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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Coastal vulnerability assessment of Puducherry coast, India using analytical hierarchical process" *by* R. Mani Murali et al.

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Response to Referee 1

Referee's Comment:

General comments

This paper presents a coastal vulnerability multicriteria mapping method based on the Analytical Hierarchical Process (AHP). The method is applied along the Puducherry coast. The method is useful as it helps in defining weights in multicriteria mapping when no purely deterministic assessment can be drawn. In addition, with respect to

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previous studies that also used AHP for mapping coastal vulnerability, this application integrates social factors. The paper is timely addressing an important topic, which is within the field of NHESS. Therefore, I think it is worth being published.

However, I have several comments and questions: 1. My main concern in the application as it is presented here is the lack of justifications for the bins in the vulnerability ranking criteria (Table 2). I recommend the authors discuss and justify how they chose the boundaries between the vulnerability classes. 2. The choice of the criteria to be evaluated should be justified. Implicitly, a conceptual model of coastal processes is adopted when selecting those criteria. 3. I recommend the authors write more explicitly what problems the AHP helps to solve in the context of vulnerability mapping. 4. I recommend that the authors explain more clearly how their results are constrained by their data and by some subjective choices made during the method implementation. Previous AHP applications address this issue through a sensitivity analysis and/or a discussion on how the results are realistic. 5. A review of previous works that used the Analytical Hierarchy Process for coastal risk or vulnerability mapping is lacking. This review is necessary to clearly show the novelty of this research. 6. Finally, these exercises of coastal vulnerability mapping are only useful in the context of their potential use for coastal prevention or for adaptation to coastal changes. I recommend the authors include a discussion on the potential use of their results (or eventually the barriers to this use) by coastal planners.

Author's Reply:

We sincerely thank the reviewer for the constructive, encouraging and positive review of our paper. We have almost addressed all the concerns of the reviewer to our best, and accordingly modified the manuscript. We hope that the manuscript is now suitable for publication.

Comment 1 and 2

The concern of the reviewer as highlighted in the first two points in the general com-

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ments has been explained by us to the best of our knowledge by adding the following paragraph at Page 517 Line 2

"Realizing the significance of expert judgment in deciding the scores and weights of the study, a 4 member interdisciplinary panel of experts consisting of a geologist, one oceanographer, an environmentalist and an ocean engineering specialist was set up. Integration of the expert opinions is an important step, especially in the case of data scarcity, uncertainty (source) and inconsistency (scale). In the case of Puducherry, the vulnerability classes and scores assigned are either categorical (Geomorphology, land-use/Land-cover, Road network, Cultural heritage) or quantitative (Coastal Slope, elevation, Shoreline change, Sea level change, significant wave height, Tidal range, Population) in nature. There is a considerable amount of subjectivity involved in the case of categorical classes; however, they can be used as indicators in the case of vulnerability assessment. The quantitative classes have been decided based on the expert judgments, literature information (Rao et al., 2008; Kumar et al., 2010; Kumar et al., 2012) and the spectrum of values of the dataset considered specific to the region. All these methodologies of classification depict site-specific relative vulnerability thresholds and thus are appropriate for regions with similar environmental conditions. Further, a scoring method is used in order to define relative rankings within the vulnerability classes. The assignment of vulnerability scores is performed using a 1-4 scale. This is contrary to the practice of using a scale of 1-3 or 1-5 in case of other vulnerability studies (Rao et al., 2008; Kumar et al., 2012). The choice of this scale is purely based on the opinion of the experts. The maximum score 4 is assigned to the most important vulnerability class and 1 on the other hand represents the least important."

Comment 3 and 5

As suggested by the reviewer, we have inserted the following paragraph at Page 514 line 18 that addresses the advantages of AHP as an effective method in the context of vulnerability mapping. The paragraph also includes a review of previous works that have used AHP for coastal risk or vulnerability mapping.

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"We have suggested this methodology as an improvement to the traditional CVI studies as we believe that AHP deduced weights provide better estimations. AHP has several advantages over these traditional methodologies; firstly, it takes into consideration expert opinions when the data involved are inconsistent or insufficient. This has immense significance, especially in the case of mapping coastal vulnerability as the data is highly heterogeneous in terms of its scale, temporal resolution, etc. The ability of AHP to integrate expert opinion as well as converting qualitative information to quantitative weights makes it very beneficial to coastal vulnerability studies. Secondly, the pair-wise comparison allows prioritization of various parameters relative to each other. This is important in the case of regional studies, where one parameter may be more dominant in one region than the other. Also, it is always desirable to use logically derived weights in the case of ranking studies (e.g. AHP derived) rather than those allocated arbitrarily. Finally, the test of consistency in the case of AHP helps to check the effectiveness of measurements and judgments, which provide certain degree of reliability to the study in comparison with random weights. AHP has been used as a decision making tool in several studies relating to landslide hazard zonation, flood mapping, soil erosion hazard mapping (Phukon et al., 2012; Bhatt et al., 2010; Sinha et al., 2008; Rahman et al.,2009). However, its use for coastal vulnerability has been very limited. Chang et al. (2012) used AHP to prioritize the protection of the Miaoli coast, Taiwan. Yin et al. (2012) and Ozyurt et al. (2010) have made an assessment of the coastal vulnerability to sea level rise for the Chinese coast and Turkish coast, respectively. A recent study (Cozannet et al., 2013) dealing with AHP and coastal vulnerability discusses the nuances (advantages, disadvantages and uncertainties) of this approach extensively. Apart from these applications, the use of AHP is rare for coastal studies and none has been reported in the case of Indian subcontinent.

Comment 4

As a response to comment 4 of the reviewer we would like to add a paragraph in the manuscript that subjectively discusses the uncertainties associated with this study.

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We would like to insert a new Table.11 in the manuscript which lists the uncertainties involved and their significance. The paragraph is placed at page 531 after line 22

"Uncertainty in the analysis: The major drawback of multi-criteria analysis is the difficulty in quantifying the inaccuracies and uncertainties involved, however a qualitative analysis can be done to enable better understanding. Table. 11 lists the various sources of uncertainty involved in the study and their significance. One of the major sources of uncertainty is the data. The vulnerability assessment includes data from several sources, which vary in scale, spatial and temporal resolutions. For example, while shoreline change analysis is taken in terms of the linear shoreline vectors, the slope dataset considered is a raster. Further, although most of the data considered in the case of PVI is in the shoreline segment scale, the socio-economic data is at a district or sub-district level. In terms of temporal resolution, PVI involves both long and short term data, whereas CVI involves data of one year, thus the latter being a more static indicator of the condition at a point in time. Another pertinent source of uncertainty can be attributed to the AHP ranking method. It is a difficult task to assign weights based on relative importance especially in the case of higher order factors such as elevation or slope. Also determining the importance of factors like sea level, significant wave height and tidal range with single data values was a difficult choice. Nevertheless, they were mostly made on the basis of drivers specific to the region as suggested in literature or as observed by the experts." Table 11. Uncertainty involved and the significance Source of Uncertainty Uncertainty Reason Significance

Datasets used Medium-High Varying spatial, temporal resolutions and scales Medium-High

Data preparation and Analysis Considered Low-Medium Better methods in terms of modeling etc are available but have not been used here Low- Medium

Ranking Criteria for individual Parameter Low Relative ranking and hence may not affect the overall analysis significantly and has been decided based on available data

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and data ranges Low

Defining the weighing criteria and factors in AHP Medium Although subjective, these can be considered more accurate than arbitrary weights as the experts consider a combination of field survey, modeled data , literature before making judgments High

Validation of result Low Validated with field surveys High

Comment 6 We are thankful to the author for this comment. The paragraph below has been added just above the conclusion section in the pdf. at page 531 .

"This paper attempts to develop a robust methodology to aid policy makers in coastal management projects. This kind of study can be used for both short and long term coastal planning. The inclusion of both physical and socio-economic gives an idea of multiple scenarios that can be used to device better adaptive strategies. The assessment of vulnerability allows to critically evaluate if the proposed adaptation strategies are actually effective or rather detrimental. For instance, the shoreline change analysis done in this study showing the accretion and erosion patterns along Puducherry throws light on how the placement of artificial hard structures has negatively affected the coastline. The results of these assessments are also very valuable for the regional stakeholders mainly involved in developmental activities along the coastal belts. Like in the case of Puducherry, a major tourist destination, it is essential that the maps obtained from this analysis are considered before setting up new establishments. Finally, maps obtained from vulnerability studies prove to be very beneficial from the risk prevention point of view as they estimate the degree to which the coastline is vulnerable during natural disasters." Detailed comments:

Referee's Comment:

Abstract: page 510: line 10. The paper should not "advocate" but demonstrate that AHP helps solving some specific problems or explains where it fails to support the analyst.

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Author's Reply:

'advocate' is replaced with 'demonstrate'

Referee's Comment:

Page 511: - Line 15: 1,5m of sea level rise by the end of the century is the upper limit of sea level projections. This sentence should be rephrased or make reference to previous studies

Author's Reply:

As suggested by the reviewer the lines have been rephrased and reference is added. "By the end of this century, the sea-level may rise by as much as 1.5m (Strohecker, 2008) due to warming of water, melting of glaciers and disappearing of ice sheets"

Referee's Comment:

Page 512: - Line 1 to 5: I don't understand the point in these two sentences - Line 11: I recommend rephrasing "(i) in terms of" potential (. . .); By the way, Romieu et al. (2010), cited by the authors, discuss the double meaning of the world vulnerability in the two fields. They states that in the climate community, vulnerability is equal to the potential impacts of climate change minus the benefits of adaption, whereas vulnerability is a component of risk (=hazard*vulnerability of exposed stakes). Am I right to understand that the authors want to point out the same here? - Line 20: I don't understand the relation with management here.

Author's Reply:

Line 1 to 5 : Rephrased to 'From the developing country prospective, the increase in number and intensity of natural hazards due to climate change and their potential impact on climate sensitive sectors, throws light on the need of finding alternatives to deal with these events more effectively before, during and after their occurrence.'

Line 11: "(i) in terms of the" is replaced by 'potential' as suggested by the reviewer

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In lines 15- 20 (Page 512) we mention that vulnerability can be understood to be a composition of multiple interacting factors . The sentence related to Romieu et al. (2010), has been added to stress the use of quantitative indices for vulnerability assessment.

Line 20: Replace 'and management' with 'which further is essential for disaster prevention, management and mitigation'

Referee's Comment:

Page 513 - Line 21: As stated by the authors, the most used coastal vulnerability index (CVI, Gornitz, 1991) uses a geometric aggregation function. This is justified by the fact that this aggregation is the most resilient to the lack of data. Conversely, AHP has a completely different approach as it helps experts in formalizing their subjective judgments and to translate it into a numerical aggregation function. I understand this is the main justification in using AHP here. The authors should explain here the specific problems in coastal vulnerability mapping that AHP is expected to solve. - Line 21: in addition to a stronger justification of using AHP in this context), a review of previous applications of AHP for coastal vulnerability mapping is necessary to explain the novelty of this paper.

Page 514 - Lines 19/21: the authors should justify why AHP deduced weights produce "better" estimations. This could be done by responding to the two comments above.

Author's Reply:

We have addressed the above comments in our reply to general comments 3 and 5. We have inserted the following paragraph at Page 514 line 18.

"We have suggested this methodology as an improvement to the traditional CVI studies as we believe that AHP deduced weights provide better estimations. AHP has several advantages over these traditional methodologies; firstly, it takes into consideration expert opinions when the data involved are inconsistent or insufficient. This has immense significance, especially in the case of mapping coastal vulnerability as the

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data is highly heterogeneous in terms of its scale, temporal resolution, etc. The ability of AHP to integrate expert opinion as well as converting qualitative information to quantitative weights, makes it very beneficial to coastal vulnerability studies. Secondly, the pair-wise comparison allows prioritization of various parameters relative to each other. This is important in the case of regional studies, where one parameter may be more dominant in one region than the other. Also, it is always desirable to use logically derived weights in the case of ranking studies (e.g. AHP derived) rather than those allocated arbitrarily. Finally, the test of consistency in the case of AHP helps to check the effectiveness of measurements and judgments, which provide certain degree of reliability to the study in comparison with random weights. AHP has been used as a decision making tool in several studies relating to landslide hazard zonation, flood mapping, soil erosion hazard mapping (Phukon et al., 2012; Bhatt et al., 2010; Sinha et al., 2008; Rahman et al.,2009). However, its use for coastal vulnerability has been very limited. Chang et al. (2012) used AHP to prioritize the protection of the Miaoli coast, Taiwan. Yin et al. (2012) and Ozyurt et al. (2010) have made an assessment of the coastal vulnerability to sea level rise for the Chinese coast and Turkish coast, respectively. A recent study (Cozannet et al., 2013) dealing with AHP and coastal vulnerability discusses the nuances (advantages, disadvantages and uncertainties) of this approach extensively. Apart from these applications, the use of AHP is rare for coastal studies and none has been reported in the case of Indian subcontinent.

Page 514 Line 20: Replace ‘The result of this’ with ‘The present’

Referee’s Comment:

Page 517 - See general comment 1: the bins (upper and lower limits in each class) should be better justified. This is most important since the results are highly dependent on this. For example: why is sea level change (1 to 2mm/year) considered as corresponding to a high vulnerability, while 0 to 1mm/year is considered to low vulnerability? Other could state that high vulnerability corresponds to sea level rise in the order of at least one centimetre per year. Similarly, it is considered that higher tidal

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ranges account for higher vulnerability. Conversely, the classical Coastal Vulnerability Index (Gornitz, 1991) considers that the lower tidal range account for greater vulnerability (e.g. a 2 days storm would reach the upper beach all the time in a microtidal environment. These choices should be justified (e.g. by knowledge of the field, by reference to previous studies or publications, by a subjective choice of experts) as all the results depend on them. If some choices are subjective, this should be indicated too. - I also strongly recommend justifying the criteria chosen here. For example: why did you choose the “observed sea level rise” and not “expected future sea level rise” as a criterion?

Author’s Reply:

We have addressed these comments as a response to comment 1 and 2 (general comments). We would like to add the following paragraph at Page 517 Line 2

"Realizing the significance of expert judgment in deciding the scores and weights of the study, a 4 member interdisciplinary panel of experts consisting of a geologist, one oceanographer, an environmentalist and an ocean engineering specialist was set up. Integration of the expert opinions is an important step, especially in the case of data scarcity, uncertainty (source) and inconsistency (scale). In the case of Puducherry, the vulnerability classes and scores assigned are either categorical (Geomorphology, land-use/Land-cover, Road network, Cultural heritage) or quantitative (Coastal Slope, elevation, Shoreline change, Sea level change, significant wave height, Tidal range, Population) in nature. There is a considerable amount of subjectivity involved in the case of categorical classes; however, they can be used as indicators in the case of vulnerability assessment. The quantitative classes have been decided based on the expert judgments, literature information (Rao et al., 2008; Kumar et al., 2010; Kumar et al., 2012) and the spectrum of values of the dataset considered specific to the region. All these methodologies of classification depict site-specific relative vulnerability thresholds and thus are appropriate for regions with similar environmental conditions. Further, a scoring method is used in order to define relative rankings within the vulner-

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ability classes. The assignment of vulnerability scores is performed using a 1-4 scale. This is contrary to the practice of using a scale of 1-3 or 1-5 in case of other vulnerability studies (Rao et al., 2008; Kumar et al., 2012). The choice of this scale is purely based on the opinion of the experts. The maximum score 4 is assigned to the most important vulnerability class and 1 on the other hand represents the least important."

We would like to add the following at Page 522 Line 20-21

Gornitz, 1991 suggests that high tidal range is associated with stronger tidal currents which have the capacity to cause erosion and transport of sediment. Further he specifies, macro-tidal coasts (>4m) will be more vulnerable than those with lesser ranges.

Page 517 Line 2: Delete 'Hence'

Page 517 Line 2: Capitalize 'T' in 'the'

Page 517 Line 3: Add 'elaborately' after 'discussed'

Referee's Comment:

Page 521 - Line 9 to 14 is unclear for me: what is the reference period for the rates of 1.29mm/yr? I recommend explaining more clearly what components of relative sea level rise (with respect to a terrestrial framework at the coast) are assessed in each approach and the time periods.

Author's Reply:

Based on the query raised by the reviewer, we have inserted the below lines in the pdf at Page 521 Line 9

In their study, they have considered all tide gauge records of the Arabian Sea and the Bay of Bengal that have duration of at least 20 years. Eventually they have estimated trends at station that have records longer than 40yrs and have applied correction for vertical land movements owing to Glacial isostatic adjustments using ICE- 5G model (Peltier, 2001;2004).

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Insert at Page 521 Line 13

“The rationale behind using this value is that this estimate is consistent with the global estimate reported in the Third assessment report of IPCC (Unnikrishnan and Shankar, 2007). Kumar et al., 2012 in their paper have assigned this value as medium vulnerability class for their study area of Chennai. As the scoring in our case varies between 1 and 4, we have classified it as high vulnerability class with a ranking of 3.”

Insert at Page 521 Lines 4 to 7:

Global Sea-level rise studies have been carried out extensively in the last two decades due to the availability of monthly mean sea level data from the permanent Service for Mean Sea Level (Woodworth and Player, 2003). That is the reason, we have also selected observed sea level instead of projected sea level rise.

Referee’s Comment:

- Lines 9 to 14: It would be necessary that the authors discuss here the likelihood of more local vertical ground motions (subsidence or uplift) affecting the coast. Levelling data, if available,could provide insight to this issue. If not, are they any geological evidences (footmarks) or any other geodetic information?

Author’s Reply:

As expected by the reviewer, local vertical ground motions certainly may affect the coast. But unfortunately, we are not able to find out any published literature or data set on ground motions and geodetic information at this region. Few studies by our National Geophysical Research Laboratory, Hyderabad have been initiated at few locations of Indian region to find out the geodynamic movements. As, we don’t have access to that data, we could not add in this study.

Referee’s Comment:

Page 521 Line 21: Equation 1 is actually homogeneous to an energy flux (J/mˆ2). In

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this context, except if all waves periods are similar, I would suggest using the the total wave energy in one wavelength per unit crest as indicator.

Author's Reply:

The suggestion of the reviewer is very knowledgeable, however, for our study the objective is to use significant wave height (SWH) as a proxy to wave energy and the addition of the formula is only to inform readers about the direct relationship between wave energy and wave height. Also, it may kindly be noted that we have used SWH derived from wave spectra only, wherein all waves are considered.

Referee's Comment:

Page 522

- Line 5: please indicate the unit of the resolution (degree °?) - Given the resolution of the NCEP/NCAR wind model, I would be quite surprised that the modelled cyclonic waves are realistic. This should be discussed.

Author's Reply:

Page 522 Line 5: As per the suggestion, the unit of the resolution (deg) is indicated.

It is true that none of the existing wave models can give accurate estimates for the wave heights prevailed during cyclones; in general, we find that NCEP (or any other winds) winds during cyclones are much lesser than the measured winds, and subsequently, model wave heights are lesser than the real wave heights. In this work, the assessment is only concerned with average SWH and not the values during the extreme weather events. Hence, we would like to delete this statement which can be misleading to the readers in the context of an extreme event such as Thane Cyclone.

Referee's Comment:

Page 524 - Land use/land cover: What is actually assessed? Land use or land use changes? - Road network: why are the values 250m/500m/1km2km chosen?

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Author's Reply:

Page 524 Line 2: Actually land use is assessed. The words "the changes in" are deleted to remove the confusion.

Page 524 Line 4: Deleted "changes in"

Page 524 Line 4: Inserted "of a region" after LULC

Page 524 Line 25: Insert the word "subjectively" after done.

Buffer zones of 250m/500m/1km/2km were selected subjectively. As per the impact of the disaster, the appropriate approach can be selected. It need not be explored to find out the availability of the road during or after the event of natural disasters.

Referee's Comment:

Page 529 - Lines 20/21: I am not sure I understand the point - All along the result section, a discussion on how the results are realistic is missing. Also, to which extent do the results reflect the actual coastal vulnerability and to which extent is it dependant of subjective choices done in the previous steps?

Author's Reply:

Lines 20/21: Sentence is deleted.

Based on the reviewer's comment, we would like add the below paragraphs in the modified manuscript. These paragraphs will be placed at the end of results and discussions section at Page 531 after line 22

Uncertainty in the analysis

The major drawback of multi-criteria analysis is the difficulty in quantifying the inaccuracies and uncertainties involved, however a qualitative analysis can be done to enable better understanding. Table. 11 lists the various uncertainties involved in the study and their significance. One of the major sources of uncertainty is the data. The vulnera-

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bility assessment includes data from several sources, which vary in scale, spatial and temporal resolutions. For example, while shoreline change analysis is taken in terms of the linear shoreline vectors, the slope dataset considered is a raster. Further, although most of the data considered in the case of PVI is in the shoreline segment scale, the socio-economic data is at a district or sub-district level. In terms of temporal resolution, PVI involves both long and short term data, whereas CVI involves data of one year, thus the latter being a more static indicator of the condition at a point in time. Another pertinent source of uncertainty can be attributed to the AHP ranking method. It is a difficult task to assign weights based on relative importance especially in the case of higher order factors such as elevation or slope. Also determining the importance of factors like sea level, significant wave height and tidal range with single data values was a difficult choice. Nevertheless, they were mostly made on the basis of drivers specific to the region as suggested in literature or as observed by the experts."

Advantages and Disadvantages of the method considered The advantages of AHP have been discussed elaborately in previous sections. As seen from its application for the coastal vulnerability of Puducherry, it is evident that it is efficient in estimating the weights required for further processing of the indices. It is very difficult to develop common methodologies at country level; hence, regional vulnerability procedures should be established to study the vulnerabilities of different regions. AHP enables relative ranking of criteria and hence the order of parameters chosen can be flexibly altered based on the dominant conditions prevailing in a particular region. Thus, we think this approach can be used successfully for the assessment of coastal vulnerability of the various coastal regions of India. It is also important to specify the disadvantages of this method, which is considerably different in the case of other vulnerability methodologies. Firstly, the hierarchical framework offers limited representation on a one-one basis, which does not take into account interaction between the parameters. Secondly, as stated earlier lack of data or data inconsistencies can affect the over-all study, which can be removed by incorporating more detailed datasets of considerable spatial and temporal resolutions. The third limitation arises due to the methodologies used in de-

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picting the parameters; for e.g. the use of NCEP/NCAR data for SWH analysis or the use of Wxtide for tidal analysis. Finally, this type of analysis mainly focuses on coastal threats as a whole rather than in the pretext of a specific event such as cyclone or sea level changes. Nevertheless, we believe, in such cases AHP can still be used, but with more elaborate long term datasets.

Potential Use of this method in Disaster management

"This paper attempts to develop a robust methodology to aid policy makers in coastal management projects. This kind of study can be used for both short and long term coastal planning. The inclusion of both physical and socio-economic gives an idea of multiple scenarios that can be used to device better adaptive strategies. The assessment of vulnerability allows to critically evaluate if the proposed adaptation strategies are actually effective or rather detrimental. For instance, the shoreline change analysis done in this study showing the accretion and erosion patterns along Puducherry throws light on how the placement of artificial hard structures has negatively affected the coastline. The results of these assessments are also very valuable for the regional stakeholders mainly involved in developmental activities along the coastal belts. Like in the case of Puducherry, a major tourist destination, it is essential that the maps obtained from this analysis are considered before setting up new establishments. Finally, maps obtained from vulnerability studies prove to be very beneficial from the risk prevention point of view as they estimate the degree to which the coastline is vulnerable during natural disasters."

Referee's Comment:

Page 532 Lines 8-10: this point would be relevant earlier in the paper Line 15: susceptibility or vulnerability?

Author's Reply:

Page 532 Lines 8-10: Yes. Similar point has been already explained in the manuscript.

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Here, we kept these lines only to emphasize that it is more advantageous in vulnerability assessment.

Page 532 Lines 7-10: replace “The analytical (. . ..)assessment” with

The analytical hierarchical process (AHP) proposed by Saaty (1977) is a popular approach to multi-criteria decision making which enables the experts to translate their subjective judgments into quantitative weights. Hence, it is more advantageous in the case of vulnerability assessment where there is a lack of a purely deterministic method owing to the huge data involved from different sources.

Page 532 Line 15:

Replace ‘susceptibility’ with ‘vulnerability’

Referee’s Comment:

Tables

Page 538: GIS data are not sources but the format; LISS III is not self-explicit here.

Author’s Reply:

Table 1 Inserted ‘The Linear Imaging Self Scanning Sensor’ after LISS III (Geomorphology) Inserted ‘Ramesh et al., 2011’ after 2011 (Tidal range)

Page 539: see major comment above

Author’s Reply:

Explained in response to general comments 1 and 2 : Mainly based on expert opinion and Literature information

Page 542: “column total” is not useful here. Conversely the resulting priority index would be useful. (i.e. as derived by calculating the eigenvector associated with the principal eigenvalue of each comparison matrix).

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Author's Reply:

Removed the term Column total. We would like to highlight here that the whole procedure of AHP involving calculating the eigen vector and finding the weights has been described in Page 526 Lines 2-5

Page 543: Table 6 is not useful (equal to normalized table 5). Same remark for table 8.

Author's Reply:

We feel the tables may be required in order to understand the methodology especially as limited literature is available in case of application of AHP in coastal vulnerability.

Referee's Comment:

Minor (wording)

Page 511: Line 6: "in lieu" or "in light"?

Author's Reply:

Replaced "in lieu" with "In light"

Page 513: Line 10: delete the space between sea and -level

Author's Reply:

Deleted

Line 17: "multi-hazard vulnerability" may be unclear: I would suggest instead: "the vulnerability of the coast to multiple types of adverse event" Line 20: I suggest to clarify what is meant with "geo-spatial technologies" in this context

Author's Reply:

"Multi-hazard vulnerability" is deleted and replaced with "vulnerability to multiple hazard scenarios"

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The terminology applied is the same as that used by the author. Here the author refers to GIS and remote sensing as Geo-spatial techniques.

Page 516 Line 1: “Methodology” refers to the science of methods. What is presented here is a “method”. Line 16: I would delete the word risk (“risk variables”) which is confusing in this context.

Author’s Reply:

Line 1: Replaced “Methodology” with “Methods and Procedures” Line 16: Deleted the word “Risk”

Page 517

- Coastal slope definition: “perpendicular to the shoreline” is missing. - What is ETOPO5?

Author’s Reply:

In the coastal slope definition, perpendicular to the shoreline is added (Page No: 517, Line No: 13)

Line 20: Inserted after ETOPO 5“(ETOPO5 is a digital data base of land and sea- floor elevations on a 5-minute latitude/longitude grid)”; pls expand ETOPO5

Page 521 Line 4/5: please rephrase (“the study (. . .) has been studied (. . .)”)

Author’s Reply:

The sentences “The study (. . .) 2003)” have been rephrased to

“Global Sea-level rise studies have been carried out extensively in the last two decades due to availability of monthly mean sea level data from the permanent Service for Mean Sea Level (Woodworth and Player, 2003)”

Page 523 Use “Disaster” instead of “calamity” (?)

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Author's Reply:

Replaced "Calamity" with "Disaster" as per suggestion

Page 525 Delete caused (?)

Author's Reply:

Deleted as per suggestion (Line No 6)

Page 526 Lines 9 to 18 are actually redundant with the introduction

Author's Reply:

These sentences could enforce the text on CVI and the different approaches of CVI by different authors.

Page 527

This part could be slightly reduced as the AHP method itself is clearly explained in Saaty's publications

Author's Reply

We felt that it is necessary to explain the methodology in detail as the readers who are new to AHP can follow it up and use it for their wide applications.

Page 528

Lines 22/23: I disagree: water pumping can affect even smaller areas and therefore, the fact that the coastal zone of interest is small is not a good justification for considering equal sea level rise.

Author's Reply

We agree with the reviewer that even water pumping can affect smaller areas. As we have used only one relevant value, it has been reported as such. Surely, in our future attempts, we will use more values.

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Page 531 Line 24: is it meant: “the rising number of coastal disasters” (?)

Author’s Reply

Yes. The word “Hazards” is replaced with “disasters”

Page 532 Line 7: acronyms should be defined earlier

Author’s Reply

Defined earlier as per the suggestion

Typing errors in the References: Thieler and Hammar-Klose (A instead of E)

Author’s Reply

Corrected as per suggestion

Vittal Hegde and Reju (2007) is actually Hegde and Reju according to my reference list (Hegde, A. V., and Reju, V. R.: Development of coastal vulnerability index for Mangalore coast, India, Journal of Coastal Research, 23, 1106-1111, 10.2112/04-0259.1, 2007.)

Author’s Reply

Corrected as per suggestion

Szlafsztein

Author’s Reply

Corrected as per suggestion

Ramesh et al. 2011 is not quoted (therefore delete)

Author’s Reply

Ramesh et.al 2011 is quoted in the Table 1 and in the Manuscript.

The following references will be added in the manuscript while preparing the modified

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manuscript.

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