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June 26, 2024

Subject: Submission of the revised manuscript (**Ms. No: NHESS-2023-191)**

Dear Dr. Brunella Bonaccorso,

Thanks for the mail communicating insightful comments of learned reviewers. We appreciate the additional suggestions of Reviewer #2. We carefully addressed the specific issues, and our response is detailed under,

As suggested by the reviewer, we have added the detailed description of the TUNAMI-N2 model in the text. The computational grid characteristics (A-D grids) and their roles in modeling are explained and added in supplementary material. Validation with field data shows our results align within a 10% error margin with observed tsunami run-up heights. The other queries regarding evaluating uncertainties, including tidal excursion, lack of barotropic surge consideration, and the mean slope in the study area, have also been explained. The shoreline positional error and its components, along with the calculation of total uncertainties, are explained in the supplementary materials. The other minor corrections in language and updated references are included in the revised manuscript. The "reply to review" also presents the details response.

As suggested, the revised submission includes the "clean" and "Track-change" versions. We hope you find the revised manuscript addressing the issues raised by Reviewer#2 appropriately and favorably consider the manuscript for publication.

We look forward to your kind response.

With sincere regards,

(Anand K. Pandey)

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Our Reply to the COMMENTS of REVIEWERS on Ms. No: NHESS-2023-191

Title: Shoreline and Land Use Land Cover Changes along the 2004 tsunami-affected South Andaman Coast: Understanding Changing Hazard Susceptibility.
https://doi.org/10.5194/nhess-2023-191

In this response file, the blue text shows the reviewers' comments, while the black text is our replies.

Reply to Reviewer #2

The authors did not adequately reply to the following previous issues:

1) The author adopted the TUNAMI-N2 model to evaluate the area submerged by the tsunami flow. The authors should describe: i) the model, ii) the calibration parameters and how they are selected; iii) the characteristics of the computational grid. The model is applied to a real event, therefore a validation with some field data could be useful.

Thanks for the detailed comments.

We have incorporated a brief about the TUNAMI-N2 modeling, grid areas A-D, model input and calibration factors and validation, etc., in the revised manuscript. New graphs and figures are added to the supplementary materials. The details of the same are in the reply as under.

I hope you find the revision adequate and satisfactory.

- No relevant description of the TUNAMI-N2 model is provided (i.e. What equations does it solve? Is the solver implicit or explicit? …)

The Tohoku University's Numerical Analysis Model for the Investigation of Near field tsunamis (TUNAMI-N2) to simulate the tsunami run-ups and impact using explicit leap-frog finite-difference methods by solving non-linear shallow water wave equations, incorporating bathymetry, earthquake source parameters, and fault geometry (Imamura and Imteaz, 1995; Imamura, 1996; Goto, 1996; Imamura et al., 2006; Yalciner et al., 2003). The 2-dimensional governing equations for tsunami modeling are:

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0$$

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + \frac{\partial}{\partial y}\left(\frac{MN}{D}\right) + gD\frac{\partial \eta}{\partial x} + \frac{gn^2}{D^{7/3}} M\sqrt{M^2 + N^2} = 0$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left(\frac{MN}{D}\right) + \frac{\partial}{\partial y}\left(\frac{N^2}{D}\right) + gD\frac{\partial \eta}{\partial y} + \frac{gn^2}{D^{7/3}} N\sqrt{M^2 + N^2} = 0 \qquad (1)$$

where D is the total water depth given by h+η, τx, and τy the bottom frictions in the x- and y-directions, A is the horizontal eddy viscosity, which is a constant in space, and the shear stress on a

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surface wave is neglected. M and N are the discharge fluxes in the x- and y- directions, which are given by

$$M = \int_{-h}^{\eta} u dz = u(h + \eta) = uD \qquad N = \int_{-h}^{\eta} v dz = v(h + \eta) = vD \qquad (2)$$

The bottom friction is generally expressed as follows

$$\frac{\tau_x}{\rho} = \frac{1}{2g}\frac{f}{D^2} M\sqrt{(M^2 + N^2)} \qquad \frac{\tau_y}{\rho} = \frac{1}{2g}\frac{f}{D^2} N\sqrt{(M^2 + N^2)} \qquad (3)$$

The friction coefficient 'f' and Manning's roughness 'n' are related by

$$n = \sqrt{\frac{f D^{1/3}}{2g}} \qquad (4)$$

It is seen that when D is small and f becomes large, then n remains almost a constant; substituting M, N, and the above values in fundamental equations of TUNAMI N2 to obtain wave propagation using the explicit Leap-Frog finite difference Scheme (Imamura, 2006).

- What are the areas A-D indicated on line 151?

TUNAMI-N2 code uses the data, which is formatted into three columns, X-coordinate (Longitude), Y-coordinate (Latitude), and Z (Land elevations as negative and Ocean depths as positive), and converted into evenly spaced grids by using surfer software. In our study, we considered grid spacing of all four grids in 1: 3 ratios, i.e., A and B grids to model the linear effects in the deep sea of 81 arc seconds and 27 arc seconds, and C and D constant grids to model the non-linear effects of the tsunami are of 9 arc seconds and 3-arc seconds. The A, B, C, and D grids are used to compute Tsunami wave height and inundation and are included in the supplementary materials as Figure (S1).

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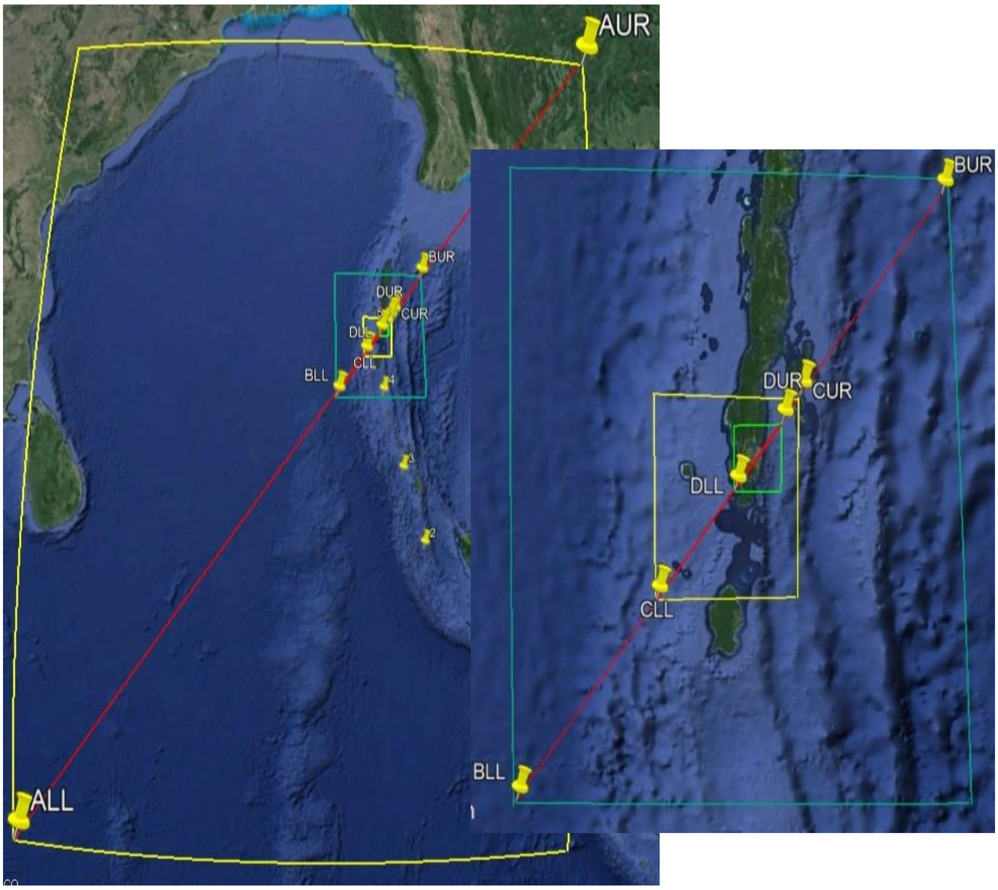

Figure S1: A-D grids used for the TUNAMI-N2 modeling in the present study

- The model input data are indicated, not the model calibration parameters (e.g., roughness, turbulence,..)

In most computations, the manning coefficient is around 0.025, consisting of gravel and sand (Masaya et al., 2020); however, different manning coefficients can be considered for rough bathymetry (Dao and Tkalich, 2007). A value of 0.01 is considered for smooth bathymetry and stony cobbles, and a roughness of 0.035 can be considered. Viscosity and roughness influence mild slopes, but they are negligible for steep slopes, and a dynamic friction coefficient from 0.01 to 0.1 can be considered (Zhang et al., 2024). For the propagation of tsunamis in shallow water, the horizontal eddy turbulence terms are negligible as compared with the bottom friction (Dao and Tkalich, 2007)

- No sort of validation is provided with data relating to the events analysed

Our results agree with the tsunami run-up heights estimation by Cho et al. (2008) and Prerna et al. (2015) at a few locations in the present study area. Since the tide gauge data are available at a few locations along the Indian coast, we rely on limited field observations along the coast to validate our

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findings. The field observations of the water marks on a light post at Bambooflat in Port Blair was seen to be around 3.8m (Cho et al., 2008) and our computations show it to be ~ 3.5m, which is within ~7% error limit. Similarly, at South Point, Port Blair, the field observations are 10m, and our computations value is 9.6m, which is ~4% deviation and the deviation is 7% at Chidiyatopu. The Bambooflat region and Harbour area of Port Blair experienced liquefaction affecting several buildings (Murty et al., 2006), and our calculations show that the tsunami wave heights were around 5.5m. At most locations, the computed values are within 10% error.

2. L. 186-187 How did you evaluate the uncertainty? What is the measured tide excursion? What is the barotropic surge? What is the mean slope in the area?

The accuracy of shoreline position and the rates of shoreline change can be influenced by various error sources, such as the position of the tidal level, image resolution, digitization error, and image registration (Jayson-Quashigah et al., 2013; Vu et al., 2020, Basheer et al., 2022). Therefore, the shoreline positional error (Ea) for each transect was calculated using Equation (6):

$$E_s = \pm\sqrt{E_s^2 + E_w^2 + E_d^2 + E_r^2 + E_p^2} \qquad (6)$$

Where Es is the seasonal error due to seasonal shoreline fluctuations, which is ~ ±5 m in extreme ocean level (EOL); Ew is the tidal error, Ed is the digitization error, Er is the rectification error, and Ep is the pixel error (Fletcher et al. 2011; Vu et al., 2021). This approach assumes that the component errors are normally distributed (Dar & Dar, 2009). The total uncertainties were used as weights in the shoreline change calculations. The values were annualized to provide errors (Eu) estimation for the shoreline change rate at any given transect, expressed in Equation (7):

$$E_u = \pm\frac{\sqrt{U_{t1}^2 + U_{t2}^2 + U_{t3}^2 + U_{t4}^2 + U_{tn}^2}}{T} \qquad (7)$$

where t_1, t_2, and tn are the total shoreline position error for the various years, and T is the years of analysis.

Table S1 Uncertainty Calculation used in the DSAS tool

Positional Error (m)	2003	2004	2017	2018	2019	2020
Seasonal error (Es))	5	5	5	5	5	5
Tidal fluctuation (E_{td})	1.17	0.38	0.86	1.1	0.84	0.85
Shoreline proxy offset (Eo)	NA	NA	NA	NA	NA	NA
Measurement errors (m)	0	0	0	0	0	0
Georeferecing/Rectification error (Er)	0	0	0	0	0	0
Digitizing error (Ed)	20	20	15	20	20	19
Toposheet survey offset (Et)	NA	NA	NA	NA	NA	NA
Pixel Error (Ep)	0	0	0	0	0	0
Total Shoreline position error (Esp) m	26.17	25.38	20.86	26.10	25.84	24.85
Year	2003-04	2004-05	2017-18	2018-19	2019-2020	2020-2021
Uncertainty	7.18	5.04	6.85	7.21	7.12	4.98

- What is the measured tide excursion?

Highest Tide Gauge Measurement: 1100 mm
Lowest Tide Gauge Measurement: 717 mm
Tide Excursion: 1100 - 717 = 383 mm
The measured tide excursion from 2017 to 2020 is 383 mm (0.383 m).

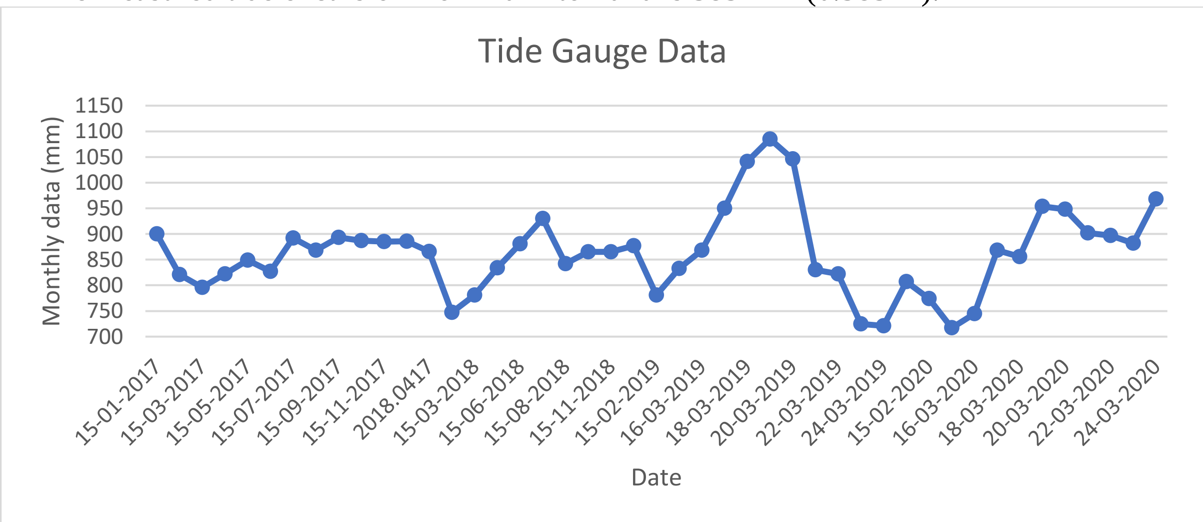

Figure S2 Monthly mean sea level data showing tide excursion (Tide Gauge data)

What is the barotropic surge?

Our current analysis focused on shoreline change detection due to tsunamis and decades after tsunamis using Landsat-8 data and the DSAS tool. The observed tidal effect is used for error analysis of inundation due to the 2004 tsunami. We did not incorporate barotropic surge by large-scale

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atmospheric pressure variations, which can cause temporary water level fluctuations and, in extreme cases, might influence shoreline change.

Including surge data could be valuable for future investigations aiming at a comprehensive understanding of shoreline dynamics in the study region.

What is the mean slope in the area?

The mean slope of an area is a crucial topographic characteristic that influences various coastal processes, including erosion, sediment transport, and shoreline stability. We digitized the shoreline along seven zones and marked a 500-meter buffer to check the mean slope along the zones. The mean slope values for these Zones are derived from a DEM using a zonal statistics tool in the ArcGIS environment.

Table S2 Mean Slope of Area

Zone	AREA (Sq. m)	MIN (Degrees)	MAX (Degrees)	RANGE (Degrees)	MEAN (Degrees)	STD (Degrees)
1	9775286.671	0	36.98	36.98	7.22	4.69
2	4079097.873	0	24.96	24.96	8.18	4.66
3	2443355.379	0	23.50	23.50	6.60	3.95
4	2830375.41	0	20.72	20.72	4.13	3.32
5	2875139.173	0	33.82	33.82	5.56	4.52
6	1612428.034	0	33.75	33.41	11.4	6.90
7	6126107.436	0	37.81	37.81	12.3	5.99

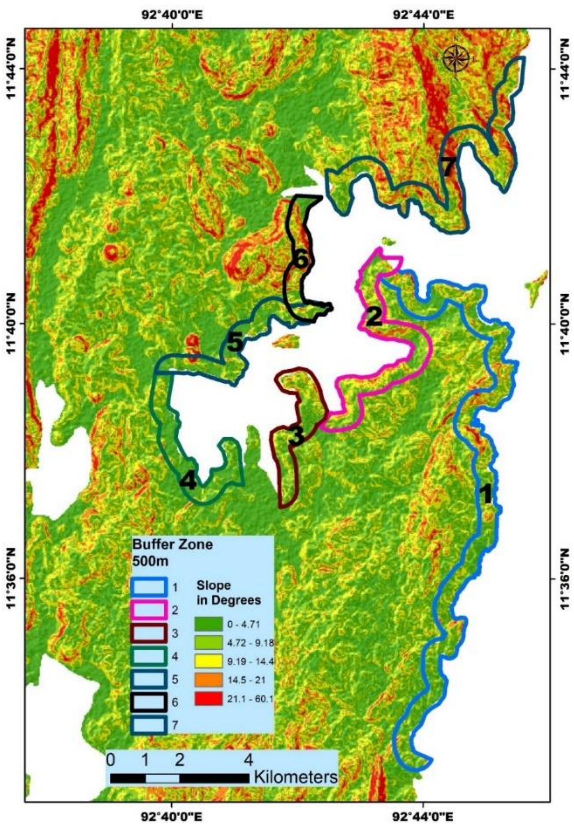

Figure S3 Slope Map showing 500m buffer marked along the shoreline

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3) Again, NSM and EPR are not "statistical" parameters since they relate to the difference between two observations.
We have incorporated your suggestion.

4) L. 342-345 It's just an opinion and not a fact. The presence of suspended sediment do not is directly associated with a reduction in the water depth.

Agree and acknowledge the limitations of solely relying on visual interpretation. However, the increased suspended sediment load derived from land use change would contribute to shoaling (shallowing of water bodies) over time, especially in bay areas.

References for the reply (added to the Ms_R2)

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The part of the above explanations is included in the text of the manuscript and figures in the Supplementary materials.

We hope reviewer#2 finds the explanations and modifications in the Ms appropriate.

Anand

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