A PARAMETRIC APPROACH FOR COASTAL FLOOD RISKS ASSESSMENT BY INTEGRATING HAZARD DATA AND MICRO-LEVEL ASPECTS OF RURAL VULNERABILITY: CASE OF SAGAR ISLAND, WEST BENGAL

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KEYWORDS: Flood vulnerability, flood risk zoning, Sundarbans, risk assessment,

ABSTRACT: Coastal floods are devastating and life-threatening. This being intensified by the changing climate, rapid population growth, unplanned development. It has a detrimental impact on human habitats and their livelihood, with rural areas suffering the most due to low resilience. Floods were the most commonly occurring natural disasters between 1998 and 2017, causing 142,088 deaths and affecting nearly two-billion people across the globe. Flood mitigation, therefore, appears as a challenging task before the policymakers, technical experts, health organizations, and civil society. Flood risk assessment and mapping is a tool for identifying the vulnerable locations and further helps in minimizing the disaster-effect. The study proposes a parametric approach for flood risk zoning by spatially analyzing flood hazard exposure and corresponding aspects of rural vulnerability from socio-demographic, economic, infrastructure, and accessibility to infrastructure domain. The relative sensitivity of the parameters is evaluated based on the domain knowledge, reclassifying them on a Likert scale of 1 to 5. Multi-Criteria Decision-Making is used to reclassify flood exposure and vulnerability that are later integrated using weighted sum technique. The flood risk zone map is obtained as the product of exposure and vulnerability parameters. The case area chosen for the analysis is for a smaller island in Sundarbans. The results showcase the significant influence of socio-demographic, economic, and accessibility parameters in enhancing coastal flood sensitivity. The risk is highest around the coastal belt and reduces as one shift to the island core. Land use plays a critical role in influencing regional flood risk as to the presence of mangroves prevent coastal inundation and saltwater intrusion. The parameter 'accessibility to infrastructure' is a novel addition in evaluating micro-level flood risk of the island caused due to the uneven resource distribution. The method allows planners and policymakers to prioritize and develop effective strategies for risk reduction in flood-prone areas. Also, the pairwise comparison method has universal application for micro-level spatial operations in a data-scarce environment. The mathematical base of the techniques effectively eases out a complex problem in the path of policymaking.

1. INTRODUCTION

Coastlines all over the world are now experiencing the constant threat of flooding due to periodic storms, anomalous tidal waves and sea level rises (Xie et al., 2019). The rising population along the coastal belts leads to overexploitation of scarce resources escalating environmental degradation and coastal risk intensification (Kron et al., 2013). Coastal risk refers to the probability of damage that may occur due to hazard exposure and related susceptibility (Messner & Meyer, 2006). Coastal regions face the perpetual risk of flooding. Losses due to coastal floods are expected to rise, jeopardising 4.5% of global GDP by the year 2200 (Desmet et al., 2018). Regardless of the constant efforts to maintain present flood probability through proactive adaptation strategy, the rising sea level and rate of land subsidence are likely to endanger coastal infrastructure worth billions of dollars by the year 2100 (Hallegatte et al.,2013). The flood frequency due to unusual high tide events is also projected to grow about 26 times per year by 2035, affecting 170 coastal communities (Spanger-Siegfried, 2017). Inundation of coastline create havoc among coastal communities, primarily those residing within the developing countries are often underequipped of the adequate resistive mechanisms (Dolan & Walker, 2006). For instance countries such as India, Bangladesh Iran, Maldives and Sri Lanka is expected to envisage the highest coastal densities by 2060 (Neumann et al.,2015; Nguyen et al., 2016), expediting disaster risks. India stands first in terms of the projected population being exposed to coastal flooding, i.e. about 14 million people by 2070 (Nicholls et al., 2007). Surrounded by sea on all three sides, the eastern coast of the peninsular nation is highly vulnerable from frequently occurring high-intensity cyclones, and storm surges conjoined with low socio-economic profile and limited amenities for adaptation (Rehman et al., 2020). The Bay of Bengal (BOB) sea is the genesis of cyclonic storms (Murty & Flather, 1994). The surges due to cyclonic event occur in the frequency ratio of 1:4 for the Andaman and BOB sea respectively, making the West Bengal – Andhra Pradesh coast highly susceptible to sea-water intrusion (Alam et al., 2003). The rising global and sea surface temperature adds to the variation in the values of relative sea-level across the BOB coastline; 0.3mm/ year in Chennai (Tamil Nadu) to 5.35mm/year near Diamond Harbour (West Bengal)(Zhang et al., 2012). However, this variation can also occur due to sinking of the Eurasian plate. The low-lying continental shelf, shallow bathymetry and funnel-shaped topography of the West Bengal coastline (bay) allow gushing tides to move further inland. Addition to this, modification of aboriginal landcover for housing and cultivation have exposed the coastline to ever-increasing flooding scenario. Thus, making disaster risk mitigation the most critical concern for sustainable development in the climate change scenario. The first step to disaster preparedness corresponds to awareness regarding the level of hazard exposure and vulnerability within a region. Regional vulnerability determines the degree of sensitivity and capability of a region to survive through a hazard event (Gornitz, 1991). Disaster risk becomes negligible if the exposed area is empty, thus making vulnerability assessment vital element in the process (Armenakis et al., 2017). Parametric approaches of vulnerability assessment, unlike the deterministic ones, extend beyond the physical aspect of hazards exposure by addressing multidimensional aspect regional vulnerability (Fekete et al., 2012). The comprehensive method is cost-effective and finds a more straightforward application in a data-scarce environment which is the usual scenario of resource crunched developing economies. The Multi-Criteria Decision-Making technique has been popular and widely accepted for developing relative scores for the diversified vulnerability parameters as per the knowledge of the expert (Feloni et al., 2020). In combination with spatial datasets and Geographic Information System (GIS), it enables visual interpretation of the zonal sensitivity and region-centric policy development (Laskar, 2003). The study proposes to develop flood risk zones for a region using spatial assessment based on the parametric approach. The vulnerability parameters are derived from freely available data sets prioritised using MCDM technique. The research tries to draw critical insights on risk scenarios by computing a time series assessment for the case-area region.

2. STUDY AREA

Sagar is the largest habited island in Sundarban estuary (figure 1). The Sagar block consists of 47 administrative villages called mouza or villages in the state of West Bengal, India. Historically, Sagar island has always been prone to inundation caused by cyclonic storm surges and anomalous high tide events (Gayathri et al., 2016). Cyclone Aila in 2009 caused large scale devastation due to saltwater intrusion in low-lying coastal areas.

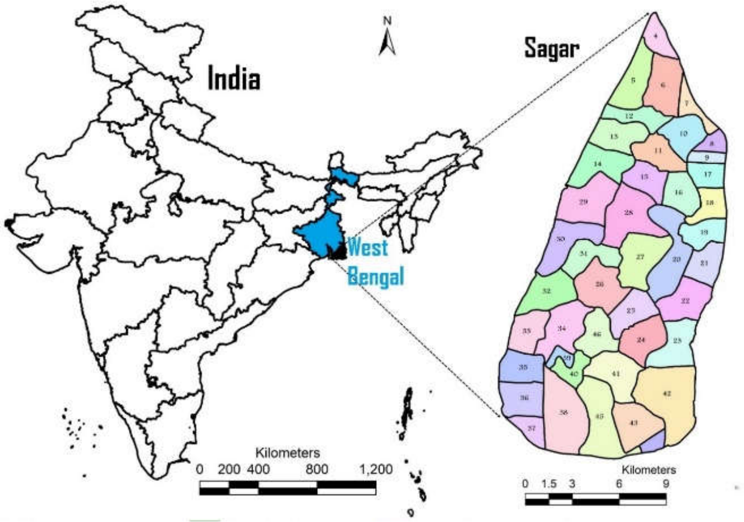

Figure 1: Sagar Island

The area of the island is 282 sq km with a population of about two lakh as per the census of India (2011). The island's proximity to Diamond Harbour (35 km) is yet another significant concern referring to variation in local sea level (Mukherjee et al., 2019). More than 50 % of the population is impoverished living in temporary housing with no land for cultivation (Ministry of Rural Development, 2011).

3. DATA AND METHOD

The current study proposes a method for developing the ‘flood risk zone map’ of Sagar Island by assessing differential vulnerability across inhabited villages in cognition to coastal flooding using parametric/ indicator-based approach. The assessment includes analyzing temporal risk by modifying the vulnerability parameter alone. The temporal change will help in identifying the major gaps in the developmental process and can also be used to derive an immediate set of actions for disaster resilience in them.

3.1. Description of data used for the analysis

Land use analysis for the years 2010 and 2020 were carried out using temporal data from Landsat 4-5 TM (30 m) from USGS. The village-level administrative boundary of Sagar block was taken from the database of Govt. of West Bengal, Census of India 2011. Topographic features such as elevation, slope, creeks, high and low tide lines were derived from 30 m ASTER DEM from Earth data database. Mousa wise vulnerability parameter was selected from District Census Handbook (Census of India, 2001) and Socio-economic and caste census, 2011 for the year 2001 and 2011 respectively. Infrastructure facilities such as schools, hospitals, jetties, roads, bus stops, banks, police stations and various others were marked for the years 2006 and 2020 using Google Earth.

3.2. Method for temporal risk assessment

The risk assessment process is based on consideration such as (i) limitations in data availability (ii) reliable data source for parameter and sub-parameter development and (iii) references from a similar group of studies. Selection of vulnerability and exposure parameters considers a broad set of literature. The chosen parameter values are reclassified in a standard scoring format (Likert scale from 1 to 5, where flood risk decreases from 1 to 5) for the ease of calculation. The reclassification rule is based on an in-depth literature survey and village-wise performance of each of the parameters. The parameter and sub-parameters are prioritised based on their flood risk sensitivity using the Analytical Hierarchical Process (AHP) (Saaty, 2008; Narendr et al., 2020). Prioritization of parameter has followed the development of composite maps using the ‘weighted sum’ technique for both exposure and vulnerability separately. The flood risk zoning map is obtained as a product of the exposure and vulnerability maps. Land use maps for the year 2010 and 2020 were developed using optical remote sensing data, and the classification into land use classes was derived using Gaussian Maximum Likelihood Classifier (GLMC) using a standard protocol as described in Bharath et al., (2017). ASTER DEM data was used to understand the topographical character of the case area and development elevation, slope and distance from the shoreline for coastal flood risk analysis.

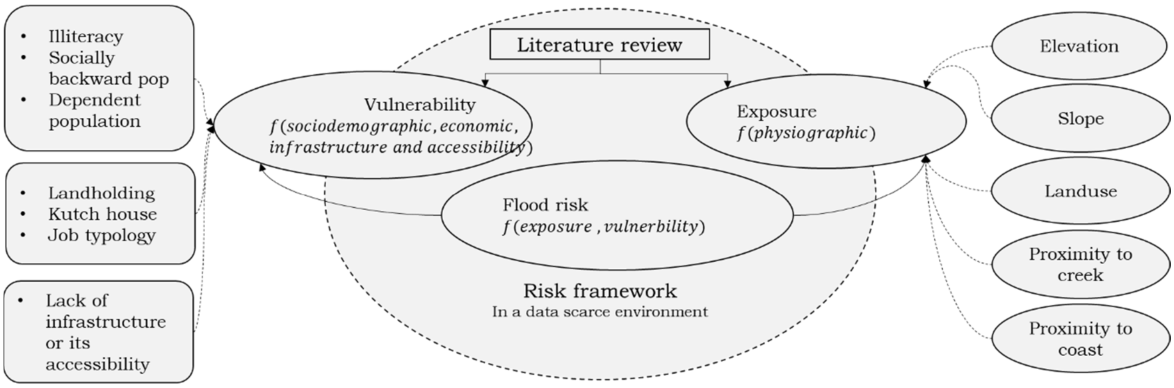

Figure 2: Flood risk mapping framework

3.3.Description of flood exposure parameters

Flood exposure parameters were used such as elevation, slope, distance to shoreline etc and is described as in table 1

Table 1: Describes the parameters used to develop flood exposure

Parameter	Description
Elevation (in meters)	Elevation above mean sea level and long term tidal variations are used for predicting the flood inundation level. Elevation value up to 2m highly sensitive to flooding
Slope (in degrees)	Affects the extent and duration of inundation; Overlaying it with inundation layer helps to identify the sensitive region.
Distance from the shoreline (in meters)	High water level and higher amplitude waves tend to breach into low-lying coastal areas. A buffer at 250 m interval as per CRZ (Coastal Regulatory Zone) norms were considered to mark relative exposure due to coastal floods
Distance from the tidal creek (in meters)	Gushing tidal waters of higher amplitude waves inundate the low-lying area. Buffer interval of 200 m considering CRZ norms were adopted for analysing relative sensitivity to flooding.
Landuse	Floods are highly destructive for semi-permanent and kutch housing typology; prolonged inundation leads to total damage; agricultural field becomes unproductive due to saltwater intrusion. Open spaces bear the least sensitivity; however, vegetation (inland vegetation, woody forest) act as a natural buffer against flooding and strong winds

Hazard sensitivity maps are derived spatially using equation 1.

$$H_f = \sum_{i=1}^{i=5} W_i * S_i \qquad \text{(Eq.1)}$$

Where H_f represents sensitivity due to flooding, W_i represents the weight of parameter i, ($\sum_{i=1}^{i=5} W_j = 1$) and S_i represents spatial sensitivity of parameter i ranging between 1 to 5, indicating very high to very low sensitivity.

3.4. Description of flood vulnerability parameters

The mouza wise data under the vulnerability parameters have been extracted from the District Census Handbook of Sagar island (2001) and Socio-economic caste census data for the year

2011 (Census of India, 2001, 2011). The degree of flood sensitivity increases with the increase in vulnerable population groups. The parameters are as described in table 2.

Table 2: Parameter using in vulnerability assessment

Parameter	Description
Dependent population	Children below 15 and adult above 65 - do not contribute to family income, hence increases vulnerability due to added liability
Socially backward population	Traditionally suppressed population are deprived of basic rights such as education, livelihood, safety and overall equal opportunity for resilience
Illiterate population	Population with no or below primary level education lacks awareness regarding the prevention, mitigation, and rescue from disaster threats.
Kutcha houses	Non- engineered housing made of locally available temporary are likely to disintegrate due to physical damages caused during floods
Land ownership	Property rights entitle claims over damages. Tenant or marginal labour would suffer economic losses both directly and indirectly
Job type	Proxy indicator for depicting the economic status; low paid jobs prevent investment on proactive strategies or climate resilience
Infrastructure services	Presence of amenities not only reduces disaster effect but also helps in speedy recovery from a hazardous situation
Vulnerability due to accessibility	Presence of infrastructure does not guarantee accessibility. Inaccessibility to such critical facilities is likely to enhance regional vulnerability due to delay in risk mitigation.

Flood vulnerability is quantified based on the parameter and sub-parameter vulnerabilities using multi-criteria evaluation process.

$$V_f = \sum_{\substack{i=1\\j=1}}^{\substack{i=2\\j=n}} W_i * W_j * V_j \qquad \text{(Eq. 2)}$$

$$= W_1 \sum_{j=1}^{j=n} W_j * V_j + W_2 \sum_{j=1}^{j=n} W_j * V_j + W_3 \sum_{j=1}^{j=n} W_j * V_j + W_4 \sum_{j=1}^{j=n} W_j * V_j$$

$\sum_{i=1}^{i=4} W_j = 1, \sum_{j=1}^{j=n} W_j = 1$;$W_1 \sum_{j=1}^{j=n} W_j * V_j$: Socio-demographic vulnerability;$W_2 \sum_{j=1}^{j=n} W_j * V_j$: Economic vulnerability;$W_3 \sum_{j=1}^{j=n} W_j * V_j$: Infrastructure vulnerability;$W_4 \sum_{j=1}^{j=n} W_j * V_j$:

Where V_f represents overall flood vulnerability, W_i represents the weight of vulnerability parameter 'i' and W_j represents the weight of sub-parameter 'j' derived using MCDM-AHP, V_j represents the vulnerability of sub-sector j ranging between 1 to 5 spatially. 'i' ranging 1 to 4 indicates 1) Socio-demographic, 2) Economic, 3) Infrastructure, 4) Accessibility parameters. Flood risk (R_f) is calculated as a product of flood vulnerability (V_f) and flood hazard (H_f) as depicted in equation 3. Smaller values of R_f represent High risk, while larger values represent low risk due to flooding.

$$R_f = (H_f * V_f) \qquad \text{(Eq.3)}$$

4. RESULT AND DISCUSSION

Land use analysis– The temporal land use variation within Sagar island is explained in detail using table 3. The area has undergone a massive transformation in the past decade. The percent change in water body has been highest with an increase of about 3.89 %. A distance of about 50 m land area along the periphery has been inundated with a rate of 5 m/year from 2010 to 2020. The loss in agriculture land has been alarming. The region has shown a sharp decrease of 4.65% generating concerns regarding food security and loss of livelihood in agriculture driven economy of Sagar. The built-up has almost doubled in the region from 1.67 % in 2010 to 3.82 % in 2020. The rise can be correlated with increasing migrant population from the nearby island. These disaster refugees are usually forced to settle around the coast that makes them highly sensitive to coastal surges and sudden tidal movement. Addition to this rising settlement encroaches the agricultural fields and clears the inland vegetation for domestic use. The mangrove vegetation has also undergone degradation due to over-exploitation of resources and poor management of native species. The reduction in mangrove density can be one of the reasons for the increase in extremely risk zone patches along the eastern coastline in figure 4

Table 3: Temporal land use statistics for Sagar island

Landuse class	2010 (%)	2020 (%)	% change
Agriculture	56.82	52.17	-4.65
Water	1.53	5.42	3.89
Others	4.75	7.22	2.47
Inland vegetation	31.75	28.03	-3.72
Mangroves	3.48	3.33	-0.15
Builtup	1.67	3.82	2.15

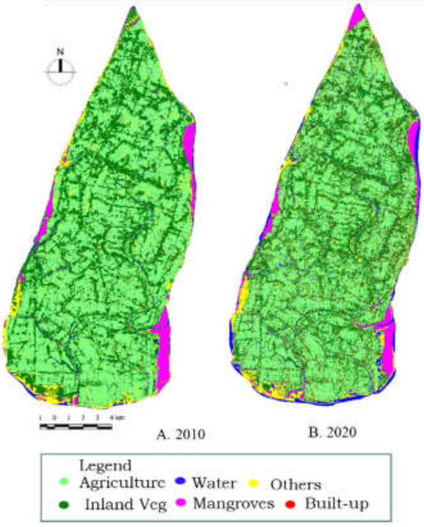

Figure 3: Temporal land use map of Sagar

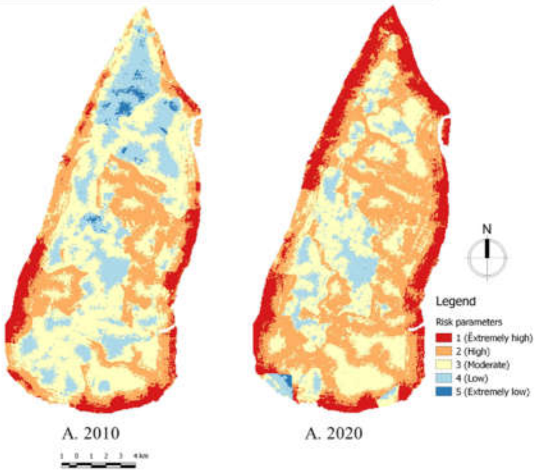

Figure 4: Temporal flood risk map for 2010 and 2020

Flood risk - The temporal flood risk results of Sagar indicates the growth of areas under extremely high-risk categories. The extremely high-risk zone have almost doubled from 8.01 % in 2010 to 16.84 % in 2020 risk map. These correspond to the rise in a built-up area that mostly comprises of migrant settlements around the coast (Brouwer et al., 2006). Rising densities and absence of protection policies for climate refugees increases the disaster sensitivity of the region. Another possible reason can be submergence of low-lying coastal peripheries due to varying the sea –level reduces the distance between water body and settlement, thus, enhancing disaster risk value for the later. With increasing saltwater intrusion and simultaneous loss of agriculture land in the region has accentuated economic vulnerability. Also, the housing typology was added a new sub parameter for the 2020 risk map under the economic domain. The housing data identifies more than 50 % of the population to be residing within the semi-permanent or kutcha structures, which tend to disintegrate during a flood event (Nabanita et al., 2019). Therefore, the entire island was found to be undergoing severe economic stress, with 85 % of the area under the extremely high vulnerability zone. Inadequate distribution of critical amenities such as mode of communication, health care facilities, and drainage inhibits disaster resilience due to delayed responses at the advent of a hazard event. It is worth noting that the equitable distribution of resources and necessary amenities could have prevented 37% areas from sinking into critical risk category in the year 2020.

5. CONCLUSION

Temporal flood risk assessment appears as a useful tool for analysing the core issues of flood sensitivity within a region (Schanze, 2006). Land use appears as one of the significant layer determining the regional risk. The temporal land use assessment indicates an increase in area under the water class by 3.89 %. The variation in SLR has increased the area under water bodies engulfing the low-lying coastal region and posing severe threats to communities residing in proximity. There also has been an alarming rate of reduction in agricultural land by 4.65 %, raising concerns regarding food security and rural livelihood. The two-fold rise in built-up and saltwater intrusion in the mainland can be one of the causative factors for reduction of agricultural area and inland vegetation within Sagar. The cumulative risk map for the region shows the dominance of local vulnerability factors in enhancing flood susceptibility. The research identifies the role of judiciously planned land use in subduing potential hazard risks as a proactive measure toward resilience. The micro-level risks due to uneven resource distribution in the region have been analysed through mapping accessibility as a novel aspect. Therefore, the endurance to disaster risk within a region can be enhanced by assuring uniform accessibility of critical services, such as healthcare, water supply and drainage. It is worth noting that the equitable distribution of resources and necessary amenities could have prevented 37% areas from sinking into critical risk category in the year 2020. With a coastline as long as 7500 km, the coastal villages are spread all across the Indian peninsula facing similar challenge due to frequent flooding incidents. Thus, the proposed methodology has a broader application base and can be instinctively used by concerned authorities planning and policymaking for coastal resilience

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