Climate risks adaptation strategies for Indian Sundarbans

Surajit Ghosh[a,b], Debarati Chakraborty[c,d], Pratik Dash[e] ,Saikat Patra[f], Payal Nandy[b] and Partho Protim Mondal[h]

[a]National Institute of Technology, Durgapur, India
[b]IORA Ecological Solutions Pvt. Ltd., New Delhi, India
[c]University of Kalyani, Kalyani, India
[d]Centre for studies in Ethnobiology, Biodiversity and Sustainability (CEiBa) Trust, Kolkata, India
[e]Adamas University, Barasat, India
[f]Zabingo Softwares, Kolkata, India
[h]University of Chinese Academy of Sciences, Beijing, China

Keywords: Geo-smart Landscape Management, *In-situ* Germplasm Conservation, Community Seed Bank, Climate Adaptation Strategies for Indian Sundarbans, Man-Mangrove Interaction

Abstract

Climate change has profoundly impacted tropical ecosystems, critical for sustaining economies and community livelihoods at local to global scales. Rapid population growth has further negatively impacted natural resource management and upsetting the socio-ecological balance. Sundarbans, world's largest contiguous tract of mangroves, is not an exception. It is shared between Bangladesh (60%) and India (40%) but the later is much more populated. Indian Sundarbans (IS) is not only the home of 4.5 million people but also of 85% total Indian mangrove habitat and 1434 faunal species. Agriculture, fishery and Non-Timber Forest Products (NTFPs) from mangroves are their major sources of income. Inhabitants of this climatically vulnerable region are facing the risks of becoming environmental refugees due to land loss by shore line changes. Moreover, storm surges because of cyclones like Aila are becoming more frequent causing sudden heavy intrusion of saline water in the freshwater stock. Further, salt accumulation in soil and water often affect agricultural and aquaculture productions. Climate risks have thus severely affected the livelihoods along with this unique ecosystem. Man-Mangrove Interactions (MMI) in IS is also obstructed by unsustainable exploitation of NTFPs, embankments in mud-flats causing failure of propagules to survive, etc. However, the risks and impacts are not in the same degree in the entire region. Hence, location-based approach is urgently needed for increasing adaptation capacity to climate risks.
Here, we propose to develop a Geo-smart management system model to reduce socio-climate risks at the landscape level. The model has five major objectives–

1. Develop index-based climate risks geospatial model
2. Conservation of traditional germplasms
3. Sustainable economic options generation for local people
4. Climate risks awareness programme and knowledge dissemination
5. Positive enhancement of man-mangrove interactions.

Corresponding author: Surajit Ghosh
Email: surajitghosh.ind@gmail.com

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26963v2 | CC BY 4.0 Open Access | rec: 27 May 2018, publ: 27 May 2018

1. Context

Though coastal zone is limited to mere 4% of the world's total land area, it houses almost one-third of the world population (UNEP-WCMC, 2006; Cochard et al., 2008). The vulnerability of coastal populations' to climate change is well documented (UNDP's Human Development Report 2007). Therefore, to combat and reduce climate risks it is necessary to enhance awareness of coastal people about their local climate risks, its probable extent and after effects so that it will be possible to formulate appropriate mitigation measures with the active prior preparation and participation of local peoples. Indian Sundarban (IS), situated in the Ganga-Brahmaputra-Meghna delta, is home to numerous rare, endangered, threatened floral, faunal and microbial species along with 4.5 million people (*Fig.1* and *2*). Being the world's largest mangrove forest, it has the largest mangrove diversity in the world. A part of IS is National Park (1984), World Heritage site (1987), Biosphere Reserve (2001). IS comprises 19 administrative blocks. Community in this area is majorly constituted of small agricultural landholders; landless labourers working in agricultural lands, aquaculture farms (locally called bheries); full time or part time coastal fishermen. Aila, a severe cyclonic storm (25 May 2009) caused ingression of the high volume of saline water in the agrarian land of IS, North and South 24 Parganas (DRCSC 2009). Aila affected over 6.77 million people, killed 137 in IS, collapsed more than 500 km of embankments and 926,000 semi-permanent houses. It wreaked havoc in 5 Blocks (Sandeshkhali-I, II, Minakhan, Hasnabad and Hingalganj) of North 24 Parganas. In Canning II (of South 24 Parganas), almost ~3.5 sq. km of land was affected by saline water due to Aila. Almost 70-80 poultry farms of Sandeshkhali-I, II and Hingalganj was completely devastated. Salt-water inundation of agricultural lands have made farming infeasible for three consequent years (DRCSC 2009). Cyclone occurrence is not an uncommon incident in IS (*Fig. 3*). Moreover, toxic trace metal pollution in mangroves of IS, sea-level rise is further aggravating the situation (Chakraborty 2014; Ghosh et al. 2017). Higher erosion

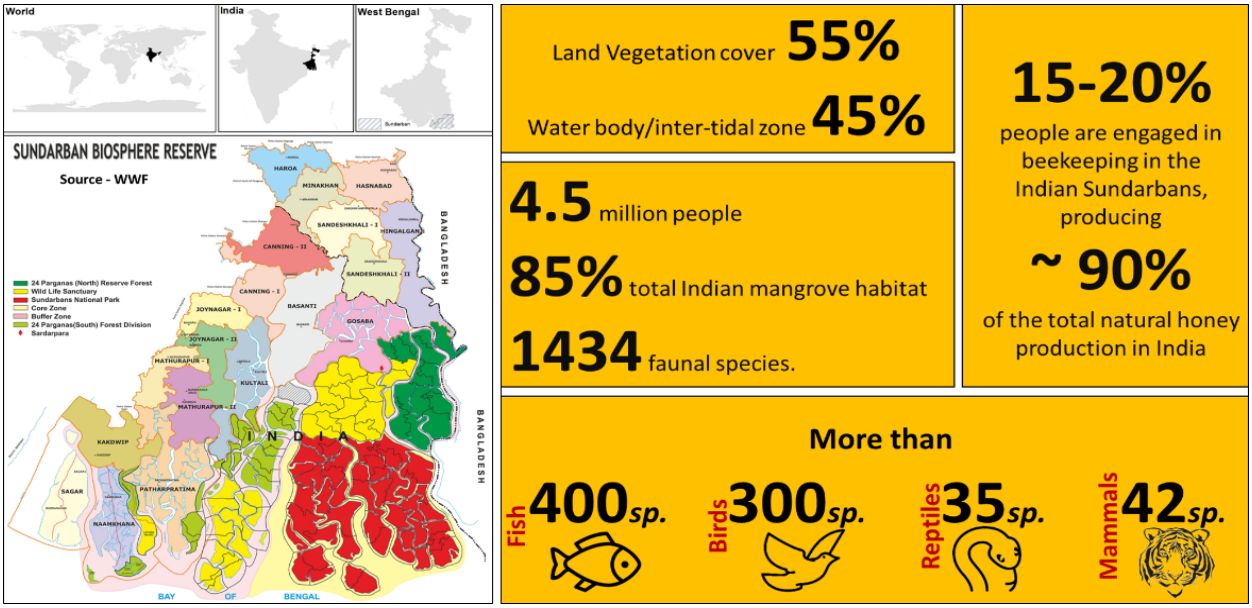

Figure 1 Indian Sundarbans and biodiversity statistics

rates than in the past due to combined effects of artificial sediment traps upstream and higher water discharges; increased potency of tidal bores increased population growth from 1951 to 2011 (Ghosh et al. 2015; Unnikrishnan et al. 2011).

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26963v2 | CC BY 4.0 Open Access | rec: 27 May 2018, publ: 27 May 2018

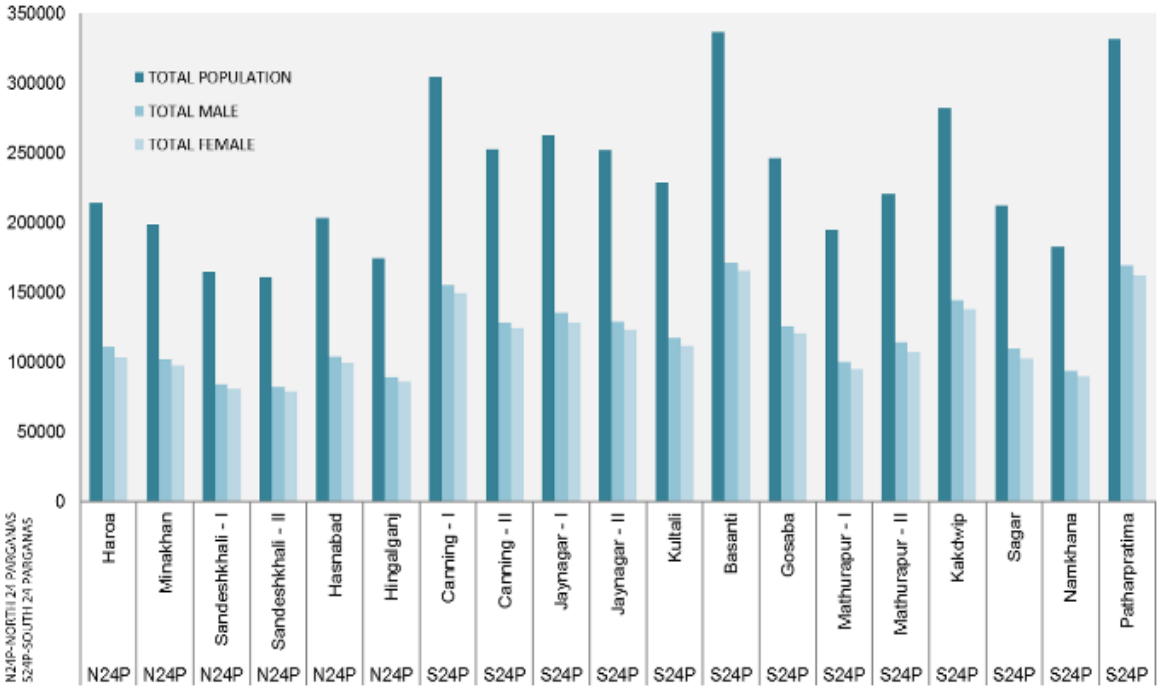

Figure 2 Block wise population (Census-2011) of Indian Sundarbans

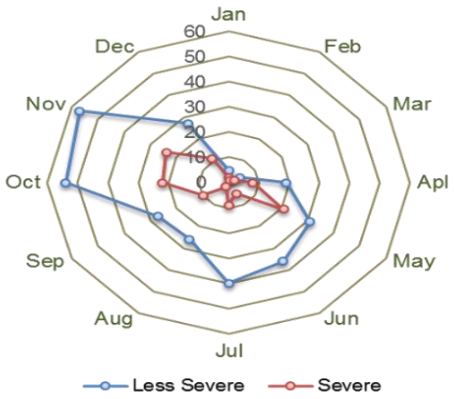

Figure 3 Monthly frequency of cyclone in the region

2. Proposed actions

According to UN Climate Resilience Initiative, we will subdivide our actions into three heads- anticipate, absorb and reshape to enhance the resilience of vulnerable target communities towards climate change.

1) Anticipate

To date, there exists no climate risk map for identifying the most climate vulnerable regions of Indian Sundarbans. Hence, we propose to generate a climate risk map for the region through satellite data and stakeholder consultation. The map will be regularly updated. The generated map will help to identify the climate risk hotspots in entire Sundarbans. It will also give information which particular livelihoods are getting hampered in which area and the underlying climate reasons if any. An app will be launched for easy usage. SMS-based response through app registration will be done. Mass awareness will be generated through organizing workshops,

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26963v2 | CC BY 4.0 Open Access | rec: 27 May 2018, publ: 27 May 2018

training for people to use the app. All these will help to lower the primary response time after a disaster. A local disaster response team will be maintained with the coordination of local Self Help Groups (SHGs). UN Climate resilience initiative advocates towards empowering the forecast of climate hazards and stresses on early warning and action. For anticipating the disaster-related risks, we propose to make an index based risk map considering climatic and socio-economic factors for micro level and macro level climatic insurance assessment analysis through geospatial modelling. The map will enable the local stakeholders to understand their landscape from climate risk aspects and to take likewise decision. A free mobile app will be developed to visualize and quantify the location-based composite risks. For example - The map will demarcate landscape according to their salinity level. This will enable crop specific monitoring of saline drought soil and aquaculture in accordance with salinity level. Required training for using the app will be provided to the stakeholders through free training sessions by SHGs. The app will enable the stakeholders to understand the nature and requirements of their lands and ponds through in-build illustrated FAQ. The app will also contain details (name, addresses, numbers) of fishermen, NTFP collectors having permits for visiting forest. People can also discuss and share their ideas and experience through this app (*Fig.4*). NTFPs of IS includes tannin bark, natural honey and bee wax; fuelwood and small poles; tree trunks; golpata (Nypa fruticans), hental (Phoenix paludosa) leaves; fishes, prawn, crab, shrimps; and lime (prepared from oyster and abalone). The average age of NTFP harvesters is more than forty years (Zohora 2011).

2) Absorb

For absorbing the climate-related risk, it is essential to take some long-term actions. Sustainable implementation and long-term maintenance require the involvement of local communities. The heart of UN Sustainable Development Goals (SDGs), 2016 is to achieve well-being for all while protecting nature. SDGs are inclusive agenda which aims to bring together not only specialists but also common people to eradicate various global problems. This is achievable by strategizing the integration of ecosystem services with human benefits. We propose the following strategies for achieving the societal adaptation to climate change in IS: *a) Formation of Self-help groups (SHGs)*-Though many SHGs exists in the Indian Sundarbans due to government and non-government initiatives what they lack is coordination among themselves and unified actions towards a particular goal. The representative forum will be formed involving farmers, fisherman, aquaculture farm owners, labours, school teachers, local traders. Women representative from each group will be selected in coordination with other existing SHGs of the region, local and international NGOs, civil societies and other experts through regular interactions, group discussions (*Fig.4*).
b) Environment protection oriented asset building through *in-situ* germplasm conservation and seed bank (*Fig.4*).

(i) Biodiversity conservation is essential for the multitude services it renders. It not only helps in maintaining ecological balance but also plays a pivotal role towards sustainable livelihoods of rural people. Agro-biodivesity conservation aids it through genetic diversity preservation, management and food security enhancement. On-farm agro-biodiversity conservation is a new, high-priority approach towards in-situ germplasm conservation. The approach sustainably maintains local, traditional cultivated crop species at farmers' field. It uses traditional agricultural, horticultural knowledge for agro-biodiversity management and is receiving great focus in the face of recent climate change scenarios. *In-situ* conservation of traditional germplasms will contribute towards the maintenance of traditional agronomic genetic resources of IS. Maintenance of distinct features of local crops will be possible through this approach. Appropriate scientific documentation of these features will further prevent biopiracy of age-old, agricultural knowledge of farmers of IS. Inputs for determining conservation approaches will be taken from both local farmers and experts in this field. Organic farming techniques will be applied to ensure minimum soil pollution.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26963v2 | CC BY 4.0 Open Access | rec: 27 May 2018, publ: 27 May 2018

(ii) *Community seed bank set-up*- A community seed bank will be set-up through active participation from local farmers, SHGs, local NGOs and government organizations. It will conserve seeds of traditional breeds of cereals, vegetables, plantation crops, fruits cultivated by organic methods. It will be constructed in the least vulnerable area of the village following the map to ensure its safety if any natural disaster occurs. SHGs will employ local people for its maintenance. Each farmer each year will donate a small part of their produce for conservation purpose and next year will get seeds free according to the decisions of village members and SHGs involved. The process should be continued each year to ensure independent supply of seeds for the local farmers. Excess seeds will be sold at local markets and exchange of breeds with other agriculture farms in lieu of money will be initiated.

(iii) *Community aquaculture pond Setup*-Similar to the previous one a community aquaculture pond will also be set-up to conserve traditional fish breeds, shrimps, prawns, crabs, oysters. SHGs will employ locals to ensure its proper maintenance in a chemical-free way. Excess produce will be sold at local markets and exchange of breeds with other aquaculture farms in lieu of money will be initiated. The money thus collected will be deposited in a bank account opened separately for these community assets. The money will be used towards maintenance of these structures, payment of employees, procuring of new varieties, exhibition organisation and other activities to be decided as and when required.

(iv) *Mangrove* mud flat restoration will be done through coordination with SHGs and local NGOs. Setting-up of mangrove nursery for saving propagules, which fails to germinate because of cement embankments. This will contribute towards climate risk reduction and coastal protection. Mangroves, provide physical protection to coastal communities and provide goods and services such as NTFPs; offering both physical protection and economic gain to the most vulnerable people. Thus, mud-flat restoration will enhance security net in the vulnerable regions while facilitating services and biodiversity restoration (*Fig.4*).

3) Reshape

Reshaping the economic character of the target areas will be achieved by :

(i) *Ensuring Bank account* - for at least one family member, preferably women. Even if climate disaster like Aila is repeated and destroys property, the money saved in the bank will provide a minimum buffer time to cope with the situation.

(ii) *Introducing* an alternative income source - Apiculture and organic manure production will help to attain this goal. Workshops will be arranged by SHG members. Opportunities for selling the products will be created through making a platform/green market. Collaboration with e-marketing sites appropriate for organic food selling will be established. Ecological tourism of the area will also be encouraged through the involvement of local communities and appropriate promotions will be made (*Fig.4*).

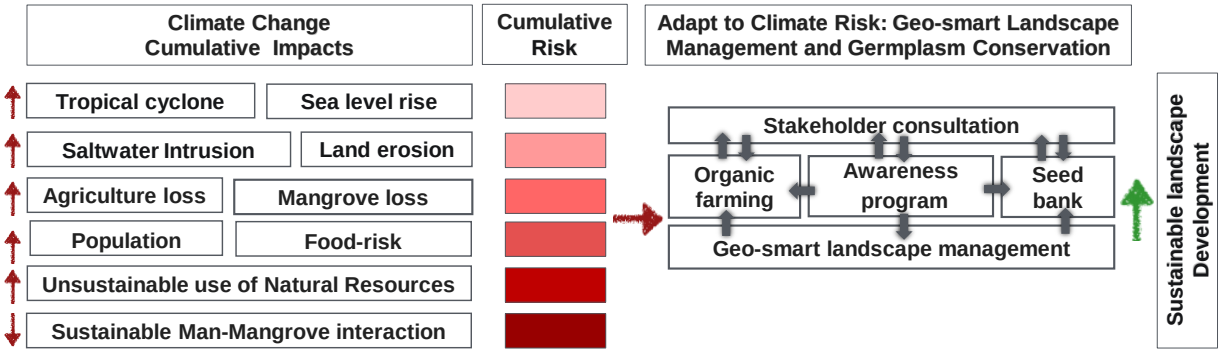

Figure 4 Climate Risks in Indian Sundarbans and adaptation strategies

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26963v2 | CC BY 4.0 Open Access | rec: 27 May 2018, publ: 27 May 2018

3. Key Benefits

The model has four major objectives–

1. Develop index-based climate risks geospatial model
2. Conservation of traditional germplasms
3. Sustainable economic options generation for local people
4. Climate risks awareness programme and knowledge dissemination
5. Positive enhancement of man-mangrove interactions. By Man-mangrove interaction we meant the critical relationship that local communities of IS have with mangrove forest ecosystem. It is constrained by unsustainable collection of NTFPs, deforestation, conflict with wild animals especially Bengal Tiger.

Objectives 1 and 2 will help to achieve SDG 2, 3,12,13,15; objective 3 will contribute to SDG 13; objectives 4, 5 to facilitate SDG 5, 8 (*Fig.5*).

1) Long-term climate risks index through a geo-smart model, which will provide landscape-level crop specific interactive map, information of traditional and salt-tolerant germplasms. The climate risks map can be further used to assess the climate insurance premium. This model can be updated on a regular basis. At the end, the model output will be accessed by the stakeholders (farmer to policymakers) through the free mobile app and web version.
2) The identification of climate risk zones through map will help to understand the risk associated with the particular zones. Hence, suitable livelihood practices can be undertaken in those regions.

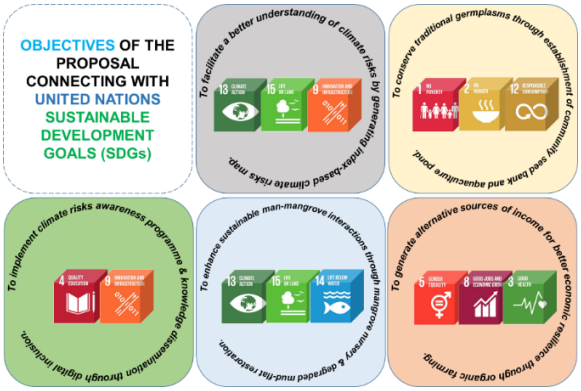

Figure 5 Objectives of the proposed actions at par with UN SDGs

3) Reduced climate risks by community seed banks and aquaculture ponds, which will help to conserve the traditional, salt-tolerant germplasms *in-situ*. Use of these germplasms will ensure better produce in saline drought affected zones and will thereby ensure enhanced economic resilience.
4) The community bank account for community seed bank and pond will ensure better self-sustenance.
5) An alternative source of income through apiculture, organic manure selling, agro-eco-tourism and keeping money in bank account will further ensure the climate insurance safety net.
6) Adoption of in-situ conservation through organic farming involves zero usage of chemical pesticides, veterinary drugs, additives and fertilizers, adoption of crop rotations, use of organic fertilizers and many other things. These will help to recover and maintain soil biodiversity and local agro-biodiversity. Long-term practices of organic farming will gradually lead to the restoration of degraded soils, enhancement of soil organic content and thereby facilitate soil water retention and pollutant circulation ability.
7) Various hands-on training to local community stakeholders will ensure better *in-situ* resilience capacity.
Indirect/Secondary benefits of the model include restoration of mangrove to ensure the better coastal protection of the area and better MMI.

4. Key insights

IS is an extremely vulnerable zone due to climate risks but lacks any baseline climate risks map (at fine scale) to date. Generation of a map will serve as a baseline dataset for calculating climate

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26963v2 | CC BY 4.0 Open Access | rec: 27 May 2018, publ: 27 May 2018

risks insurance premium. This map will also serve towards better landscape management of this area. Community germplasm bank, restoration of degraded mud flats will extend climate safety net and food security in the area and also agro-biodiversity conservation. Creation of mass awareness towards climate risks and establishing coordination with local NGOs of the area will aid further towards better performance of our model. This model on successful implementation can be replicated in other areas with similar problems.

5. Stakeholder Involvement/ Participation

Self-help groups (SHGs) will be formed based on group discussions and active participation by local community stakeholders and field experts (*Table 1*). Specialists will provide regular hands-on training to the local SHGs to enhance their resilience capacity. Thereafter, regular surveys will be done by SHGs to identify the zones having high soil salinity, vulnerability due to sea-level rise, degraded mud-flat etc. SHG members will regularly visit schools and organise camps for promoting a clear idea about the importance of organic farming, *in-situ* germplasm conservation, community seed bank and others parts of the model. Student representatives from school will be selected who will be involved in workshops while addressing their parents involved in farming, fishing, NTFP collection. Group discussion sessions will be regularly arranged to gather inputs from all community stakeholders. Next, training sessions for using the map and likewise decision-making will be organized. The SHGs will execute community seed bank and pond formation, and appropriate maintenance, mangrove nursery set-up, maintenance, degraded mud-flat restoration, organic farming initiation in the proposed area in collaboration local community stakeholders, international and local NGOs. Produced organic products of the project implementation area will be promoted through various e-marketing sites. Value of climate risk insurance will be promoted through mass awareness campaigns engaging various organizations. Workshops for generating alternative sources of income, *e.g.,* apiculture, organic manure preparation, eco-tourism and capacity building will be organized by SHGs in collaboration with government organizations, international and local NGOs.

Table 1 Stakeholder list

Sl. No.	Govt. Institute/ Organization	Non Govt. Organization	Individual
1.	Central Govt. institute/ organization	Local and regional Non Govt. Organizations	Farmer (both Male and Female)
2.	State Govt. institute/ organization	Private organization	Student (10th standard and above)
3.	District level Administrative staff	Research and advocacy group	Local Environmental and social activist
4.	Block/Panchayat Administrative staff		

6. Implementation step

People of IS are primarily dependent on agriculture, fishery and NTFP. The model will contribute towards sustainable attitude building which will help to sustain the actions in a long-term manner. However, the success of the model depends on the involvement of local people and integrity among many NGO's operating in the region.

The major components of the model are –

1. Identification and assessment of risks
2. Geo-smart model development
3. Formation of SHGs and collaboration with existing local and international NGOs, civil societies and government organizations

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26963v2 | CC BY 4.0 Open Access | rec: 27 May 2018, publ: 27 May 2018

4. Formation of community seed bank and fish stocking pond
5. In-situ conservation of traditional agricultural germplasm
6. Workshop and training for capacity building and awareness

The SDG goals UN are stipulated to be achieved within 2030. Hence we propose the following timeline for achieving SDG goals related to our model (2,3,5,8,12,13,15) in IS :

Short term (1-3 years)

1. Development of indexed based climate risk Geo-smart model
2. Formation of SHGs
3. Setting up of community seed bank and fish stocking ponds
4. Apiculture and organic manure production
5. Mobile application development
6. Training and workshop for knowledge dissemination

Medium term (3-7 years)

1. Mangrove nursery set-up
2. Restoration of soil quality through organic farming and fish breeding
3. Restoration of degraded mangrove mud-flat
4. Training and workshop for knowledge dissemination

Long-term (10-12 years)

1. Build a permanent Capacity Building Centre
2. Near-real-time climate risk assessment tool development
3. Establish precision agricultural and aquacultural concept
4. Ensure to achieve few targets of Sustainable Development Goals (SDGs)

7. Climate Insurance

Measuring the pattern of resource availability, regional development, as well as, inequality will essentially help policymakers and administrators to implement the social scheme, and resolve social problems. Integrated poverty index (IPI) is one of the indicators to measure socioeconomic growth, poverty and regional inequality. The census statistics (2011) of the selected eleven variables were used to derive IPI through principal component analysis (PCA) for different blocks of South 24 Parganas district. These variables are work participation rate, ratio of main worker to total worker, proportion of urban population, sex ratio, literacy rate, female literacy rate, proportion of household having concrete house, proportion of household having electricity, drinking water facility and sanitation facilities. Higher the index value better is the economic conditions and quality of life; while low index value indicates poor quality of life. Based on IPI values, blocks are classified into five group *i.e.,* very low IPI (−1.22 to −0.70), low IPI (− 0.70 to −0.30), moderate IPI (−0.30 to 0.00), high IPI (0.00 to 0.50), and very high IPI (0.50 to 1.33). Basanti, Canning-II, Kultali, Jaynagar-II and Gosaba blocks have very low IPI value, indicating poor socioeconomic conditions (*Table 2*). On the contrary, Thakurpukur-Mahestala, Solapur, Bhangar-II and Bishnupur-II blocks (However, these blocks are not fallen in IS, but adjacent to IS) showed very high IPI values. It is clear that most of the blocks located adjacent to Kolkata are found in high IPI value, while blocks in extreme south and southwest part of the district (falling in IS) have very low index value.

Table 2 IPI values of different blocks

Sl. No.	Block	IPI
1.	Basanti	-1.22
2.	Canning – II	-1.09
3.	Kultali	-1.04
4.	Jaynagar – II	-0.96
5.	Gosaba	-0.88
6.	Bishnupur – II	0.91
7.	Bhangar – II	1.12
8.	Thakurpukur- Mahestala	1.33

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26963v2 | CC BY 4.0 Open Access | rec: 27 May 2018, publ: 27 May 2018

Sundarban is under severe stress and the community is quite vulnerable to climate change. Moreover, intrusion of saline water into the agricultural land - results in loss of yields and greater risk to the farmer. Permanent intrusion causes loss of agricultural land and making people migrate. Change in monsoon pattern also causes severe stress on agriculture. The economic impact of various components of our model submitted as a project to MIT, Climate Co-Lab's contest Absorb -ing Climate Impact were assessed into following categories[1] (*Table 3* and *4*). This assessment can be very much helpful to assess the impact of climate risk in this region (*Table 5*). Climate risk insurance can play numerous roles - at individual, community, country, regional and global levels - in providing security against the loss of assets, livelihoods and even lives in the post-disaster losses, insurance can support

Table 3 Impact assessment of the concept

Table 4 Definition of impact assessment parameter

		Low Estimate	*High Estimate*
1	Economic damages [$]	25000 (25.0%)	40000 (40.0%)
2	Fatalities [ppl]	25000 (25.0%)	40000 (40.0%)
3	People severely affected [ppl]	250000 (25.0%)	400000 (40.0%)
4	People affected [ppl]	500000 (25.0%)	800000 (40.0%)

Sl. No	Category	Description
1.	Economic damages	Total economic damage as often referred to in 'damage summaries' of hurricanes and similar extreme weather events.
2.	Fatalities	Number of human lives lost due to direct or indirect causes.
3.	People severely affected	Number of humans affected by the long-lasting or permanent loss of home, restriction to food access with risk of starvation, major injuries or sickness, long-lasting or permanent job loss or loss of income.
4.	People affected	Number of humans affected the temporary loss of heat/electricity without danger to life, temporary restriction to food access (without risk of starvation), temporary loss of home (days to weeks), mild injuries or sickness from which full recovery follows within weeks, temporary job loss or loss of income.

Table 5 Important parameters for impact and climate risk assessments

Sl. No.	Sectors	Parameters
1.	Agriculture	Animal health ; Animal Production; Crop production; Crop type
2.	Biodiversity	Invasive Species; Vulnerable/Endangered species Species distribution; Ecological processes; Phenology
3.	Coastal zone	Flooding due to storm surge; Coastal dynamics/geomorphology Salt water intrusion
4.	Forestry	Distribution and disturbance; Carbon storage
5.	Hydrology	Water quality; Water supply; Streamflow; Flooding; Drought; Renewable supply/water stress
6.	Land degradation	Soil erosion
7.	Demography	Population distribution and growth; Human health
8.	Climate	Precipitation; Temperature

climate risk management by mapping, catastrophic impact of disasters, enable timely recovery and contribute to sustainable, climate resilient development of the area. By analyzing, period;

[1]https://www.climatecolab.org/contests/2017/absorbing-climate-impacts/phase/1318973/proposal/1334389/tab/ADAPTATION_IMPACT

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26963v2 | CC BY 4.0 Open Access | rec: 27 May 2018, publ: 27 May 2018

ensuring reliable and dignified post-disaster relief; setting incentives for prevention; providing certainty for weather-affected investments and easing disaster-related poverty and spurring economic development by spreading the risk of economic development by spreading the risk of loss among people and across time, insurance reduces the negative impacts of natural hazards, enables a timely recovery and can help to promote adaptation. Insurance-related solutions facilitate the asse-ssment of loss and damage potential as a pre-requisite for identifying needs and policy priorities. Insurance schemes complement many others approaches aimed at reducing the vulnerability of poor people and enhancing their resilience. As climate change continues to go unchecked in this area, climate risk insurance has the potential to reduce the assessing risks and potential prioritizing, and pricing risk. Climate insurance also contributes on increasing resilience, by reducing vulnerability and providing timely financial relief for the recovery of the livelihoods and also for post-disaster period.

Acknowledgement
The authors are thankful to Dr. Avijit Mistri for his comments on some aspects of this work.

Declaration
A part of this article has been submitted to MIT, Climate Co-Lab's contest named Absorbing Climate Impacts. This article is an enhanced version of the previous document.

Bibliography
Alongi DM. 2008. Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science*. 76(1):11-13.
Building Resilience for Sustainable Development of the Sundarbans. **Link**
Chakraborty D. 2014. Bio-monitoring of Heavy Metal Pollution of Mangrove Ecosystem using Biochemical-Markers. M.Phil Thesis. School of Oceanographic Studies. Jadavpur University. DOI: 10.13140/RG.2.1.4146.0327
Chakraborty S. 2015. Investigating the impact of severe cyclone Aila and the role of disaster management department-A study of Kultali block of Sundarban. *American Journal of Theoretical and Applied Business.*1:6-13.
Cochard R, Ranamukhaarachchi SL, Shivakoti GP, Shipin OV, Edwards PJ, Seeland KT. 2008. The 2004 tsunami in Aceh and Southern Thailand: A review on coastal ecosystems, wave hazards and vulnerability. *Perspectives in Plant Ecology Evolution and Systematics*. 10(1): 3-40.
Danda AA, Sriskanthan G, Ghosh A, Bandyopadhyay J, Hazra S. 2011. *Indian Sunderbans delta: A vision*. World-Wildlife Fund for Nature-India, New Delhi.
DRCSC. 2009.*Agriculture and livelihood after AILA*. **Link**
Editorials. 2009 (6 June). Climate Refugees. *Economic & Political Weekly*. **Link**
Ghosh S, Hazra S, Nandy S, Mondal PP, Watham T, Kushwaha SP. 2017. Trends of sea level in the Bay of Bengal using altimetry and other complementary techniques. *Journal of Spatial Science*. 63(4): 49-62.
Ghosh A, Schmidt S, Fickert T, Nüsser M. 2015. The Indian Sundarban mangrove forests: history, utilization, conservation strategies and local perception. *Diversity*. 7(2):149-69.
Gopal B, Chauhan M. 2006. Biodiversity and its conservation in the Sundarban mangrove ecosystem. Aquatic Science. 68:338–354.
Hazra S, Ghosh T, Dasgupta, R, Sen, G. 2002. Sea level and associated changes in the Sundarbans. *Science and Culture*. 68 (9–12): 309–321.
IPCC. 2007. *Climate Change: The Physical Science Basis.* Report of Working Group I. 50: 63-82.
IUCN. International Union for the Conservation of Nature—Bangladesh: The Bangladesh. **Link**
IUCN. 2001. *Sundarbans: A Photo Real Sojourn*. **Link**

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26963v2 | CC BY 4.0 Open Access | rec: 27 May 2018, publ: 27 May 2018

Rabbani G, Rahman, A. and Mainuddin, K. 2013. Salinity-induced loss and damage to farming households in coastal Bangladesh. *International Journal of Global Warming*. 5(4): 400–415.

Rahman S, Rahman H, Shahid S, Khan RU, Jahan N, Ahmed ZU, Khanum R, Ahmed MF, Mohsenipour M. 2017. The impact of cyclone Aila on the Sundarban forest ecosystem. *International Journal of Ecology and Development*. 32(1): 88-97.

Spalding M, Kainuma M, Collins L. 2010. *World Atlas of Mangroves*. Earthscan: London, UK. p. 319.

Traore S, Owiyo, T, Sokona, Y. 2013. Dirty drought causing loss and damage in Northern Burkina Faso. *International Journal of Global Warming*. 5(4):498-513.

UNDP. 2007. *Human Development Report 2007/2008*. Fighting Climate Change: Human solidarity in a divided world. **Link**

UNEP-WCMC. 2006. *In the front line: shoreline protection and other ecosystem services from mangroves and coral reefs*. Cambridge, UK, UNEP-WCMC.

Unnikrishnan AS, Kumar MRR, Sindhu B. Tropical cyclones in the Bay of Bengal and extreme sea-level projections along the east coast of India in a future climate scenario. Curr. Sci. India 2011, 101, 327–331.

Zohora FT. Non-timber forest products and livelihoods in the Sunderbans. Rural Livelihoods and Protected Landscapes: Co-management in the Wetlands and Forests of Bangladesh. Nishorgo Network, Dhaka. 2011:99-117.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.26963v2 | CC BY 4.0 Open Access | rec: 27 May 2018, publ: 27 May 2018