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Inundation based Assessment of Social Vulnerability in Krishna River Delta, Andhra Pradesh, India

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Abstract

The deltaic plains are bestowed with lush coconut gardens, extensive croplands, evergreen mangroves, etc. The Krishna river delta in east coast of India was hit by intense storms causing enormous damage to the region. The human population is experiencing increased threats caused by these storms. Though, there is a gradual increase in the population at risk but the loss of human lives remained minimal in most of the recent cyclonic events. Satellite and airborne sensors are providing the required information in a timely and reliable way**.** In the present study, the satellite datasets of three flood events are analysed. Further, the Inundation based Social Vulnerability (ISV) of Krishna delta is arrived by considering population at risk, population density, house-holds density, illiterates, and non-workers. The minimum ISV value is observed in Nadendla mandal (1.55) and maximum ISV is in Bhimavaram mandal (206.59). The ISV values are classified into five vulnerability classes. Bhimavaram and Ponnur mandals are under the extreme vulnerability class (5). The ISV is expected to reflect the realistic social vulnerability, with due emphasis to coastal flooding. The results of this study can serve as the basis for prioritization efforts, emergency response measures, channelizing funds, and policy interventions for mitigating disaster vulnerability.

Keywords: Flooding, Krishna delta, social vulnerability,

1. Introduction

Deltas are the fertile flood plains for agriculture, and home to abundant biodiversity which continues to attract people from all walks of life in transforming them into densely populated areas. Coastal hazards are claiming several lives, damaging croplands, destroying infrastructural facilities, disrupting communication networks, etc. Tropical storms are the most destructive recurring natural hazards along the coast and are characterized by destructive winds, exceptionally heavy rainfall, and storm surge. The economic benefit that accrues from access to ocean navigation, coastal fisheries, tourism, and recreation support human settlement are often more concentrated in the coastal zone than elsewhere. The human population of the world's coastal areas is experiencing threats caused by natural and anthropogenically accelerated changes in the coastal environment [1]. Thus the pressure on land is immense, compelling the poorer section of the population to settle on the recurring flood affected region. The hazard mitigation models are developed for the nine coastal districts of Andhra Pradesh [2]. The geospatial database and real-time meteorological data are integrated with the hazard models for dissemination of improved cyclone forecasting and decision support system. It is realized that instead of hydrodynamic approach, the geomorphic classifiers are computationally less intensive and can be considered for demarcation of flood risk zones [3]. A geomorphology based flood hazard zonation is attempted in the Krishna delta [4]. It is identified that about 11% of the population (7% rural and 4% urban) in nine coastal district of Andhra Pradesh (AP) are at risk [5]. Further, it is identified that there is a gradual increase in the population at risk due to recurring storms. One of the earliest known storms that hit the Krishna delta in east coast of India was on 12th October 1779. During this event, the surge reached a height of about 12 feet and about 20,000 people were believed to have been drowned. Other noteworthy severe storms that hit this region include November 1864, October 1949, November 1976, November 1977, May 1979, October 1980, November 1987, May 1990, Laila (May 2010), Helen (November 2013), etc. However, the loss of human lives during the recent event is relatively lesser when compared with the past cyclones. This is mainly due to the improvement in the dissemination of timely warnings.

Satellite and airborne sensors are providing the required information in a timely and reliable way, as demonstrated in the case of Hurricane Katrina [6]. The usefulness of remote sensing data, insitu observations, numerical modeling, and GIS analysis tools serve as a broad indicator of a threat to people living in the coastal zone [7]. They developed the coastal vulnerability index for Orissa state using eight relative risk variables. The flood vulnerability index is computed and observed that nearly 19% and 28% of the Indian Territory are very highly and highly vulnerable to flooding respectively [8]. The maximum depth of inundation (50 years return period) for Godavari delta region is analyzed, and observed to be ranging between 3.6 m and 5.2 m based on the Delft3D flow model [9]. The mandal level physical and social vulnerabilities based on storm surge inundation zones are studied [10]. The socio-economic parameters include population, senior citizens, women, children, type of housing, income level, cyclone shelters, hospitals & medical centres, schools, and caste based population. Nukpezah stressed the need for increased spending in education by the Government to enhance their access to resources for increasing their social capital [11]. The social indicators along with ecological parameters are considered to study the vulnerability of community to extreme events in

Machilipatnam mandal, AP [12]. Mahapatra classified the tropical cyclone hazard proneness in 96 coastal districts of India [13]. Three of the total twelve districts under very highly prone category are in AP State. A significant constituent of coastal population in the developing countries does not possess adequate capacity to cope with extreme events. This makes the poorer section of the population more vulnerable to disasters. Kantamaneni, et. al., reviewed the drivers and effects of hazards and vulnerabilities [14]. These findings are useful for stakeholders seeking to reduce the impact of coastal disasters on the economy, environment, and population.

The Coastal Vulnerability Index (CVI) is one of the most commonly used and simplest methods to assess coastal vulnerability [15]. The CVI provides a simple numerical basis for ranking different administrative units. This scoring system enables mathematical operations on variables measured. Gornitz ranked the coastal vulnerability in a scale of 1 to 5. The classification of coastal information has been greatly aided by the GIS capability [16]. The Coastal Vulnerability Index (CVI) for the Indian coast is derived [17]. Proper planning and protection strategies must be taken swiftly by the coastal management and policy makers to safeguard coastal ecosystem and livelihoods. It is proposed that if the adaptive strategies are not taken, the vulnerabilities will lead to adverse impacts on livelihoods [18].

2. Objectives

Floods are common natural disasters worldwide, frequently causing loss of lives and huge economic and environmental damages. The main objective of the present study is to identify the vulnerable population mainly due to the coastal flooding. Thus, the inundation based social vulnerability is expected to reflect the region specific relative vulnerability.

3. Study Area

The Krishna river delta region is subjected to recurring storms of varying intensity, more often during the months of May, and November. As the deltaic environment is mostly even, the progression of coastal flooding extends to very large areas. This region is also considered to be the rice bowl of the state. Hence, the associated damages are also significant. In view of this, the Krishna river delta region is identified for assessment of population vulnerable to flooding. The Krishna delta (Fig. 1) is in parts of four districts, 87 mandals and 1404 villages in the State of AP, India.

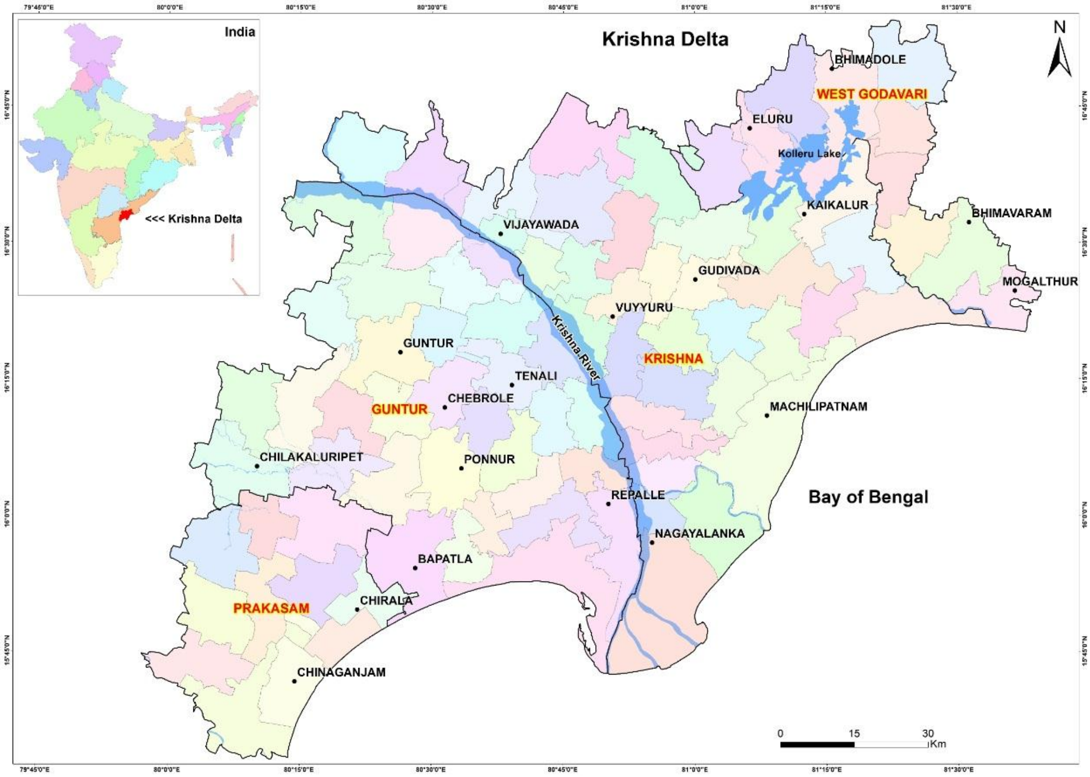

Figure 1: Location map of the study area

4. Methodology

In the present study the spatio-temporal inundation obtained from remotely sensed data is integrated with the socio-economic data to derive improved social vulnerability classification. Three flood events i.e., May 1990 (T1); September 2005 (T2); and September 2016 (T3) are identified. Each of these three flood events are derived from single/ multi date satellite imagery. Appropriate weightages (between 0 and 1) are given based on the frequency of inundation. Certain parameters of census data of 2011 are reworked to derive population density, household density, vulnerable population, Illiterate population and non-workers (Fig. 2). Based on the extent of weighted inundation and aggregated social classes in each of the 87 mandals of the delta, five levels of social vulnerability classes are categorized.

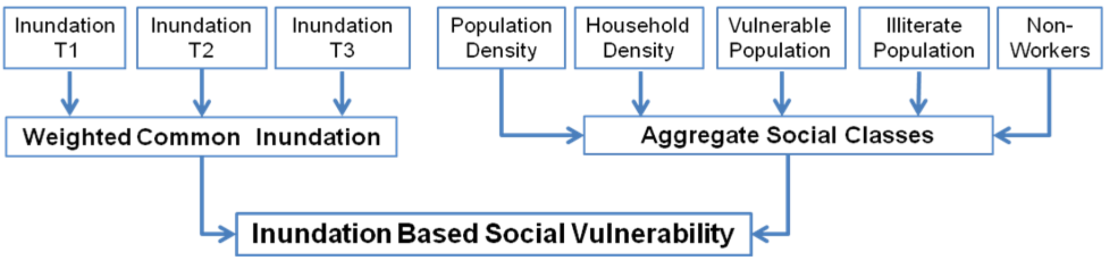

Figure 2: Methodology

5. Results and Discussions

In the recent years, remote sensing and GIS data has been in focus for coastal vulnerability assessment. In the present study, the flood vulnerability of Krishna river delta region is assessed with inputs from remote sensing and secondary data in GIS environment. Socio-economic vulnerability is analyzed based on the women population, children, aged, literacy, and non-workers. These socio-economic indicators are taken into consideration because of their relevance to enhance or minimize the impact of flooding on population. The data for each variable is placed into different classes by assigning a rank between 1 and 5 according to their relative vulnerability: Low (1), Moderate (2), High (3), Very High (4), and Extremely High (5). Finally, the socio-economic factors based on the inundation history is analysed at mandal level and discussed.

5.1 Inundation during different events

The availability of space borne sensors from earth observation satellites on a regular basis has enabled to address various disaster management issues. Floods are among the most destructive natural disasters affecting the human population and infrastructure. River floods and coastal storm surges affect the lives of more people than most other weather related disasters [19]. Satellite-derived flood inundation maps produced in near-real time provides valuable information to identify the affected areas. This facilitates the local Government in taking up rescue and relief operations. The extent of flood inundation in a given area during multiple past events is an important indicator for vulnerability assessment. The deluge during the three flood/ cyclone events of May 1990, September 2005, and September 2016 are analyzed.

A) May 1990 Cyclone event:

A severe cyclone storm crossed the coast near the mouths of river Krishna (south of Machilipatnam) at about 1900 hrs. IST on 9th May 1990, and took a toll of 967 lives. The post-cyclone satellite images of 11th May 1990 and 18th May 1990 were analysed. The flood waters can be seen behind the beach ridge & swale complex in the deltaic plain between Bapatla and Ponnuru in Guntur district. Inundation is also present in the southern parts of Machilipatnam and in the eastern parts of Nagayalanka in Krishna district. Thus, the temporal satellite datasets within a flood event can be used for updating in terms of progression, recession, and persistence. Three distinct inundation classes identified includes: Very Highly Flood Affected Areas (VHFAA), Highly Flood Affected Areas (HFAA), and Moderately Flood Affected Areas (MFAA). The VHFAA and HFAA are observed along Budameru river; around Kolleru lake; and near Chirala, Bapatla, Ponnur, Nagayalanka, Machilipatnam, etc. The total extents of VHFAA, HFAA and MFAA in Krishna delta are about 340 km^2, 364 km^2, and 2108 km^2 respectively.

B) September 2005 flood event:

A system was concentrated into a cyclonic storm and crossed the coast near Kallingapattanam (north-east AP) in the morning of 19th September 2005. The torrential rains triggered by the cyclonic storm have inundated several villages. The areas inundated are mapped based on the IRS LISS-III imagery of 22nd September 2005. It is observed that the entire Krishna river course between either banks (except elevated islands) exhibited the turbid waters. The extent of inundation is also mapped based on the satellite imagery of 2nd October 2005. The flood affected areas are observed in south-west of Ponnuru village, around Nagayalanka village, south of Machilipatnam, and around Kolleru lake (north of Kaikalur). The total extent of inundation in the Krishna river delta region is about 1,408 km^2.

C) September 2016 Cyclone event:

The challenges in using optical data because of cloud cover are overcome with the use of microwave data. The inundation maps are being generated within 5-6 hours on receipt of raw satellite data products, and disseminated to the concerned Departments [20]. The geographical extent of inundation during September 2016 event is delineated from three data sets (i.e. 23rd, 25th and 27th September 2016). The total extent of inundation during the September 2016 flood event is 1274 km^2. The extents of VHFAA, HFAA, and MFAA in the Krishna delta region are 620 km^2, 77 km^2 and 576 km^2 respectively.

D) Combined inundation during all three flood events:

The temporal satellite datasets acquired for three flooding events during 1990, 2005 and 2016 in Krishna delta region are integrated in GIS environment. The integrated flood extents are re-classified into three categories based on the frequency of inundation. The Combined Very Highly Flood Affected Areas (CVHFAA) include those areas which are under inundated during all the three flood events. The Combined Highly Flood Affected Areas (CHFAA) are those regions that are under inundation in any of the two flood events, and Combined Moderately Flood Affected Areas (CMFAA) are under inundation during only one of the three flood events. The maximum extent of inundation during all the three flood events is about 4,242 km^2. The extents of VHFAA, HFAA, and MFAA in the delta are about 924 km^2, 381 km^2 and 2,936 km^2 respectively. The significant extent of inundation in all the three flood events is observed in Krishna district (2,007 km^2). The maximum extent of inundation in the remaining three districts i.e., Guntur, West Godavari and Prakasam districts is about 1225 km^2, 518 km^2, and 492 km^2 respectively.

The three inundation categories (CVHFAA, CHFAA and CMFAA) are combined to obtain a unique value for each of the 87 mandals. Appropriate weightages are given to these three categories to enable aggregation at mandal level. In the present study, the weightage of 10, 6, and 3 are assigned to the spatial extents of CVHFAA, CHFAA and CMFAA respectively. The Combined Weighted Flood Inundation (CWFI) value during all the three events is derived by the summation of “CVHFAA multiplied by 10, CHFAA multiplied by 6, and CMFAA multiplied by 3”. The maximum CWFI value of 2066.56 is observed in the Machilipatnam mandal of Krishna district; and the average CWFI value of 87 mandals is 330.49. The inundation based vulnerability is ranked in a scale of 1 to 5 [16]. The advantage of ranking enables combining variables with different units mathematically. The CWFI values of different mandals are categorized into five vulnerability classes: Extremely Vulnerable (EV), Very Highly

Vulnerable (VHV), Highly Vulnerable (HV), Moderately Vulnerable (MV), and Low/ Least Vulnerable (LV) mandals.

5.2 Socio-economic Vulnerability (SEV)

Coastal flooding directly or indirectly affects the lives of population. The impact of natural disasters has been severe on the population and economy, which lacks the capability to deal with such calamities due to their poverty, illiteracy, and inability to undertake mitigative measures. Thus, the coastal flooding can cause disruption to many economic activities. Noteworthy amongst them are tourism, fisheries, navigation, industries, agriculture, and portable water. The basic data for the social vulnerability analysis to floods is taken from the census. The impact of natural disasters is considered to be enormous on female, aged, and child population. The other socio-economic indicators having their impact on flood vulnerability include the population and house-hold densities; illiterates, and non-working population.

A) Population and their vulnerability

The evacuation of vulnerable population based on the early warning is indispensable for their safety. The vulnerable community expressed the need of cyclone warning at least 8 hrs in advance before evacuation [21]. Improvement in the cyclone warning is helping the local administration in timely evacuation. The order for consideration while evacuation and rescue is to begin with the aged population, followed by female and children population. Aged and children are among the most vulnerable segment of the population. In order to estimate the population older than 60 years of age, the statistical handbooks of four districts within Krishna delta are consulted. The percentage population of over 60 years in the districts of Krishna [22], Guntur [23], Prakasam [24], and West Godavari [25] are about 11.52%, 10.64%, 10.90% and 11% respectively. The total population of Krishna delta based on Census of India is 83,23,072 [26]. Of which the male population is 41,54,992 and the female population is 41,68,080. The population group (constituting females, children, and aged) is classified into 5 vulnerability classes and shown spatially in Fig. 3A. There are 57 mandals in low/ least vulnerable category (1); 17 mandals in moderate vulnerability class (2); 7 mandals in high vulnerability class (3); 3 mandals each under very high (4), and extreme vulnerability class (5). The mandals in very high vulnerability class include Tenali in Guntur district; Machilipatnam in Krishna district; and Bhimavaram mandal in West Godavari. All the three urban mandals i.e., Guntur, Vijayawada (Urban), and Eluru mandals are in extremely vulnerable class.

B) Population Density:

Population density is considered to be one of the important indicators for determining the social vulnerability. During a flood event, localities with high population density are more likely to face problems than otherwise. Further, the evacuation difficulties are enormous and the possibility of increased risk of disease transmission is also high. The density of the population is basically a measure based on the total number of people living in a unit area (total). In the present study, only the built-up area of Krishna delta constituting about 778.62 km^2 is taken into consideration for assessing the modified population density of the delta. The modified population density of the delta is about 10,689.52 per km^2. The population density of all the mandals is grouped into five vulnerability classes. There are 17 mandals in low/ least vulnerability class-1 (persons per km^2); 24 mandals in moderate vulnerability class-2; 25 mandals in the high vulnerability class-3; 14 mandals in very high vulnerability class-4; and there are 7 mandals in extreme vulnerability class-5. The spatial distribution of population density in different mandals is shown in Fig. 3B.

C) House-holds:

The total number of households in Krishna delta are 22,82,129; which constitutes about 18% of the total households of the state. All the 87 mandals in the study area are grouped into 5 classes viz., LV class (1), MV class (2), HV class (3), VHV class (4) and EV class (5) depending on average house-hold size. As such it is observed that there are 12 mandals in the LV class (1); 24 mandals in the MV class (2); 33 mandals in the HV class (3); 14 mandals in the VHV class (4); and 4 mandals in the EV class (5). The district level house-hold size perspectives of Guntur, Krishna, Prakasam, and West Godavari are 3.57, 3.49, 3.6, and 3.6 respectively. The household vulnerability is spatial presented in Fig. 3C.

D) Illiterates

Not all people are equally educated in a society. One of the major problems of illiteracy is the lack of access to updated information regarding the forthcoming disaster and its possible damages [27]. Hence, the knowledge empowerment of the people with updated information on disaster management can be perceived as an easy solution towards their enrichment. The total number of illiterates in parts of Guntur, Krishna, Prakasam and West Godavari districts of Krishna delta are 27,44,440 (about 33% of the total population). The percentage illiterates are classified into 5 vulnerability classes. The spatial distribution of illiterate population percentage in Krishna delta is shown in Fig. 3D, which depicts LV class (1) constitutes 11 mandals; MV class (2) constitutes 14 mandals; 29 mandals in HV class (3); VHV class (4) constitutes 23 mandals; and EV class (5) has 10 mandals.

E) Non-Working population

The greater dependence of non-workers on the limited working members of a family is assumed to enhance the vulnerability. The total number of non-workers in the Krishna delta is 45,78,281; which constitutes about 55% of the total population of the delta. The percentage of non-workers to the total respective mandal population is classified into five vulnerability categories and spatial shown in Fig. 3E. There are 4 mandals in EV class (5); 10 mandals are in VHV class (4); 17 mandals in HV category (3); the remaining 56 mandals are in MV class (2) and LV class (1).

F) Combined Social Vulnerability

The socio-economic impact of natural disaster is complex depending upon the vulnerability of the place and mitigation strategies that are put in place. Meteorology plays a crucial role in forewarning people about the severe/ extreme weather systems.

A community that is located in a highly hazard prone area, that has a history of experiencing tropical storms, will have a higher likelihood of experiencing an actual disastrous event. In the present study, the social vulnerability of Krishna delta is arrived by aggregating five different sections of vulnerable population. They include select population (based on age, and gender), population density, house-holds density, illiterates, and non-workers. These aggregates are classified into five vulnerability classes. The spatial distribution of Combined Extremely Vulnerable (CEV) class 5, Combined Very High Vulnerability (CVHV) class 4, Combined High Vulnerability (HV) class 3, Combined Moderate Vulnerability (CMV) class 2, and Combined Low Vulnerability (CLV) class 1 in different mandals is shown in Fig. 3F. There are seven mandals in Krishna delta under the CEV category (5); ten mandals under CVHV (4) class; thirty-six mandals under CHV (3) category; 26 mandals under the CMV category (2); and the remaining 8 mandals of LV class (1).

5.3 Inundation Based Composite Vulnerability

The Combined Social Vulnerability (CSV) is deduced through aggregation of selected socio-economic parameters in the delta. Instead of considering the social vulnerability values the way they are in different mandals over the entire delta, it is proposed that inundation based social vulnerability would be more appropriate from flooding perspective. The percentage flood affected area in different mandals derived from three events (May 1990, October 2005 and September 2016) is reassessed based on the Combined Weighted Flood Inundation (CWFI) values. The sum of social vulnerability parameters (i.e., select population, population density, house-holds density, illiterates, and non-workers) for each mandal presented in Fig. 3F is averaged over five parameters. The Inundation based Social Vulnerability (ISV) is calculated based on the product of percentage flood affected areas, and averaged social vulnerability. The minimum ISV value is observed in Nadendla mandal (1.55), and maximum ISV is in Bhimavaram mandal (206.59). The ISV values are classified into five vulnerability classes. Bapatla, Nizampatnam, Ponnur, Repalle mandals in Guntur district; Machilipatnam in Krishna district; Parchur in Prakasam district; and Bhimavaram, and Eluru mandals in West Godavari districts are under the extreme vulnerability class (5). Nine mandals are in very high vulnerability class (4), sixteen mandals are in high vulnerability class (3), thirty-seven mandals are in moderate vulnerability class (2), and seventeen mandals are under low or least vulnerability class (1). Differences are observed between the CSV and ISV class levels, except in the case of 14 mandals. There is significant improvement in the R-square value from 0.001 to 0.84 between the percentage flood affected area and the Inundation based Social Vulnerability.

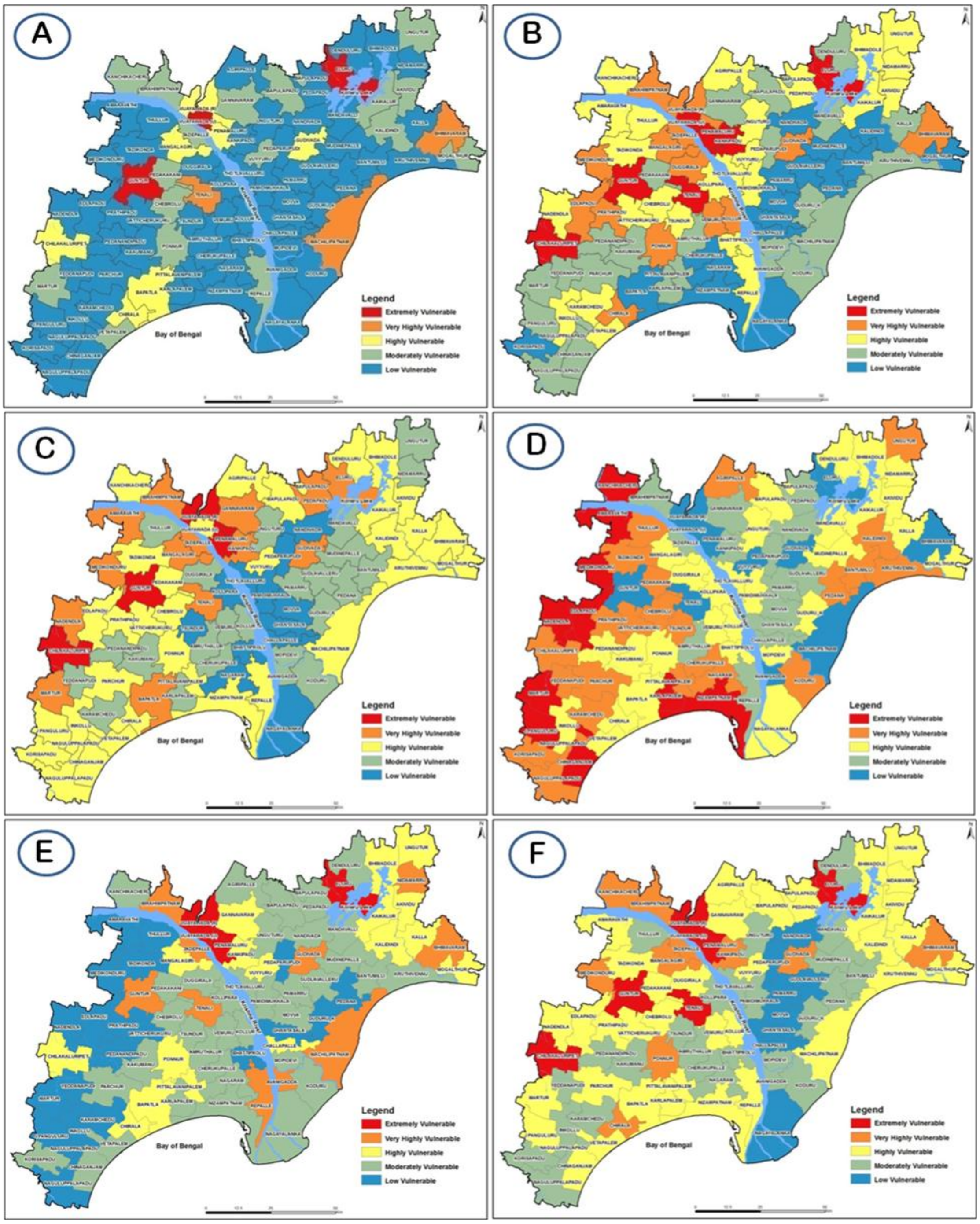

Figure 3: Socio-economic Vulnerability: A-Vulnerable population; B-Population density; C- House-hold density, D-Illiterates; E-Non-working population; and F-Combined Social vulnerability.

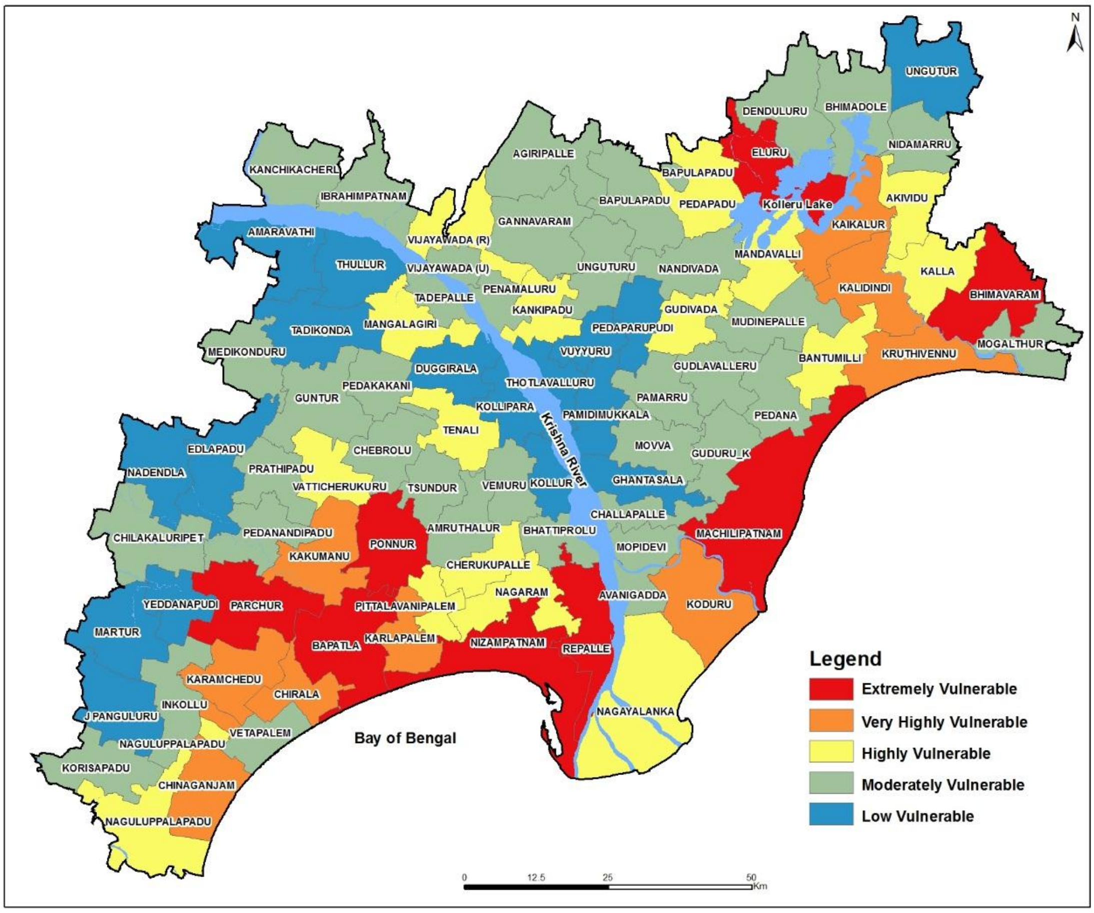

Figure 4: Inundation Based Social Vulnerability

6. Conclusions

The coastal stretch of Andhra Pradesh state with a coast line of about 974 km is prone to tropical storms of varying intensities. There is an increased threat to the human population due to the intense recurring storms. In order to implement suitable measures, there is a need for adoption of appropriate tools and reliable methods in managing the coastal disasters. It is observed that the inundation based social-vulnerability method is superior to the composite social-vulnerability. The vulnerability maps of the Krishna delta area would be of great use for planning, and disaster management. The extreme vulnerable mandals of the delta i.e., Bapatla, Nizampatnam, Ponnur, Repalle, Machilipatnam, Parchur, Bhimavaram, and Eluru requires attention. The results of this study can serve as the basis for prioritization efforts, emergency response measures, channelizing funds, raising environmental concern and policy interventions at the local level for disaster mitigation. The vulnerability of the region can be significantly reduced with improved hazard monitoring, early warning system, and by adopting best disaster management practices.

7. Acknowledgements
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