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ORIGINAL PAPER

Vulnerability from storm surges and cyclone wind fields on the coast of Andhra Pradesh, India

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Abstract The results presented here are from a study conducted for the government of the state of Andhra Pradesh (GOAP) in India, as part of a World Bank project on cyclone mitigation. A set of detailed maps were prepared depicting the Physical Vulnerability (PV), specifically storm surge inundation zones are shown for frequent occurrence, 50-year return period, likely scenario for global warming and extreme global warming. Similarly vulnerable areas from strong wind field from tropical cyclones (TCS) are also presented for the same four parameters. Vulnerability zones are presented from a social point of view also based upon certain socio-economic parameters that were included in determining the overall vulnerability of each Mandal in a coastal district (a Mandal represents a group of villages and towns) include: population, senior citizens, women, children under different age groups, type of housing, income level, cyclone shelters, hospitals and medical centres, schools and caste based population. The study is about scenarios that could happen if global warming and the predicted intensification of TCS actually occur as predicted by some numerical models.

Keywords Tropical cyclone · Vulnerability · Storm surge · Flooding · Inundation · Disaster mitigation

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1 Introduction

The Bay of Bengal region (Fig. 1) is among the most impacted regions on the globe, from a socio-economic point of view by tropical cyclones (TCS). In India, the state of Andhra Pradesh (AP) is the second most impacted state, just after Orissa, which is also a coastal state lying immediately north of AP.

The Physical Vulnerability (PV) from cyclones occurs at least in three different ways. First of all, there is the inundation of the land by ocean water, pushed up by tangential wind stress at the ocean surface by the wind field associated with the cyclone (Murty 1984). This land inundation is referred as storm surge, second the strong winds from the cyclone does damage to the coastal structures. Third, the heavy precipitation from the cyclone can cause flooding in the rivers.

In this study, only the first two physical effects are considered. However, river flooding directly from surge penetration into the rivers is considered, but not river or coastal flooding from precipitation. Figure 1 shows the nine coastal districts of AP. This study addressed the PV of these coastal districts from storm surges and wind fields. The numerical models used to compute storm surges have been described in detail in other publications and some in this journal also (Chittibabu et al. 2004a, b; Dube et al. 1994, 1997; 2000a, b; Rao et al. 1997; Dube et al. 2004). Hence the numerical aspects will not be repeated here, only the vulnerability maps will be presented. For the wind damage zones, we did not develop any numerical models of our own, but simply took the results from Anon 1997 and adapted them into our required format. The storm surge inundation as well as wind damage zone maps are determined for the following four situations.

(1) Frequent (Return period of 10 years)
(2) 50-year return period
(3) Global warming-likely scenario
(4) Global warming-extreme case

It is clarified here that we are not endorsing the concept of global warming due to human induced anthropogenic activities. All we are saying is that, as some

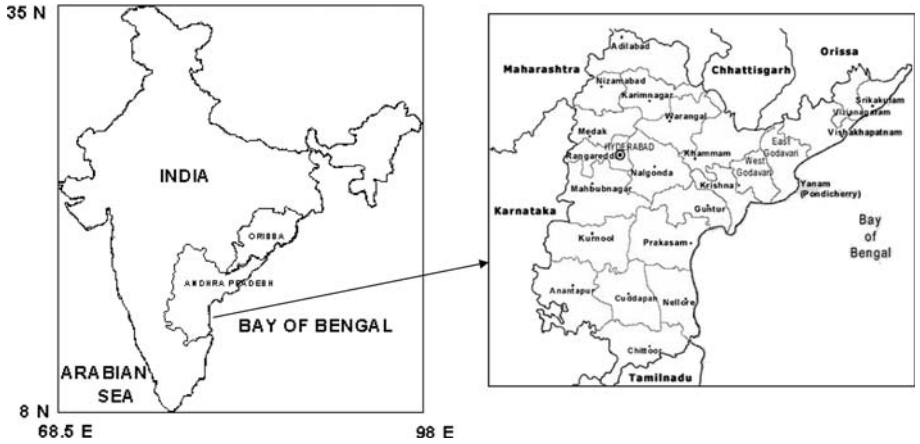

Fig. 1 A map of India, showing the Bay of Bengal and state of Andhra Pradesh

numerical/analytical models predict enhanced intensity of TCS due to Global Warming (e.g., Emanuel 1987, 2005), if it actually occurs, then what are the possible scenarios? We chose, based upon the literature, a likely case and an extreme case. Based upon the PV maps, as well as certain socio-economic factors, overall cyclone vulnerability maps are also prepared for the eight coastal districts. (Unfortunately the map for East Godavari district could not be prepared because of missing socio-economic data.

2 Physical vulnerability maps

The following relevant points should be noted for the scientific basis and the data used in the determination of the PV.

- A database of Tropical Cyclone generated Storm Surges impacting the AP coast has been produced using data mostly from the India Meteorological Department (IMD) as well as from several other national and international sources (SMRC 1998).
- For situations of disagreements in the data between IMD and other sources, IMD data only was used.
- The master table for storm surges in AP has 95 entries.
- Because of climate change, projections into future have been limited to 50-year return period.
- All the available cyclone tracks for AP have been synthesized into composite tracks to cover each of the coastal districts of AP.
- Making use of the projected pressure drop, the IIT-D Storm Surge Model was run using the synthetic tracks to determine the maximum possible storm surge amplitude (during a 50-year period) at various locations along the AP coast.
- The Total Water Level envelope was then determined by addition of the tide and wave setup.
- These water levels are then projected onto the coastal land making use of Topography data provided to us by Government of Andhra Pradesh (GOAP), to demarcate the horizontal extent of inundation.
- This conservative approach may slightly over-estimate the extension of inundation, but is desirable for hazard mitigation as well as for Coastal Zone Management, and is widely used around the world.
- A more detailed study of inundation as well as calculation of the depth of inundation at various locations on land could be made ideally with an Irregular Triangular Grid in a Finite Element Model. However, this is not part of our Terms of reference (TOR) and our understanding is that these results may be available from other studies.

The computations as well as the maps used the Mandal as the smallest geographical unit. In AP, each district is divided into several mandals and mandals contain cities, towns and villages. Figures 2 and 3 respectively show the surge inundation map and wind damage maps for the districts of east Godavari and Krishna.

3 Surge penetration through the river systems

There are three large river systems in AP which are subjected to storm surge penetration, Godavari, Krishna and Pennar. The storm surge penetration through these

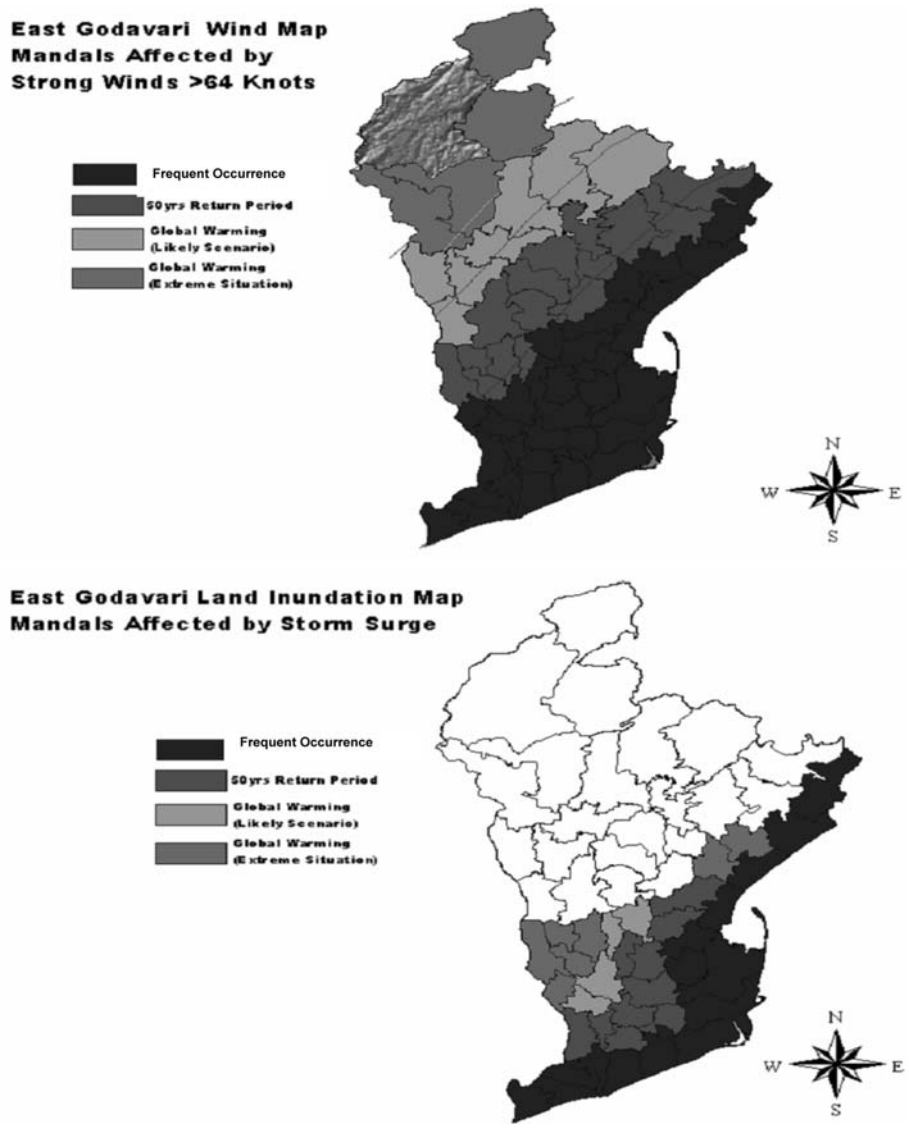

Fig. 2 Wind and surge inundation map for East Godavari district

three systems was determined by projecting the water levels under the following assumption.

Because of less friction than over land, the storm surge would penetrate 10–15% more distance through the river systems, which is a generally accepted assumption globally. If the river system has too many meanders, the increased penetration distance is limited to 10%, otherwise it is 15%. Figure 4 shows the penetration of the storm surge through the Godavari, Krishna and Pennar river systems (main stem and tributaries).

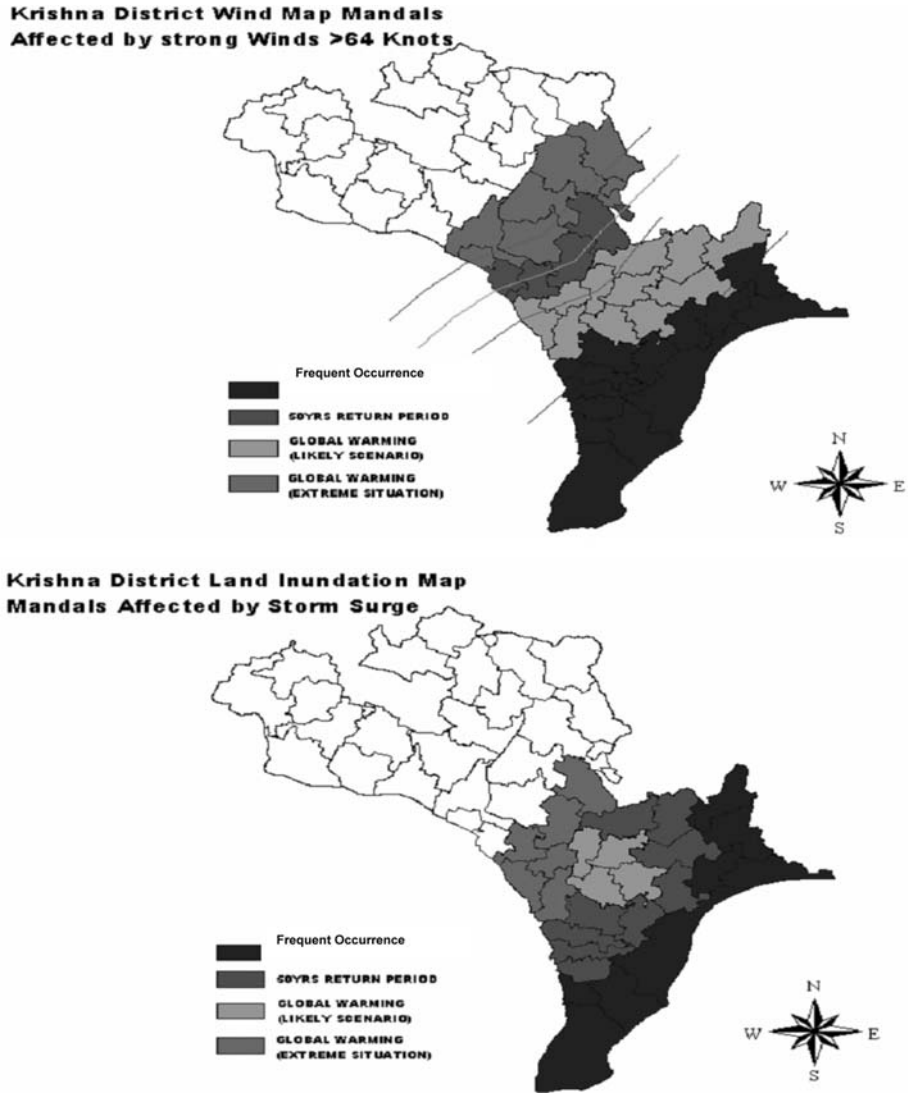

Fig. 3 Wind and surge inundation map for Krishna district

4 Overall cyclone vulnerability

The PV analysis identified Mandals in each coastal district that will be affected by storm surge inundation and/or strong winds from the cyclone, making use of the vast database on social factors in the state, provided to us by GOAP. A series of maps are created for each affected Mandal. By clicking on a given Mandal, all these maps can be seen in GIS format in pictorial format (Histograms) as well as in tabular data format.

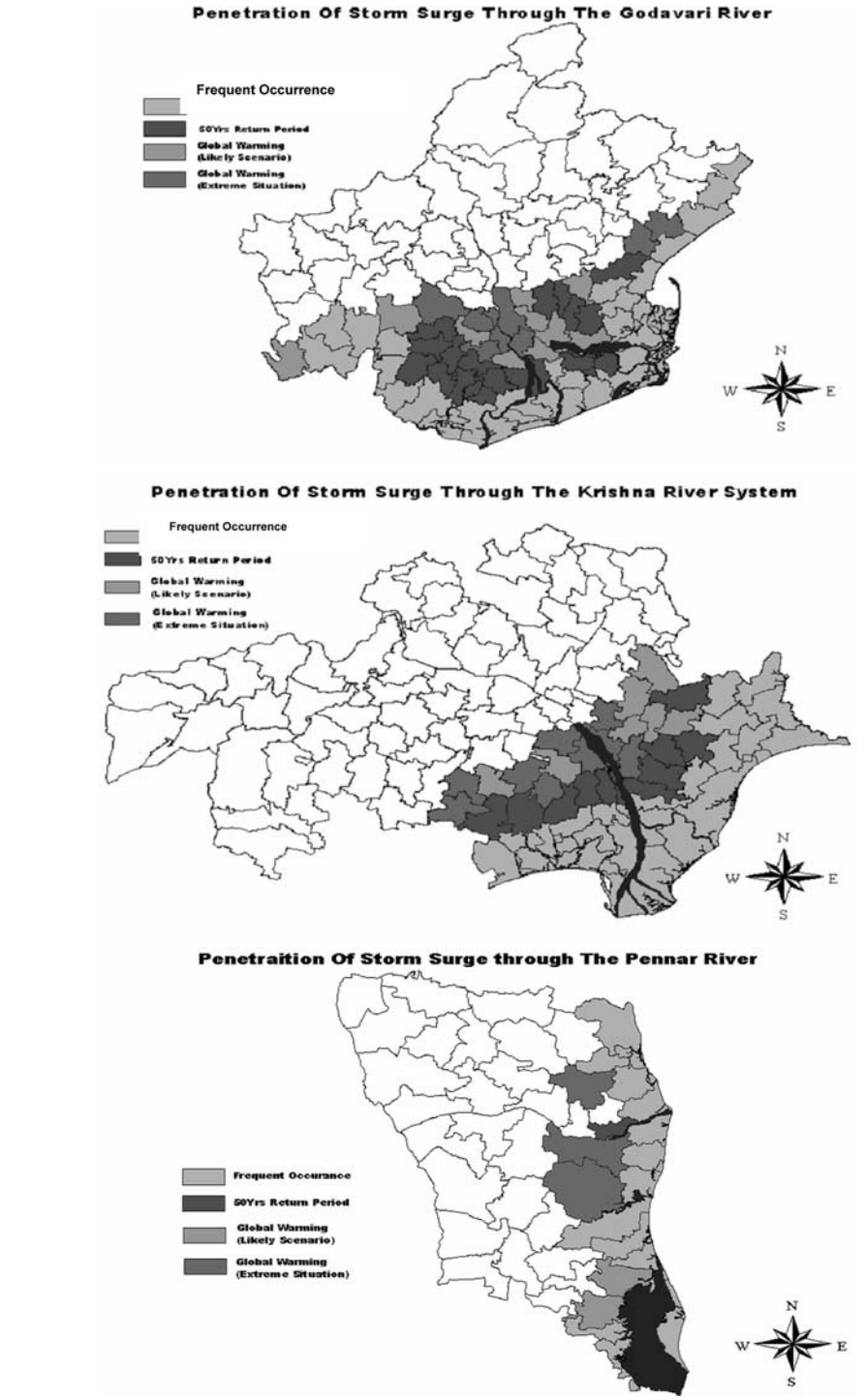

Fig. 4 Penetration of storm surge through the Godavari, Kristna, Penanr River systems

Table 1 Weight-point criteria used to rank affected Mandals in each coastal district of AP

Parameter	Weight point
1. Inside frequent inundation	33
OR	
2. Inside 50-year inundation zone	28
3. Inside frequent wind zone	19
OR	
4. Inside 50-year wind zone	14
5. Population	5
6. Senior citizens	5
7. Women	5
8. Children under 6 years	5
9. Children under 6–15 years	4
10. Type of housing	5
11. Income level	5
12. Cyclone shelters	3
13. Hospitals and medical centres	3
14. Schools	3
15. Scheduled castes, stand backward caste population	5
Total	100

The most important Social Vulnerability (SV) map prepared separately for each Coastal District is one in which the affected Mandals in the District are ranked using a weight-point system shown in Table 1, for the 50-year inundation.

It should be noted that the maximum possible SV index number in any Mandal can have under this scheme is 100. The higher the index value, the higher is the overall vulnerability of the Mandal to cyclone winds and storm surge inundation.

It should be noted that in the table above only frequent and 50-year return period criteria were used, because it was felt that any long-term planning made now is expected almost to be valid for 50-years and not beyond.

Using this table, overall cyclone vulnerability maps are prepared which are shown in Figs. 5–12.

5 Summary and conclusions

It can be seen from Figs. 5–12, that the widest surge inundation and wind affected areas are from East Godavari to Guntur districts and then again in southern Nellore district. For wind, the zone is more uniform (in width) through out, with greatest width in Visakhapatnam district.

As for overall cyclone vulnerability, the highest index in Srikakulam district is 90. In Vizianagaram district, the highest number is 86 (one mandal) in Visakhapatnam district it is 87 (one mandal).

In West Godavari, the highest index is 81. In Krishna district, the highest index is 83. In Guntur district, it is 85, in Prakasam district, it is 86 and in Nellore district, it is 99. In Nellore district there are 6 mandal with index of 90 or higher. Thus one has to conclude that, Nellore district is the most vulnerable from TCS.

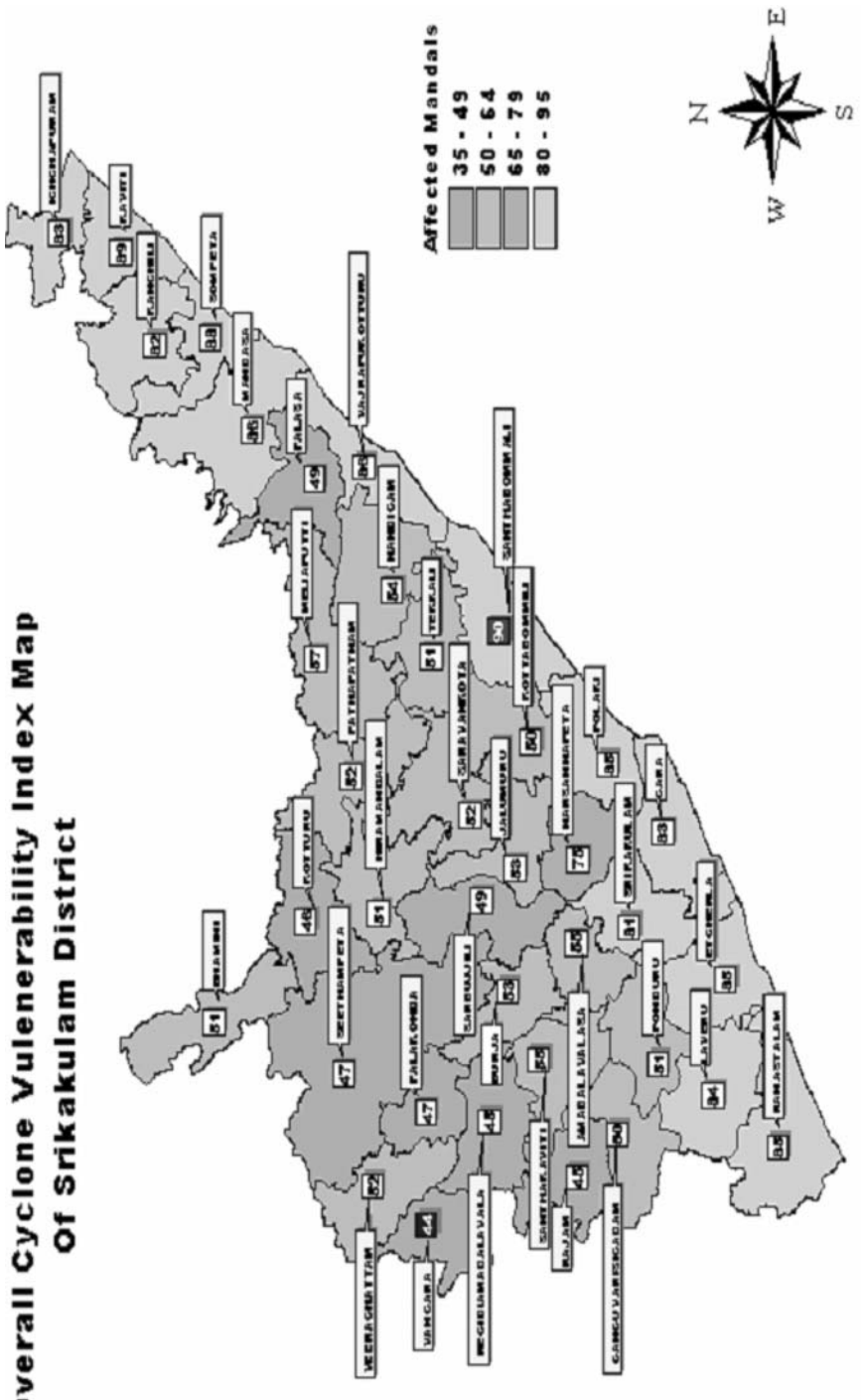

Fig. 5 Overall cyclone vulnerability map for Srikakulam district

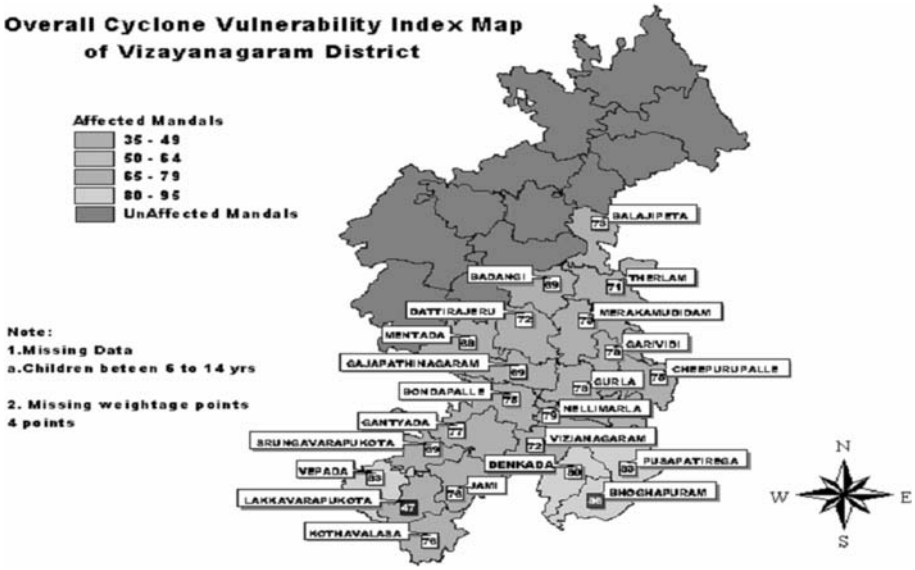

Fig. 6 Overall cyclone vulnerability map for Vizianagram district

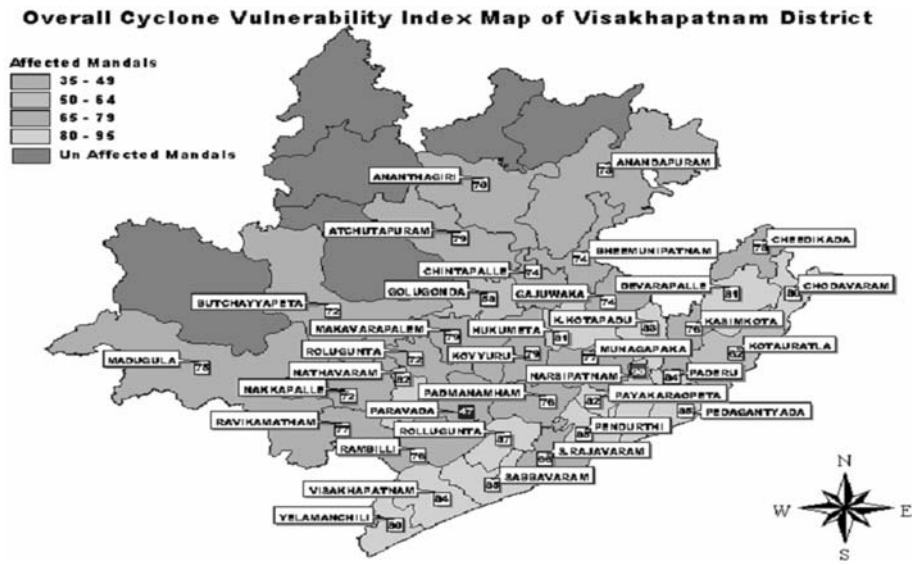

Fig. 7 Overall cyclone vulnerability map for Visakhapatnam district

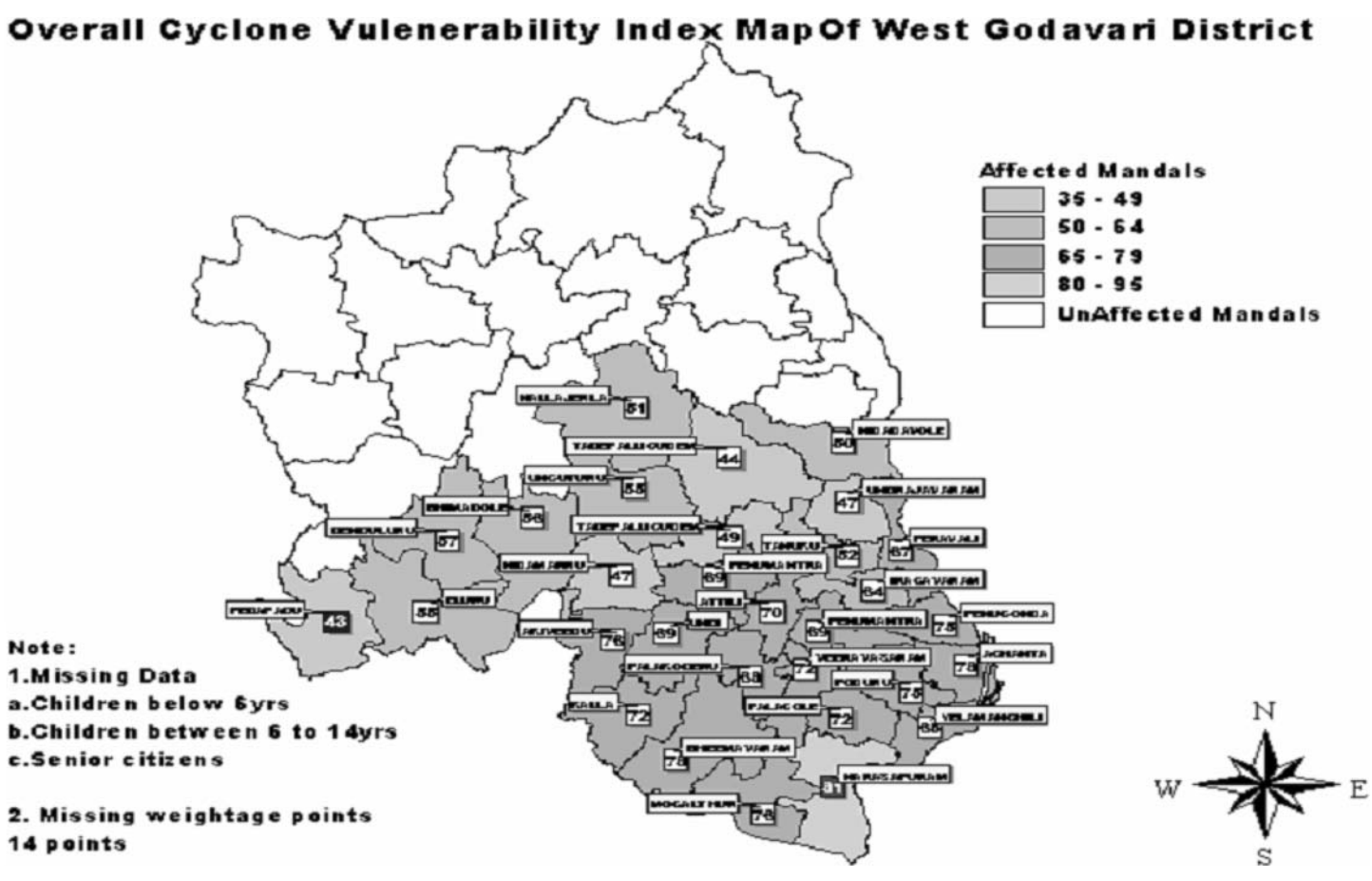

Fig. 8 Overall cyclone vulnerability map for west Godavari district

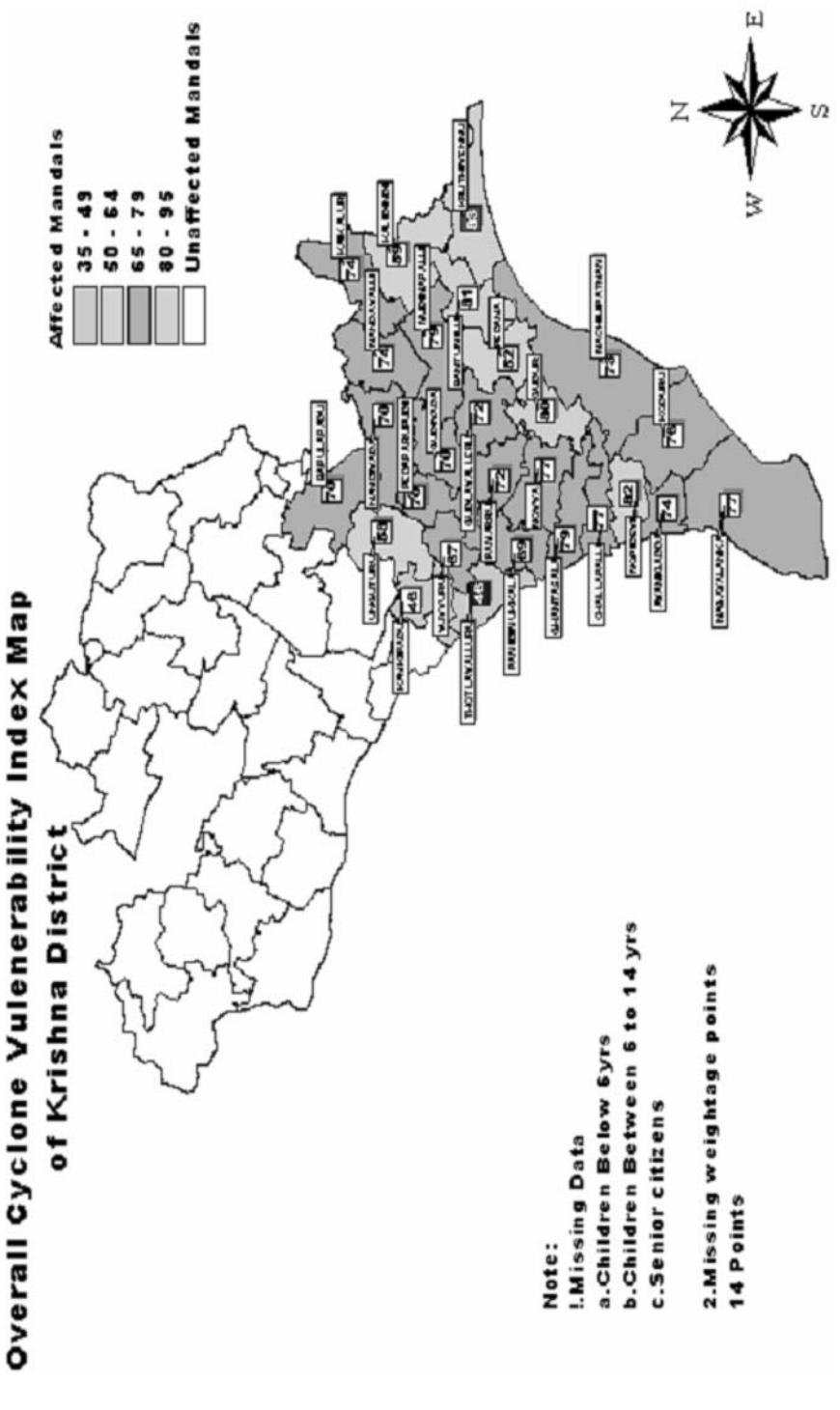

Fig. 9 Overall cyclone vulnerability map for Krishna district

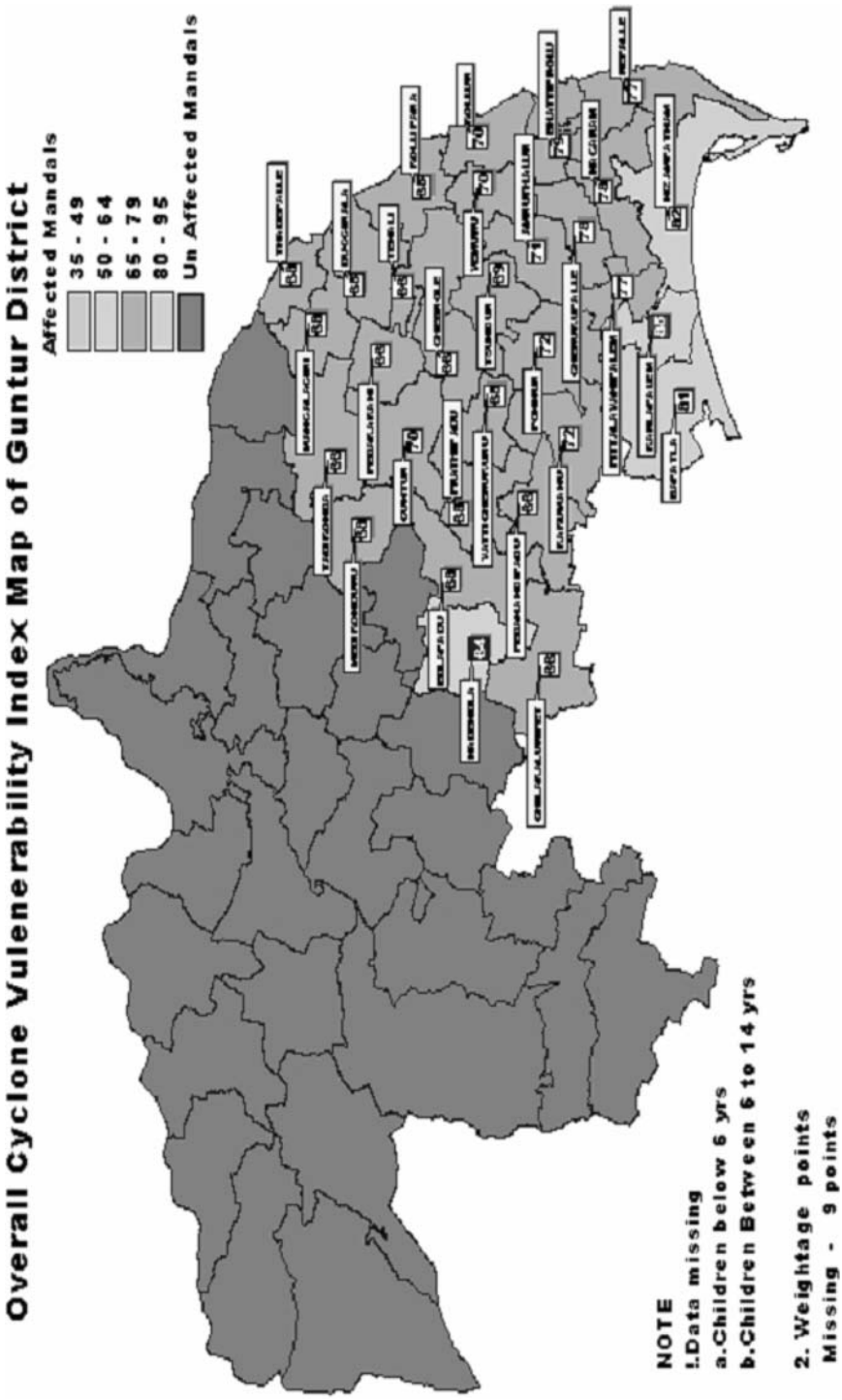

Fig. 10 Overall cyclone vulnerability map for Guntur district

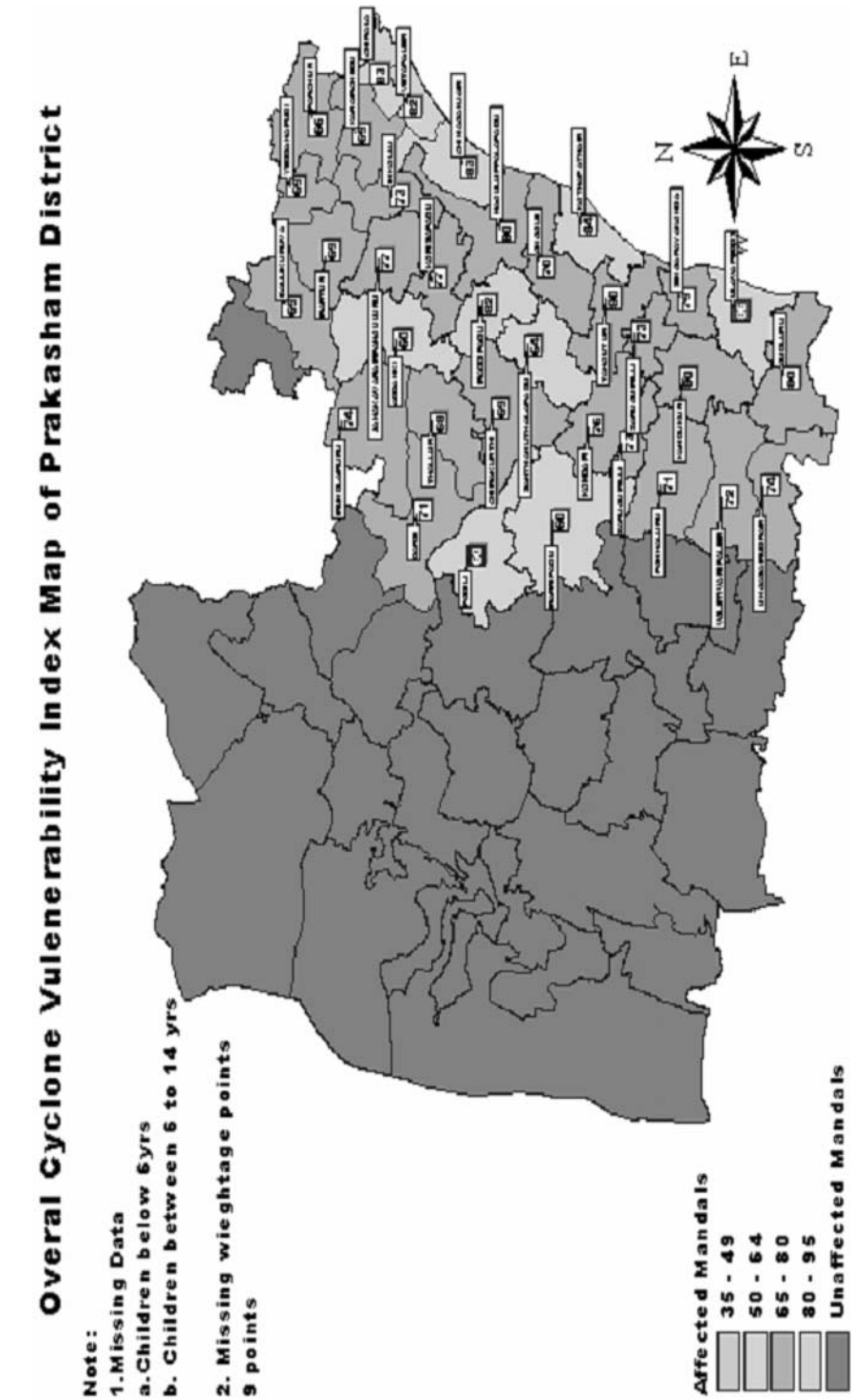

Fig. 11 Overall cyclone vulnerability map for Prakasam district

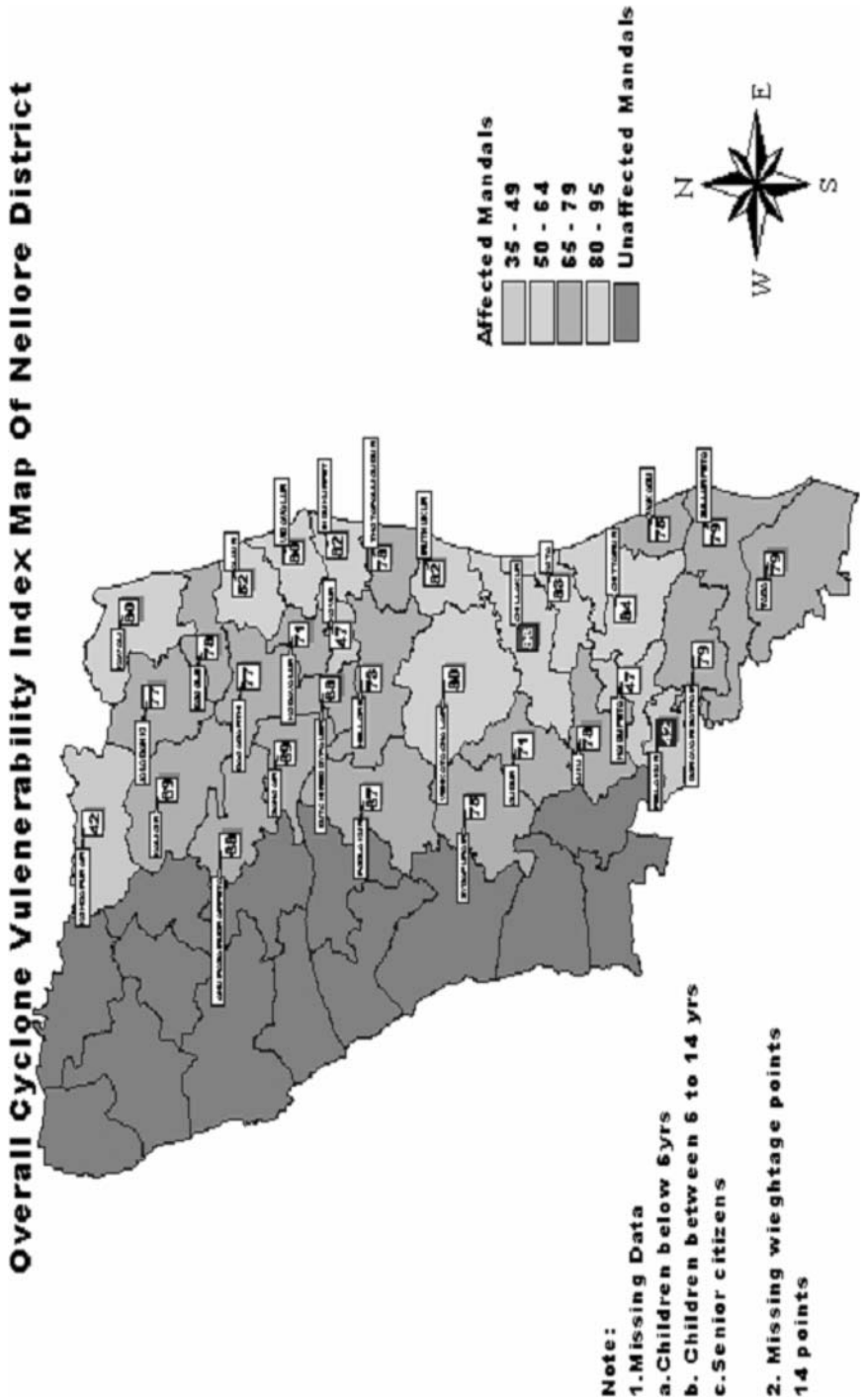

Fig. 12 Overall cyclone vulnerability map for Nellore district

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