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Full Length Article

A composite human wellbeing index for ecosystem-dependent communities: A case study in the Sundarbans, Bangladesh

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ABSTRACT

Ecosystem-dependent communities (EDCs) rely on ecosystem services for their wellbeing in many ways, but there is a lack of robust metrics to estimate their human wellbeing in a multi-dimensional manner. Existing approaches are not tailored to EDCs, hence failing to adequately reflect their distinct characteristics and strong links to social-ecological systems. We used the domains of human wellbeing determined by the Millennium Ecosystem Assessment (i.e. *basic materials, health, freedom, social relation,* and *security*) to develop a novel conceptual framework and a composite index of human wellbeing for EDCs. The actual indicators and variables were determined through an extensive literature review and a participatory method around the Sundarbans forest in Bangladesh. Data obtained from focus group discussions (FGDs), interviewing households as well as experts, were used to estimate the Human Wellbeing Index for EDC (HWI-EDC). The composite index results suggest that the EDCs in the study area had moderate human wellbeing, which was primarily consisted of the *freedom* and *basic materials* domains due to the comparatively high priority values allocated by the local communities. The *Social relation* domain was the least contributor to the composite wellbeing of EDCs, as the widespread poverty forced most of the people to prioritize their livelihoods and basic family needs over social relations. Sensitivity analysis suggests that the HWI-EDC is robust and internally consistent, which demonstrates its promise and potential applicability in other EDCs contexts worldwide. Besides providing a unique lens for understanding human wellbeing and its determinants, it can open up new avenues for holistic research efforts to assess the development projects and policies in regards to achieving positive wellbeing outcomes for EDCs.

1. Introduction

Ecosystem services make manifold contribution to human wellbeing, especially for many poor and marginalized communities around the world (MA, 2005; Costanza and Liu, 2014; Schröter et al., 2018). Human wellbeing in social-ecological systems emerges and sustains through the complex relationships between the ecosystem service provision and different beneficiaries including local communities (Domptail et al., 2013; Suich et al., 2015). Although enhancing human wellbeing through the effective management of social-ecological systems has been a major development goal in many parts of the world, typically it is based on very general assumptions about the specific features of a good life (Ashton and Jones, 2013; Sachs et al., 2019).

In particular, increasing income is usually perceived to be the main strategy for enhancing human wellbeing, and has become a signature notion of development (Costanza et al., 2007). However, the underlying assumptions of this viewpoint have been challenged on different philosophical, ethical, and practical grounds (Costanza et al., 2007; Layard, 2007). Similarly, many scholars have been arguing that enhancing human wellbeing and achieving sustainability would require the charting of new development pathways amidst the current state of extreme resource degradation, and unsustainable consumption and production patterns in many parts of the world (MA, 2005; Kaczorowska et al., 2016).

There have been many efforts over the past four decades to develop alternative measures of human wellbeing. For example, the Index of

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Sustainable Economic Welfare (ISEW) (Daly et al., 1994), the Genuine Progress Indicator (Kenny et al., 2019), and the Inclusive Wealth Index (Roman and Thiry, 2016). These indices adopted a monetary approach by adding environmental and social dimensions to standard economic measures. Some composite indices[1] have been developed to incorporate different dimensions of human wellbeing most notably the Multidimensional Poverty Index (Alkire and Santos, 2014), the OECD Better Life Index (D'Acci, 2011), the Human Development Index (Anand and Sen, 2000), the Gross National Happiness Index (Daga, 2014), the Wellness Index (Slivinske et al., 1996), and the Composite Global Well-Being Index (CGWBI) (Chaaban et al., 2016). Due to their ability to bring together very diverse indicators representing different aspects of human wellbeing, these composite indices have indeed good potentials to represent this multi-dimensional concept of wellbeing (Nardo et al., 2005, McGillivray and Noorbakhsh, 2007, Chaaban et al., 2016).

However, the composite indices outlined above have been designed for measuring human wellbeing at the national level. Thus, they have relied on quantitative secondary data of "objective" indicators of human wellbeing such as income, wealth, health, education, and environmental status and so on. Moreover, fewer have included indicators of the subjective aspects of human wellbeing (Cox et al., 2010, Daga, 2014, Kenny et al., 2019). In any case, despite their methodological similarities and differences, the high level of aggregation makes their operationalization difficult at local level, especially in highlighting ecosystem contribution to human wellbeing (Bagstad and Ceroni, 2007, Garriga Ricard and Foguet Agustí, 2010).

It has been argued that alternative and context-specific conceptualizations and metrics of human wellbeing can be more appropriate in the context of social-ecological systems especially when there is poverty, high dependence on ecosystem services, and/or extensive ecosystem degradation (Ashton and Jones, 2013, Suich et al., 2015). This is because, on the one hand, the common economic conceptualizations and metrics of human wellbeing do not always adequately represent the characteristics of local communities (TEEB, 2010) including marginalized Ecosystem-Dependent Communities (EDCs)[2]. On the other hand, the generic nature of the above mentioned composite indices lack the ability to represent the specific social-ecological contexts (Stewart, 2005). Thus, despite their general ability to capture multiple dimensions of human wellbeing, such composite indices fail to reflect the many context-specific linkages between ecosystem services and human wellbeing. Furthermore, specific methodological decisions, such as indicator selection, weighing, and normalization in such metrics tend to evoke debates about relative importance across dimensions (McGillivray and Noorbakhsh, 2007, Dolan and Metcalfe, 2012). Such indices are developed by the value-articulating institutions that dictate very specific ways to perceive the study phenomena (Gasparatos, 2010, TEEB, 2010).

The Millennium Ecosystem Assessment (MA) Conceptual Framework promoted a multi-dimensional understanding of human wellbeing in connection with ecosystems and the services they provide. The main elements of human wellbeing encapsulated in the MA conceptual framework are basic materials, health, social relation, security, and freedom of choice and action (MA, 2005). However, there have been relatively few efforts to operationalize this notion of human wellbeing (MA, 2005, Leisher et al., 2013, Barrington-Leigh and Escande, 2018). Furthermore, although the MA framework indeed offers a solid foundation for a multi-dimensional understanding of human wellbeing across different social-ecological contexts, great efforts are needed to develop locally and contextually appropriate tools for consistent operationalization (Carpenter et al., 2009). Several studies have developed composite indices of ecosystem services provision to highlight the dependency on ecosystem services (Yang et al., 2013) at different geographical contexts and scales (Dodds et al., 2013, Alam et al., 2016, Abenayake et al., 2018, Lü and Lü 2021). However, such studies have not made explicit links to the human wellbeing components prescribed by the MA conceptual framework. Some of the very few initiatives to develop composite indices of human wellbeing by operationalizing the MA framework have tended to focus on larger scales such as river basins (Akinsete et al., 2019) or municipalities (Freitas et al., 2007). Few studies have undertaken participatory composite index development at the local level (Pereira et al., 2005), but not necessarily focusing on EDCs. To the best of our knowledge, only a handful of studies have developed such composite indicators in the context of ecosystem dependency, but have either adopted a largely expert driven approach (Yang et al., 2013, Yang et al., 2015a) and/or focused on larger spatial scales using secondary data (Yang et al., 2015b).

Similarly, there have been no efforts to develop composite indices of human wellbeing within the context of EDCs by following the conceptual frameworks of other major ecosystem services initiatives such as The Economics of Ecosystems and Biodiversity (TEEB) and the UK National Ecosystem Assessment (UK-NEA), despite acknowledging the need for values and methodological pluralism to estimate the economic value of ecosystem services (TEEB, 2010, UK-NEA, 2011). Beyond these efforts, there have been some sporadic attempts to develop composite indices of human wellbeing in the context of ecosystem services by adopting other conceptual frameworks of human wellbeing (Villamagna and Giesecke, 2014) or developing generic approaches (Smith et al., 2013). However, these studies have mainly focused on larger spatial scales (e.g. municipality level) and not on EDCs per se.

The above suggests significant gaps in understanding of multidimensional characteristics of human wellbeing for EDCs. This highlights the practical importance of developing robust approaches for assessing the wellbeing of EDCs and the need to consider multiple notions of value and human wellbeing as articulated by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Pascual et al., 2017). Therefore, the aim of this paper is to develop a novel approach for estimating a human wellbeing index for EDCs that takes into account the multi-dimensional nature of their wellbeing. In particular, The HWI-EDC offers a new lens for understanding human wellbeing dynamics and its determinants in social-ecological systems characterized by high ecosystem dependency. The index has potential implications in assessing the human-nature relationships as well as determining adaptability and resilience. Thus, the HWI-EDCs can have significant roles in developing management and policy strategies for sustainable socio-ecological systems.

This paper consists of six sections. Section 2 outlines the structure of the HWI-EDC and the approach used for its development. Section 3 presents the relative contribution of the different human wellbeing domains and indicators on the HWI-EDC and sensitivity test of the index. Section 4 critically discusses the main findings and outlines the potential applications of the composite index. After the conclusion in Section 5, we also described the limitations of the study and made recommendations in Section 6.

2. Methodology

2.1. Conceptual framework

Traditional interface of ecosystem dependency and human wellbeing have mainly focused on the steady flow of ecosystem services (e.g. timber products), to ensure certain economic benefits (e.g. stable employment/income in the timber and non-timber industry) (Uberhuaga et al., 2012; Adam et al., 2013). However, this conception is

[1] Greco et al. (2019) collate a series of definitions for composite index. In this paper we define composite index as the outcome of the process of compiling individual domains "into a single index, on the basis of an underlying model of the multi-dimensional concept that is being measured" (Nardo et al., 2005).

[2] For this paper we define Ecosystem Dependent Communities (ECDs) as those that consist of households *"whose income mostly comes from ecosystems, collect food items, building materials, fuelwoods, and attached to the ecosystems for cultural experiences and identity"* (Newton et al., 2016).

arguably aligned more closely to the social-ecological contexts where formal and market-based livelihoods are dominant (e.g. in urban/peri-urban areas, areas with extensive commercial agriculture or forestry). Conversely, although EDCs maintain some level of formal economic activity, these are relatively minor (Newton et al., 2016; Kibria et al., 2019), as EDCs depend predominately on non-marketable ecosystem services for their livelihoods. This highlights the need to move beyond standard economic metrics of human wellbeing to multi-dimensional concepts of human wellbeing that are context-specific.

In this study, we develop a composite index of human wellbeing for EDCs, named the Human Wellbeing Index for Ecosystem Dependent Communities (HWI-EDC). The composite index consists of five sub-indices across the five distinct domains of human wellbeing of the MA conceptual framework namely (a) basic materials for a good life, (b) health, (c) social relation, (d) security, and (e) freedom of choice and action (Narayan et al., 2000; MA, 2005; OECD, 2013). Fig. 1 and Table 1 outline the structure of the HWI-EDC and its sub-indices. Hence, the HWI-EDC offers essentially a multi-dimensional conceptualization of human wellbeing in EDCs contexts, capturing a wide array of objective and subjective wellbeing indicators (Costanza et al., 2007).

2.2. Study site

The Shyamnagar upazila[3] was selected as our study area due to its geographic location. The upazila is situated just beside the Sundarbans Mangrove Forest and among a network of tidal rivers (Grant et al., 2015) located between 21°36′ and 22°24′ N and 89°00′ and 89°19′ E. The Sundarbans mangrove forest is located in the southwestern region of Bangladesh extending over the Khulna, Satkhira, and Bagerhat districts (Fig. 2).

It is the largest mangrove area in the world and provides multiple ecosystem services to the poor and marginalized communities scattered along its boundary (Iftekhar and Islam, 2004). About 3.5 million people from the surrounding areas rely on the ecosystem services of the mangrove forest which include provisioning services such as timber, medicinal plants, wild food, and fuelwood among others (Salam et al., 2000; Choudhury, 2001; Iftekhar and Islam, 2004). These provisioning ecosystem services are consumed either directly by the households or sold in formal and informal markets locally (e.g. honey, mixed fish) and further away (e.g. crabs, shrimp). Furthermore, freshwater is very important in the region, both for direct consumption and supporting livelihoods (e.g. agriculture, aquaculture) and transport. Beyond the provisioning services mentioned above, the mangrove forest provides various regulating (e.g. protection from storms and cyclones), and cultural ecosystem services (e.g. aesthetic values, knowledge). Considering the high dependency on this vast forest, it is an ideal social-ecological system for developing a human wellbeing index for EDCs.

2.3. Sampling and data collection

The study villages from Shyamnagar upazila were Moukhali, Burigoalini, Gabura, Kalbari, Purbo Kalinagar, Kadamtali, Harinagar, Datinakhali, and Dhankhali. These villages were randomly selected from a complete list of villages in the area obtained from a local office of the Centre for Natural Resource Studies, Bangladesh. These villages were also agreed to be representative of the EDCs found in the region. As described above, most members of these local communities rely on ecosystem services from the Sundarbans forest, agriculture and aquaculture for their livelihoods.

Data collection was undertaken in two stages. During Stage 1, a series of focus group discussions (FGDs) were conducted to (a) identify the relevant domains, indicators, variables, and scores of human wellbeing for the composite index from the list complied through an extensive literature review, and (b) elicit their comparative priority for local communities through Analytic Hierarchy Process (Section 2.4.1). During Stage 2, a household interview was undertaken using a questionnaire (developed from the outcomes of Stage 1) to populate the HWI-EDC (Section 2.4.2).

During Stage 1, the lead author conducted one FGD with males and females in each village. Each group consisted of at least one key informant (usually an elderly person with many years of experience collecting ecosystem services), 2 to 3 ecosystem services collectors and users, and one trader. However, the participation was open to other collectors and village elders. In the FGDs, firstly, they identified the ecosystem goods and services obtained from the forest and described how those contribute to their family wellbeing. Secondly, they identified the most relevant human wellbeing domains and indicators from our pre-developed list. Thirdly, they prioritized these domains and indicators through pairwise comparisons during an Analytic Hierarchy Process exercise. Following the initial identification of indicators, variables, and scores under each domain, all were rephrased in front of the participants to reach a unanimous consensus where the lead author acted as a facilitator whenever necessary. To compare between the domains and indicators, participants were asked to undertake pairwise comparisons between the domains and indicators of human wellbeing using the Analytic Hierarchy Process method. Participants conducted pairwise comparisons, initially among the five domains and subsequently between the indicators of each domain (Fig. 1 and Table 1). During the whole process, participants were asked to work as a team and assign a numerical ranking to represent the importance of each decision (Kurttila et al., 2000; Saaty and Vargas, 2012). A ranking scale of 1 to 9, was used to quantify the comparisons, where scores were as follows: 1 = equally preferred; 3 = moderately preferred; 5 = strongly preferred; 7 = very strongly preferred, and 9 = extremely preferred (2, 4, 6, and 8 were intermediate values between the preferences) (Saaty, 1993). The participants in the same group needed to agree upon the ranking before it was recorded, which sometimes required some iterations and discussions to achieve consensus within the group, which was facilitated by the lead author. The domains, indicators, variables, and scores were subsequently cross-checked with follow-up discussions with elderly villagers, members of local NGOs, and government officials.

During Stage-2, in each village, about 10 households (in total 104 households) were randomly selected and interviewed to gather information to populate each indicator to estimate the HWI-EDC (Section 2.4.2 to 2.4.3). The households were selected following transect walks in each village to ensure the randomization in sampling. In particular, the lead author visited each village and walked or took vehicles to random paths. Our sample households were drawn from the villages of Moukhali (N = 10), Burigoalini (N = 10), Gabura (N = 10), Kalbari (N = 15), Purbo Kalinagar (N = 10), Kadamtali (N = 10), Harinagar (N = 13), Datinakhali (N = 14) and Dhankhali (N = 12). The head of each selected household was interviewed in person.

2.4. Data analysis

2.4.1. Pairwise comparison of domains and indicators

The Analytic Hierarchy Process method is used for evaluating alternatives in a ratio scale; hence, the pairwise comparison value a_{ij} means the ratio of the weights w_i and w_j of alternatives i and j. When the exact weights of all alternatives are already known, each comparison value a_{ij} equals to w_i/w_j exactly. In this case, a pairwise comparison matrix A can be written as shown in Eq. (1):

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \quad (1)$$

[3] Upazilas are the second lower administrative entities in Bangladesh, and functionally act as sub-districts. Upazilas consist of villages.

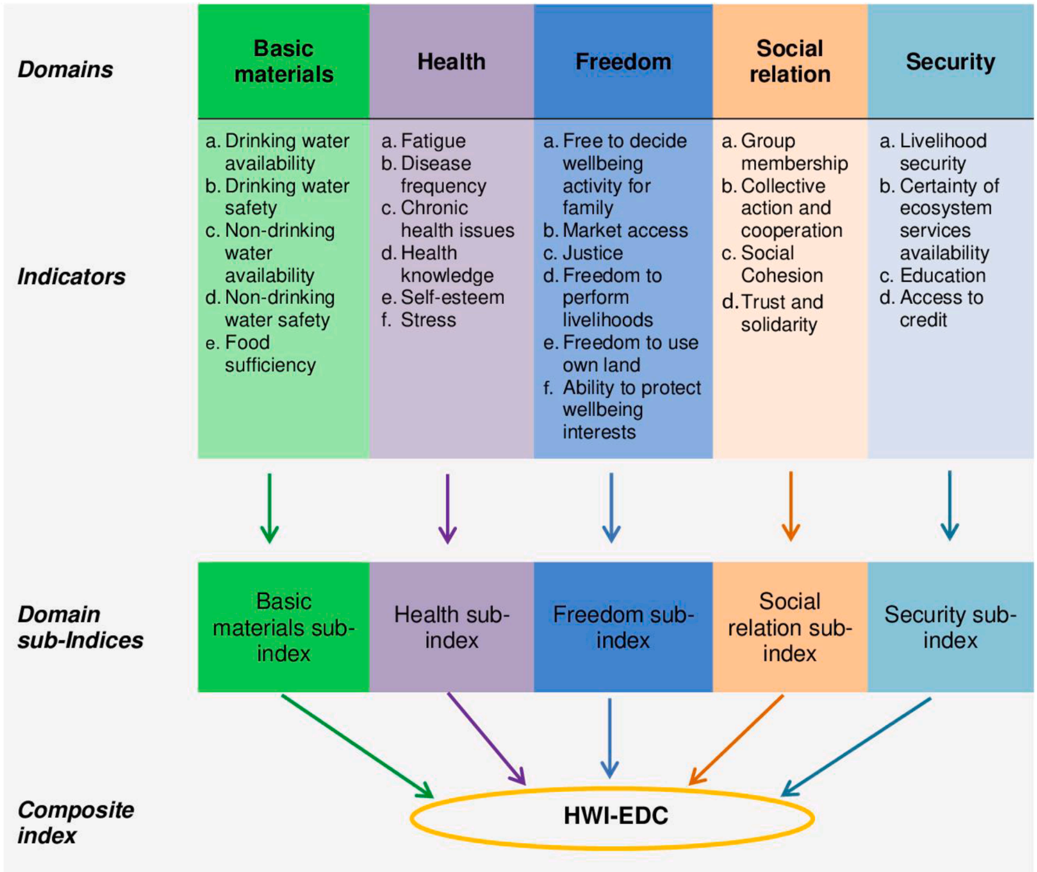

Fig. 1. Conceptual structure of the Human Wellbeing Index for Ecosystem-Dependent Communities (HWI-EDC).

Here, rows represent the ratios of weights of each factor with respect to others (Eq. (1)). In the matrix, when i = j, then $a_{ij} = 1$. If matrix A is multiplied by the transpose of the vector of weights w, we get Eq. (2):

$$Aw = nw \tag{2}$$

Here $w = (w_1, w_2, \ldots\ldots\ldots\ldots w_n)^T$ and n is the number of rows or columns. Hence, Eq. (2) can be written as:

$$(A - nI)w = 0 \tag{3}$$

Here n is also the largest eigenvalue (λ_{max}) or trace of matrix A, and I is the identity matrix of size n.

This situation is completely consistent meaning the rank of A is one. However, in practice, this is often not the case due to inconsistency in responses in pairwise comparisons. Moreover, if the most popular linear scale (e.g. 1/9, 1/7, 1/5, 1/3, 1, 3, 5, 7, 9) is used for a comparison value, it is hardly expected that the comparison matrix would have rank one. Saaty and Vargas (2012) argued that $\lambda_{max} = n$ is a necessary and sufficient condition for consistency. Therefore, matrix A should be tested for consistency using the formula in Eq. (4):

$$CI = \frac{(\lambda_{max} - n)}{(n - 1)} \tag{4}$$

The rating values derived from the comparisons were used to calculate the factor priority and consistency index (CI). During the FGDs, the lead author facilitated the pairwise comparison exercise until all the participants reached the desired consistency index value of a matrix (Section 2.3). One of the critical steps of the Analytic Hierarchy Process is the creation of the comparison matrices. When the number of alternatives increases, more comparisons between alternatives are required that can easily cause excess consistency of the model. Therefore, a consistency check is required for the pairwise comparison matrix (Saaty and Vargas, 2012). The consistency ratio (CR) was used to gauge the general consistency of responses, which is a measurement of the error in response regularity that is considered the maximum acceptable level of error for this type of analysis (Kurttila et al., 2000). If the CR value is less than 0.1 or 10%, the pairwise ranking is acceptable (Kurttila et al., 2000; Saaty and Vargas, 2012). The consistency ratio CR was calculated following Eq. (5) (Saaty, 1993; Saaty and Vargas, 2012):

$$CR = \frac{CI}{RI} \tag{5}$$

Here, CI = Consistency index, RI = Random index generated for a random matrix of order n, and CR = Consistency ratio (Saaty, 1993). Then global priority vectors can be calculated by using the formula mentioned in Eq. (6) (Margles et al., 2010; Kibria et al., 2015):

$$GP = LPD{*}LPI \tag{6}$$

Here, GP = Global priority vector, LPD = Local priority vector of a domain, LPI = Local priority vector of an indicator.

2.4.2. Normalization and aggregation

We developed sub-indices for each of the five domains of human wellbeing with scores ranging on a scale 0 to 1. We used the formula mentioned in Eq. (7):

$$DWI_j = LPD_j{*}\left(\sum_{i=1}^{n} IWI_i\right) = LPD_j{*}\left[\sum_{i=1}^{n}\left(\frac{WS_i}{SV_t}{*}LPI_i\right)\right] \tag{7}$$

Here, DWI_j = sub-index of j^{th} domain (on scale 0 to 1), LPD_j = Local priority vector of j^{th} domain, LPI_i = Local priority vector of i^{th} indicator,

Table 1
Domains, indicators and scores of the Human Wellbeing Index for Ecosystem-Dependent Communities (HWI-EDC).

Domains	Indicators	Variables of the indicators	Scores
Basic materials	Drinking water availability	Scarcity of drinking water during the year	No scarcity throughout the year = VHW = 5 Manageable seasonal scarcity = NHNLW = 3 Unmanageable seasonal scarcity = VLW = 1
	Drinking water safety	Risk of diseases from drinking water	No risk = VHW = 5 Low risk = HW = 4 High risk = VLW = 1
	Non-drinking water availability	Seasonal scarcity of non-drinking water during the year	No scarcity throughout the year = VHW = 5 Manageable seasonal scarcity = NHNLW = 3 Unmanageable seasonal scarcity = VLW = 1
	Non-drinking water safety	Risk of diseases from non-drinking water	No risk = VHW = 5 Low risk = HW = 4 High risk = VLW = 1
	Food sufficiency	Seasonal scarcity of food	No scarcity throughout the year = VHW = 5 Minimal seasonal scarcity = HW = 4 Manageable seasonal scarcity = NHNLW = 3 Major seasonal scarcity = LW = 2 Unmanageable seasonal scarcity = VLW = 1
Health	Fatigue	Self-reported perceived fatigue levels of the household head who collects ecosystem services	Very low fatigue levels = VHW = 5 Low fatigue levels = HW = 4 Neither low nor high fatigue levels = NHNLW = 3 Low fatigue levels = LW = 2 Very high fatigue levels = VLW = 1
	Disease frequency	Frequency experiencing diseases during year	1 to 3 times per year = VHW = 5 3 to 5 times per year = HW = 4 5 to 10 times per year = NHNLW = 3 10 to 15 times per rear = LW = 2 1 to 3 times per year = VLW = 1
	Chronic health issues severity	Self-reported perceived severity levels of chronic diseases that affect the livelihood of the household	Very mild = VHW = 5 Somewhat mild = HW = 4 Neither mild nor severe = NHNLW = 3 Somewhat severe = LW = 2 Very severe = VLW = 1
	Health awareness	Self-reported perceived health awareness levels	High awareness = VHW = 5 Moderate awareness = NHNLW = 3 Low awareness = VLW = 1
	Self-esteem	Self-reported perceived self-esteem levels of the household head who collects the ecosystem services	Very high self-esteem = VHW = 5 High self-esteem = HW = 4 Neither high nor low self-esteem = NHNLW = 3 Low self-esteem = LW = 2 Very low self-esteem = VLW = 1
	Stress	Self-reported perceived stress levels of the household head who collects ecosystem services	Very low stress levels = VHW = 5 Low stress levels = HW = 5 Neither low nor high stress levels = NHNLW = 3 High stress levels = LW = 2 Very high stress levels = VLW = 1
Security	Livelihood security	Perceived level of security of the main household livelihood	Very high security = VHW = 5 High security = HW = 4 Neither high nor low security = NHNLW = 3 Low security = LW = 2 Very low security = VLW = 1
	Certainty of ecosystem services availability	Perceived level of certainty for obtaining ecosystem services from the forest	Very high certainty = VHW = 5 High certainty = HW = 5 Neither low nor high certainty = NHNLW = 3 Low certainty = LW = 2 Very low certainty = VLW = 1
	Education	Level of education attainment of the household head who collects ecosystem services	Bachelor/ Postgraduate = VHW = 5 Higher secondary = HW = 4 Secondary = NHNLW = 3 Primary = VLW = 1

(*continued on next page*)

Table 1 (*continued*)

Domains	Indicators	Variables of the indicators	Scores
	Access to credit	Perceived ease of obtaining a loan from a person/organization	Very easy to get = VHW = 5 Easy to get = HW = 5 Neither easy nor difficult = NHNLW = 3 Difficult to get = LW = 2 Very difficult to get = VLW = 1
Freedom	Freedom to take wellbeing decisions	Perceived level of freedom to choose any wellbeing activity for the household	Very free = VHW = 5 Somewhat free = HW = 4 Neither free nor unfree = NHNLW = 3 Somewhat unfree = LW = 2 Very unfree = VLW = 1
	Market access	Perceived access to markets for selling the collected ecosystem services or farm produce	Very easy = VHW = 5 Somewhat easy = HW = 4 Neither easy nor restricted = NHNLW = 3 Somewhat restricted = HW = 2 very restricted = VLW = 1
	Justice	Perceived level of justice impartiality the households faces	Very impartial = VHW = 5 Somewhat impartial = HW = 4 Neither impartial nor partial = NHNLW = 3 Somewhat partial = LW = 2 Very partial = VLW = 1
	Freedom to perform livelihoods	Perceived level of freedom to perform livelihoods	Very free = VHW = 5 Somewhat free = HW = 4 Neither free nor unfree = NHNLW = 3 Somewhat unfree = LW = 2 Very unfree = VLW = 1
	Freedom to use own land	Perceived level of freedom to use own land for income-generating activities	Yes = VHW = 5 No = VLW = 1
	Ability to protect wellbeing interests	Perceived ability to protect family wellbeing interests	Very capable = VHW = 5 Somewhat capable = HW = 4 Neither capable nor incapable = NHNLW = 3 Somewhat incapable = LW = 2 Very incapable = VLW = 1
Social relation	Group membership	Number of formal and informal groups the household head belong	>4 groups = VHW = 5 3-groups = HW = 4 2-groups = NHNLW = 3 1-group = LW = 2 No group = VLW = 1
	Collective action and cooperation	Likelihood of household members engaging in collective action and cooperation for ecosystem conservation	Very high likelihood = VHW = 5 High likelihood = HW = 4 Neither high, nor low likelihood = NHNLW = 3 Low likelihood = LW = 2 Very low likelihood = VLW = 1
	Social cohesion	Perceived sense of closeness of household members to other community members	Very close = VHW = 5 Somewhat close = HW = 4 Neither close nor distant = NHNLW = 3 Somewhat distant = LW = 2 Very distant = VLW = 1
	Trust and solidarity	Perceived level of trust for helping each other financially in the society	Very high trust = VHW = 5 High trust = HW = 4 Neither high nor low trust = NHNLW = 3 Low trust = LW = 2 Very low trust = VLW = 1

Note: VLW = very low wellbeing = 1, LW = low wellbeing = 2, NHNLW = Neither high nor low wellbeing = 3, HW = high wellbeing = 4, VHW = very high wellbeing = 5.

WS_i = wellbeing score of i^{th} indicator, IWI_i = Wellbeing value of i^{th} indicator, SV_t = the highest value of the scale (for this study the value is 5).

The five sub-indices were then aggregated into a composite index to obtain the final HWI-EDC by using the formula mentioned in Eq. (8):

$$HWI\ of\ EDC = \sum_{j=1}^{N} DWI_j \tag{8}$$

Here, HWI of EDC = Human Wellbeing Index for EDC or HWI-EDC (on scale 0 to 1), and DWI_j = sub-index of j^{th} domain. In this study, we categorized human wellbeing into three types: [a] Low wellbeing (HWI-EDC < 0.50), [b] Moderate wellbeing (HWI-EDC = 0.50 to 0.70), [c] High wellbeing (HWI-EDC > 0.70).

2.4.3. *Sensitivity analysis*

We conducted a sensitivity analysis to test the robustness of the composite index. Such analysis would improve the accuracy, credibility, and interpretability of final results, and thereby minimize the risks of producing a misleading wellbeing index (Tate, 2012). There are multiple methods to conduct sensitivity analysis for composite indices (Saisana et al., 2005), but in this paper, we determined the significantly contributing factors and then performed stepwise regression modelling. In this approach, a multiple linear regression model was fitted to the data in an iterative fashion.

The procedure starts with the variable that explains most of the variation in the model response, and it then adds additional variables one at a time, in order of their influence on the response to maximize the

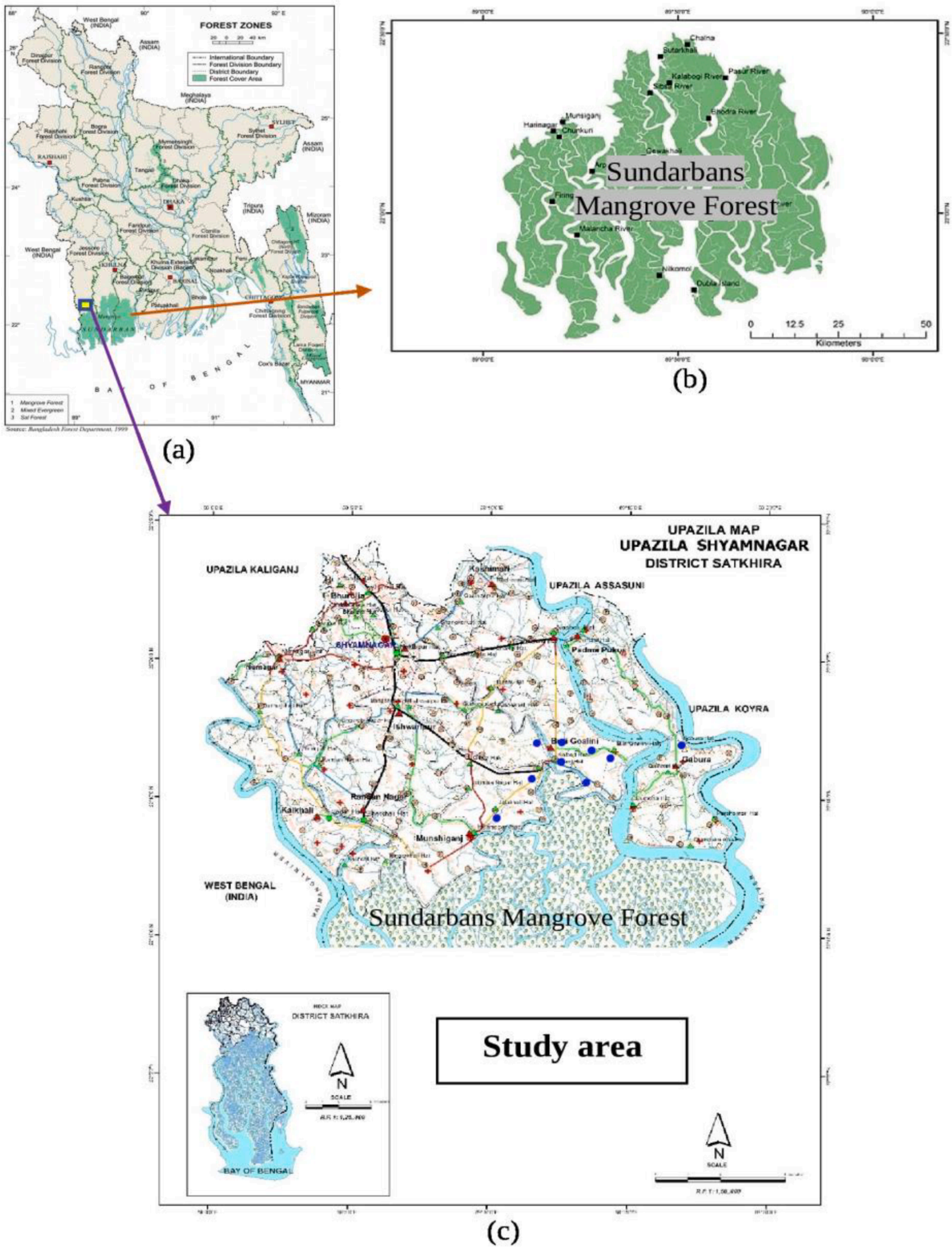

Fig. 2. The Sundarbans forest and study site. (Panel: (a) indicates the forest zones of Bangladesh (Bangladesh Forest Department, 1999) cited in (Roy et al., 2013); (b) indicates the Sundarbans mangrove forest (Hossain et al., 2015); and (c) indicates the Shyamnagar upazila in Satkhira district, with the study villages marked in blue dots (LGED, 2017)).

improvement in model fit (Rickwood and Geneviève, 2007; Salciccioli et al., 2016). A Variation Inflation Factor (VIF) identified multi-collinearity among the independent variables. We assumed an acceptable VIF value to be <5 based on the suggestions made by many researchers in their papers (Craney and Surles, 2002; Rogerson, 2011; Vu et al., 2015; Kibria et al., 2018).

3. Results

3.1. Weights of composite index components

Fig. 3a presents the priorities of different domains of the human wellbeing. The domain with the highest effect on human wellbeing was *freedom* (49%), followed by *health* (20%), *basic materials* (17%), and *security* (11%). The *social relation* had surprisingly the least effect (4%) on the total wellbeing score. The high priority assigned to the "freedom

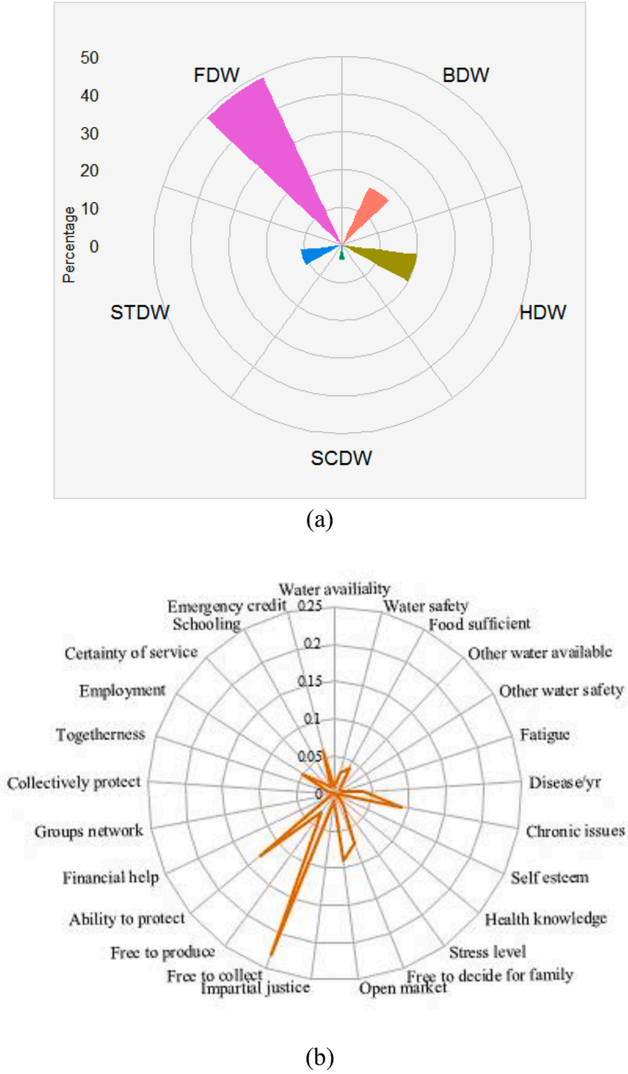

Fig. 3. Overall or global priorities of (a) domains and (b) indicators of human wellbeing. (Note: FDW = Wellbeing of domain *Freedom*, BDW = Wellbeing of domain *Basic materials*, HDW = Wellbeing of domain *Health*, STDW = Wellbeing of domain *Security*, SCDW = Wellbeing of domain *Social relation*).

to collect ecosystem services" implies the huge importance of ecosystem services in human wellbeing development in the study area. All the respondents were engaged in collecting provisioning services (e.g. honey, fish, fuelwood, timber, nypa leaf) to meet their basic needs. Security in their livelihoods was essential for the collectors to continue their livelihood activities, get sufficient access to the ecosystem services, improve the ability by education, and ensure financial credit for the initial investment. Pirate's attack deep inside the forest was reportedly common where profitable ecosystem services were also available. Villagers who had some education led the group formation for ecosystem services collection. They were also likely to have better access to credits from multiple sources. Lack of financial and social security restricted many collectors to decide their livelihood activities and harvesting profitable resources. Social relation was important for those who wanted to collect profitable ecosystem services, as harvesting those ecosystem services required strong teamwork. Close connections with fellow villagers, high trust relations, collaborations, and engagement in various institutions (formal or informal) allowed people to be engaged in more profitable livelihood activities. However, many households were not able to join the team to collect the profitable ecosystem services because of health and financial limitations. Therefore, maintaining good social relations extensively in their society was not a priority for all.

Fig. 3b shows the overall or global priorities of the indicators in their wellbeing composition. The five most important indicators affecting human wellbeing were freedom to collect ecosystem services (0.23), ability to protect against threats (0.13), market openness (0.09), chronic health issues within the family (0.09), and freedom to take decisions (0.07). The remaining indicators had very low overall priorities (<0.05) for their wellbeing. Freedom to collect ecosystem services was the highest priority, as it was the key to their income and food security. The ability to protect their interests from any threats was also important to continue the activities for their wellbeing. Profit from any collected ecosystem services or agricultural produce was subjected to the existing market conditions. Hence, they showed high overall priority to the market openness for their wellbeing. The same level of priority was also found for chronic health issues in their families. The household heads were not able to stay out of their house for a longer period, if there was someone in the family chronically ill. Hence, they struggled to maintain a steady income and manage the treatment costs. Despite the freedom of collecting ecosystem services many respondents also mentioned that freedom to decide what is best for their wellbeing was also a priority for maintaining greater wellbeing.

3.2. Scores of the composite index and sub-indices

The aggregate score of the HWI-EDC was found 0.66 on a 0 to 1 scale. This implies that on aggregate the surveyed households had moderate level of wellbeing. However, given the very aggregate nature of this score it is important to look deeper into the specific sub-indices (Fig. 1 and Table 2).

The *basic materials* sub-index accounted for 0.127 of the overall HWI-EDC and was primarily determined by drinking water safety (0.278) and food sufficiency (0.232). This reflects the crucial roles of clean drinking water and food in shaping the community wellbeing. Ensuring enough clean drinking water for their families was prioritized over food sufficiency, as the water in the rivers and streams was brackish i.e. it was harder to get clean drinking water (Table 2). However, people mentioned that food insecurity was one of the main reasons why they depend on the Sundarbans forest (food or income to buy food). For example, a fisherman from Jelepara, Shyamnagar said:

> "*Although we catch fish, we don't eat the best ones. It is for the richer people. From a catch, we sell the big or high-priced fish as they are profitable, and the smaller or low-priced fish we keep for family consumption. Money is more important to us than eating tastier food.*"

Clean and safe drinking water collection was a major daily activity in the study area. Some of them had their own water-well but the majority of the people were dependent on the common reserves such as ponds, common wells, which were not generally clean, and posed risks of waterborne diseases. At the same time, most households needed a substantial amount of water for other domestic activities such as cleaning, washing, irrigation, and livestock rearing. They were mostly dependent on the rivers and streams (brackish water) and village ponds (sweet water). Many households were not able to access the sweet water ponds due to long distance from their houses. This suggests that rather precarious access to drinking and non-drinking water, which greatly influenced the HWI-EDC as a whole.

The score of the *health* sub-index was 0.156, which was dominated by the effect of chronic health issues, as respondents were very careful in maintaining their livelihoods and avoiding long-term treatment costs. This reflects the general lack of social safety nets in the study area. Aspects linked to mental health contributed less to the overall sub-index compared to the issues related to physical health (Table 2). This reflects the fact that respondents generally had to spend a substantial amount of time in agricultural activities or harvesting ecosystem services, and therefore, they were prone to injuries, diseases, and hazards.

Table 2
The HWI-EDC and domain sub-indices.

Domains and indicators	Local priority vector	Wellbeing score (0 to 5)	Wellbeing index (0 to 1)	HWI-EDC (0 to 1)
Basic materials	***0.168***		***0.127***	0.66
Drinking water availability	0.060	4.880	0.057	
Drinking water safety	0.320	4.350	0.278	
Food sufficiency	0.420	2.790	0.232	
Non-drinking water availability	0.080	5.000	0.082	
Non-drinking water safety	0.120	4.330	0.107	
TOTAL			*0.756*	
CR (%)	*5.217*			
Health	***0.197***		***0.156***	
Fatigue	0.070	3.050	0.040	
Disease frequency	0.240	3.620	0.174	
Chronic diseases severity	0.520	4.850	0.501	
Self-esteem	0.030	3.240	0.016	
Health awareness	0.040	2.180	0.019	
Stress	0.110	1.960	0.043	
TOTAL			*0.793*	
CR (%)	*8.831*			
Freedom	***0.486***		***0.295***	
Freedom to decide livelihoods	0.120	3.620	0.087	
Market access	0.160	4.980	0.155	
Justice	0.020	1.000	0.005	
Freedom to perform livelihoods	0.420	2.500	0.209	
Freedom to use own land	0.050	5.000	0.049	
Ability to protect family	0.240	2.170	0.102	
TOTAL			*0.606*	
CR (%)	*7.862*			
Security	***0.114***		***0.068***	
Livelihood security	0.370	3.140	0.230	
Certainty over ecosystem services	0.140	4.000	0.114	
Education	0.050	1.125	0.016	
Access to credit	0.440	2.640	0.235	
TOTAL			*0.594*	
CR (%)	*6.439*			
Social relation	***0.035***		***0.018***	
Trust and solidarity	0.440	2.390	0.213	
Group membership	0.100	1.910	0.040	
Collectively action and cooperation	0.080	3.340	0.051	
Community cohesion	0.380	2.900	0.218	
TOTAL			*0.521*	
CR (%)	*3.386*			
CR (%) of subjective evaluation about domain	***6.237***			

Note: CR = Consistency ratio.

Some participants reported that major chronic physical health issues for the ecosystem services collectors (or their family members) prevented them from venturing far from the village, which often compromised the profitability of ecosystem services collection. One male collector in Kalbari, Shyamnagar said:

> "*My wife has severe migraine and some mental problems, so I can't stay out of the house for several days to collect profitable resources. For this reason, I collect within a distance from where I can come back daily.*"

At the same time, several respondents also stated that they (or other community members) spent a portion of their spare time besides the rivers or forests, which might have contributed to reducing the stress or anxiety caused by the precarious nature of their livelihoods and their poor economic conditions. Many village tea stalls and stationery shops were built along the rivers around the forest where people spent time with other community members. These places essentially acted as hubs of social interactions which facilitated building social relations between community members, and consequently having positive effects on health and social relation.

The score of the *freedom* sub-index was 0.295 and had comparatively the largest contribution (0.61) to the overall HWI-EDC largely due to its high weight. The biggest value (0.209) to the domain sub-index was added by the freedom to perform livelihood activities followed by market access (0.155), ability to protect any threats to their livelihoods and wellbeing (0.102), free to make decisions (0.087), free to grow agricultural produce (0.049), and the existence of impartial justice system (0.05) (Table 2). It is interesting to note the effect that poverty plays for some of the domains in this sub-index. Poor households were less likely to get justice for any conflict. It was repeatedly mentioned that "*…the richer are powerful and often can secure justice in Somaj (informal village legal body).*" The household who failed to position themselves within the power structure, gradually their opportunities for the profitable collection were diminished. The wealthier families had greater social and economic capacities to overcome the challenges for maintaining their wellbeing activities.

The *security* sub-index also contributed relatively little (0.068) to the overall HWI-EDC. This is partly because there was less uncertainty in the livelihood activities they were engaged in and the ecosystem services they collected. The capital required for conducting the activities was also fairly easily available from traders or microfinance organizations with interests. The schooling level of household heads or their children was costly for those predominantly poor communities. Hence, the priority of *security* as a wellbeing domain was one of the least influencing factors for their wellbeing. This domain of wellbeing was primarily created by the access to emergency credit (0.235), and livelihood security (0.230) (Table 2). Credit availability at the time of need was crucial to secure the position in a collection group by sharing the cost of the activities. The remoteness of the natural ecosystems also made their livelihood endeavor a constant battle against natural disasters, communal conflicts, pirate's attack, and wild animals, and so on.

The *social relation* sub-index was the least contributor to the overall HWI-EDC (0.018), mainly due to the lowest priority (0.035) among all the sub-indices. The highest contribution of this sub-index came from social cohesion (0.22), followed by trust and solidarity (0.21), collective action and cooperation (0.05), and groups and networks (0.04) (Table 2). Greater social cohesion assisted people to engage in more group activities to increase profitable ecosystem services collection. Trust among community members was very important in this context of high dependence on ecosystem services, as it was an important contributing factor for improving social bonds among community members (especially those less fortunate) to facilitate group formation for enhancing the profitability from the ecosystem services collection. Collecting ecosystem services alone was not only less profitable, but also more dangerous due to the harsh conditions of the mangrove forest, as well as the possibility of pirate's attacks, injuries, and attacks by animals. Collective action mediated the values, rules, norms, and forms of natural resource utilization among community members. Although there were formal and informal rules in place, local resource users often violated those for their own profit. However, those actions assisted in reducing the conflicts for competing resource collection. These elements of social relation facilitated information sharing about ecosystem service availability and harvesting techniques. Thus, higher social relation increased their family income, food security and social harmony, and thereby enhanced their wellbeing. For example, a respondent from Moukhali village expressed frustration for low social relation which was echoed by many households during in person interview as follows:

> "*I don't have enough money to join a group. Nobody gives me money thinking that I would not be able to pay them back. Some groups had*

people I don't like. Therefore, I collect resources on my own. Very rarely, I can go with a group. So, I earn less. "

3.3. Sensitivity analysis

Fig. 4 represents the relations of the sub-indices for each domain of human wellbeing with the HWI-EDC. All the sub-indices had significant correlations with the HWI-EDC of the EDCs. This demonstrates that all the domains individually played roles in composing HWI-EDC. Although a domain might affect the HWI-EDC in both positive and negative ways, each domain, as a whole, had a positive influence on the composite wellbeing of EDC.

Table 3 demonstrates the sensitivity of the composite index in regards to the sub-indices. The results show the method presented in this article creates a consistent model between the dependent variable (HWI-EDC) and independent variables representing four of the five sub-indices for basic materials, social relation, freedom, and security. This confirms that the HWI-EDC is indeed a robust index in the specific study context. In this model, the only variable that was excluded is the sub-index for health, as the stepwise regression model only considers the best fit variables i.e. the variable has the $p < 0.05$. In Fig. 4 it is also found that the health sub-index had a weak correlation with HWI-EDC.

4. Discussion

This study developed a composite wellbeing index for EDCs (HWI-EDC) by following a participatory approach that operationalized the MA conceptual framework of human wellbeing across its five domains namely- basic materials for a good life, health, good social relation, freedom of choice and action, and security (MA, 2005). For each domain, we developed a sub-index that included objective and subjective indicators (Barrington-Leigh and Escande, 2018; Sachs et al., 2019). In developing the sub-indices and the composite index, the priority of each domain and indicator was taken into account as elicited through an Analytic Hierarchy Process exercise in FGD settings. Subsequently, through a household survey, we collected primary data from 104 households to populate the HWI-EDC and estimated the index at the household level. Thus, the composite index was developed through a participatory approach which represents the human wellbeing of EDCs in a comprehensive manner.

On aggregate, the HWI-EDC had a score of 0.66 on a 0 to 1 scale, i.e. overall, the EDCs had a moderate level of wellbeing. At the sub-indices levels, the *Freedom* sub-index had the highest effect and the *Social relation* sub-index had the lowest effect on total wellbeing. The *Health*, *Basic materials,* and *Security* sub-indices contributed less to the overall wellbeing. Generally, the need for basic materials is reportedly the most important aspect of wellbeing among EDCs in different parts of the world (Belcher et al., 2015; Rasmussen et al., 2017), but our study found that the *Freedom* domain contributed the most to human wellbeing. The large contribution of the *Freedom* also reflects the findings from many other regions of the world stating that the institutional and political power to gain access to the various socio-economic capitals is essential for maintaining the freedom to sustain the livelihoods of local EDCs (Bebbington, 1999; Thulstrup, 2015; Berbés-Blázquez et al., 2017; Minh et al., 2020). The *Social relation* was the least contributing domain on overall wellbeing which is aligned with previous studies reporting that social capital often has a low or sometimes negative effect on wellbeing of the rural marginalized people (Ding et al., 2018; Xu et al., 2019).

We found that only the scores of wellbeing domains and indicators on a Likert scale did not predict human wellbeing accurately unless the priorities for the domains and indicators were taken into account. Traditional wellbeing indices use transformed wellbeing scores without

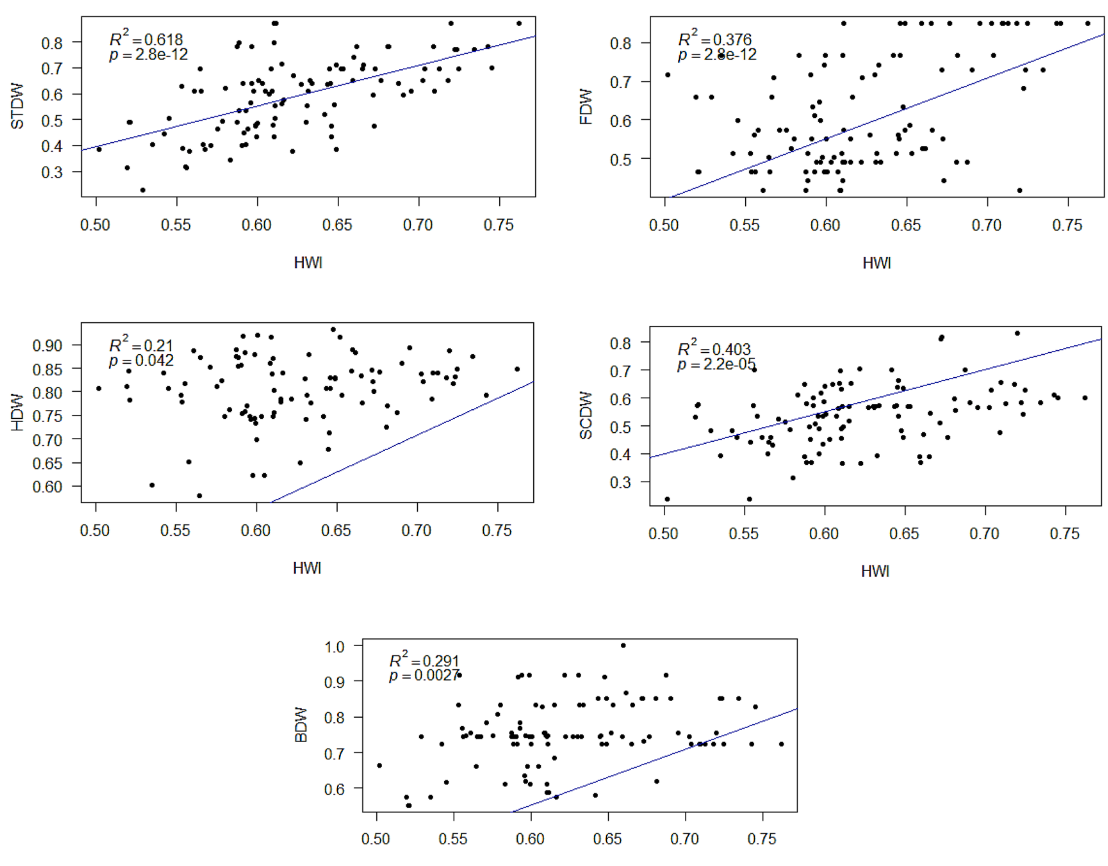

Fig. 4. Relations between sub-indices and the HWI-EDC at the household level.

Table 3
Stepwise regression analysis of the HWI-EDC and sub-indices.

Model[§]		Unstandardized Coefficients		t-value	Sig.	Collinearity Statistics	
		B	Std. Error			Tolerance	VIF
1	(Constant)	0.466	0.021	22.740	0.001		
	Security	0.054	0.007	7.965	0.001	1.000	1.000
2	(Constant)	0.340	0.022	15.455	0.001		
	Security	0.055	0.005	10.690	0.001	0.999	1.001
	Freedom	0.040	0.005	8.176	0.001	0.999	1.001
3	(Constant)	0.213	0.019	11.438	0.001		
	Security	0.056	0.003	16.331	0.001	0.999	1.001
	Freedom	0.041	0.003	12.827	0.001	0.997	1.003
	Social relation	0.045	0.004	10.936	0.001	0.998	1.002
4	(Constant)	4.710E-017	0.000	0.000	1.000		
	Security	0.050	0.000	246,719,032	0.000	0.968	1.033
	Freedom	0.050	0.000	256,591,275	0.000	0.919	1.089
	Social relation	0.050	0.000	206,092,393	0.000	0.983	1.017
	Basic materials	0.050	0.000	162,530,589	0.000	0.881	1.135

Note: [§]*Dependent variable HWI-EDC.*
Model-1: R^2adj.-value = 0.402, p-value = 0.001.
Model-2:R^2adj.-value = 0.651, p-value = 0.001.
Model-3: R^2adj.-value = 0.849, p-value = 0.001.
Model-4: R^2adj.-value = 0.999, p-value = 0.001.

considering the priority of the domains and indicators (Anand and Sen, 2000; Bates, 2009; Daga, 2014). This can potentially misrepresent the wellbeing, as the high wellbeing score on a certain scale (e.g. 1 to 5 scale) for a person may not mean equal to another person due to their different levels of the priorities for the particular domain and indicator (D'Ambrosio and Frick, 2012; Kim et al., 2015; Greco et al., 2019). We have applied the Analytic Hierarchy Process method to overcome the challenge, hence our method offers a more comprehensive estimation of human wellbeing.

The sensitivity analysis revealed that despite the stepwise regression, the model outcomes showed no significant changes. This demonstrates that the proposed index is robust and internally consistent in the context of the specific application. This suggests that our HWI-EDC is capable of measuring the multi-dimensional human wellbeing of EDCs in a robust manner and shedding light on the trade-offs between the wellbeing domains which would be crucial for identifying the ways to enhance the resilience of EDCs against environmental change (Copeland et al., 2020).

We believe that the HWI-EDC, and similar approaches, could assist in answering three key questions for the sustainable management of social-ecological systems: (a) What shapes long-term human wellbeing trends for EDCs and ecosystem services extraction? (b) What are the key human wellbeing trade-offs for EDCs in relation to the natural environment and the ecosystem services it provides? (c) How does human wellbeing (and its change) determine the adaptability, vulnerability, and resilience of EDCs in the contexts of environmental change?

5. Conclusion

This paper started from the axiom that human wellbeing is a multi-dimensional concept and that its current measures are not capable enough to estimate it appropriately for EDCs who are highly reliant on ecosystem services. Thus, this research is sought to provide a novel lens for estimating the human wellbeing of EDCs through the development of a multi-dimensional composite index (HWI-EDC) that operationalized the MA framework. In particular, we developed and applied the proposed framework through a bottom-up participatory approach in the mangrove social-ecological systems of the Sundarbans forest in Bangladesh. Beyond identifying the wellbeing of the studied EDC, we explored the validity of the method and identified possible methodological challenges and future research directions.

The analysis suggests that the index is robust and internally consistent in the context of the specific case study, which demonstrates its promise and potential for application in other sites. Comparative studies spanning major socio-ecological systems and different time periods can offer a better glimpse of complex relations between the factors affecting the human wellbeing of EDCs. The proposed framework can potentially contribute to designing and monitoring the development projects and policies, and thereby positively influence the wellbeing outcomes of sustainable development interventions for EDCs. However, even though the general approach should be readily applicable in other contexts, the specific elements would most likely need to be tailored to reflect different ecological, socioeconomic realities and needs through participatory processes.

6. Limitations and lessons learned

Despite its wide scope and robustness, we identified the HWI-EDC has three key challenges. First, this composite index has been developed for EDCs who are highly dependent on ecosystem services for their livelihoods, culture, and identity. Hence, its application might be less effective in the social-ecological systems where local livelihoods exhibit high levels of heterogeneity within the local community (i.e. between community members). Further applications of the HWI-EDC would be needed in other similar social-ecological systems around the world, in order to test its universality. Second, while the general development approach should be readily transferable in other contexts, the research team has to have an ample understanding of the local contexts. There would also be a need for reaching consensus when identifying the domains/indicators and eliciting the weights, which would require an inclusive participatory process that would allow participants to contribute freely. These social aspects could create challenges and demand more resource requirements. However, it might be possible to save time and resources by revising the domains and indicators through in-depth discussions with local experts before undertaking the participatory exercise with the local communities (Cinner et al., 2009; Speranza et al., 2014). Third, the "rank reversal" problem may arise. This is a common methodological challenge in pairwise comparisons, referring to changes in the order of the judgment alternatives after adding a new alternative (Barzilai and Golany, 1994). This would require careful planning, extensive field observations, and preliminary discussions to decide the conceptual framework for domains and indicators of the composite index.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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