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Future Mangrove Suitability Assessment of Andaman to strengthen sustainable development

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ABSTRACT

Islands are threatened by various natural and anthropogenic factors including climate change, overpopulation, unsustainable use of natural resources and increasing trend in seismic events. Therefore, studies on island in specific aspect (ecological, social and economic) is very essential for sustainable resource management and future development. Mangroves are highly important natural resources of coastal regions in respect to coastal livelihood and natural defense. Although, around 46% of the mangrove forest area has vanished worldwide in the last few decades. In this present research, Future Mangrove Suitability Index (FMSI) using the Analytic Hierarchy Process (AHP) method has been performed for sustainable forest management under the United Nations Sustainable Development Goal no 15. It is a new framework applied on North and Middle Andaman Island to determine the future distribution of mangrove forest. Land-use and land-covers (LULC) are prepared in supervised classification (maximum likelihood algorithm) techniques with 3000 signatures. A total number of fourteen parameters has been used in multi-criteria decision making (MCDM) platform to generate future scenarios. Among them, Representative Concentration Pathways (RCPs) projected climatic data (RCP 6.0 scenario shows the best result comparing to 4.5 and 8.5) and projected population data has been used for the first time in the investigated area. The final results are validated using 556 field sample point. Seven major sensitive parameters have been selected from sensitivity analysis and three statistical correlation analysis has been performed using 300 field points to generate the actual correlation between the parameters. The final outcome shows that major unsuitable zones are located in Diglipur tehsil whereas; highest suitable zones are located in Rangat tehsil region which are the result of the continuous increase of sea surface height (1.5 mm observed during 1980–2009), seismic events with frequent storm surges, anthropogenic influences and impact of climate change. Thus a planned sustainable development practice is essential to control the biodiversity loss and future livelihood management. Moreover, this study will strengthen future planning projects and researches in mangrove ecosystem management of Andaman.

1. Introduction

Sustainable Development (SD) is a complex theme which comprises many individual systems and having multiple definitions. In general, sustainability means “meeting society's current needs without compromising the future generations ability to meet their own needs.” The three components of sustainability are economic viability, environmental responsibility, and social acceptability (Ghelichkhan et al., 2018). To strengthen SD practice for future development, a total number of seventeen global goals has been fixed in United Nations General Assembly, 2015) (Chow, 2018). The prime focus of these agendas is integrated and balance the triple bottom development (social-economic-environmental) in a socio-ecological system. Forest management, control biodiversity loss

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and reserve land degradation (Goal 15) is one of the key aspects in SD goals which is the broad theme of this study. Among them, the mangrove ecosystem, one of the threatened ecosystems found in the transaction region of saline and freshwater environment of tropical and sub-tropical coastal stretches, has a significant impact on SD. Mangrove ecosystem offers a variety of livelihood services namely tourism, fuel-wood, fisheries (Estoque et al., 2018; Kiruba-Sankar et al., 2018) with ecosystem services including the nursing ground of juvenile coral reef. It also works as a nutrient sink in the coastal ecosystem and helps to improve water quality from waste-water outlets and carbon sequestration (Pelegri and Twilley, 1998; Nagelkerken et al., 2000). The root system of *Rhizophora* species is highly favorable for the prey and predator community due to its structural heterogeneity (Laegdsgaard and Johnson, 2001). Simultaneously, it works as a natural shield from cyclones, storms, tsunamis and other natural phenomena (Alongi, 2008). Although, numerous researches describe that the depletion rate of mangrove ecosystem is high due to the impact of climate change, an increasing trend of population growth, industrial and urban development, conversion of forest land to agriculture and aquaculture use and associated anthropogenic influences (Pham et al., 2018; Alongi, 2002). Around 46% of the mangrove forest area has vanished worldwide in the last few decades (Romañach et al., 2018).

Except for Antarctica, mangrove exists on every continent and among them, Asia has the highest agglomeration in terms of species diversity and richness which encompassing 42% of world mangrove area (Giri et al., 2011). In Asia, around 7% of mangrove region is located in India and Andaman and Nicobar Islands (ANIs) covers 617 sq. km, which are considered as the most vulnerable coast in South East Asia (Giri et al., 2011). This coastal zone is affected by frequent natural calamities such as tsunami, earthquake, cyclones, and storms through the mangroves of ANIs are considered as the best in India due to its density and diversity (Kiruba Sankar et al., 2018). In the last decade, researchers found ANIs has a total of 38 true species which belongs to 13 families and 19 genera (Goutham-Bharathi et al., 2014; Ragavan et al., 2014, 2018). In India, mangrove depletion has occurred rapidly during the last few decades which sentence the major threats of over-exploitation, habitat destruction, population growth, and frequent natural calamities. Therefore, mangrove distribution-conservation-monitoring has become a major concern and burning environmental issue in the era of SD.

Remote sensing technique has been widely used in mapping and monitoring of mangrove forest (Kuenzer et al., 2011). This technique helps to identify the regional and temporal changes along with various biophysical information. Land use and land cover monitoring using remote sensing data is a useful technique to quantify the natural resource distributional dynamic of any region. Numerous researches work on land use and land cover monitoring has been completed to estimate the distributional and structural changes of mangrove (Misra and Vethamony, 2015; Zulfa and Norizah, 2018). Species distribution and compositional analysis have been done rigorously in last decades through laboratory measurement of hyperspectral leaf reflectance which helps to understand the stress, disease, and health of mangrove forest (Hussain and Badola, 2010; Asner et al., 2009; Chun et al., 2011). Species-based future prediction of Bangladesh Sundarbans had been done using Markov chain model and cellular automata (Mukhopadhyay et al., 2015). Apart from the above, innumerable amount of work has been done on the mangrove ecosystem in remote sensing domain. Few contemporary and intense approaches are the role of mangrove in climate change mitigation and disaster management (Hilmi, 2018; López, 2018), the economic value of mangrove and community-based livelihood approach (Sari et al., 2018; Putranto et al., 2018; Mehvar et al., 2018).

Besides the various work in the mangrove field, multi-criteria decision making (MCDM) system has a valuable footprint in comparative analysis and SD studies. Among various MCDM techniques, Analytic Hierarchy Process (AHP) model is widely used in environmental vulnerability and groundwater research (Singh et al., 2018; Sahoo et al., 2016), land suitability analysis (Kahsay et al., 2018; Parry et al., 2018), forest management (Etongo et al., 2018; Akay et al., 2018), decision making - planning (Abdel-Basset et al., 2018; Hamurcu and Eren, 2018) and forestry/forest management planning (Abdel-Basset et al., 2018).

In the present study, future distribution of mangrove forest of Andaman island has been proposed through future mangrove suitability index (FMSI) using AHP model. The outcome predicts the future distributions of mangroves using multi-criteria analysis of fourteen parameters which will help in planning and development under SDGs Goal 15. Among the parameters, RCPs projected Nor-ESM1-M based climatic data and projected population data play the major roles. NorESM1-M (RCPs scenario 4.5, 6.0 and 8.5) is widely used projected climate model in the world which has been applied in this study based on in-depth work of Chaturvedi et al. (2012) on the Indian peninsula. On the other hand, AHP is one of the best multi-criteria analysis model developed by Saaty, 1980); Saaty (1980) (Abdel-Basset et al., 2018). Despite multi-dimensional work in mangrove and MCDM domain, AHP based future mangrove scenario assessment is a unique approach presented through this work by using future mangrove suitability index and statistical correlation techniques.

2. Study area

The study area covers the north and middle Andaman districts (Fig. 1). Mangroves have been differentiated from other land use/land cover based on tone, texture, shape, location, and association. Mangrove patches of the eastern side of the study area are chosen for field verification as west part are restricted and inaccessible. A healthy concentration of mangrove is located in south-eastern part (Rangat) of the region but a degraded and highly destroyed mangrove are found in north-western part (Elizabeth Bay, Shyamnagar, Kishori Nagar regions of Diglipur) of the region due to 2004 tsunami. Though moderate concentration has been found in Diglipur (Aerial BAy, Swarajgram, Radhanagar, Kalighat) and Mayabunder coastal belt which are dominated by *Rhizophora apiculata* and *Bruguiera gymnorhiza* species with *Lumnitzera littorea, Rhizophora mucronata* and *Ceriops tagal* (George et al., 2018; Gupta et al., 2018). Mangrove in the study area has been formed mainly on Sandstone with shale parting, coal partings, clay, conglomerate, and coral debris. The ocean color also has a prominent variation up to three visible shades, such as living coral dominated shallow water, sand-bedded shallow water, and deep water. This color variation is prominent in Mayabunder region due to the good concentration of living coral, mangrove forest and low tourist agglomeration. The interconnectivity between the coral and mangrove ecosystem are very clear over the region which is the key factor behind the selection of the investigation area. Hot and humid weather (daily temperature ranges from 27 °C to 38 °C in summer and 21 °C–25 °C in winter) with an average annual rainfall of ≈3295 mm are the favorable factor of mangrove development (Majumdar et al., 2018) in this region.

3. Material and methods

3.1. Data used

In this study, fourteen parameters in five different groups has been used which are climatic variables (maximum temperature,

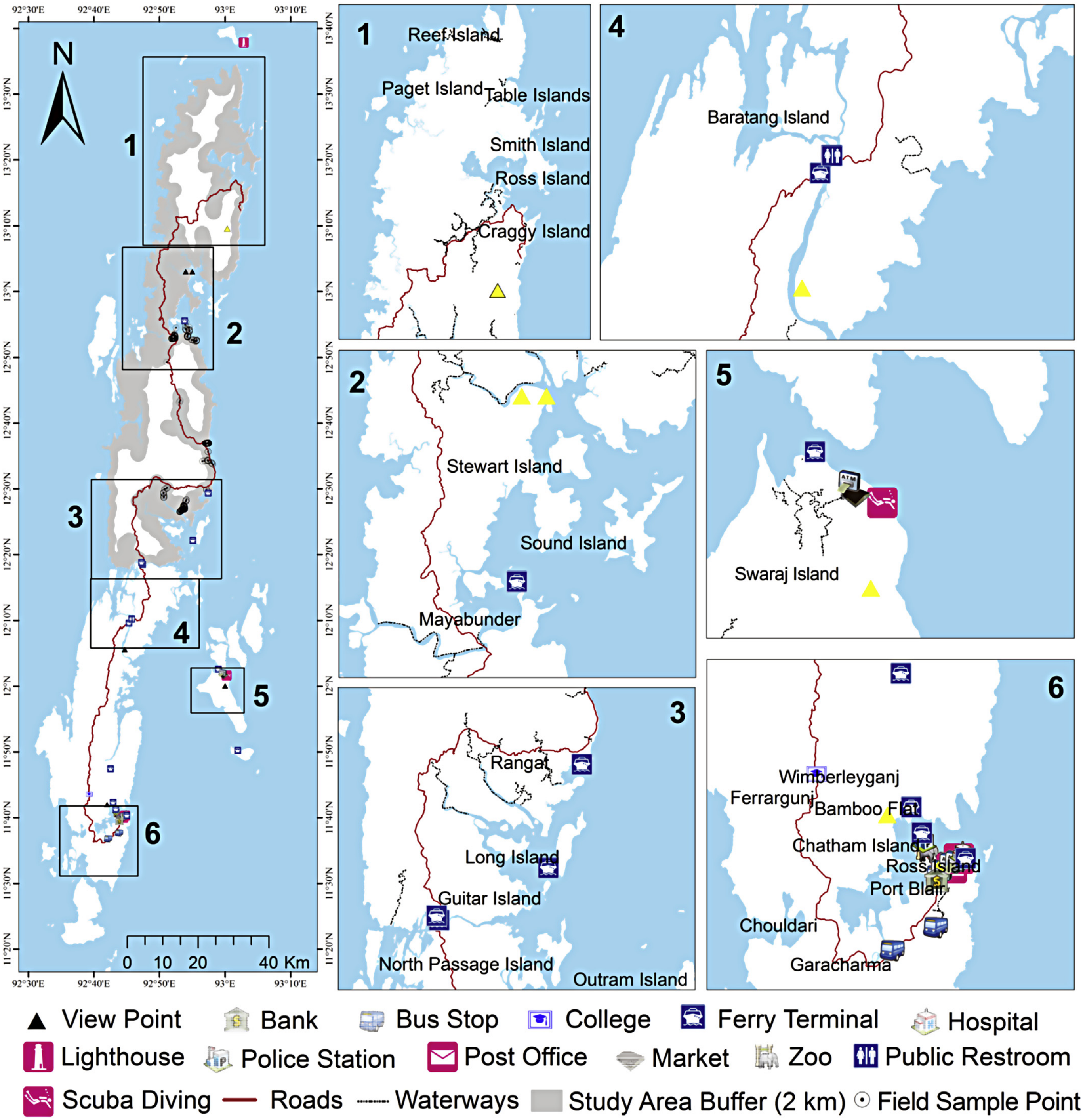

Fig. 1. Study area.

minimum temperature, precipitation, solar radiation, and wind speed), geomorphic variables (elevation, slope, geomorphology and lithology, Land-use/Land-cover), edaphic variable (soil moisture and soil salinity), floral condition (NDVI) and human interface (population). Projected Climatic data, RCPs (Figs. 4 and 5), of Norwegian Earth System Model (NorESM1-M) has been collected from Intergovernmental Panel on Climate Change (IPCC) assigned Coupled Model Inter-comparison Project, Phase 5 (CMIP5) database (http://gismap.ciat.cgiar.org/MarksimGCM/) for the duration of 40 years time span (2010–2050). Surface wind speed map (Fig. 3) are generated using The Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) database (monthly data, unit = m/s-1) which is collected from Giovani web portal (http://giovanni.gsfc.nasa.gov/giovanni/). Geomorphic variables, i.e., Elevation and Slope maps (Fig. 3), has been prepared using ALOS PALSAR images (high resolution radiometric and terrain corrected-12.5 m) dated 21st June 2008 which is downloaded from Alaska Satellite Facility (https://vertex.daac.asf.alaska.edu/). Geomorphology and lithology maps (scale = 1:50,000) are collected (Fig. 3) from district forest office, Rangat, Middle Andaman. Soil

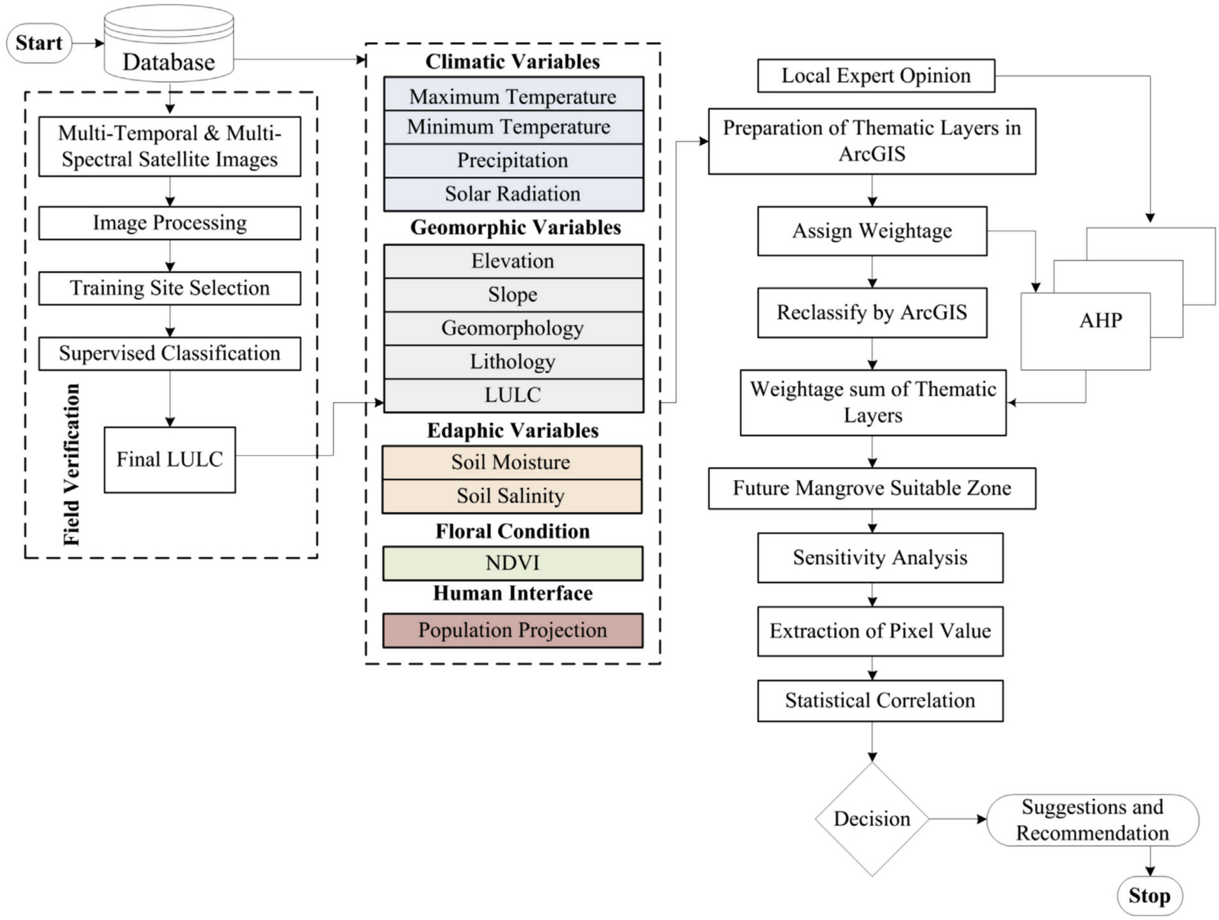

Fig. 2. Overall methodology.

moisture data (unit = kg/sq. m/s) has been downloaded (Fig. 3) from MERRA-2 database. Soil salinity index (Fig. 3) has been generated from Landsat OLI satellite images (spatial resolution-30 m, acquisition date: 2018-03-19) collected from USGS Earth Explorer web portal (https://earthexplorer.usgs.gov/). LULC and NDVI based floral condition have been mapped (Fig. 3) from Landsat OLI images. Simultaneously, population data (unit - no of person/village or hamlet)of the year 1991, 2001 and 2011 (Fig. 3) has been collected from Census of India web portal (http://censusindia.gov.in/).

3.2. The architecture of the proposal

The workflow (Fig. 2) is divided into two segments, (i) AHP based future mangrove suitability modeling and (ii) statistical modeling for interconnectivity assessment of sensitive parameters. These models are generic and flexible in nature which has been simulated from the micro-to-macro region.

3.2.1. Future mangrove suitability mapping using the analytic hierarchy process

The ultimate result of this work is future mangrove suitability mapping which has been generated from Future Mangrove Suitability Index (FMSI), prepared using multi-criteria decision-making techniques. Fourteen parameters are divided into five segments depending upon the nature of the components.

3.2.1.1. Land Use/Land Cover (LULC). A supervised order classifier (maximum likelihood algorithm) has been used to prepare the Land Use/Land Cover (LULC) map (Fig. 6). The raw images are corrected through field points and atmospheric correction performed using the FLAASH module. A total number of 3000 signatures has been taken into account to increase the classification accuracy. Among the total signatures, each class contains at least 200 number of signature. The maximum signature has been taken in Mangrove class (500).

3.2.1.2. Normalized Difference Vegetation Index (NDVI). Normalized Difference Vegetation Index (Fig. 3) is a numerical indicator which uses Near-infrared and Visible electromagnetic spectrums to analyze the condition of healthy green vegetation. It normalized the scattering of green leaves in near-infrared (NIR) wavelength and interpolation of chlorophyll in red wavelength. The theoretical value varies between −1 and 1 in which healthy vegetation ranges from 0.20 to 0.80 (Kayet et al., 2016). The calculation of NDVI is

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (1)$$

3.2.1.3. Normalized Difference Salinity Index (NDSI). Normalized Difference Salinity Index (Fig. 3) also deal with NIR and Red spectra to assess the salinity condition of the salt-affected area (Ojo and Ilunga, 2018). The brightness value in white has been analyzed as salt-affected land. The formula of NDSI is

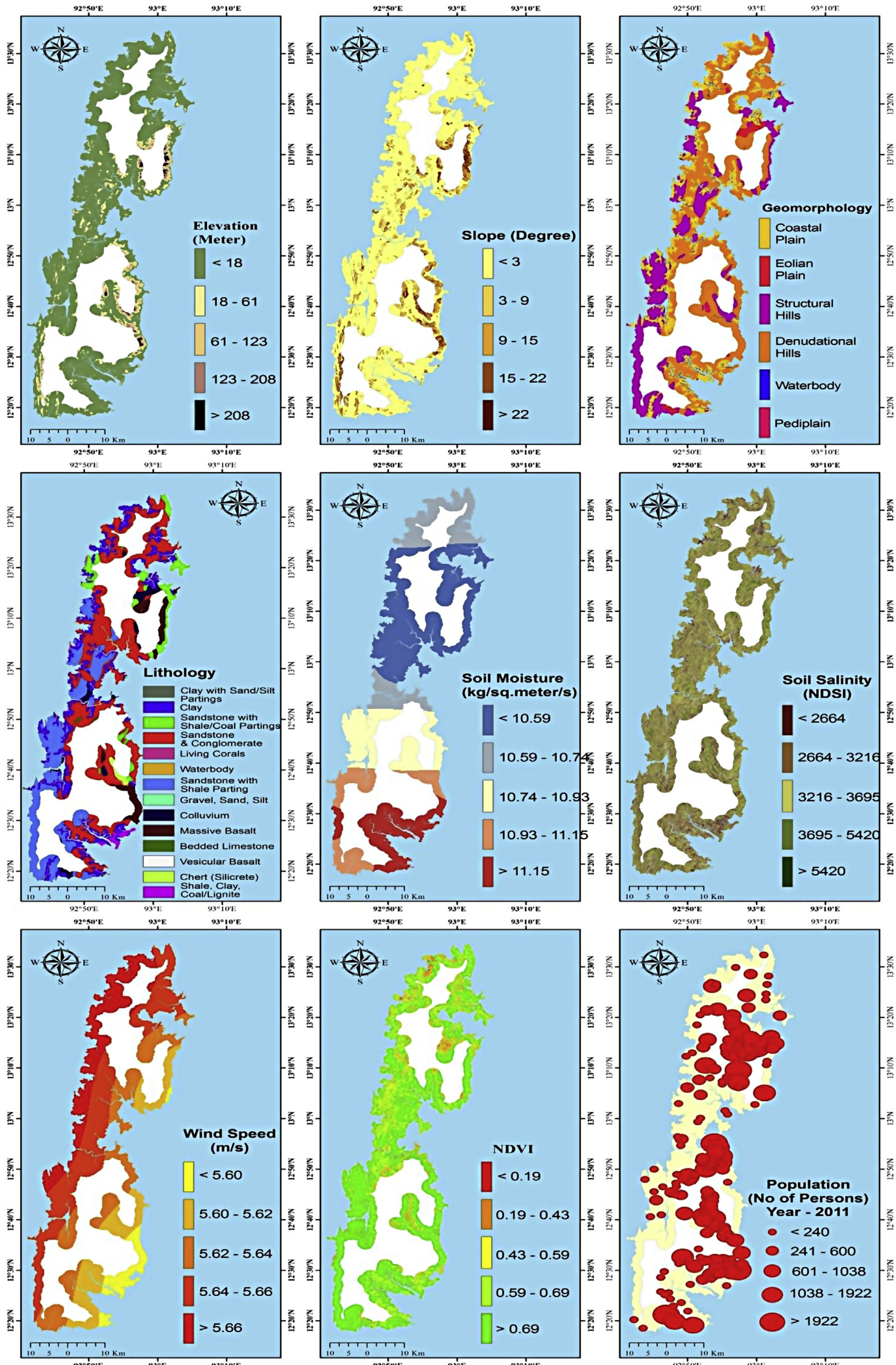

Fig. 3. Present condition of various aspects (Elevation, Slope, Geomorphology, Lithology, Soil Moisture, Soil Salinity, Wind Speed, NDVI, Population).

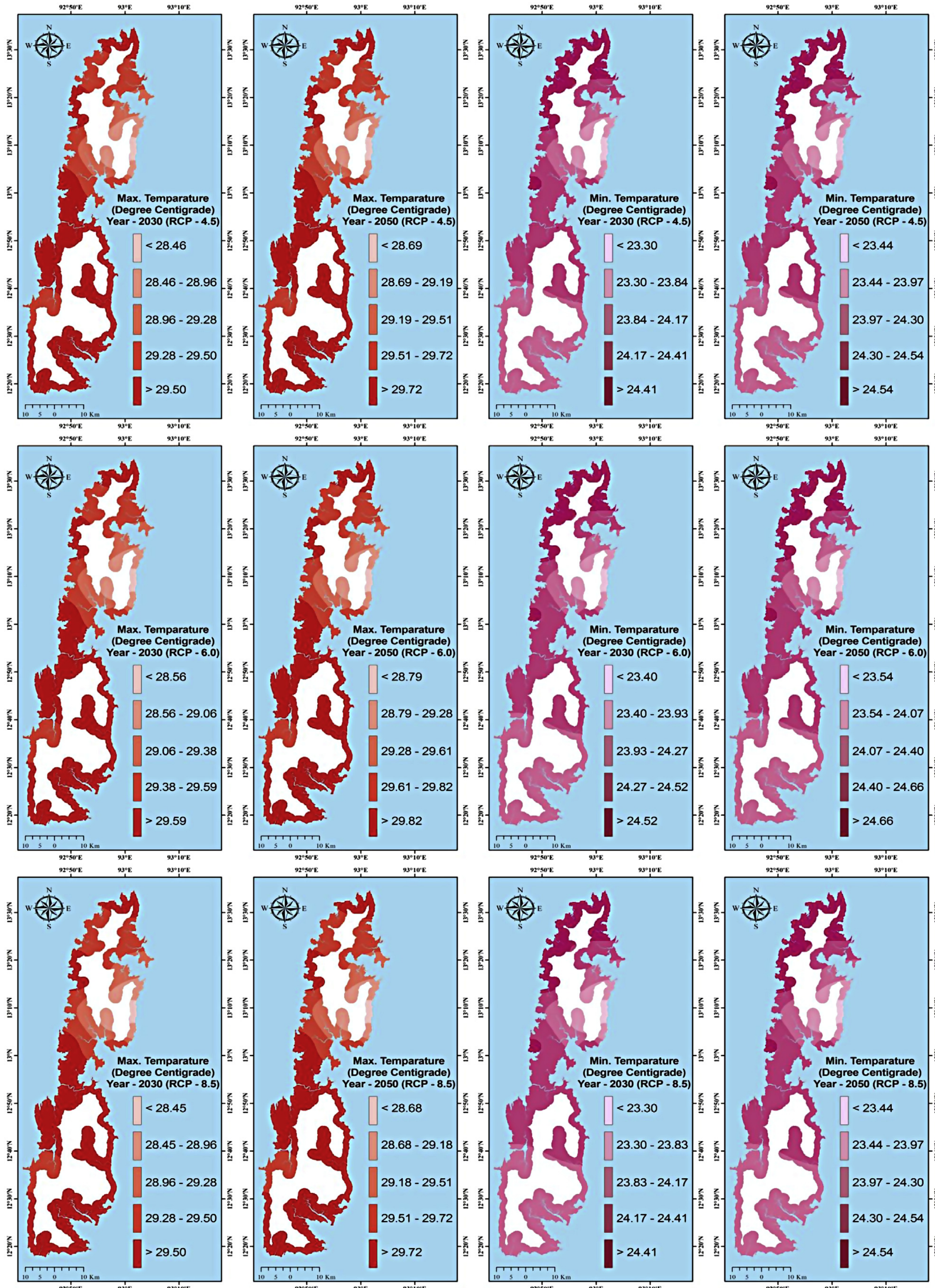

Fig. 4. Maximum Temperature and Minimum Temperature of three different RCP scenario (4.5,6.0 and 8.5).

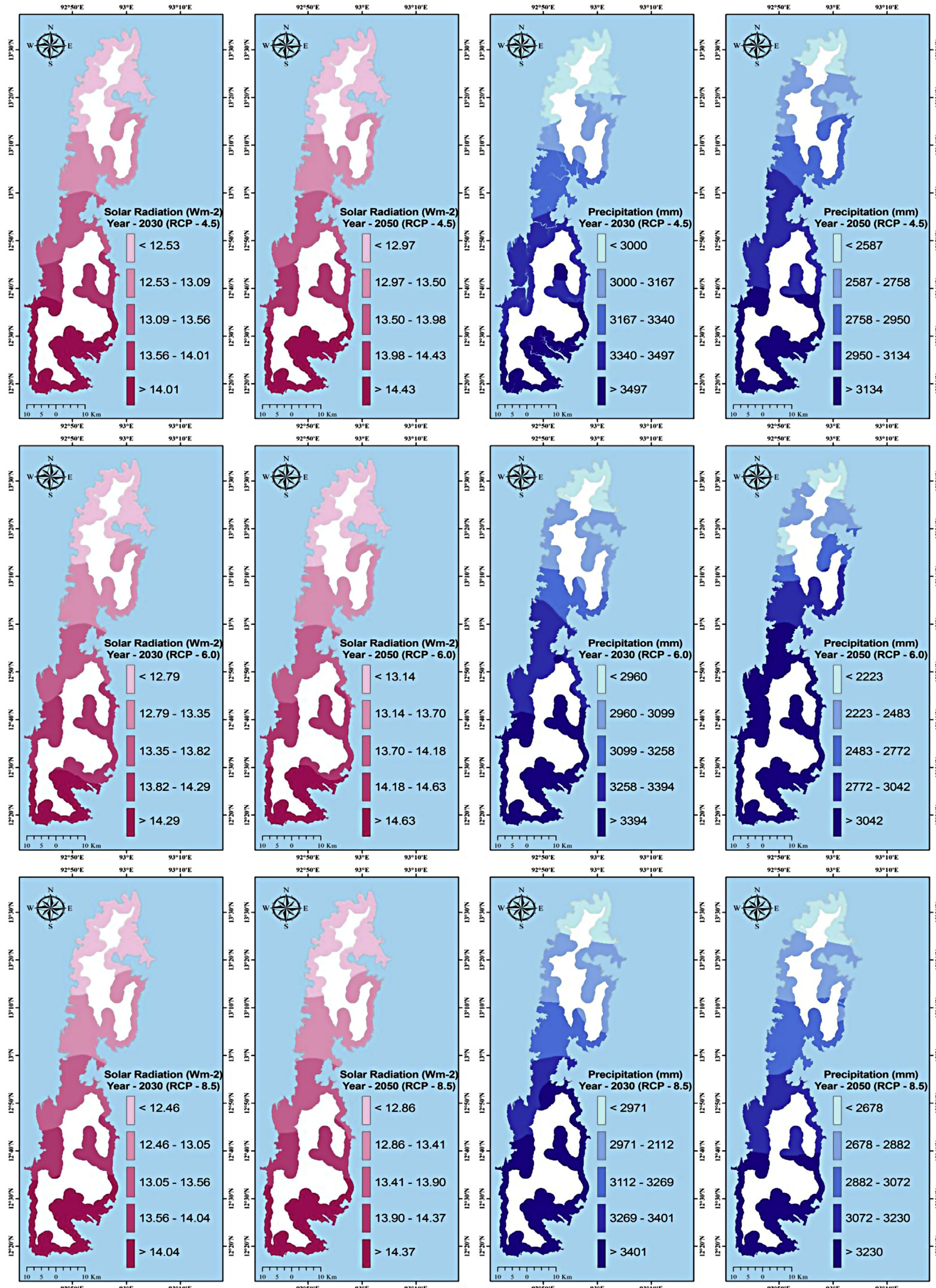

Fig. 5. Precipitation and Solar Radiation of three different RCP scenario (4.5,6.0 and 8.5).

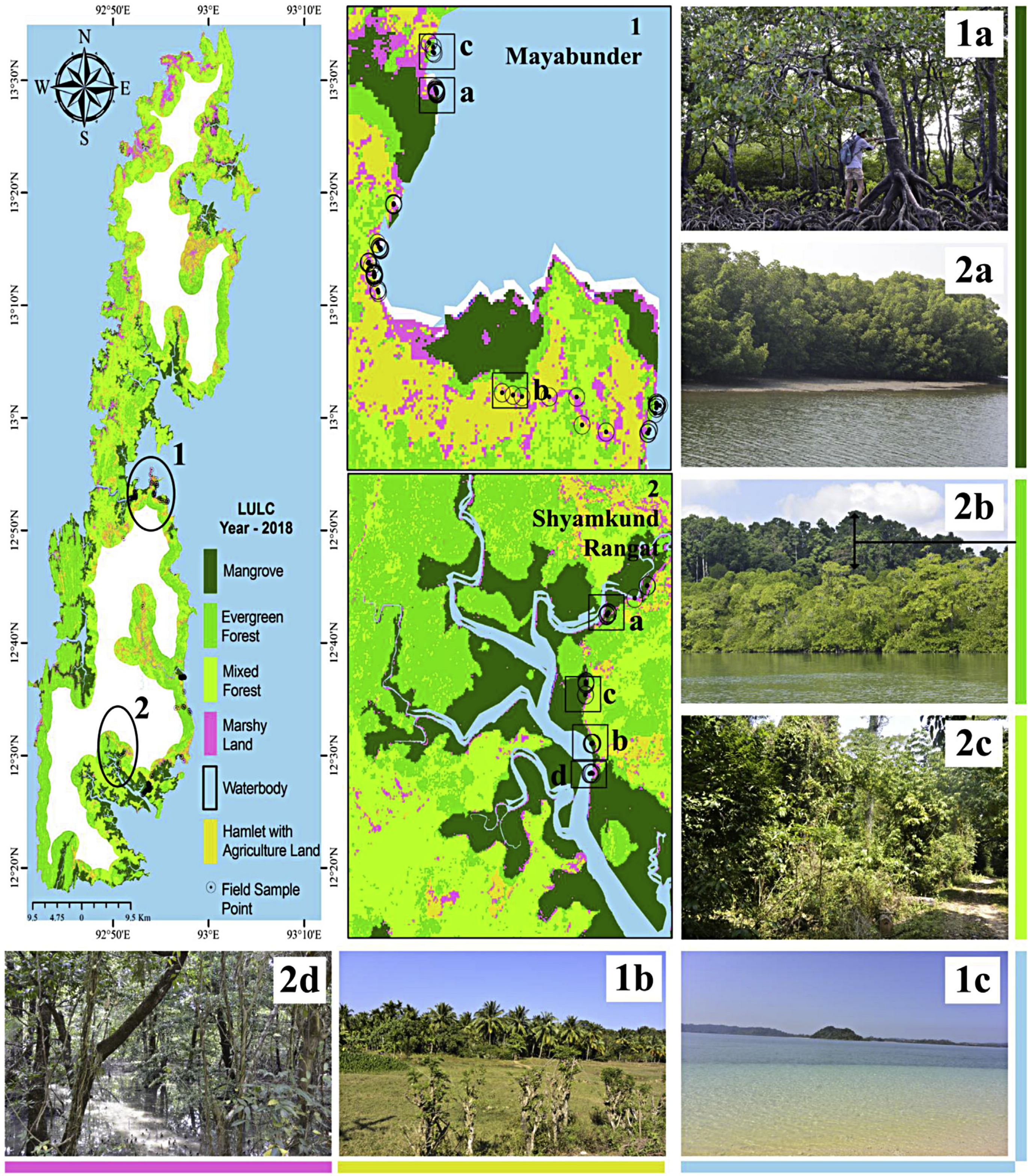

Fig. 6. Land-use and Land-cover (2018) (1a. & 2a. Mangrove Forest, 1b. Hamlet with Agriculture Land,1c. Variation of water color, 2b. Evergreen Forest, 2c. & 2d. Mixed Forest.). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

$$NDSI = \frac{(RED - NIR)}{(RED + NIR)} \tag{2}$$

3.2.1.4. Population projection. Population projection, important for any planning and policy-making studies, is a method to extrapolate historical data (environmental, climatic and disaster data are not taken into account in this calculation) into the future. It attempts to describe the scenario which likely to happen under some explicit assumptions about the future related to the immediate past. It can be calculated using the following steps (De Andreis and Ricci., 2005).

$$P_t = P_0 e^{rt} \tag{3}$$

and

$$r = \frac{1}{t} In\left(\frac{P_t}{P_0}\right) \tag{4}$$

In this equations $P_t$is population at time t, $P_0$is Population at an earlier time 0 , r is exponential growth rate, t is time.

3.2.1.5. Analytic Hierarchy Process (AHP). The Analytic Hierarchy Process is a priority based decision - making model, sketched to deal with complex and multi-factor problems which were originally developed by Saaty (Saaty, 1980; Zhang et al., 2013). Here, the AHP technique is used to predict the Future Mangrove Suitability Index (FMSI). Weights of different parameters (Table 1) have been fixed by considering local expert opinions and comprehensive literature reviews.

Future Mangrove Suitability Index (FMSI) can be calculated as (Dhar et al., 2015)

$$FMSI_{\nu x, \nu y} = \sum_{i=1}^{N_F} W_i \left(\sum_{k=1}^{N_{SF}^i} R_k^i \chi_{A_k^i} \left(C_{\nu x,\nu y}^p \Big|_i \right) \right) \tag{5}$$

where, indices (ik) denote feature and sub-feature respectively; N_F is the total number of features; N_{SF}^i is the number of sub-features for i th feature; W_i is the weight of i th feature; R_k^i is the rating of k^{th} sub-feature for i^{th} feature; $C_{\nu x,\nu y}^p\Big|_i$ denotes the class value of the cell $(\nu x, \nu y)$ for i^{th} feature; A_k^i denotes the sub-feature interval; $\chi_{A_k^i}$ denotes the indicator function for k^{th} sub-feature of ith feature and defined as

$$\chi_{A_k^i}\left(C_{\nu x,\nu y}^p\right) = \begin{cases} 1 & \text{if } C_{\nu x,\nu y}^p\Big|_i \in A_k^i, \\ 0 & \text{if } C_{\nu x,\nu y}^p\Big|_i \notin A_k^i. \end{cases} \tag{6}$$

Analytic Hierarchy Process can be applied for the estimation of relative weight (W_k) and normalized weight (R_l^k) (Eq. (7)). In AHP (Hamurcu and Eren, 2018), 1–9 scale (i.e., extremely unimportant, strongly unimportant, moderately unimportant, unimportant, equally important, moderately important, more important, strongly important, extremely important) is adopted for constructing judgment matrices. The following steps are adopted for the calculation of weights and consistency ratio (C.R.):

Step I Development of judgment matrices (**A**) by pairwise comparison.

Step II Calculation of relative weight W_k:

$$W_k = GM_k / \sum_{m \in F} GM_m \tag{7}$$

Where the geometric mean of the kth row of judgment matrix is calculated as.

$GM_k = \sqrt[N_F]{a_{k1}a_{k2}...a_{kN_F}}$, $N_F$is the total number of features.

Step III Strength assessment of judgment matrix based consistency ratio (C.R.)

$$C.R. = C.I./R.C.I. \tag{8}$$

Consistency index (C.I.) is evaluated as

$$C.I. = \frac{\lambda_{\max} - N_F}{N_F - 1} \tag{9}$$

where the latent root of judgment matrix is calculated as

$$\lambda_{\max} = \sum_{m \in F} \frac{(\mathbf{AW})_m}{N_F W_m} \tag{10}$$

where**W** is the weight vector (column), Random consistency index (R.C.I.) can be obtained from standard tables (Alonso and Teresa Lamata, 2006). C.R. value of less than 0.1 is acceptable for a specific judgment matrix. However, revision in the judgment matrix is needed for C.R. $\geq$ 0.1.

The same procedure should be followed forR_l^k calculation. Finally, index maps can be generated from the above-mentioned procedure.

3.2.2. Statistical analysis for interconnectivity assessment among sensitive parameters

Inter-connectivity of various parameters has been calculated using sensitivity analysis (Mandal et al., 2016) and statistical correlation operations. Sensitivity analysis is an operation of omitting individual features used in the AHP model. This process helps to identify the influencing parameters in the final suitability map. The general, sensitivity can be calculated as:

$$MS_i^j = \frac{S_{-i}^j - S_F^j}{S_F^j} \times 100\ (\%) \tag{11}$$

in this equation, i reflects the number of parameters and j represents types of gradation in AHP output (i.e., unsuitable, low suitable, moderately suitable, suitable and high suitable). MS_i^j denoted the percentage change ($\pm$) in j^{th} type of FMSI regions due to the absent of i^{th} parameter. Subsequently, S_{-i}^j represents the j^{th} type of FMSI area due to exclusion of i^{th} component, and S_F^j stands for the j^{th} type of FMSI regions using all parameters.

Three different correlation methods (Pearson, Spearman and Kendall Tau correlation) has been applied to find out the interconnectivity among the parameters.

Pearson correlation, r (Hamby, 1994), is a linear correlation measure between two variable X and Y which shows the value between +1 and −1, where 1 denoted total positive correlation and 0 refers total negative correlation. Spearman correlation, ρ, or the rank correlation coefficient can be calculated by Pearson's r using the exception of rank transformation operation (Hamby, 1994).

The calculation of Pearson correlation is

$$r = \frac{\sum_{j=1}^{n}(X_{ij} - \overline{X}_i)(Y_j - \overline{Y})}{\left[\sum_{j=1}^{n}\left(X_{ij} - \overline{X}_i^2 \sum_{j=1}^{n}(Y_j - \overline{Y})^2\right]^{1/2}} \tag{12}$$

Table 1
Details of feature layers and their features ranks and normalized weights.

SL No.	Theme	Weight	Feature Classes	Area in %	Weight Assigned (Sub-class)	Normalized Weight (Sub-class)
1.	Elevation (Meter)	6.5	−4–18	87.40	8	0.2963
			18–61	7.45	7	0.2593
			61–123	3.04	6	0.2222
			123–208	1.54	4	0.1481
			208–517	0.57	2	0.0741
2.	Slope (°)	6	0–3.33	80.42	9	0.2571
			3.33–9.39	6.78	8	0.2286
			9.39–15.35	6.37	7	0.2000
			15.35–22.44	4.60	6	0.1714
			22.44–52.08	1.83	5	0.1429
3.	Population (In Persons) Year - 2011	4	1–240	41.84	9	0.3214
			241–600	31.01	8	0.2857
			601–1038	17.00	5	0.1786
			1039–1922	8.31	4	0.1429
			1922–3781	1.84	2	0.0714
4.	Soil Moisture (kg/sq.m/s)	7	10.45–10.60	33.63	1	0.0370
			10.601–10.75	16.53	5	0.1852
			10.75–10.94	20.41	6	0.2222
			10.94–11.16	17.30	7	0.2593
			11.16–11.40	12.14	8	0.2963
5.	Maximum Temperature (°C)	4.5	27.94–28.57	1.06	2	0.0833
			28.57–29.06	5.33	3	0.1250
			29.06–29.38	8.51	8	0.3333
			29.38–29.60	26.20	7	0.2917
			29.60–29.82	58.89	4	0.1667
6.	Minimum Temperature (°C)	5.5	22.77–23.83	4.84	4	0.1333
			23.83–24.21	33.20	5	0.1667
			24.21–24.39	24.14	6	0.2000
			24.39–24.58	25.54	7	0.2333
			24.58–24.81	12.28	8	0.2667
7.	Precipitation (mm)	7.5	2848.66–2965.18	9.51	5	0.1429
			2965.18–3109.09	19.84	6	0.1714
			3109.09–3279.77	14.12	7	0.2000
			3279.77–3420.75	34.70	8	0.2286
			3420.75–3514.58	21.83	9	0.2571
8.	Solar Radiation (Wm^{-2})	4.5	12.15–12.82	22.73	3	0.1102
			12.82–13.39	24.51	4	0.1469
			13.39–13.88	16.71	6	0.1919
			13.88–14.38	22.93	7	0.2571
			14.38–15.19	13.12	8	0.2939
9.	Geomorphology	7.5	Coastal Plain	14.93	9	0.3333
			Eolian Plain	1.69	4	0.1481
			Structural Hills	29.81	1	0.0370
			Denudational Hills	52.51	2	0.0741
			Water body Mask	0.46	8	0.2963
			Pediplain	0.61	3	0.1111
10.	Land-Use/Land-Cover	8	Mangrove	8.07	9	0.3214
			Hamlet with Agriculture Land	19.36	1	0.0357
			Evergreen Forest	35.22	2	0.0714
			Tropical Mixed Forest	24.26	3	0.1071
			Marshy Land	11.59	6	0.2143
			Inland waterbody	1.50	7	0.2500
11.	Lithology	6.5	Clay with sand/silt partings	0.22	6.5	0.0961
			Clay	22.26	7	0.1035
			Sandstone with shale/coal partings	7.33	7.5	0.1109
			Sandstone & conglomerate	37.54	6	0.0887
			D corals	0.26	1	0.0148
			Water body mask	0.57	6	0.0887
			Sandstone with shale parting	21.60	8	0.1183
			Gravel, sand, silt	0.20	5.5	0.0813
			Colluvium	2.48	3	0.0480
			Massive basalt	5.25	2	0.0320
			Bedded limestone	0.14	6	0.0887
			Vesicular basalt	0.64	1.5	0.0222
			Chert	0.50	3	0.0480
			Shale, clay, coal/lignite	1.00	4	0.0591
12.	Wind Speed (m/s)	3	5.57–5.61	11.65	7	0.3889
			5.61–5.63	18.61	5	0.2778
			5.63–5.65	23.27	3	0.1667
			5.65–5.67	30.63	2	0.0556
			5.67–5.69	15.84	1	0.1111
13.	All Vegetation NDVI	8	−0.50–0.19	1.17	1	0.0408
			0.19–0.43	4.18	3	0.1224

Table 1 (*continued*)

SL No.	Theme	Weight	Feature Classes	Area in %	Weight Assigned (Sub-class)	Normalized Weight (Sub-class)
			0.43–0.58	8.00	5	0.2041
			0.58–0.68	32.60	7	0.2857
			0.68–0.95	54.05	8.5	0.3469
14.	Soil Salinity (NDSI)	8.5	206–2664	5.51	6.5	0.1854
			2664–3216	35.71	8.5	0.2425
			3216–3695	40.05	7.5	0.2140
			3695–5421	18.65	6	0.2155
			5421–13,790	0.09	5	0.1426

In this equation, n is sample size, X_i, Y_j, X_{ij} are individual sample point which is indexed with i and $\overline{X} = \frac{1}{n}\sum_{j=1}^{n} x_i$ is the sample mean. which is corresponding to $\overline{Y}$.

The Kendall Tau (Dhar et al., 2014) is a non-parametric statistical measure which applied for time series trend analysis to estimate correlations between two ranked variables. It represents the probability trend between the variables. The prime goal of this operation to test the monotonic trend. The operation can be formulated as

$$\tau = \frac{N_c - N_d}{\frac{1}{2} N (N-1)} \tag{13}$$

Here, N_c represents the no of concordant pairs, N_d stands for the discordant pairs and N is the total number of attributes in the series. In this test τ value always varies between −1 and 1.

4. Results and discussion

4.1. Future suitability assessment

4.1.1. Analysis of drivers controlling future mangrove suitability assessment

Fourteen individuals are identified for preparation of FMSI, among them five futuristic [RCP climate data (maximum temperature, minimum temperature, precipitation, solar radiation)and population projection data], four accumulated (lithology, geomorphology, soil moisture, and wind speed) and rest of the other (elevation, slope, soil salinity, LULC, and NDVI) are calculated from 2018 satellite images. Climatic components (Figs. 4 and 5) has a significant influence on the growth of all vegetations and mangrove has a unique capacity to adopt the new climatic conditions. Although, various researches stated that the impact of climate change will accelerate the alternation of species compositions (Chow, 2018). Therefore, the RCPs 4.5, 6.0 and 8.5 scenario based climatic variables have been incorporated for suitability mapping of 2030 and 2050. The result of RCP 6.0 is showing the best result comparing to other scenarios. There is a heterogeneous pattern found among the climatic variables with an increasing trend in temperature (maximum and minimum) and solar radiation, but a decreasing trend in precipitation. The rate of the downfall of precipitation is 0.3% annually during 2010–2050. Simultaneously, the rate of increase in maximum temperature and solar radiation is 0.05 °C and 3%. Each parameter is divided into five classes and assigned a unique weight (Tables 1 and 2) of each subclass (ST. 2 - ST. 3) to distinguish individual class influence on mangrove suitability. The major variation of climatic parameters is found in Diglipur and Mayabunder tehsil comparing to Rangat over the period. Although population plays a major role in ecosystem management. Coastal villages beside and behind the mangrove creeks have a potential influence on ecosystem wellbeing. Population projection has been calculated based on the exponential growth rate based model which shows that significant increase of population in the coming twenty years over the villages. In 2030 Dilipur and Mayabunder villages have the highest population comparing to Rangat regions.

Apart from the climatic variables, high elevation and slope also control the distribution of mangrove. The elevation (Fig. 3) ranges between −4 m and 517 m in which the major percentage (87.40%) of the region are laying within 18-m height from the mean sea level. Slope (Fig. 3) ranges up to 52° in which 87.2% of the area is situated within 9° of a slope, which is suitable for mangrove growth. A total number of fourteen lithological units (Fig. 3) are available over the region. Among them, sandstone-conglomerate (37.54%), clay (22.26%) and sandstone with shale parting (21.60%) occupy major landmass. The notable concentration of sandstone with shale parting is found in the southwestern and western part of the region while sandstone - conglomerate are found scattered over the area with a high concentration in the middle and northeastern part. In perspective of geomorphology (Fig. 3), it is a agglomeration of structural hills (29.81%), denudation hills (52.51%), coastal plain (14.93%), eolian Plain (1.69%), water-body (0.46%) and pediplain (0.61%). On the other hand, soil moisture (Fig. 3) varies between 10.45 and 11.40 kg/sq. m/s. A wide distribution of low soil moisture (33.63%) is noticed in northern part while high concentration (12.14%) are found in the southern part of the region. But in case of NDSI derived soil salinity (Fig. 3), the value ranges from 206 to 13790 where the major areas are located within low (35.71%) to moderate (40.05%) salinity range. Simultaneously, LULC change has a significant influence on future estimation. Six prominent LULC (Fig. 6; SF. 1) change (in 1988 and 2018) has been found over the region. These are mangrove forest (15.12% and 8.07%), tropical evergreen forest (36.73% and 35.22%), tropical mixed forest (23.84% and 24.26%), marshy land (9.70% and 11.59%), hamlets with agricultural land (12.30% and 19.36%) and inland water-bodies (2.33% and 1.50%). A significant transformation (ST. 1) between the LULC categories has been noticed within the two classes of mangrove forest and hamlets with agriculture land (the year 2018 and year 1988). The major downward changes are noticed in mangrove forest (−47%) and inland water-bodies (−36%) with marginal changes in tropical evergreen forest (−4%), while upward changes happen in hamlet with agriculture land (57%) and marshy land (20%) with low changes in tropical mixed forest (2%). Thereafter, moderate and high NDVI values (Fig. 3) ranging between 0.58 and 0.95 (32.60% and 54.05%) dominated over the entire region which reflect the enrichment of healthy vegetation including all forest range. Subsequently, wind speed (Fig. 3), ranging between 5.57 and 5.69 m/s, is another important factor for growth and stabilization of vegetation. Low and moderate wind speed helps coastal vegetation to reach the highest succession level while high speed creates negative impacts on growth. In this study moderate, moderately high and high wing speed (23.27%, 30.63%, and 15.84%) control the major region which is a important factor of unsuitable condition in mangrove growth.

Table 2
Pair-wise comparison matrix and normalized weights.

	Elevation	Slope	Population Projection	Soil Moisture	Maximum Temperature	Minimum Temperature	Precipitation	Solar Radiation	Geomorphology	Land-Use/Land-Cover	Lithology	Wind Speed	Vegetation NDVI	Soil Salinity	Normalized Weight
Elevation	6.5/6.5	6.5/6	6.5/4	6.5/7	6.5/4.5	6.5/5.5	6.5/7.5	6.5/4.5	6.5/7.5	6.5/8	6.5/6.5	6.55/3	6.5/8	6.5/8.5	0.0748
Slope	6/6.5	6/6	6/4	6/7	6/4.5	6/5.5	6/7.5	6/4.5	6/7.5	6/8	6/6.5	6/3	6/8	6/8.5	0.0690
Population Projection	4/6.5	4/6	4/4	4/7	4/4.5	4/5.5	4/7.5	4/4.5	4/7.5	4/8	4/6.5	4/3	4/8	4/8.5	0.0460
Soil Moisture	7/6.5	7/6	7/4	7/7	7/4.5	7/5.5	7/7.5	7/4.5	7/7.5	7/8	7/6.5	7/3	7/8	7/8.5	0.0805
Maximum Temperature	4.5/6.5	4.5/6	4.5/4	4.5/7	4.5/4.5	4.5/5.5	4.5/7.5	4.5/4.5	4.5/7.5	4.5/8	4.5/6.5	4.5/3	4.5/8	4.5/8.5	0.0517
Minimum Temperature	5.5/6.5	5.5/6	5.5/4	5.5/7	5.5/4.5	5.5/5.5	5.5/7.5	5.5/4.5	5.5/7.5	5.5/8	5.5/6.5	5.5/3	5.5/8	5.5/8.5	0.0632
Precipitation	7.5/6.5	7.5/6	7.5/4	7.5/7	7.5/4.5	7.5/5.5	7.5/7.5	7.5/4.5	7.5/7.5	7.5/8	7.5/6.5	7.5/3	7.5/8	7.5/8.5	0.0862
Solar Radiation	4.5/6.5	4.5/6	4.5/4	4.5/7	4.5/4.5	4.5/5.5	4.5/7.5	4.5/4.5	4.5/7.5	4.5/8	4.5/6.5	4.5/3	4.5/8	4.5/8.5	0.0517
Geomorphology	7.5/6.5	7.5/6	7.5/4	7.5/7	7.5/4.5	7.5/5.5	7.5/7.5	7.5/4.5	7.5/7.5	7.5/8	7.5/6.5	7.5/3	7.5/8	7.5/8.5	0.0862
Land-Use/Land-Cover	8/6.5	8/6	8/4	8/7	8/4.5	8/5.5	8/7.5	8/4.5	8/7.5	8/8	8/6.5	8/3	8/8	8/8.5	0.0920
Lithology	6.5/6.5	6.5/6	6.5/4	6.5/7	6.5/4.5	6.5/5.5	6.5/7.5	6.5/4.5	6.5/7.5	6.5/8	6.5/6.5	6.5/3	6.5/8	6.5/8.5	0.0747
Wind Speed	3/6.5	3/6	3/4	3/7	3/4.5	3/5.5	3/7.5	3/4.5	3/7.5	3/8	3/6.5	3/3	3/8	3/8.5	0.0345
Vegetation NDVI	8/6.5	8/6	8/4	8/7	8/4.5	8/5.5	8/7.5	8/4.5	8/7.5	8/8	8/6.5	8/3	8/8	8/8.5	0.0920
Soil Salinity	8.5/6.5	8.5/6	8.5/4	8.5/7	8.5/4.5	8.5/5.5	8.5/7.5	8.5/4.5	8.5/7.5	8.5/8	8.5/6.5	8.5/3	8.5/8	8.5/8.5	0.0977

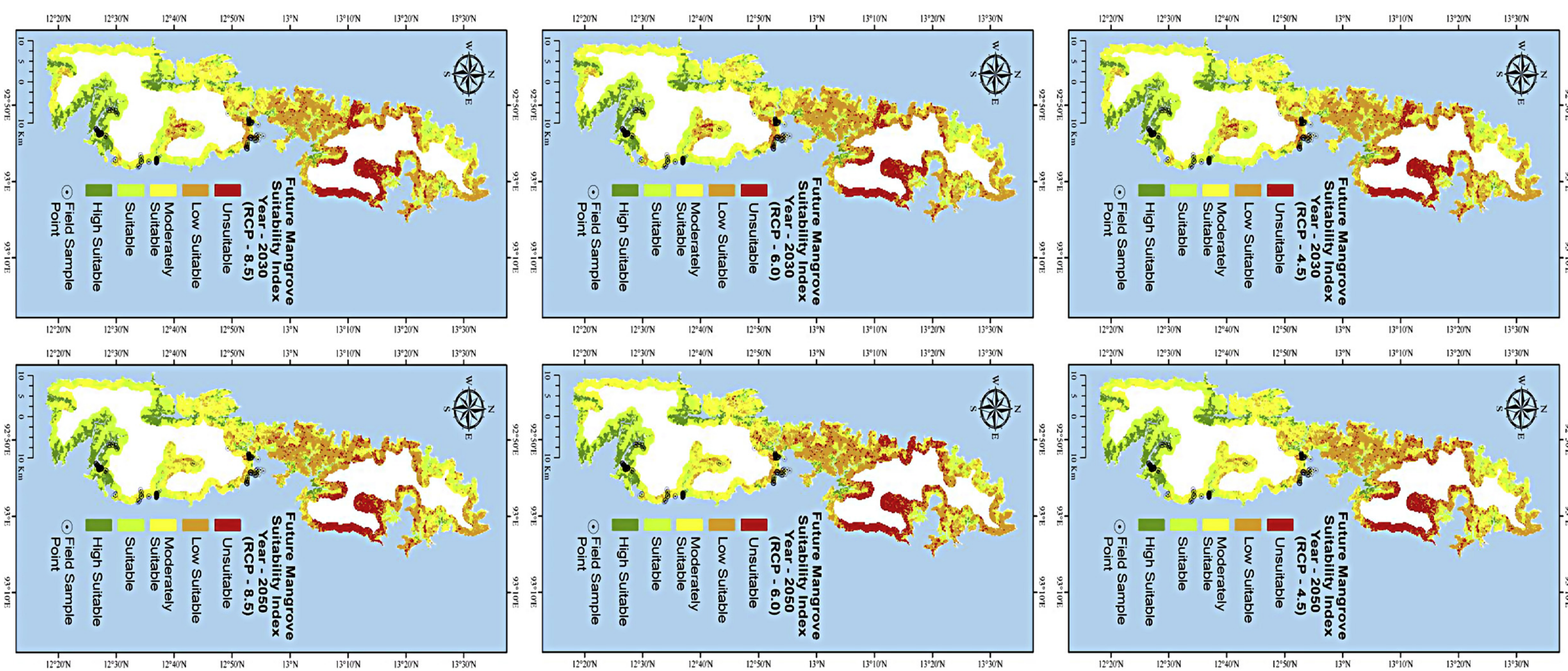

Fig. 7. Future Mangrove Suitable Zones of three different RCP scenario (4.5,6.0 and 8.5).

4.1.2. *Multi-criteria decision making approach in future mangrove suitability assessment*

Future Mangrove Suitability Assessment (FMSI) (Fig. 7) has been calculated using the AHP technique which is a widely used method in MCDM. In this process model, each parameter and the sub-parameters of consequent parameters has assigned a particular weight based on the individuals (class and subclass) impact on mangrove growth. These weights are fixed from local experts opinions and comprehensive literature survey which are finally converted into normalized weight (ST. 6) to generate the RCPs based future scenario preparation using overlay operation in a geospatial environment. The output of FMSI (Fig. 7), (2030 and 2050), has been characterized into five zones which are unsuitable, low suitable, moderately suitable, suitable and high suitable with a significant difference in spatial coverage (Table 3) between RCPs 4.5–6.0 and RCPs 6.0–8.5, in which RCPs 4.5–6.0 result is less erroneous comparing to RCPs 6.0–8.5. In the year of 2030, the highest positive difference, in between RCPs 4.5–6.0 and RCPs 6.0–8.5, found in suitable class (0.50%) and low suitable class (0.76%) while the highest negative difference is concentrated in moderately suitable (−0.37%) and suitable (−0.78%) classes. In the same way, in 2050, the larger positive difference has been noticed in suitable (3.29%) and unsuitable (2.79%) classes with negative changes in unsuitable (−2.54%) and suitable (−3.75) class. Apart from this differentiation analysis, each RCP based output has been correlated with present LULC classes with field sample points (ST. 7) to select the best RCP scenario. Here, we found that the RCP 6.0 scenario (Fig. 8) has a good match with 2018 LULC and field information. Thereafter, this positive and negative changes, in scenario-based difference analysis, floats scatter over the region, but it is comparatively clear in northern region of the area due to few influencing factors, which are growth of population, degradation of mangrove forest due to land upliftment in 2004 tsunami, encroachment of forest land for development and decrease of precipitation. Though southeastern part of the region (Rangat) is in beneficial condition due to the nominal subsidence in the tsunami. In these regions, tidal flow travels a long distance which changes the landscape into mangrove forest slowly. Therefore, suitable and high suitable zones are scattered over the southern and south-eastern part of this study area. Hence considering the various aspects, it is clear that the impact of the natural and anthropogenic component on mangrove suitability has a complex nature over this study region.

4.2. Validation

The investigated region has been threatened by various natural and anthropogenic factors namely, changes of the landmass in seismic influences, the impact of climate change, population growth, degradation of the underwater ecosystem due to the tsunami and climate change and poor awareness on mangrove conservation. These complex impacts are more clearly understood during the time of field sampling. A total number of 558 points has been surveyed on the ground to verify each LULC classes (February 2018). These points are scattered over the eastern part of Mayabunder and Rangat tehsil, while no points have been covered in western part due to the lack of accessibility. Therefore the western part has been validated using Google Earth observations. However, another observation (i. e, measurement of soil temperature) has been collected during the field to strengthen mangrove suitability assessment. This sample has been collected using a soil moisture meter and GPS, for 30 different points in mangrove and non-mangrove areas. The variations of soil temperature are very low in mangrove regions (29 °C - 30 °C) but higher variations are found in non-mangrove zones (21 °C - 28 °C), which indirectly conclude the gradation the future mangrove suitability ranging from unsuitable zone to high suitable zones.

4.3. Identification of triggering factor with statistical correlation analysis

Sensitive analysis (Table 4) has been performed among the fourteen parameters to identify the individual's influence on future suitability. This analysis resulted that there are seven parameters among fourteen parameters which have high command on future suitability. These parameters are lithology, geomorphology, soil salinity, LULC, population, maximum temperature, and precipitation. The inter-connectivity between dominant parameters has been calculated using individual parameters pixel based class values, which are extracted in respect to the filed sample points and analyzed using Pearson correlation, Spearman correlation and Kendall Tau correlation methods (Tables 5–8). A total number of 300 sample observation (ST. 5) has been selected for correlation analysis which shows a complex relationship. A comparative highly trend of negative correlation explains the unfavorable conditions whereas highly trend of positive correlation describes the suitability, like high temperature and precipitation, has an inverse impact on population growth due to hard lifestyle, simultaneously high precipitation and temperature control the lithological structure. Therefore the changes of lithology negatively dominate the changes of geomorphology which has direct control over mangrove succession.

4.4. Sustainable development and future mangrove suitability

Mangrove ecosystem has a significant influence on socio-ecological interconnectivity and overall sustainable development in coastal zones. It provides a variety of services and protects from several threats. Therefore, mangrove management and conservation took a valuable aspect in United Nation sustainable development agenda. Three vital goals (Chow, 2018) are related with mangrove ecosystem including action planning in climate change and its impact (goal 13), conservation and sustainable use of marine resources (goal 14) and management policy formulation and implementation to prevent biodiversity loss, forest protection and reduce desertification (goal 15). Mangrove has a notable influence on climate change, carbon sequestration and halts ecosystem services. But the necessity to take urgent action in the conservation of this important ecosystem is essential for sustainable management of coastal zones. There is a possibility of higher productivity if atmospheric CO_2 increases continuously in coming days, but very limited

Table 3
Percentage of aerial coverage in future mangrove suitability zones.

Class	Senerio_4.5		Senerio_6.0		Senerio_8.5	
	Year 2030	Year 2050	Year 2030	Year 2050	Year 2030	Year 2050
Unsuitable	8.92	7.97	8.69	10.51	8.93	7.72
Low Suitable	28.63	26.87	28.86	28.94	28.10	26.82
Moderately Suitable	29.09	30.64	29.46	29.55	29.36	30.42
Suitable	23.90	24.21	23.40	20.92	24.18	24.67
High Suitable	9.46	10.30	9.59	10.08	9.43	10.36

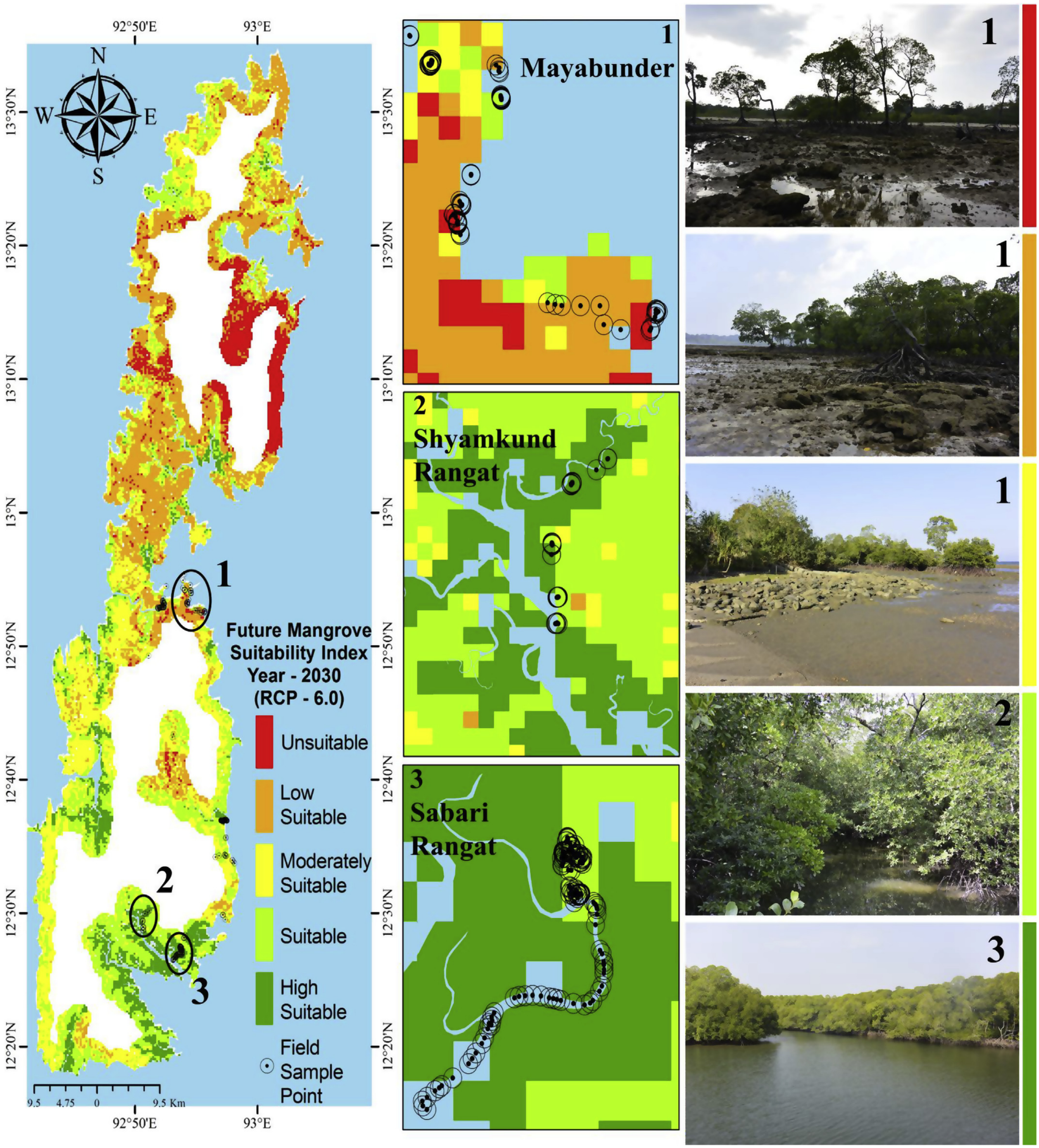

Fig. 8. Future Mangrove Suitable Zones in RCP 6.0 scenario.

studies illustrate that the response of all species will not homogeneous which may lead towards high depletion (Alongi, 2002; Chow, 2018). Consequently, the continuous increase of sea surface height (1.5 mm observed during 1980–2009) and seismic events with frequent storm surges are the key threats which uproot the trees and expose soils for high erosion (Alongi, 2008). This impact trend is clearly noticed during last three years in the investigation area. Therefore future prediction will provide the overall scenarios to take urgent action in conservation practice. In this study area, major unsuitable and low suitable zones are situated in Mayabunder and Diglipur tahsil. Therefore, a strong conservation action plan is highly essential for these regions to control biodiversity loss and desertification. It is also essential to take necessary steps in mangrove plantation (Chowdhury et al., 2018) in degraded locations..

Table 4
Soil temperature.

Regions	Latitude	longitude	Soil Temperature (°C)	Regions	Latitude	longitude	Soil Temperature (°C)
Mangrove Dominated Regions	12.490,115	92.843,683	28.00	Non-Mangrove Dominated Regions	12.909,392	92.908,388	21.00
	12.490,178	92.843,642	28.30		12.909,425	92.908,413	21.30
	12.482,452	92.844,572	28.50		12.903,048	92.90,895	22.00
	12.482,443	92.844,562	28.00		12.903,048	92.908,952	21.50
	12.48,245	92.844,562	28.40		12.902,742	92.90,931	21.70
	12.482,368	92.84,446	28.80		12.877,735	92.915,065	22.60
	12.48,237	92.84,455	28.70		12.877,553	92.915,965	23.00
	12.482,427	92.844,607	28.60		12.877,453	92.91,673	23.60
	12.482,432	92.844,608	29.50		12.874,882	92.923,758	24.60
	12.50,283	92.852,802	29.00		12.885,027	92.904,798	23.50
	12.50,285	92.85,286	29.60		12.885,188	92.904,752	24.20
	12.616,382	92.955,642	29.70		12.885,207	92.904,748	24.60
	12.616,468	92.955,822	29.80		12.885,203	92.904,747	26.70
	12.616,487	92.955,877	29.60		12.906,105	92.89,872	27.50
	12.616,527	92.955,703	30.00		12.90,616	92.898,675	27.50
	12.614,985	92.952,098	30.10		12.90,617	92.898,665	23.50
	12.614,913	92.952,237	29.80		12.615,603	92.950,477	24.60
	12.614,905	92.952,227	29.50		12.571,632	92.947,625	22.90
	12.615	92.952,515	29.70		12.57,167	92.947,648	21.30
	12.614,967	92.952,485	29.80		12.471,915	92.901,675	22.60

Table 5
Sensitivity analysis results.

	Unsuitable (%)	Low Suitable (%)	Moderately Suitable (%)	Suitable (%)	High Suitable (%)
Elevation	**+3.12**	**+2.36**	**+1.25**	**+0.96**	+0.99
Slope	+0.72	**+1.25**	**+0.95**	**+2.34**	**+1.59**
Future[1] Population	-0.41	**+1.06**	**+1.07**	**+0.85**	**+2.96**
Soil Moisture	**+3.52**	**+1.16**	**+1.05**	**+0.72**	+0.95
Future[2] Maximum Temperature	**+3.33**	**+3.35**	**+1.06**	**+0.83**	**+1.36**
Future[3] Minimum Temperature	**+2.36**	**+1.04**	**+1.05**	**+0.97**	+0.95
Future[4] Precipitation	-0.32	**+0.86**	**+3.25**	**+2.36**	**+2.99**
Future[5] Solar Radiation	-0.68	**+1.89**	**+2.36**	**+0.99**	**+2.36**
Geomorphology	**+1.56**	**+2.36**	**+1.25**	**+1.03**	+0.74
LULC	**-1.13**	**+1.99**	**+0.97**	**+1.20**	**+1.58**
Lithology	**+1.98**	**+0.99**	**+1.56**	**+1.35**	**+1.66**
Wind Speed	**-1.61**	**+1.05**	**+1.25**	**+1.09**	**+3.25**
NDVI	**-2.04**	**+3.36**	**+2.98**	**+1.35**	**+1.25**
Soil Salinity	**+1.30**	**+1.98**	**+1.96**	**+1.36**	**+1.56**
All parameters	+11.71	+24.69	+22.01	+17.40	+24.19

Bold values (% of area) indicate significant results.

Table 6
Spearman correlation analysis.

	Lithology	Geomorphology	Maximum Temp	Precipitation	Soil Salinity	LULC	Population (Year, 2030)
Lithology	1.00	−1.00	1.00	1.00	0	0.83	−0.88
Geomorphology	−1.00	1.00	−1.00	−1.00	0	−0.83	0.88
Maximum Temp	1.00	−1.00	1.00	1.00	0	0.83	−0.88
Precipitation	1.00	−1.00	1.00	1.00	0	0.83	−0.88
Soil Salinity	0	0	0	0	1.00	0	0.31
LULC	0.83	−0.83	0.83	0.83	0	1.00	−0.89
Population (Year, 2030)	−0.88	0.88	−0.88	−0.88	0.31	−0.89	1.00

Table 7
Pearson correlation analysis.

	Lithology	Geomorphology	Maximum Temp	Precipitation	Soil Salinity	LULC	Population (Year, 2030)
Lithology	1.00	−1.00	1.00	1.00	0.00	0.87	−0.92
Geomorphology	−1.00	1.00	−1.00	−1.00	0.00	−0.87	0.92
Maximum Temp	1.00	−1.00	1.00	1.00	0.00	0.87	−0.92
Precipitation	1.00	−1.00	1.00	1.00	0.00	0.87	−0.92
Soil Salinity	0.00	0.00	0.00	0.00	1.00	0.00	0.27
LULC	0.87	−0.87	0.87	0.87	0.00	1.00	−0.92
Population (Year, 2030)	−0.92	0.92	−0.92	−0.92	0.27	−0.92	1.00

Table 8
Kendall Tau correlation analysis.

	Lithology	Geomorphology	Maximum Temp	Precipitation	Soil Salinity	LULC	Population (Year, 2030)
Lithology	1.00	−1.00	1.00	1.00	0.00	0.79	−0.85
Geomorphology	−1.00	1.00	−1.00	−1.00	0.00	−0.79	0.85
Maximum Temp	1.00	−1.00	1.00	1.00	0.00	0.79	−0.85
Precipitation	1.00	−1.00	1.00	1.00	0.00	0.79	−0.85
Soil Salinity	0.00	0.00	0.00	0.00	1.00	0.00	0.25
LULC	0.79	−0.79	0.79	0.79	0.00	1.00	−0.87
Population (Year, 2030)	−0.85	0.85	−0.85	−0.85	0.25	−0.87	1.00

4.5. Suggestions and recommendation in the context of sustainable development

The recorded depletion rate (47%) of the mangrove ecosystem is high during 1988–2018. While the highly suitable zones also decreasing in nature in 2030 and 2050. Therefore it is necessary to take urgent action on degradation hotspot over the region. There is two major degradation hotspot identified for 2030 and 2050, and these are Mayabunder and Diglipur region. The major threats of these regions are population growth and the influence of climate change. Thus a few recommendations and suggestions have been proposed for conservation built resilient ecosystem.

a) Collapse all construction within the 500-m buffer region from Mangrove forest.
b) Stop waste disposal in mangrove creeks and built proper waste management practices.
c) Initiate artificial plantation in the Western part of the regions which was destroyed in the 2004 tsunami.
d) Initiate policies to halt the conversion of mangrove wetland to agricultural or built-up lands.

5. Conclusion

Island studies have significant importance in the conservation of threatened socio-ecological diversity. In this assessment, we presented a new framework (Fig. 9) for the identification of future mangrove suitability zones using the AHP method in the north and middle Andaman island. In this work, fourteen parameters have been used to calculate suitable zones of mangrove distribution for

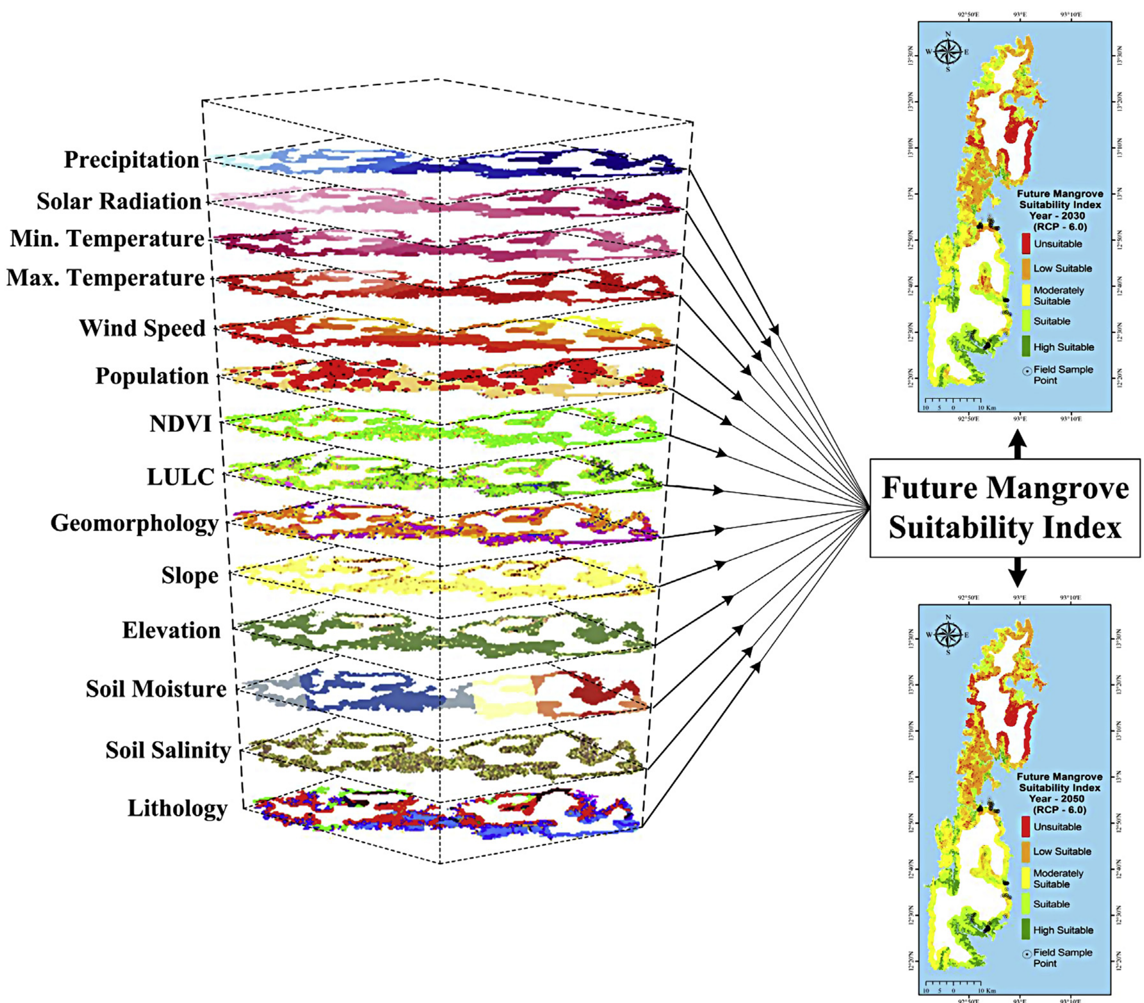

Fig. 9. Graphical representation of Future Mangrove Suitability mapping.

the year 2030 and 2050. RCPs and population projection data has high importance in this analysis which has not been considered for future assessment in previous studies. Three RCP scenario (RCP 4.5, 6.0, 8.5) has been considered for this study and among then RCP 6.0 shows the best result. This assessment is mainly focused on mangrove ecosystem due to its socio-economic-ecological importance and high depletion rate (around 47% during 1988–2018). The high vulnerable zones are found in the northern part of the study area which is threatened by climate change, seismic influence, and anthropogenic impacts. A total number of 556 sample location in the eastern side of the region has been surveyed to validate the present land-use/land-cover scenario while the western side has not been surveyed due to lack of accessibility. Seven major sensitive parameters have been selected from sensitivity analysis and three statistical correlation analysis has been performed using 300 filed points to generate the actual correlation between the parameters. The final outcome generates valuable and necessary information to trigger sustainable development planning and implementation. It will also helpful in carbon sequestration estimation, future livelihood management and policy-making, ecological restoration sites for plantation, landscape beautification and future tourism development planning. Moreover, this database will help in future research on mangrove ecosystem in Andaman and Nicobar Islands.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2019.06.257.

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