



Measuring Livelihood Sustainability by PCA in Indian Sundarban

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Abstract

Sustainable livelihoods can cope with and recover from stress and can maintain or improve its resources and properties. We have adopted an integrated approach to measure livelihood sustainability for Indian Sundarban through the composite livelihood sustainability index incorporating natural, human, physical, and socio-economic dimensions. Principal component analysis (PCA) is a systematic and reliable quantitative method for measuring composite score. The livelihood sustainability performances of 19 blocks of Sundarban are measured, benchmarked, and ranked. PCA-based CLSI acts as a comprehensive analytical method for evaluating the spatial variation and indicator of strength and weakness in livelihood sustainability. Moreover, it may assist local authorities in implementing any policy or project more feasibly to ensure livelihood sustainability in the study area.

Keywords Livelihood sustainability · Principal component analysis · Composite score · Bench marked · Spatial variation

1 Introduction

In the period of late 1980, the idea of livelihood emerged. It is a replacement for the technocratic ‘employment’ framework to demonstrate the struggling way of people for achieving a decent living (Scoones 2009). The definition of sustainable livelihoods includes several different parameters, some of which can conflict (Scoones 1998). Sustainable living stands out people, their skills, and their ways of living, including various amenities, employment, and properties (Chambers and Conway 1992). This approach has a holistic viewpoint and focuses on three essential developmental dimensions: environment, economy, and society (Dempsey et al. 2011). There are numerous studies for the development of methodological frameworks for sustainability assessments based on a rigorous foundation of ecological science and environmental policy theory (Esty et al. 2005; Zhang et al. 2019). Sustainable

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livelihood suggests an overall scenario of the enmeshment of vulnerable communities rather than basic awareness (Brocklesby 2003; Jeevamani et al. 2021). The central theme of the sustainability framework is an inquiry into five forms of properties owned by individuals for building their livelihoods, including natural, human, physical, social, and financial resources (Bebbington 1999; Scoones 1998). Various research works have highlighted sustainable livelihood approaches over the last two decades (Gibbes et al. 2020).

Li et al. (2020) have elaborated on the contribution of livelihood assets for measuring the sustainable development of smallholder farmers. Zhang and Fang (2020) have adopted a quantitative assessment for evaluating livelihood vulnerability and sustainability for the Koshi river basin community in Nepal. Paul et al. (2020); Everard et al. (2020) have developed a composite measurement of livelihood sustainability for shifting cultivation and forest resources-dependent communities of Northeastern India. Kim and Marcouiller (2020) have examined the patterns of socio-economic resilience for achieving sustainable livelihood to flood hazards along the Mississippi River. Liu et al. (2020) find out the interdependence between livelihood resilience and livelihood sustainability in rural China. Sathyapriya and Asokhan (2020) establish the contribution of agricultural schemes for achieving livelihood sustainability. Gebrekidan Abbay et al. (2019) have evaluated the impact of social status on sustainable livelihood. Ibrahim et al. (2018) have measured sustainable livelihoods for the marine-dependent population of Malaysia. The development of tourism industries can play an essential role in acquiring livelihood sustainability (Aazami and Shanazi 2020; Srijuntrapun et al. 2018; Twining-Ward et al. 2018; Chen et al. 2018). A healthy association exists between sustainable livelihoods and food security, aquaculture, and agricultural systems (Ahmed 2007; Lockie 2001; Qi and Dang 2018). Natural resources and sustainable livelihoods are related (Norfolk 2004). Local individuals may be active in defining specific, sustainable livelihood interventions, thus ensuring that local factors have been assessed (Chambers 1994). Sustainable livelihood approaches can influence policy processes of various countries like Mali, Ethiopia, Zimbabwe, Africa, and Bangladesh (Keeley 2001). This concept has been accepted widely as an essential conceptual framework for providing effective planning designs for the enhancement of any region (Williams et al. 2000; Garai et al. 2019).

Though, spatial thinking and analysis have recently been fruitfully adopted in several research fields (Orford 2001; Elliott and Wartenberg 2004; Lawson 2013), yet they remain marginalized in study and practice evaluation (Koschinsky 2013). There is little research to examine the spatial variations of the micro-level sustainability of livelihoods. The study aims to construct a composite index for measuring livelihood sustainability in Indian Sundarban.

2 Methodology

2.1 Study area

World Heritage Site, the Sundarban (Indian and Bangladesh jointly), is the biggest known block of mangroves forest in the world (Das and Mandal 2016). The present study has focused on the Indian Sundarban, covering 9630 sq. Km area, bounded by Bangladesh in the east, the Hooghly River in the west, imaginary Dumpier and Hodges line in the north and Bay of Bengal in the south (Mitra et al. 2009). Today, the ever-expanding population, growing commercialism, and natural resources exploitation have resulted in

a population-resource imbalance that has gained global dimensions directed to environmental instability (Singh and Hiremath 2010). The case study of Indian Sundarban is no exception. It is among the least-developed regions in India. The area faces numerous developmental constraints. Weak networks for transportation and communication, lack of traditional electricity, and shortage of drinking water, together with frequent natural disasters like cyclones and storm surges, are the dominant problems in this area (Shabnam 2012).

In the Indian Sundarban, very few works have been done, particularly in socio-economic and livelihood aspects (Nandi and Pramaniik 1994).

2.2 PCA at a glance

In 1901, Karl Pearson introduced PCA. This multivariate statistical process employs the orthogonal conversion of a considerable number of associated variables. As a result, another set of non-correlated variables have been constructed, known as the principal components (PCs). The first few PCs can retain the maximum variation of actual variables (Pearson 1901; Jolliffe 2003; Hossein MH 2011). Currently, PCA has an enormous application in exploratory data analysis. For instance, Jollands et al. (2004) refer to PCA for the assessment of combined eco-efficiency measurements. PCA can operate as a comprehensive ranking method to measure university quality (Muzamhindo 2017) and the sustainability status of manufacturing companies (Li et al. 2012). Goel and Garg (2018) apply PCA for evaluating health infrastructure in Hariyana.

2.3 Selection of livelihood sustainability Indicators

Sustainability indicators are measurable and identifiable attributes of a system (Cui et al. 2004). There is no set of indicators universally acknowledged for measuring livelihood sustainability (Parris and Kates 2003). To identify livelihood sustainability indicators, we employ four broad indices of capital endowment (natural, physical, human and socio-economic capital). Indicators used in the livelihood sustainability evaluation should align with a quantitative index that preserves all dimensions of sustainability (Soler and Soler 2008). The indicators must be policy-relevant, quantifiable, analytical, and able to provide practical, concise, and accurate information in such a way that is easily clear to policymakers and other target groups (Niemeijer and de Groot 2008). Furthermore, it has also suggested other features such as clarity, spatial representation, ease of understanding, and possible incorporation in comprehensive evaluation techniques (Swart 2008).

The present research work entirely depends on secondary sources of data. Data sources for this paper are District Census Handbook (DCHBa (2011), DCHBa (2011)), District Statistical Hand Book (DSHB2011), and District Human Development Report DHDR ((2010), DHDR (2010)) of North and South 24 Paraganas. We took help from various reporting initiatives to select a set of livelihood sustainability indicators and related publications also act as a reliable source of references (Kamaruddin and Samsudin 2014; Horsley et al. 2015; Rigby et al. 2000; Speranza et al. 2014). The main three criteria for selecting livelihood sustainability indicators are as follows:

- Criteria 1: Analytical accuracy
- Criteria 2: Dependable and easily accessible
- Criteria 3: Policy relevance and presentable

We have identified 35 indicators and divided them into four sets (natural, physical, human, and socio-economic) for measuring livelihood sustainability. It is requisite to test whether the data set is appropriate for performing the PCA. Concerning this fact, we calculate the Kaiser–Meyer–Olkin (KMO) assessment of sampling adequacy (Constantin 2014). Kaiser–Meyer–Olkin (KMO) statistics help to evaluate the strength of association among variables. Its value varies between 0 to 1. If the KMO statistic is equal or higher than 0.60, the data are acceptable for PCA.

Table 1 denotes the key information regarding chosen indicators. This paper relies entirely on secondary data sources. As a result, all livelihood opportunities cannot be included, like income from tourism, income from forest resources, per capita income, involvement in community-based programs, and so on. But we consider most of the major livelihood opportunities like agriculture, aquaculture, rural artisans, involvement in organized and unorganized sectors, etc. In Sundarban, the forest is not a considerable natural capital resource in connection with livelihoods. Sundarban is a reserved forest and UNESCO World Heritage Site since 1987 (Nishat 2019). There is a sharp and clear boundary between the reserved forest and the reclaimed habitation zone in Sundarban. So, the concept of forest coverage to individual marginal population does not arise here. Besides, people are not allowed to collect resources in the core areas. Only they are allowed to collect forest resources like honey, wood, wax, etc., in the buffer areas with permission from the forest department. Resources are also limited and cannot provide sufficient livelihood options for the people or forest entrants. Other than agriculture and fishing, the collection of NTFP (non-timber forest products) is another area of livelihood. But, people in the fringe zone of Sundarban are forest dwellers who traditionally could spend their livelihood through a collection of resources emanating from the forest. These occupations include the collection of plant resources (*Nypa fruticans*, *Sonneratia apetala*, *Heritiera fomes*, etc.), fuelwood collection, and apiculture. But, these are mostly seasonal, and the collection of resources is also limited. Besides, they collect such resources as a secondary or tertiary occupation. In this work, we have focused mainly on primary occupations or emphasized the main sources of livelihoods.

All calculations of this paper have been done by applying OriginPro 2019b and IBM SPSS Statistics 25.

2.4 Construction of CLSI

2.4.1 Normalization of indicators

The selected indicators (Table 1) of livelihood sustainability have different measurement units. As an initial step for developing an index, normalization is indispensable. The process of normalization can transform the data set into identical measures. We employ ‘Linear Scaling Technique’ or ‘Min-Max Normalization’ (Sharpe and Andrews 2012) to standardize the current data on livelihood sustainability indicators. Equation 1 represents this normalization process.

$$X_{ij} = \frac{x_{ij} - \min_j x_{ij}}{\max_j x_{ij} - \min_j x_{ij}} \quad (1)$$

where x_{ij} represents the value of the j th sustainable livelihood block in i th indicator ($i = 1, 2, 3, \dots, m$; $j = 1, 2, 3, \dots, k$) and $\min_j x_{ij}$ and $\max_j x_{ij}$ are the lowest and highest values of x_{ij} , respectively, for i th indicator. However, if x_{ij} is negatively associated with the status of sustainable livelihood, the previous equation can also be formulated in equation 2.

$$X_{ij} = \frac{\max_j x_{ij} - x_{ij}}{\max_j x_{ij} - \min_j x_{ij}} \quad (2)$$

2.4.2 Capital Index

For measuring the capital index of any capital indicators (natural, human, physical and socio-economic), we have computed the PCA matrix of m variable (indicators) \times k observation (blocks) and then Eq. 3 has been applied.

$$\text{Capital Index}_j = \sum_{p=1}^q \sum_{i=1}^m \frac{e_{pi}}{\sqrt{\lambda_p}} X_{ij} \quad (3)$$

where X_{ij} is the standardized value of the i th indicator of the j th block, e_{pi} is the factor loadings of i th indicator for p th principal component and λ_p denotes eigenvalue of p th principal components. The retained number of components for study determines to elucidate at least 90% variance of the original data set. In this way, we have measured four capital indices [natural capital index (NCI), human capital index (HCI), physical capital index (PCI), and socio-economic capital index (SECI)].

2.4.3 Composite Livelihood Sustainability Index (CLSI)

We have constructed the composite livelihood sustainability index (CLSI) considering four sustainability indicators (natural, physical, human, and socio-economic). The numbers of natural, physical, human, and socio-economic sustainability indicators denote by a , b , c , and d , respectively, e.g., the PCA matrix for measuring NCI is a variable (natural capital indicators) \times k observation (blocks), and so on. The matrix of PCA for CLSI is r indicators \times k observation (blocks). In this method, $a + b + c + d \geq r$, it implies that the indicators for composite livelihood sustainability need to short out from the natural, physical, human, and socio-economic indicators. However, the selected indicators for the sustainability of composite livelihoods may be less than the total of all capital indicators. The numbers of indicators (r) are separately identified based on the KMO test. In the present study, we have identified 17 indicators as the final set for calculating the CLSI. Accordingly, in this study, $(a + b + c + d) - 18 = r$. For calculating the CLSI, we have implemented the PCA matrix of r variable (indicators) \times k observation (blocks), and Equation 3 has been applied afterward.

3 Results and discussions

3.1 Performances in NCI, PCI, HCI, and SECI

At first, we computed PCA for seven natural capital indicators. Table 2 represents the analyzed results, including eigenvalues, factor loadings, and accumulation of variance of correlated indicators. Five principal components explain a total of 91.49% of the overall variance of the data. The first principal component accounts for 41.26% of the total variance. The first component (PC1) is significantly associated with the percentage of agricultural land (0.427), the % of aquaculture land (-0.426), fish productivity (-0.411), and productive cultivable land (0.545). We have obtained productive cultivable land by deducting cultural wasteland from total agricultural land. The second component has a notable correlation with paddy productivity (0.774). PC3 remarkably correlates with fertilizer depots (0.700). Rain-fed paddy farming, the main economic activity in the Sundarban, is made possible by the construction of earthen embankments to hold the brackish tidal water at bay. Limited irrigation facilities contribute to Sundarban mono-cropping agriculture, which is also limited by groundwater and surface water salinity. Farmers have no choice for alternate crops other than tall traditional rice varieties in Kharif (Sarangi et al. 2015). As a result, many agricultural lands are getting converted to high output-intensive brackish water farming during the last three or four decades (Mandal et al. 2019a). That is why PC1 shows near the contrast relationship between % of agricultural land and aquaculture land (Table 2).

Table 3 depicts the PCA on seven physical capital indicators. Five principal components explain 91.45% variance of data. The first component (PC1) has a striking positive association with the accessibility to safe drinking water (0.478). The second component (PC2) has mostly correlated with road density (0.474), accessibility to primary school (0.560), and villages with mobile phone coverage (-0.609). PC3 has a remarkable correlation with medical institutions' accessibility (0.646) and availability of power supply for all uses (0.528).

Similarly, PCA analysis has also been executed for ten human capital indicators and eleven socio-economic capital indicators, represented in Tables 4 and 5, respectively. We have retained five principal components for human capital data, and they explain a total of 93.08% of the overall variance of the data. In the case of human capital indicators, PC1 is primarily associated with population density (0.405). PC2 has mostly correlated with literacy rate and female literacy rate. In the case of socio-economic capital indicators, six principal components explain 92.8% variance of data. PC1 has primarily associated with electricity (0.479) and the availability of television in households (0.410). The second component has a striking correlation with the availability of mobile (0.414), job card employment (0.520), and women self-help groups (-0.511). PC3 has a significant correlation with an improved latrine in households (0.721) and the availability of market facilities in the village (0.404).

We have measured capital indices [natural capital index (NCI), physical capital index (PCI), human capital index (HCI), and socio-economic capital index (SECI)] for each block of Sundarban with the PCA analysis. Table 7 illustrates the constructed index results and the benchmark ranking for each block of Sundarban. Jaynagar-I is in the best position, while Namkhana receives the lowest score on physical capital sustainability measurement. In the case of natural capital sustainability measurement, Jaynagar-I is the best performing block, and Sandeshkhali-I is the worst performing block. Patharpratima ranks first, and

Jaynagar-II ranks last in human capital sustainability. If we consider socio-economic livelihood sustainability measurement, Canning-I is in the best position, and Sandeshkhali-I is the worst performing block.

3.2 Achievement towards Composite Livelihood Sustainability

Table 6 provides a detailed study (eigenvalues, factor loading, and accumulation of variance of associated indicators) of the sustainability of composite livelihoods. Seven principal components explain 92.59% of the overall difference of the original data set. PC1 accounts for 52% of the total variance. Out of 17 variables, 11 variables (Paddy productivity, fertilizer depots, self-employed rural artisans, % of the main worker, population served/bank, net collection from small savings, permanent households, households with electricity, a television in households, % of APL households, and accessibility to primary schools) have a positive association with the first principal component. It means that they vary together. If one increases, then the remaining ones tend to increase as well. PC2 has a significant association with fertilizer depots (0.480), gender equality in workforce participation (0.405), and accessibility to primary schools (0.323). So, these components primarily measure the standard of living of the region. The third component has a large positive association with the population served/bank (0.338), televisions in households (0.356), villages with the market facility (0.530), and villages with P.O, sub-P.O (0.479).

Figure 1 shows PCA biplot, which consists of a PCA score plot and loading plot. The left and lower axes are of the PCA scores of the blocks, and the top and right axes belong to the loading plot. In this study, the first two components account for more than sixty percent variance of the data. The loading plot graphs the coefficients of each variable for the first component against the factors for the second component. Loading plots identify which variables have the most substantial effect on each element. Loadings can range from -1 to 1 . Loadings close to -1 or 1 mean that the factor strongly influences

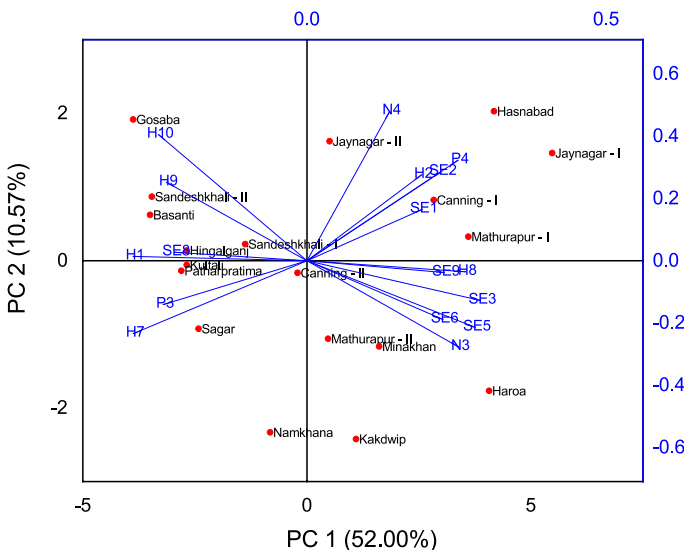


Fig. 1 PCA biplot

Table 1 The selected indicators for composite livelihood sustainability

Selected Indicators		KMO Value	
Natural capital indicator	N1	% of Agricultural land	0.609
	N2	% of irrigated land	
	N3	Paddy productivity	
	N4	Fertilizer depots/Sq. Km agricultural land	
	N5	% of aquaculture land	
	N6	Fish productivity	
	N7	% of productive cultivable land	
Physical capital indicator	P1	% of villages with power supply for all uses	0.709
	P2	Road density	
	P3	% of villages with P.O, Sub P.O	
	P4	Primary school/Sq. Km	
	P5	Medical institution/100,000 population	
	P6	Availability of safe drinking water	
	P7	% of villages with mobile phone coverage	
Human capital indicator	H1	% of Cultivator	0.63
	H2	Self-employed rural artisans, hawkers (those who do not employ others)	
	H3	Labor oriented regular job in the unorganized sector	
	H4	Job in the organized sector	
	H5	Literacy rate	
	H6	Female literacy rate	
	H7	Population density	
	H8	% of main worker to total worker	
	H9	Work force participation rate	
	H10	Gender equality in workforce participation rate	
Socio-economic capital indicator	SE1	Population served/bank	0.633
	SE2	Net collection from small savings/capita	
	SE3	Permanent house	
	SE4	Improved latrine	
	SE5	Household with electricity	
	SE6	Television in household	
	SE7	Mobile facility in household	
	SE8	% of villages with market facility	
	SE9	% of APL (above poverty line) households	
	SE10	Job card employment	
	SE11	% of women self help groups	

the variable. Loading value close to 0 means that the factor has a weak influence on the variable. One another important fact we can obtain from the angles between the variables of the loading plot. This angle depicts the degree of association between variables. In Figure 1, SE9 (% of APL households) and H8 (% of the main worker to total worker) are very close, forming a slight angle, it means they are positively correlated. N3 (paddy productivity) and N4 (fertilizer depots) meet each other at about right angles, and they

Table 2 PCA results for natural capital indicators

Correlation Matrix							
	N1	N2	N3	N4	N5	N6	N7
N1	1.00	- 0.20	0.25	0.29	- 0.35	- 0.41	0.64
N2	- 0.20	1.00	0.12	- 0.28	0.36	0.22	- 0.47
N3	0.25	0.12	1.00	0.18	0.21	- 0.03	0.04
N4	0.29	- 0.28	0.18	1.00	- 0.15	- 0.11	0.17
N5	- 0.35	0.36	0.21	- 0.15	1.00	0.34	- 0.67
N6	- 0.41	0.22	- 0.03	- 0.11	0.34	1.00	- 0.66
N7	0.64	- 0.47	0.04	0.17	- 0.67	- 0.66	1.00
PCs retained	PC1	PC2	PC3	PC4	PC5		
Eigenvalues	2.888	1.310	1.007	0.616	0.585		
Variance explained (%)	41.26	18.71	14.38	8.79	8.35		
Cumulative (%)	41.26	59.97	74.35	83.14	91.49		
Factor Loadings							
N1	0.427	0.330	- 0.163	0.276	0.179		
N2	- 0.341	0.225	- 0.525	0.657	- 0.266		
N3	0.028	0.774	- 0.109	- 0.252	0.362		
N4	0.228	0.358	0.700	0.315	- 0.454		
N5	- 0.426	0.333	- 0.006	- 0.473	- 0.320		
N6	- 0.411	- 0.006	0.401	0.321	0.666		
N7	0.545	- 0.053	- 0.191	- 0.051	0.118		

are not likely to be associated. When two variables diverge and form large angles (close to 180 degrees), they are negatively correlated. In our study, H10 and N3 have a negative correlation.

A composite sustainability index recognizes integrated evaluation of the sustainability of any system, after taking into account all information provided by indicators (Rao and Rogers 2006). Based on the PCA method, we constructed a unique composite livelihood sustainability index (CLSI) that can convert the impacts of livelihood indicators into a single score to measure and assess livelihood sustainability. It can explain the status of the overall livelihood sustainability of each block of Sundarban quantitatively. CLSI can adequately clarify the differences in the viability of living conditions between the blocks, but it can also identify the strength and weaknesses of each block. Thus, potential improvement requirements may be suggested by studying CLSI and as well as each indicator also.

The livelihood sustainability index, so computed, lies between 0 and 1, with 1 indicating maximum sustainability and 0 indicating no durability at all. The last two columns of the Table 7 depict block-wise overall livelihood sustainability performance and the benchmark ranking results. Through this analysis, it is evident that spatial variations exist in sustainable livelihoods in Sundarban. So far, Hasnabad (0.543) is in the best position in providing opportunities for sustainable livelihoods to its ordinary people. It follows Jaynagar-I, Canning-I, and Haroa having the rank of second, third, and fourth positions, respectively. Basanti, on the other hand, is the worst-performing block in livelihood sustainability with CLSI 0.040. Sandeshkhali-II, Kultali, and Patharpratima are in the 18th, 17th, and 16th positions and reflect an alarming scenario in this context.

Table 3 PCA results for physical capital indicators

Correlation Matrix							
	P1	P2	P3	P4	P5	P6	P7
P1	1.00	0.33	-0.46	0.30	-0.26	0.57	0.37
P2	0.33	1.00	-0.25	0.48	-0.20	0.54	0.05
P3	-0.46	-0.25	1.00	-0.44	0.47	-0.45	-0.34
P4	0.30	0.48	-0.44	1.00	-0.17	0.34	-0.05
P5	-0.26	-0.20	0.47	-0.17	1.00	-0.56	-0.32
P6	0.57	0.54	-0.45	0.34	-0.56	1.00	0.34
P7	0.37	0.05	-0.34	-0.05	-0.32	0.34	1.00
PCs retained	PC1	PC2	PC3	PC4	PC5		
Eigenvalues	3.13	1.256	0.77	0.729	0.513		
Variance explained (%)	44.73	17.96	11	10.42	7.34		
Cumulative (%)	44.73	62.69	73.69	84.11	91.45		
Factor Loadings							
P1	0.408	-0.091	0.528	-0.224	-0.594		
P2	0.348	0.474	0.259	0.433	0.367		
P3	-0.418	0.079	0.330	0.548	-0.024		
P4	0.321	0.560	-0.155	-0.398	0.225		
P5	-0.366	0.277	0.646	-0.361	0.117		
P6	0.478	-0.018	0.072	0.404	-0.202		
P7	0.269	-0.609	0.315	-0.102	0.638		

4 Conclusions

The present work demonstrates how to implement PCA as a technique for evaluating and benchmarking livelihood sustainability performances. The advantages of CLSI involve a thorough and fruitful analysis of the sustainability performance of blocks, as well as improvement opportunities for livelihood sustainability management.

The study shows that inter-block spatial variation exists in livelihood sustainability in Sundarban as the CLSI ranges from 0.543 (Hasnabad) to 0.040 (Basanti). Not only PCA scores help us to find out what produces the differences among blocks, but also can identify the strength and weaknesses of each block by analyzing each indicator. For example, Patharpratima stands 16th in CLSI out of 19 blocks of Sundarban, mostly because of not achieving satisfactory performance in NCI (13th) and PCI (14th). However, this is the best performing block in HCI (1st). Sagar ranks third in HCI & SECI. But it stands 13th in CLSI, mostly because of bad performance in NCI (11th) and PCI (16th). As we elaborated in Table 2, in the case of natural capital indicators, PC1 has a significant positive association with the percentage of agricultural land, productive cultivable land, and PC2 has a striking association with paddy productivity. If we consider physical capital indicators (Table 3), the first component has a notable correlation with the availability of safe drinking water. PC2 is positively associated with road density and accessibility to primary school. So, this is evident that Patharpratima and Sagar have acute livelihood sustainability drawbacks in these four aspects (agriculture, road

Table 4 PCA results for human capital indicators

Correlation Matrix										
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
H1	1.00	-0.56	-0.29	-0.45	0.08	-0.01	0.72	-0.60	0.70	0.66
H2	-0.56	1.00	0.57	0.23	-0.44	-0.43	-0.71	0.39	-0.50	-0.23
H3	-0.29	0.57	1.00	0.59	-0.36	-0.35	-0.42	0.31	-0.19	-0.14
H4	-0.45	0.23	0.59	1.00	0.10	0.16	-0.40	0.40	-0.07	-0.37
H5	0.08	-0.44	-0.36	0.10	1.00	0.98	0.47	-0.24	0.38	0.01
H6	-0.01	-0.43	-0.35	0.16	0.98	1.00	0.39	-0.12	0.31	-0.09
H7	0.72	-0.71	-0.42	-0.40	0.47	0.39	1.00	-0.58	0.59	0.43
H8	-0.60	0.39	0.31	0.40	-0.24	-0.12	-0.58	1.00	-0.49	-0.71
H9	0.70	-0.50	-0.19	-0.07	0.38	0.31	0.59	-0.49	1.00	0.76
H10	0.66	-0.23	-0.14	-0.37	0.01	-0.09	0.43	-0.71	0.76	1.00
PCs retained	PC1	PC2	PC3	PC4	PC5					
Eigenvalues	4.618	2.204	1.343	0.687	0.456					
Variance explained (%)	46.18	22.04	13.43	6.87	4.56					
Cumulative (%)	46.18	68.22	81.65	88.52	93.08					
Factor Loadings										
H1	0.374	-0.265	0.086	0.338	-0.057					
H2	-0.355	-0.160	0.147	-0.552	0.005					
H3	-0.272	-0.123	0.585	0.105	-0.456					
H4	-0.219	0.293	0.574	0.239	0.002					
H5	0.242	0.541	0.096	-0.276	-0.051					
H6	0.202	0.587	0.070	-0.204	0.015					
H7	0.405	0.042	-0.026	0.247	-0.468					
H8	-0.346	0.189	-0.078	0.464	0.492					
H9	0.362	-0.046	0.433	0.086	0.491					
H10	0.312	-0.356	0.302	-0.333	0.290					

density, accessibility to primary school, and availability of safe drinking water), and some measures should be adopted to improve them.

Increasing the share of agricultural land does not increase productivity or enhance opportunities for livelihoods. A big problem is the salinity of the Sundarban. Construction of embankments along with forest clearance made extensive human housing possible in the Sundarban (Sánchez-Triana et al. 2018). In the Indian Sundarban, around 56% of the landmass lies within the coastal low lying ecosystems with an elevation of fewer than 5 meters above mean sea level. Some parts are even below the mean sea level (Mandal et al. 2019b). Most of the farmers of Sundarban are aware of the demerits of the use of HYV seeds which are of higher productivity but of low salt tolerance. However, the experience of cyclone *Aila* in 2009 or *Sidar* in 2007 has made them aware of the positive side of salt-tolerant local rice varieties. These varieties (*Chamarmani*, *Darsal*, *Dudhersar*, *Rupsal*, *Chinekamini*, *Gobindabhog*, *Gopalbhog*, *Khejurchori*, *Lilabati*, *Lal Dhan*, *Kalabhat*, *Patnai* etc.) have low productivity, but they are important for the local food security. These varieties require little or no chemical fertilizers as well as pesticides for their stable growth. They are completely indigenous varieties and practiced for the last six to seven decades by the marginal farmers of Sundarban. In fact, these paddy varieties are very susceptible to chemical fertilizer and pesticides (Ghosh and Chattopadhyay 2017). All these factors force the region into a monoculture, as well as low agricultural productivity. Reasonable steps must be taken to develop a well-planned pattern of land use by reducing, to the greatest extent possible, cultivable wasteland to increase land productivity and achieve livelihood sustainability.

Jaynagar-I ranks second in CLSI, but it is one of the worst-performing blocks in the human capital index (HCI). In HCI, it stands 17th out of 19 blocks. In human capital indicators (Table 4), PC1 has a significant positive association with % of the cultivator, population density, workforce participation rate, and gender equality in workforce participation. PC2 shows a remarkable association with the overall literacy rate and female literacy rate. Jaynagar-I experiences drawbacks in the educational and occupational sectors. If we want to achieve the livelihood sustainability of Jaynagar-I, we have to mitigate the problem of unemployment, literacy rate, and gender discrimination in occupation.

PCA, in a nutshell, discards no variables. Instead, it decreases the overwhelming number of dimensions by building the main components that convey the most variation in the data set. This quantitative method can identify variables that significantly influence principal components. Thus, PCA-based CLSI acts as a comprehensive analytical method for evaluating the area-specific and indicator-specific strengths and weaknesses. Besides, it possibly helps the local governing bodies and higher authorities to extend their vision in a viable way of achieving livelihood sustainability in Sundarban. As principal components rationalize for most significant variations, PCA contributes a practical methodology for identifying spatial variations and ranking also. We embrace PCA as a reliable method because it does not take account of weights as a priority; instead, the result emphasizes the principal components that optimize the variance explanation.

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Table 5 PCA results for socio-economic capital indicators

Correlation Matrix											
	SE1	SE2	SE3	SE4	SE5	SE6	SE7	SE8	SE9	SE10	SE11
SE1	1.00	0.53	0.52	0.02	0.41	0.36	0.09	-0.21	0.16	-0.06	-0.06
SE2	0.53	1.00	0.63	0.16	0.44	0.25	-0.15	-0.22	0.35	-0.35	0.47
SE3	0.52	0.63	1.00	0.24	0.69	0.42	0.07	-0.56	0.51	-0.22	0.22
SE4	0.02	0.16	0.24	1.00	0.40	0.21	0.30	0.14	0.28	-0.18	0.38
SE5	0.41	0.44	0.69	0.40	1.00	0.84	0.54	-0.44	0.80	0.15	-0.02
SE6	0.36	0.25	0.42	0.21	0.84	1.00	0.74	-0.26	0.59	0.37	-0.28
SE7	0.09	-0.15	0.07	0.30	0.54	0.74	1.00	0.01	0.27	0.54	-0.44
SE8	-0.21	-0.22	-0.56	0.14	-0.44	-0.26	0.01	1.00	-0.31	0.11	-0.15
SE9	0.16	0.35	0.51	0.28	0.80	0.59	0.27	-0.31	1.00	0.22	-0.06
SE10	-0.06	-0.35	-0.22	-0.18	0.15	0.37	0.54	0.11	0.22	1.00	-0.70
SE11	-0.06	0.47	0.22	0.38	-0.02	-0.28	-0.44	-0.15	-0.06	-0.70	1.00

Table 5 (continued)

Correlation Matrix										
PCs retained	PC1	PC2	PC3	PC4	PC5	PC6	PC3	PC4	PC5	PC6
Eigenvalues	4.072	2.759	1.373	0.955	0.411	0.299				
Variance explained (%)	37.02	25.08	12.48	8.68	5.8	3.74				
Cumulative (%)	37.02	62.1	74.58	83.26	89.06	92.8				
Factor Loadings										
SE1	0.269	-0.110	-0.331	0.652	-0.168	-0.319				
SE2	0.280	-0.362	-0.086	0.312	0.326	0.470				
SE3	0.390	-0.238	-0.156	-0.047	-0.075	-0.328				
SE4	0.183	-0.099	0.721	0.067	-0.153	-0.417				
SE5	0.479	0.050	0.084	-0.105	0.024	0.017				
SE6	0.410	0.247	0.033	0.063	-0.117	0.397				
SE7	0.247	0.414	0.244	0.095	-0.416	0.270				
SE8	-0.240	0.147	0.404	0.580	0.429	0.027				
SE9	0.379	0.057	0.079	-0.303	0.629	-0.193				
SE10	0.058	0.520	-0.110	-0.015	0.256	-0.010				
SE11	0.003	-0.511	0.301	-0.137	-0.069	0.357				

Table 6 PCA results of composite livelihood sustainability indicators

PCs retained	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Eigenvalues	8.839	1.797	1.488	1.357	1.126	0.635	0.499
Variance explained (%)	52	10.57	8.75	7.98	6.62	3.73	2.94
Cumulative (%)	52	62.57	71.32	79.3	85.92	89.65	92.59
Factor Loadings							
Paddy productivity	0.253	- 0.277	- 0.090	0.171	0.099	- 0.066	0.286
Fertilizer depots/Sq.Km agricultural land	0.139	0.480	- 0.136	0.391	- 0.035	- 0.044	- 0.461
% of cultivator	- 0.290	0.014	- 0.224	0.112	0.233	0.099	0.240
Self-employed rural artisans, hawkers (those who do not employ others)	0.192	0.276	- 0.010	- 0.302	- 0.399	0.470	0.202
Population density	- 0.290	- 0.234	0.027	- 0.007	0.174	- 0.212	- 0.149
% of main worker	0.265	- 0.036	- 0.094	- 0.209	0.412	0.280	- 0.114
Workforce participation rate	- 0.235	0.252	0.204	0.210	0.399	- 0.072	0.365
Gender equality in workforce participation	- 0.248	0.405	- 0.002	0.155	- 0.087	- 0.068	0.402
Population served/bank	0.193	0.165	0.338	- 0.364	- 0.049	- 0.600	0.041
Net collection from small savings	0.224	0.286	0.090	- 0.216	0.485	0.206	0.067
Permanent households	0.290	- 0.129	- 0.062	- 0.144	0.272	- 0.121	0.054
Households with electricity	0.281	- 0.214	0.197	0.260	0.066	- 0.036	0.131
Televisions in households	0.227	- 0.189	0.356	0.230	- 0.250	0.132	0.357
Villages with market facility	- 0.221	0.027	0.530	- 0.042	0.150	0.340	- 0.136
% of APL households	0.229	- 0.038	0.120	0.516	0.069	0.141	- 0.187
Villages with P.O, Sub P.O	- 0.240	- 0.141	0.479	- 0.069	- 0.044	0.110	- 0.261
Primary school/Sq. Km.	0.252	0.323	0.237	0.096	0.016	- 0.214	- 0.048

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Table 7 Block-wise composite livelihood sustainability index of Sundarban

Block Name	NCI	Rank	PCI	Rank	HCI	Rank	SECI	Rank	CLSI	Rank
Canning-I	0.278	15	0.268	5	0.123	16	0.611	1	0.434	3
Canning-II	0.339	9	0.359	3	0.088	18	0.312	12	0.190	10
Mathurapur-I	0.459	3	0.384	2	0.133	15	0.443	9	0.376	5
Jaynagar-I	0.514	1	0.639	1	0.092	17	0.475	6	0.534	2
Jaynagar-II	0.429	5	0.207	9	0.066	19	0.296	13	0.274	8
Kultali	0.392	7	0.094	18	0.234	12	0.249	15	0.094	17
Basanti	0.311	12	0.162	15	0.255	10	0.235	17	0.040	19
Gosaba	0.341	8	0.183	11	0.518	2	0.413	10	0.163	11
Mathurapur-II	0.509	2	0.217	7	0.287	7	0.510	4	0.291	6
Kakdwip	0.293	14	0.208	8	0.290	6	0.595	2	0.288	7
Sagar	0.313	11	0.141	16	0.483	3	0.543	3	0.150	13
Namkhana	0.254	16	0.083	19	0.421	5	0.462	7	0.129	14
Patharpratima	0.302	13	0.170	14	0.533	1	0.403	11	0.122	16
Sandeshkhali-I	0.035	19	0.127	17	0.248	11	0.147	19	0.126	15
Sandeshkhali-II	0.194	17	0.179	13	0.259	9	0.164	18	0.059	18
Hasnabad	0.458	4	0.182	12	0.272	8	0.444	8	0.543	1
Hingalganj	0.413	6	0.250	6	0.458	4	0.252	14	0.152	12
Haroa	0.123	18	0.340	4	0.163	14	0.483	5	0.430	4
Minakhan	0.324	10	0.197	10	0.220	13	0.243	16	0.257	9

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