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SOCIO-ECONOMIC AND ECOLOGICAL ADAPTABILITY ACROSS SOUTH ASIAN FLOODPLAINS

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Highlights

- Flood Risk has been viewed as Socio-Economic Pollutant and "Adaptability" has been analyzed as an optional tool to reduce the Concentration of such Socio-Economic Pollutant.
- Managerial and Ecosystem based approaches of Integrated Flood Management Strategies have been explored for Flood Adaptability.
- Distributions of various Socio-Economic and Ecological parameters have been analyzed for their influences over Adaptability across South Asian Floodplains.
- Importance of balanced enhancement of socio-economic and ecological adaptability have been Explored.
- Projections based on two dimensional Socio-Environmental Scenarios have been used for presenting the benefits of balanced enhancement of socio-economic and ecological adaptability.

Abstract. Flood Risk Potential across South Asian Floodplains corresponding to 2010 economic exposures had been reported to be about 11 billion US2012$ and contributing more than 10% of Global values. Ecosystem approaches, based on Integrated Flood Management strategy of World Meteorological Organization, have been explored for balanced socio-economic and ecological adaptability enhancement, considering degradation of ecosystem services as fundamental issues and adaptation as optional solution. Adaptive Management methods have been explored for Flood Risk Minimization. General benefits of balanced socio-economic and ecological adaptation have been reviewed. Distributions of flood hazards, Gross Domestic Product, flood risk, Net Primary Productivity, carbon dioxide emissions and landscapes heterogeneity have been presented and analyzed for its influences over socio-economic and ecological adaptability. Distributions of Expected Annual Exposed socio-economic resources across 500 Years floodplains have been presented. Projected results corresponding to various two dimensional socio-environmental scenarios have been presented. Low Adaptable regions have been delineated.

Keywords: integrated flood management, socio-economic adaptability, socio-ecological adaptability, landscape management, South Asian Floodplains, environmental sustainability, environment monitoring.

Introduction

Synergy had been defined as the interaction and cooperation capacities of two or more individual elements with the objectives of achieving benefits of combined effects which are expected to be higher than the sum of benefits of separate individual effects (Cambridge University Press, 2021). To deal with uncertain events like Flood Hazard, Adaptive Management (AM) Strategy have been recommended by many literatures including Allen and Garmestani (2015) for achieving the objectives under uncertain Scenario, and also has been accommodated in the Integrated Flood Management (IFM) Methodology which integrates the efforts of governing authorities of Floodplain with that of entire River Basins towards optimum allocation of Resources (World Meteorological Organization [WMO], 2009). Gradual increase in Synergy Level in order to build up Adaptability has been reported as one of the characterizing parameter of a Complex Adaptive System (Bar-Yam, 2002). Assuming Floodplain Ecosystem as one such Complex Adaptive System, AM Strategy involves periodic assessment of adaptability levels towards Flood Risk Minimization (FRM) using balanced development of Socio-Economic and Ecological Adaptability (SE-EA)

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levels as per Sustainable Development standards of United Nations (UN, 2015). South Asian Economy is consistently increasing in par with that of USA, China and European Countries (World Bank, 2021). Anyhow, Flood Risk Potential across South Asian Floodplains corresponding to 2010 Economic Exposures had been reported to be about 11 billion US2012$ and contributing more than 10% of Global Values (United Nations Office for Disaster Risk Reduction [UNISDR], 2015). Historical growths of Global Population, Global Gross Domestic Product (GDP) and corresponding carbon dioxide (CO_2) emissions have been compared using Figure 1a. The possible reason for the change of Trend and sharp increase in growth rate of Population and GDP after 1950 as in Figure 1 is attributed to the invention of Semiconductor Transistor by 1948. Based on the principles of miniaturization, the Vacuum Tube had got replaced by Transistor after the invention of this Semiconductor device by Bell Telephone Laboratories, Murray Hill, New Jersey, USA (Bardeen & Brattain, 1948). Anyhow this had caused for the further development of VLSI System across 1970s and become the foundation for the development and existence of current Computer based System of Internet Communications. In the name of Adaptation, it becomes the work of Cement to bind the coarse and fine Aggregates in order to develop a stronger Construction Materials having Strength higher than that of component Materials. Similarly the Synergy or Adaptation Level across Global Social Systems (GSS) had got increased or stimulated or excited by the development of Virtual Adaptor in the form of Semiconductor Devices based Global Electronics Communication System binding the Aggregate GSS into Concrete GSS towards Globalized Economy. Keeping the radiative forcing at constant high level, projected socio-economic developments corresponding to Globalised and Localized Economy have been compared as in Figure 1b in order to delineate the benefits of high socio-economic adaptable Globalised solutions with respect to low socio-economic adaptable localized solutions. The possible benefits of Socio-Economic Adaptation across the floodplains are expected to be similar to the sharp increase in Socio-Economic Development what had happened after 1950 as in Figure 1a. Irrespective of Globalised or Localized Economy, Fossil Fuelled (FF) development represented by high radiative forcing had caused for high CO_2 Emissions and has been presented in Figure 1 for emphasizing the need of balanced SE-EA developments. This article explores strategies to enhance Economic Development, using AM based FRM. Based on the principles of IFM, SE-EA analysis at floodplain level has been compared with corresponding parameters at basins level and Global level.

1. Materials and methods

1.1. Study area

For the purpose of SE-EA Analysis, the Study Area of South Asian Floodplains has been delineated based on the Criteria proposed by USGS Hydrologic Derivatives for Modeling and Applications (HDMA) database (Verdin, 2017) into three Units of Groups of River Basins such as GBMS (Ganga, Brahmaputra, Meghna and Supernarekha) Basins, SLSS (Sindhu, Luni, Saraswathi and Sabarmati) Basins, and GKSI (Godavari, Krishna and other South India) Basins and Floodplains of only Peninsular River Basins have been analyzed without considering South Asian islands including Sri Lanka. The Location and Boundaries of the 500 Years Floodplains along with that of Peninsular River Basins and corresponding National administration of South Asia across the Basins are presented in Figure 2. Based on the Criteria of Critical Action Floodplains that had been recommended by FEMA (1986), 500 Years Floodplains have been considered as reference Floodplain and referred simply as "Floodplains" for Adaptability Analysis. Global 500 Year 30s gridded Flood Hazard Maps provided by United Nations Environment Programme and Global Resources Information Database (UNEP-GRID, 2015) and European Commission and Joint Research Centre (EC-JRC, 2016) have been combined as Union using the "OR" Logic, to get 500 Years Floodplains including the water bodies as in Figure 2. Indo-Gangetic Floodplains

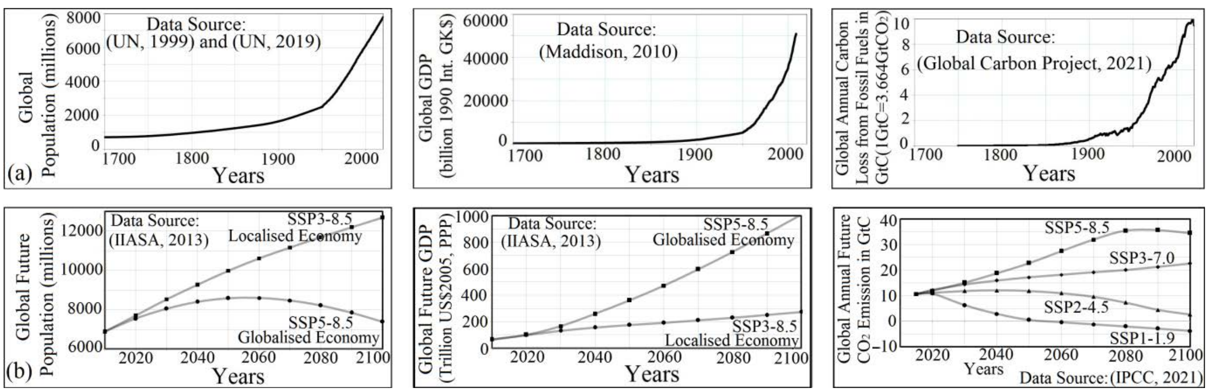

Figure 1. Benefits of Socio-Economic Adaptation and corresponding CO_2 Emissions demanding for balanced increase in Socio-Ecological Adaptation (source: Global Carbon Project, 2021; International Institute for Applied Systems Analysis, 2013; Maddison, 2010; UN, 1999, 2019)

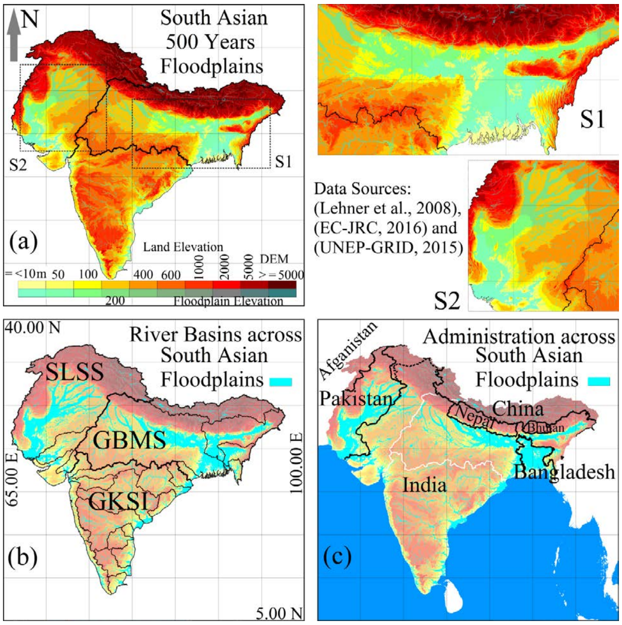

Figure 2. Administration and Basin boundaries across South Asian Floodplains

of GBMS and SLSS unit had been distributed over the alluvial soil deposits at the foot of Himalayan Range of mountains. More than 55% of 500 Years Floodplain are located at an elevation less than 100 m and across Indo-Gangetic plains and the delta regions of all three units of river basins (Lehner et al., 2008).

1.2. Socio-economic and socio-ecological adaptability

Based on the Principles of Adaptation (Chapin et al., 2011) and (Intergovernmental Panel on Climate Change [IPCC], 2007), it had been characterized that for a System to get adapted with an external Stimuli as Entity X, the System has to absorb the losses generated by the negative attributes of Entity X in order to exploit the benefits offered by positive attributes of Entity X. Hence the Adaptability of a System to external Stimuli can be considered as a Parameter representing the Level of trade-off between the benefits exploited by the System and the losses absorbed by the System during the process of adaptation with the external Stimuli in the form of Control Action from the Environment representing the boundary of Control Volume within which the System works to achieve the objectives. Accordingly, assuming flood control investments across floodplains towards 1) Flood Prevention, 2) Flood Protection and 3) Flood Loss Recovery are represented as a function of Expected Annual Damage (EAD), the Adaptive Capacity of Socio-Ecological System of Floodplains has been defined using Equations (1) and (2). Similar to dataset sources such as UNEP-GRID (2015) and World Resources Institute (WRI, 2015), 2010 have been considered as base reference year towards adaptability analysis. Unless stated otherwise, all monetary USD units represents constant 2015 USD Value.

$$AC1 = \frac{\text{Floodplain annual GDP Gain of the specified year}}{\text{Expected Annual Flood Damage of the corresponding year}}; \quad (1)$$

$$AC2 = \frac{\text{Floodplain annual NPP Gain (Carbon absorption) of the specified year}}{\text{Floodplain annual Carbon emission of the corresponding year}}, \quad (2)$$

where: AC1 = Socio-Economic Adaptability of floodplains for the specified year; AC2 = Socio-Ecological Adaptability of floodplains for the specified year.

1.3. Principles of two-phase adaptation across floodplains

Using the objectives of Multi-Benefit Floodplain Management (MB-FPM), all the Benefits of MB-FPM have been grouped into benefits to society and that to ecosystems, while MB-FPM have been recommended to achieve new levels of synergies where there will be balanced distribution of benefits across social and ecological systems. Conventional Flood control methods, based on Structural measures have produced social benefits at the cost of adverse environmental consequences (Serra-Llobet et al., 2022). Using the principles of Sustainable Flood Risk Management, synergies between different policy fields including floodplain restoration, ecosystem services, and other nature based solutions representing the ecological dimensions have been emphasized along with minimization of economic losses (European Environment Agency, 2016). It has been recommended by Congressional Research Service (2020) to maximize the contribution of Flood Risk Reduction capacities of Natural and Nature-Based Features (NNBFs) along with the use of traditional structural and non-structural methods in order to balance the benefits across social and ecological systems. Even though Globalised Economy representing high level of Socio-Economic Adaptability across GSS, GDP development process has caused for sharp increase in CO_2 emissions during last 6 decades as in Figure 1a and corresponding degradation of Socio-Ecological Adaptability representing imbalance over the distribution of benefits across social and ecological systems. This indicates unbalanced Socio-Economic (Phase-1) Adaptation over Socio-Ecological (Phase-2) Adaptation.

Both Climate Change Adaptation (CCA) and Climate Change Mitigation (CCM) had been recommended by IPCC (2007), to reduce the losses or impacts of Climate Change Issues. Socio-Economic Adaptation across Floodplains has been accommodated as component of CCA (United States Government Accountability Office, 2016). In the name of Socio-Ecological Adaptation, any of the attempts to reduce CO_2 emissions (including SDG 15.1 and SDG 7.2) have been considered as component of CCM.

Benefits can be maximized by the optimum combination or Trade-off between Mitigation and Adaptation (IPCC, 2007). Hence balanced implementation of CCA and CCM has been referred as two-phase system of managing the climate change issues including flood issues.

Accordingly, the procedures of gradual conversion of single phase floodplain adaptation measures into two-phase adaptation has been adopted in this article and analysis has been aimed towards balanced development of both socio-economic and socio-ecological adaptability across South Asian Floodplains and has been referred as two-phase system of floodplain adaptation. Assuming Mitigation as Technical (Hardware) Solution and Adaptation as Managerial (Software) Solution for IFM, only Adaptation has been focused. In this article no attempt has been made to present any of the Floodplain adaptation practices or floodplain management practices. Floodplain socio-economic adaptability level has been analyzed and presented to be considered as an input parameter to determine best or optimum mix of flood management strategies as recommended by WMO (2009) towards efficient distribution of limited flood control investment across the floodplains. Low adaptable regions have been presented with the expectation that more priority will given to those regions towards allocation of flood control investment and/or implementation of flood regulated developments. Multi-criteria based Cost-Benefit Analyses (CBAs) as recommended by IPCC (2007), has been proposed for deciding the operating point representing balanced benefits between social and ecosystems across the selected local regions, where the results presented in this article such as socio-economic and socio-ecological adaptability levels are expected to be used as limiting values of the constraint equations along with objective functions of Multi-Criteria Decision Making (MCDM) model. Based on the principles of Socio-Ecological Stewardship as defined by Chapin et al. (2011), socio-ecological adaptability analysis is expected to be useful for motivating the human community and to remind the responsibility of Social System to improve Ecosystem Resilience and thereby enhancing life supporting capacity of Planet Earth. Accordingly, similar to Cost-Benefit Ratio (CBR) of a Project, Adaptability results has been considered as an exciting or stimulating agent, to act as catalyst towards further developments.

1.4. Projections based on Two-Phase Scenarios

Scenarios are being used by IPCC to drive Global Circulation Model (GCM) in order to generate future projected results. Based on the level of radiative forcing values by the year 2100, ranging between 8.5 W/m^2 and 2.6 W/m^2, Representative Concentration Pathways (RCPs) scenarios having only Environmental dimensions had been used by IPCC AR5 towards the projection of future socio-economic and environmental parameters (IPCC, 2013). Such one dimensional Scenarios based projections of IPCC AR5 has got improved by two dimensional Scenarios based projections of IPCC AR6 where, social value or social dimension denoted as Shared Socioeconomic Pathways (SSPs) have also been accommodated and represented by combined RCPs and SSPs (IPCC, 2021). The mapping of SSPs and RCPs based Scenarios matrix over Social and Environmental dimensions has been presented in the Figure 3 using the narratives of Riahi et al. (2017). The projections of future Population, GDP, Expected Annual Damage (EAD), CO_2 Emissions used in this article are corresponding to the two-dimensional reference scenarios as mentioned against the projected results.

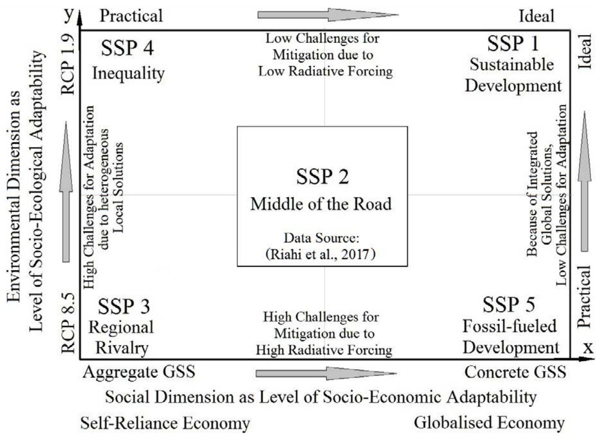

Figure 3. Two dimensional Socio-Environmental scenarios matrix

2. Results and discussions

2.1. Analysis of Expected Annual Exposed (EAE) resources

Area of 500 Years Floodplains and corresponding Basins has been presented in Table 1 using the same accuracy level of 30s resolution as that of Flood Hazard database. Based on the Submergence Areas corresponding to Floods of Return Period ranging from 5 to 500 Years, EAE Floodplain Area have been estimated using the methods reported by many literatures including Apel et al. (2016), and also presented in Table 1. The Probable Maximum Loss (PML) contributed by the Flood of 2 Years Return Period, have been reported by WRI (2015) to be Zero and hence not considered in EAE Analysis. Accordingly 10% of 500 Years Floodplains of South Asian River Basins is expected to be annually exposed to Flood. The % EAE Floodplain Area of GBMS Basins is relatively higher with respect to that of other two units of Basins such as SLSS and GKSI.

Flood Frequency Distribution across a Grid converts the Grid Resources into EAE Resources, while the loss depends on Vulnerability Function or Damage Model used (Apel et al., 2016). Irrespective of the Vulnerability, only EAE Floodplain, EAE 2010 Population and EAE 2010 GDP have been analyzed for its distribution across the study area using Figure 4 and Table 2. The distributions of EAE Floodplain, EAE population and EAE GDP as a percentage of corresponding 2010 Floodplain exposures has been

Table 1. Distribution of 500 Years Floodplains across South Asian Peninsular River Basins (source: Lehner et al., 2008; EC-JRC, 2016; UNEP-GRID, 2015)

Delineation of Study Area	Basin Area (sq. km)	500 Years Floodplain Area (sq. km)	Expected Annual Exposed (EAE) Floodplain Area		
			sq. km	% of Floodplains	% of Basins Area
GBMS Basins	1770848	401005	52074	13	3
SLSS Basins	1436643	305079	24421	8	2
GKSI Basins	1406570	166478	10903	7	1
South Asia Basins	4614061	872562	87398	10	2

Table 2. Distribution of base reference year 2010 Socio-Economic Exposures across South Asian Floodplains (source: UNEP-GRID, 2015)

Floodplain units	Floodplain Population 2010 (millions)	EAE Population 2010 (millions)	Floodplain Population Exposed to Flood (%)	Floodplain GDP 2010 (billions of 2000 USD)	EAE GDP 2010 (billions of 2000 USD)	Floodplain GDP 2010 Exposed to Flood (%)
GBMS	374	42.0	11	192	17.7	9
SLSS	88	1.1	1	61	0.7	1
GKSI	79	1.6	2	86	1.3	1
South Asia	541	44.7	8	339	19.7	6

Table 3. Density of Socio-Economic Exposures across South Asian Floodplains

Flood Plain Units	Density of Population (Count per sq. km) (Data: SEDAC, 2018)			Density of Built-Up Area (%) (Data: EC-JRC, 2018)			Density of GDP (PPP) (million 2011Int$ / sq. km) (Data: Kummu et al., 2020)		
	1990	2000	2015	1990	2000	2015	1990	2000	2015
GBMS	633	786	1000	2.5	2.9	3.4	1.15	1.52	3.93
SLSS	184	236	318	0.4	0.8	1.4	0.77	0.92	1.95
GKSI	354	420	499	0.7	1.1	1.4	1.01	1.56	4.41
SA	423	524	666	1.4	1.8	2.3	0.99	1.32	3.33

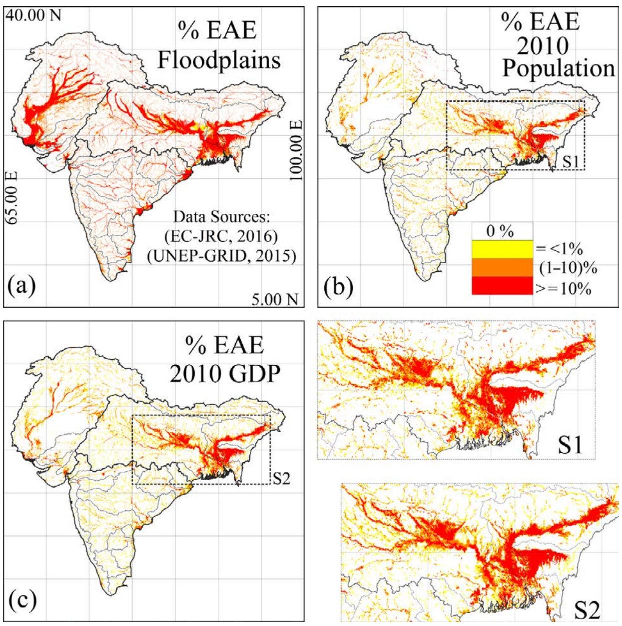

Figure 4. Distributions of EAE resources as percentage of 2010 Floodplain resources

presented in Figure 4. The corresponding lumped values of 2010 Floodplain resources and % EAE resources across the three units of South Asian river basins have been compared in Table 2. More than 9% of Floodplain GDP becomes EAE GDP for the case of GBMS basins while it is about 1% in case of SLSS and GKSI basins units. The 2010 Floodplain GDP density is estimated to be 48, 20 and 52 units (million US2000$ per sq. km) for GBMS, SLSS and GKSI basins respectively. Hence the Probability of Floodplain resources to become EAE resources is relatively high across GBMS with respect to other two basins units. Even with this high percentage of Expected Loss, the rate of historical development of Concentration Density of Population, Built-Up Area and GDP Exposures from 1990 to 2015 across the Floodplains of GBMS unit is reported to be higher than that of other two units as in Table 3. More than 19% of Global EAE GDP had been contributed by GBMS unit (UNEP-GRID, 2015). More than 100,000 sq. km (69%) of Bangladesh area had got inundated during 1998 Flood reported as 90 Years Return Period. 7.5% GDP had been reported as highest Flood Damage due to 1974 Flood (World Bank, 2011).

2.2. Analyses of socio-economic and socio-ecological adaptability

The Economic and Ecological Performances across the Study Area have been presented using Figure 5 and Figure 6 respectively. The grid wise distributions of 2010 Economic performance across South Asian Floodplains in terms of GDP gain, Expected Annual Loss and the Gain-Loss ratio representing Economic Adaptability estimated using Equation (1) have been shown in Figure 5. Low socio-economic adaptable floodplain regions have also been delineated in Figure 5. Similarly the grid wise distributions of 2010 Ecological performance across South Asian Rivers Basins in terms of CO_2 Absorption, CO_2 Emission and the ratio of CO_2 Absorption to CO_2 Emission representing the Ecological Adaptability estimated using Equation (2) have been shown in Figure 6. Low socio-ecological adaptable regions have also been delineated in Figure 6.

The distributions of Flood Risk Potential in terms of Expected Annual Damage (EAD) corresponding to 2010 GDP Exposures provided by UNEP-GRID (2015) dataset were used. Based on the NASA Earth Observations (2018) NPP dataset, the distribution of 2010 annual NPP representing CO_2 Absorption has been estimated. Using the International Energy Agency (2021) dataset representing the Nation wise CO_2 Emission Equivalent of each unit of corresponding national GDP of specified Year, the distribution of 2010 GDP provided by UNEP-GRID (2015) has been converted to distribution of equivalent CO_2 Emission. While the Flood Loss is applicable only for Floodplains, the parameters NPP, CO_2 Emission, Socio-Ecological Adaptability are applicable for entire Basin and hence the grid wise distribution of these three parameters has been presented across entire Basins including Floodplains.

Higher the Socio-Ecological Adaptability represents higher the Ecosystem Resilience to absorb the anthropogenic impact of high CO_2 Emission and corresponding Climate Change Adaptation (CCA) Capacity. Hence irrespective of the Ecosystem Threshold, the distribution of Socio-Ecological Adaptability also represents the corresponding distribution of Ecosystem Resilience to absorb CO_2 Emission. Higher the GDP can cause for the increase in Floodplain Economic Adaptability while, the corresponding increase in CO_2 Emission can cause for the decrease in Ecological Adaptability. It represents the existence of possible trade-off between Economic Adaptability and Ecological Adaptability. As an element of AM Strategy, Adaptability Assessment is a continuous process and need to be updated periodically towards the design and implementation of Control actions to improve the Adaptability Level as well as maintaining optimum combination of Economic and Ecological Adaptability Levels to achieve the final quantitative objectives in collaboration with Sustainable Development Goals (SDGs).

2.3. Contributions of United Nations, World Bank and Local Governments towards SE-EA enhancement

All the efforts of UN, starting from 1945, towards successful developments of SDGs framework and up to date implementations of SDGs across the world in collaboration with national Governments are the contributions of UN, towards balanced SE-EA development both across basin and floodplain levels. SDG 7.2 has the potential to reduce CO_2 Emission contribution of GDP. SDG 15.1 has the Potential to increase CO_2 Absorption Capacity. SDG 17 demands for the participation and partnership of all local

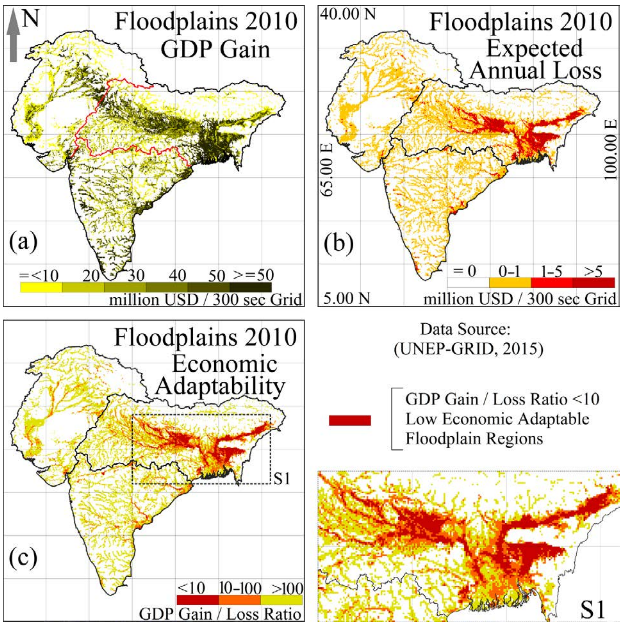

Figure 5. Economic Performance across South Asian Floodplains

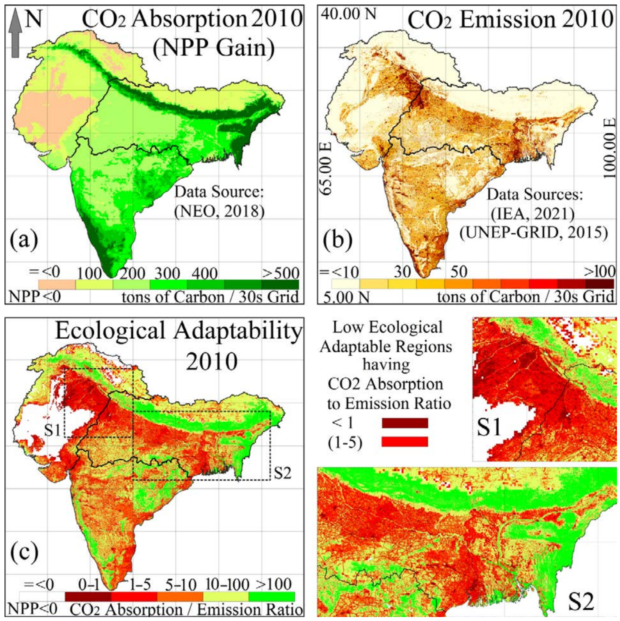

Figure 6. Ecological Performance across South Asian Basins

Governments to implement SDGs and submit annual progress for their regions (UN, 2015). National Institution for Transforming India (2019) is annual 2019 SDGs progress of India. World Bank had provided nation wise distribution of adaptation cost to climate change which includes cost of flood adaptation and corresponding recommendations to improve SE-EA levels across South Asian Countries (World Bank, 2010). Based on the historical flood loss estimates and its distribution across the states, Government of India (GoI) is regularly updating relative ranking of high flood risk regions and corresponding annual flood loss. Average annual flood loss across India during 2011–2020 has been estimated as 3586 million US2015$ (Government of India & Central Water Commission, 2020). Annual Flood Risk of India as estimated by UNEP-GRID (2015) is about 7472 million US2012$. Under Flood Management Programme of India, GoI had invested about 216 million US2015$, during 2017–2019 in order to reduce Flood Risk, (Government of India & Ministry of Water Resources, 2020). Every $1 investment against Flood Control Infrastructure in India has potential to reduce the EAD by $238 (WRI, 2020). The basic aim of this Paper is to explore efficient use of such flood control investment towards FRM and balanced development of SE-EA levels.

2.4. Analysis of Projected Future Flood Damages based on 2010 base year values

Basin level lumped values of projected GDP and EAD have been compared using Table 4, for selected scenarios represented as SSP2-4.5, SSP2-8.5 and SSP3-8.5. Increase in radiative forcing level from 4.5 to 8.5 W/m^2 for same SSP2 scenario have caused for corresponding increase in EAD. This is interpreted as the impact of low socio-ecological adaptability causing for increased EAD. Similarly keeping the radiative forcing at constant 8.5 W/m^2 level, SSP2 having high socio-economic adaptability with respect to SSP3 as in Figure 3, have caused for increased GDP development over SSP3 scenario. Hence, balanced increase in socio-economic adaptability and socio-ecological adaptability is expected to cause for minimizing EAD. Comparing the projected performances of three units of basins, GBMS unit is reported to have highest Climate sensitive EAD while, SLSS unit is reported to have lowest Climate sensitive EAD.

2.5. Analysis of Landscape Heterogeneity

When the Economic Adaptability of Floodplains is highly influenced by the Flood hazard and vulnerability of the Floodplain Exposures, the Ecological Adaptability is highly influenced by Ecosystem Performance which is being controlled by spatial heterogeneity of Landscape as the Floodplain Ecosystem does not exist as isolated unit on the Floodplain Landscape (Chapin et al., 2011). Land Use and Land Cover (LULC) data set of EC-JRC (2004) and (Land Processes Distributed Active Archive Center [LP DAAC], 2021) based on the Land Cover Classification System (LCCS) of Food and Agriculture Organization (Di Gregorio, 2005) has been grouped into five basic

Table 4. Projection of average basin level GDP and corresponding Expected Annual Flood Damage (EAD)

Basins	Year	Two dimensional socio-environmental reference scenarios (source: WRI, 2015)								
		RCP 4.5 / SSP 2			RCP 8.5 / SSP 2			RCP 8.5 / SSP 3		
		GDP	EAD	EAD	GDP	EAD	EAD	GDP	EAD	EAD
		billion $2005, PPP		%	billion $2005, PPP		%	billion $2005, PPP		%
GBMS	2010*	1560	21	1.4	1560	21	1.4	1560	21	1.4
	2030	5154	122	2.4	5154	151	2.9	4819	142	3.0
	2050	11515	306	2.7	11515	403	3.5	8100	294	3.6
	2080	25377	838	3.3	25377	1107	4.4	13082	621	4.7
SLSS	2010	878	9	1.0	878	9	1.0	878	9	1.0
	2030	2551	35	1.4	2551	47	1.8	2387	45	1.9
	2050	6096	90	1.5	6096	103	1.7	4252	78	1.8
	2080	15949	217	1.4	15949	292	1.8	8045	172	2.1
GKSI	2010	1844	23	1.2	1844	23	1.2	1844	23	1.2
	2030	6191	141	2.3	6191	155	2.5	5693	136	2.4
	2050	14092	371	2.6	14092	457	3.2	9546	287	3.0
	2080	30963	989	3.2	30963	1334	4.3	15090	598	4.0
SA	2010	4281	53	1.2	4281	53	1.2	4281	53	1.2
	2030	13896	298	2.1	13896	353	2.5	12899	323	2.5
	2050	31702	767	2.4	31702	962	3.0	21898	659	3.0
	2080	72289	2044	2.8	72289	2733	3.8	36216	1392	3.8

Note: *2010 as base reference year for projection.

elements of Landscape Composition such as Urban, Forest, Agriculture, Bare land and Wetland as adopted from Chapin et al. (2011). The Sparse Vegetation, Snow and Ice have been included as bare land. Herbaceous use has been included in the Agriculture. The most specific Wetland distribution dataset of Center for International Forestry Research (CIFOR, 2017) has been accommodated in the Landscape Composition.

Accordingly the Landscape Composition of the entire basins of the Study Area has been compared for the year 2000 and 2020 using Figure 7 and Table 5. The distribution of Landscape composition is in Figure 7 while the lumped values of areas of individual types of Landscape pattern across the three units of basins and corresponding Floodplains units are in Table 5. Distributions of Wetlands with respect to other landscapes, approximately represents that of floodplains.

It is interpreted that there is sharp increase in bare land of more than 3,50,000 sq. km and corresponding decrease in Agricultural and Forest Area during this 20 years from 2000 to 2020 across SLSS unit. Reduction in NPP capacity across SLSS unit is attributed to such inappropriate change in Landscape composition. It is also interpreted that Wetland Area across all the three units of basins is consistently getting decreased from 2000 to 2020 and also being occupied by Urban Area and causing for corresponding increase in Urban Area. Any anthropogenic disturbance to Wetland can bring down the Ecosystem NPP performance Chapin et al. (2011). Hence protection and restoration of Wetland Ecosystem, is expected to enhance the Ecological Adaptability Level.

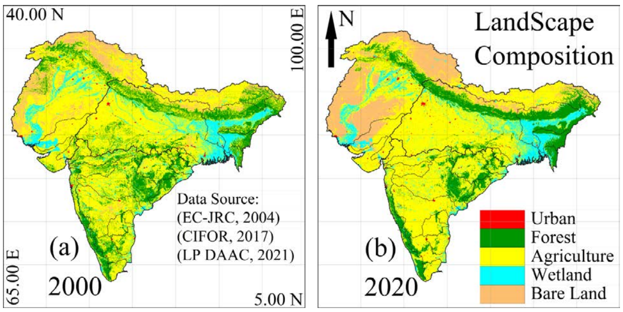

Figure 7. Distributions of LandScape Composition

Conclusions

Temporal smoothing of Flood loss using regular AAL investment had been recommended by UNISDR (2015) as one on the Adaptation Strategy towards Flood Adaptation by balancing the Flood Loss for exploiting the Productive Capacities of Floodplains. In a Social System, to solve a family problem within the family has been considered to be somewhat better than moving towards a third party including public court system. Even though the Flood discharge is contributed by entire River Basins, the Flood Loss is concentrated only across Floodplains. Adaptation to Flood based on Adaptive Management (AM) Strategy can be considered as judicial and logical option to place the Responsibility of Flood Loss over the corresponding Floodplain Social Systems rather than forcing the authorities of upper stages of river basins for proper Land and Water Management to reduce the Peak Flood Discharge. Enhancement of Economic and Ecologic Adaptability across the Floodplains by the minimization of Flood Risk Potential using an optimum mix of Localized Structural and non-Structural measures having minimum influence to NPP capacity of the undisturbed Natural Floodplain Ecosystem can be framed as the basic objectives of this AM strategy. Spatial Smoothening of Flood Loss can be exercised by proper implementation of Flood Insurance Schemes similar to that being practiced by Federal Emergency Management Agency of USA (FEMA, 2020). To maximize the level of Socio-Economic Adaptability, both Spatial and Temporal Smoothening of Flood Loss need to be implemented in collaboration with Flood Risk Minimization (FRM) measures. Using the existing

Table 5. Composition of Basin and Floodplain Landscapes across Study Area (source: EC-JRC, 2004; CIFOR, 2017; LP DAAC, 2021)

		Landscape Composition 2000 (billion sqm)					Landscape Composition 2020 (billion sqm)				
		Urban	Forest	Agri-culture	Wetland	Bare	Urban	Forest	Agri-culture	Wetland	Bare
Floodplains	GBMS	3	21	182	192	2	6	26	182	184	3
	SLSS	2	5	163	115	21	3	4	112	105	81
	GKSI	2	23	92	48	2	4	14	106	42	0
	SA	7	49	437	355	25	13	44	400	331	84
Basins	GBMS	10	370	1037	258	96	16	386	1001	249	120
	SLSS	6	112	884	142	293	12	74	575	129	647
	GKSI	10	403	881	90	23	17	275	1032	81	1
	SA	26	885	2802	490	412	45	735	2608	459	768

Geographic Information System (GIS) Databases, basin wise development of Multi-Criteria Decision Making (MCDM) models needs to be designed and implemented to ensure the optimum blend of investment among various Structural and Non-Structural Flood Protection measures towards minimization of Flood Risk potential across the Floodplains. In order to ensure successful implementation of AM Strategy for Flood Risk Minimization across the Floodplains of transboundary River Basins of South Asia, a separate administrative authority may be in the name of National Board of Floodplain Adaptation needs to be organized to work in collaboration with existing Disaster Emergency Management Agencies so that AM based pre flood management operations will get synchronized with the post flood management operations from low level village to high level national administration towards the purpose of enhancing Socio-Economic Adaptability. Similarly successful implementation of both SDGs 7.2 and 15.1 has the potential to enhance the level of Socio-Ecological Adaptability and thereby to maintain balanced socio-economic and ecological performance across the floodplains.

The localized elevated land regions surrounded by flood inundation is expected to suffer from at least low vulnerable indirect losses produced by surrounded flood inundation. Anyhow such localized elevated Regions surrounded by flood inundation have not been accommodated as Floodplains and assumed to be not influenced by flood inundation. The NPP performance of regions of Wetland Ecosystem surrounded by flood inundation and adjacent to flood inundation is highly influenced by frequency and intensity of flood inundation (Chapin et al., 2011). Anyhow such indirect influences of flood inundation over the NPP Performance of adjacent elevated regions of Wetland Ecosystem have not been considered in this Socio-Ecological Adaptability analysis. Based on Area Elevation topography of the 500 Years Floodplains, more than 15% of South Asian Floodplains are located over Low Elevation Coastal Zones (LECZ). The Flood Risk across LECZ is being developed by a scenario of compound coastal flooding having different possible combinations of Riverine flood, tidal waves, tsunami waves, storm surges coupled with cyclonic rain, wave run-up, climate change induced sea level rise trend (McGranahan et al., 2007). Anyhow Economic losses due to such Compound Coastal Flooding over the Floodplains of Coastal Delta Regions of all River basins of the Study Area have also not been considered in this Adaptability Analysis. The Flood Hazard Maps provided by UNEP-GRID (2015) and EC-JRC (2016) are applicable only for fluvial Flood and not accommodating both pluvial and coastal flood hazard. These Global fluvial flood hazards had been estimated using derived River networks at 30 sec accuracy and 3 sec SRTM DEM data (Trigg et al., 2016). Hence the Flood Protection capacity of existing Flood Embankment having width less than 90 m has not been accommodated in the Flood hazard Map. Current Socio-Economic and Ecological Adaptability analysis is applicable for 2010 Scenario of Flood Hazard and Exposures distributions. Hence Projected Adaptability needs to be analyzed corresponding to various socio-environmental SSP-RCP scenarios.

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Data availability statement

All the Data used in this article had been published based on Open License Criteria and available for free access at the database locations cited in the Reference against the Results. Only data analysis has been presented.

Conflict of interest

The authors have no financial or proprietary interests in any material discussed in this article. Conflict of interest: The authors declare no competing interests.

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