management and oversight of water resources[14].

Preparation of Contour: The data for the preparation of contours was obtained from Google Earth. The data was processed in ArcMap 10.8.1; the contours were prepared for the study area with one-meter intervals. Contours are a collection of lines found on maps that show mountains, valleys and other landforms. In other words, contours are the representative features of elevation of a place from mean sea level. If the contours are widely spaced, it means that the surface has a low elevation or is flat. Whereas if the contours are closely spaced, the surface has a high elevation or the surface is very steep.

Generation of Digital Elevation Model (DEM): Data on the elevations of the land surface are needed in order to study the effects of coastal inundation[20]. DEMs are computer representations of the topographic features of the Earth that are free of vegetation, man-made structures and other surface features. DEM data can be used to create a map of the area that will be flooded as a result of rising sea levels. The topography of Earth can be represented digitally and this is known as a Digital Elevation Model (DEM). DEM is a tool for discovering topographic features, geo-morphometric parameters and other terrain-related data[4].

The digital elevation model (DEM) is generated by using one-meter interval contour data, which is extracted from Google Earth imagery. GPS Visualizer software and ArcMap 10.8.1 software were used to process the data in preparation for DEM; the process includes the following steps:

- Stream mode path creation on Google earth imagery for the study area which is saved into a KML file.
- KML file was processed to convert GPX file with elevation using GPS visualizer, a free tool.
- GPX file was converted as point type shape layer in ArcGIS software.
- The point layer was processed for kriging to get a raster and contour was generated from the raster.
- Contour to tin and from tin to raster which is called DEM, was generated in ArcGis software.

Computation of inundated areas: The DEM was used to determine the locations that are susceptible to inundation by assigning a value of 5 metres to a hypothetical scenario in which the sea level rises.

Identification of Affected Settlements/Areas: The areas that are vulnerable to the inundation, were identified through the analysis of DEM, contour map, sea level imagery from Global Mapper and by overlaying the inundated regions with the digitized settlements.

Identification of Safe Areas: The areas and settlements which are above 5m contour elevation, are designated as safe areas and are considered as the zones of rehabilitation at the time of natural calamities.

Results and Discussion

Analysis of Base Map: Base maps are the foundation upon which other maps, or layers, can be superimposed to provide a more detailed overview of a specific area of interest. It contains the geographical data necessary for analysis and offers information on landforms, highways, landmarks, political boundaries etc. It is the fundamental component that will be used as a platform for developing any map[16]. The base map (Fig. 3) clearly shows the risk of flooding due to the proximity of villages, towns and cities to major streams and rivers. At the time of cyclone, these rivers will overflow and make their way to the nearby settlements.

Drainage Map analysis: The rivers, streams and canals in the study area are overflowing during the monsoon period, causing widespread flooding. The coastal location of the research region increases the extent to which it will be inundated.

It was clearly depicted from the drainage map analysis that the settlements are in close proximity to the major streams and rivers, making them vulnerable to the inundation at the time of cyclones due to heavy rainfall (Fig. 4). One of the major rivers of A.P. state was discovered to be flowing perilously close to the project area's boundary, putting a risk to the low-lying areas on its periphery.

Contour Map analyses: The contours (Fig.5) were drawn to depict the difference between the mean sea level and the elevation of the study area using satellite data. The procedure was used to measure the impact of rising sea levels up to the elevation of the 5 metre. The blue color contours are showing the elevation up to 5 m and the rest of the contours are above 5m elevation which can be considered as high elevation areas. This suggests that most of the studied area's settlements could be submerged due to rise in sea level. As a result of sea level rise, there is an increase in the risk of coastal flooding, which is accompanied by an increase in the frequency of storm surge-induced overtopping by comparatively smaller events[8].

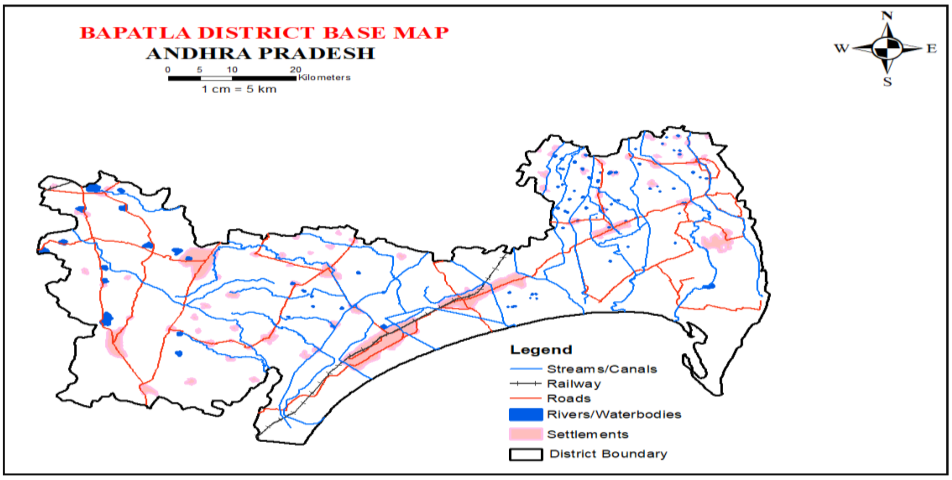

Fig. 3: Base map of the study area

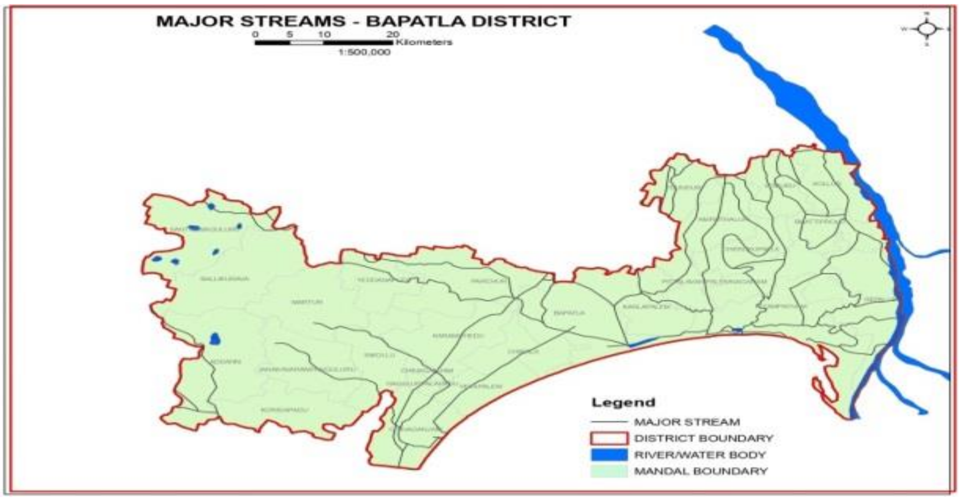

Fig. 4: Map showing the major streams and rivers of study area

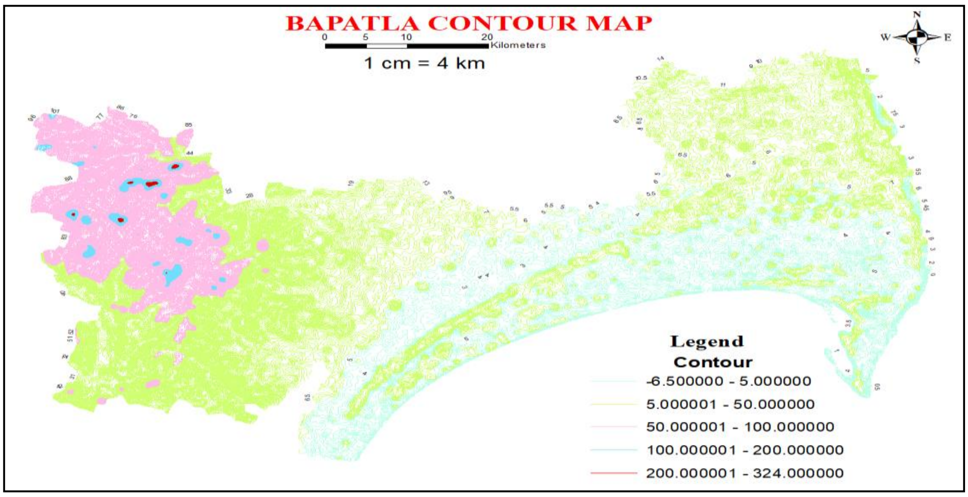

Fig. 5: Map showing the contour elevation of study area

Sea Level Map analysis: The software programme Global Mapper was used to create a map of the sea level (Fig. 6) which is often referred to as the surface level. This map was used to conduct the analysis of the rise in water level[1]. The 5 M contour was superimposed on the water level imagery to determine the regions that are at risk of being flooded if there is a rise in sea level of 5 metres. The areas above 5 M contour elevation are the areas that are designated safe. Based on this, it was clearly observed that the possibility for coastal submergence in the study area is very high.

Analysis of Digital elevation model (DEM): The Digital Elevation Model (DEM), in collaboration with overlay techniques in GIS, is utilized to identify the inundation zones that occur along the coastal region. The DEM (Fig. 7) was analyzed in 3d using ArcScene/ global mapper with submergence of area for 5 m contour to find the areas that will get inundated in the study area. The elevation data is classified to obtain the region up to 5m elevation, which is the area that may inundate and is referred to as vulnerable to submergence.

Deng et al[7] created a methodological framework to recreate the delta front morphology by integrating the data from historical shorelines, regional distribution of depositional environments, relative sea-level fluctuations and a contemporary digital elevation model (DEM)[7]. The spatial relationship between mud basin morphology, the subaerial DEM and the historical shoreline is a crucial process.

Based on the analysis of sea level rise (5 meter), a large area of the study area is on the verge of coastal inundation (Fig. 8). The total numbers of settlements that are vulnerable to the submergence are 170 that count 27% of the total settlements. According to the study, the predicted inundation area is 25.0394 square kilometers and was determined using data from digital elevation models, digital image processing and GIS software. The map represents the submerged areas/ built up when the sea level rises up to 5 m.

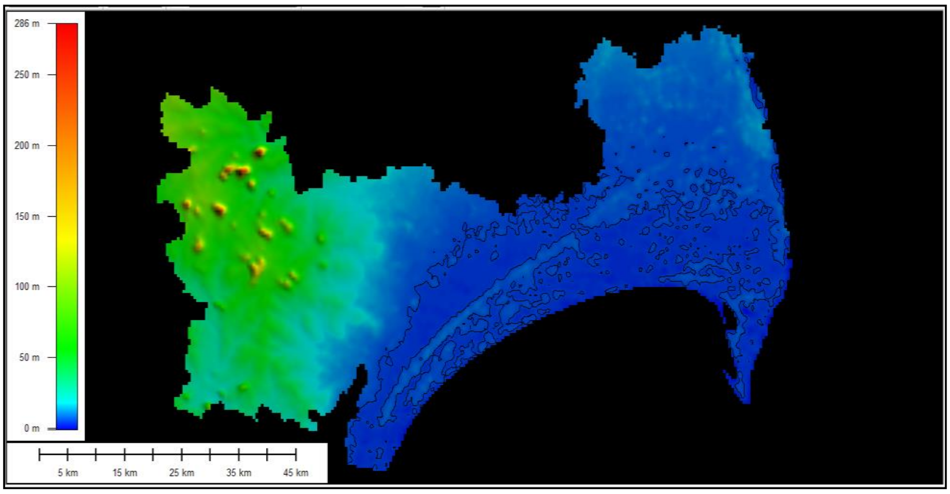

Fig. 6: The sea level map of study area

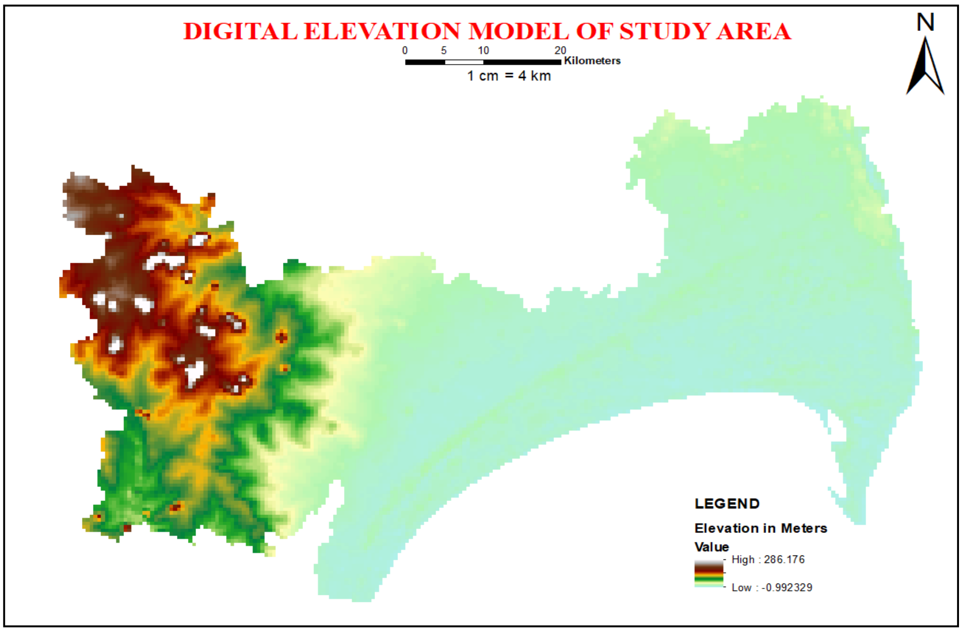

Fig. 7: Digital elevation model of study area

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In the study region, an area of 176 square kilometres of coast was mapped, with 25% of the mapped coast designated as very high risk owing to potential seal level rise (SLR). This makes it pretty apparent that the Bapatla coast is extremely susceptible to sea level rise in future and that a wide variety of LU/LC features, such as coastal dunes coastal villages, aquaculture ponds, wetland, salt pans, beaches and agricultural land are at high risk of flooding as a result. People currently residing in these locations would have to relocate as a result of this.

The pie charts below (Fig. 9 and 10) are depicting the submerged regions as well settlements due to 5M sea level rise. In the event of a tsunami or an increase in sea level, low-lying regions within the study area are at a high risk of being submerged.

The total villages and towns analyzed for coastal inundation are 610 which cover 176.49 sq. km areas. 170 settlements i.e. 25 sq. km areas are identified as most vulnerable to coastal submergence which counts for the 27% of the study area. Another 440 settlements i.e. 151.45 sq. km areas are identified as unaffected to coastal submergence which counts for 72% of the study area. This unaffected region completely may not be considered as safe, because the climate change has been leading to drastic rise in the sea level. This results to the inundation of the unaffected regions in the future. The livelihood, socio-economic impacts also show severe impact in the unaffected region along with affected area.

After the analysis, some safe areas have been identified (Fig. 11) for the rehabilitation of the people at the time of threat due to the floods, cyclone, tsunamis etc. The region above the 5m elevation is deemed safe as shown in the map below and can be designated as the zone for rehabilitation at the time of coastal inundation especially during the period of south west monsoons.

The present study determined the most severely inundated areas by employing GIS software, digital elevation model data and digital image processing. As the study is done for about 25 km boundary area from the coast, the mandals that come under the specified area include Bapatla, Karlapalem, Chinaganjam, Vetapalem, Pittalavanipalem, Nagaram, Chirala, Nizampatnam and Repalle. The regions from the above mentioned mandals that are designated to be under the threat of coastal inundation are shown in the table 1.

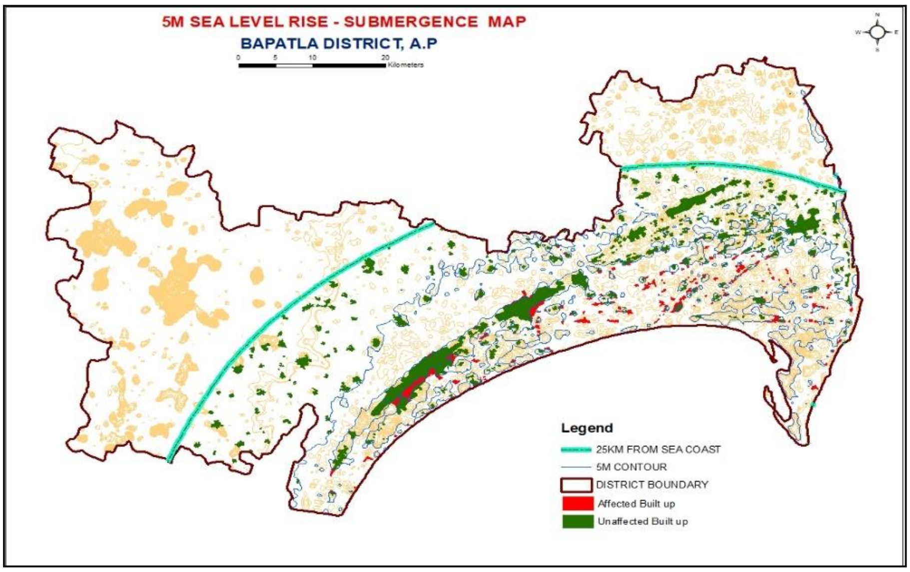

Fig. 8: The inundation of settlements

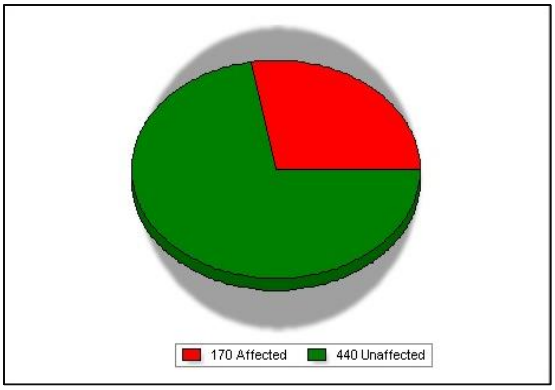

Fig. 9: Graph showing the inundation affect on Settlements due to Sea level rise

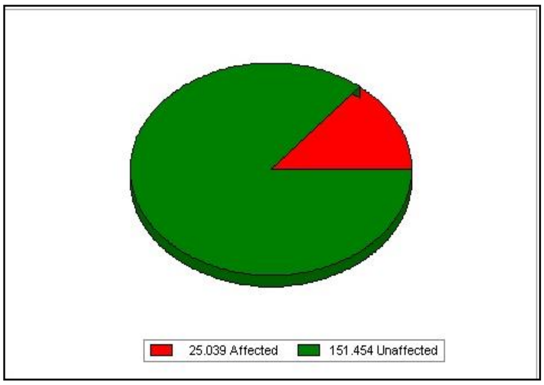

Fig. 10: Graph showing the inundation affect in terms of area (Km^2) due to Sea level rise

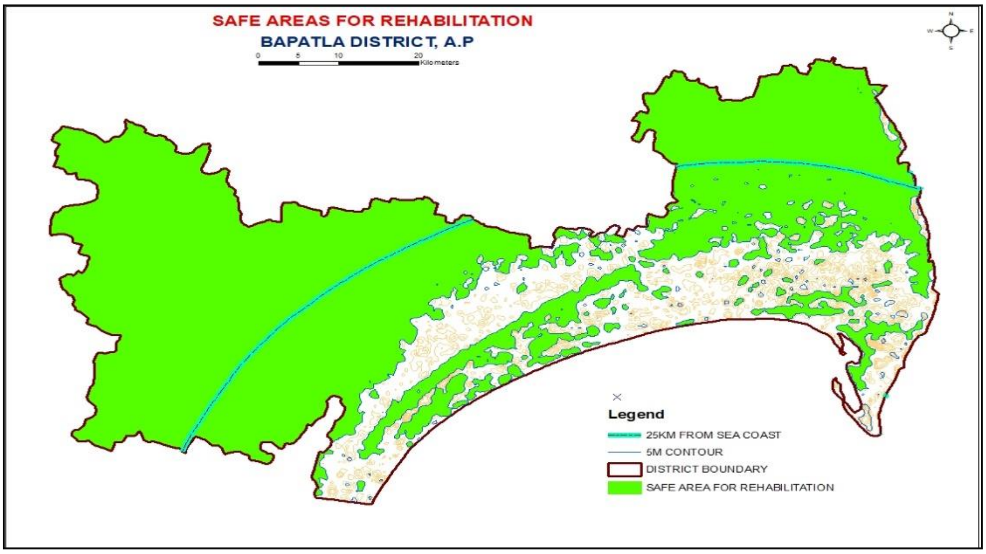

Fig. 11: The safe areas for Rehabilitation

Table 1
Presenting the majorly affected settlements (towns and villages)

Mandal Name	Areas (Villages/Towns) To Be Affected
Bapatla	Rajula Cheruvu, Oori Cheruvu, Vidhaya Nagar, Srinivas Nagar, Gudipudi, Etheru, Kankatapalem, Murukondapadu, Ramnagar, Muthyapalem, Hyderpeta, Chinabethapudi, Basvireddy Palem, Pandurangapuram, Krupa Nagar, Suryalanka, Pittuvari Palem, Vedullapalli, Mallapali, Krupa Nagar
Karlapalem	Buddam village, Perali, Perali, Parlipadu, Nagarajupalem, Mananagar, Pedagollapalem, Sammeta Vari Palem
Chinaganjam	Pedanaganjam, Yetimoga, Pallepalem
Vetapalem	Pandilla Palle, Katam Chenchulu, Nayanipalli Rural, Nayanipalli
Pittalavanipalem	Khajipalem, Pittalavani Palem, Pothanakattavaripalem, Manthenavaripalem, Alakapuram
Nagaram	Nagaram, Allaparru, Dasulapalem, Srirama puram, Apparaopuram, Pudiwada, Bodduvaripalem, Nagallavaripalem, Pedapalli, Meesala vari palem, Tadivakavari palem, Pedamatlapudi
Chirala	Vodarevu, Kavurivari palem, NTR Nagar, Rosaiah nagar, vadde sangham, Andhra kesari nagar
Nizampatnam	Pallapatla, Nizampatnam, Amudallapalli, Kuchinapudi, Adavuladeevi, Muthupalle Agraharam, Gurunadha Nagar, Aachyunthapuram, Pullamaraka, Kalipalampalli, Konaphalam, Pragnyam Colony, Atlavaripalem, Pillavaripalem, Garuvupalem, Chintarevu, Kuchinapudi, Maraka vari palem, Putlagunta
Repalle	Kaithepalli, Penamudi, Nalluru, Kottapalem, Lankevanidibba, Gudikayalanka, Paturu, Mallagunta, Harijanawada, Thummala, Chennupalli vari palem, Piratlanka, Vaddevaripalem, Bondalagaruvu, Jonnavaripalem, Potumeraka, Nalluripalem

Table 2
Presenting the Safe Areas for Rehabilitation

Mandal Name	Areas (Villages/Towns) Designated Safe For Rehabilitation
Bapatla	Pandurangapuram, Bapatla main, Kankatapalem, Murukondapadu, Muthyapalem, Chinabethapudi, Bapatla west rural, stuartpuram, hanuman nagar, Appikatla, marripudi, chundurupalli, narsaya palem, Jillellamudi, Bapatla main
Karlapalem	Sammeta Vari Palem, Pedagollapalem, Maraka Vari Palem, Reddypalem
Chinaganjam	Kadavakuduru, Chunthagum Palle, Chinnagujam Town
Vetapalem	Potti subbaiaha palem, katari palem, katari palem
Pittalavanipalem	Alakapuram, Dammanavari Palem, Sangupalem Koduru, Komali
Nagaram	Putlagunta, Pamidimarru, , Chirakalavaripalem, Peddavaram, Manthripalem
Chirala	Pullayapalem, Gavinivaripalem, Kavurivari Palem, Ipurapalem, Chirala Town
Nizampatnam	Kalipalem, Talla Tippa, Konapalem, Dindiadavala, Nakshtra Nagar, Adavuladeevi, Bavaji Palem, Bavaji Palem
Repalle	Gangadipalem, Repalle Town, Thummala, Potumeraka, Turpupalem, Repalle Town

It was important to identify, within the study area, zones that are close to susceptible areas, so that people could relocate there to avoid potential danger from natural disasters[21]. The major probable areas those are considered safe and designated as the zones for rehabilitation at the time of coastal inundation, are listed in table 2.

Conclusion

Coastal zone management will be hampered by climate change-caused shoreline shifts, storm surge flooding and other forms of coastal flooding. Therefore, it is of the utmost importance to assess the current climate change trend and its impacts on the Indian coasts and to devise a plan to deal with the problem. Mapping the area under investigation with DEM, image processing and geographic information system software can assist in determining the areas that the rise in sea level will impact.

Superimposing the 5 M contour on water level imagery identified areas at danger of flooding if sea levels rise 5 meters. Safe zones are above 5 M contour elevation. This indicates that coastal submersion in the research area is likely. Due to sea level rise, settlements up to 5 m high may be flooded in the study area. Sea level rise increases coastal flooding and storm surge-induced overtopping by smaller events. Approximately 25% of the 176 square kilometres of coast in the research zone was considered very high risk due to anticipated seal level rise. This shows that the Bapatla coast is vulnerable to sea level rise and that coastal dunes, villages, aquaculture ponds, wetland, salt pans, beaches and agricultural land are at risk of flooding.

The different land use classifications that are affected by the inundation, may also be approximated, which will be helpful for planners and decision-makers who are trying to devise contingency plans to tackle the challenges caused by sea-level rise along the coast of India. Data acquired from impact assessments can be applied in a variety of contexts including port planning and coastal infrastructure construction, establishment of rehabilitation centers, etc. Planners and administrators can use this information to create effective adaptation strategies for sustainable disaster management over the long run.

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