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ORIGINAL ARTICLE

Change in Structural Components Due to Seasonal Flooding Governs Provisioning Ecosystem Service Delivery and Livelihood Diversification: A Case Study from a Tropical Floodplain Wetland in Barak Valley Region of India

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Abstract

Annual flood events lead to periodic changes in structural components within seasonal floodplain wetlands. Such change in structural components may determine the type and quantity of provisioning ecosystem services (ES) that offer resident communities opportunities for diverse livelihood activities. We elucidate this hypothesis using the case study of a seasonal floodplain wetland—Chatla—located in Assam, northeast India, by integrating spatially explicit data of structural components of the wetland with social-ecological information following standard methods. The structural components of Chatla during dry and wet seasons were mapped using LANDSAT 8 satellite data. The provisioning ES was quantified and the corresponding economic value was estimated through household- and market surveys. About 51% of Chatla remained inundated during the wet season, which served as a capture fishery source for the riparian communities. Only 6% of the wetland area retained water during the dry season, supporting culture fishery, while a substantial area was brought under paddy cultivation. Both fishery and paddy cultivation served as the major source of income for riparian households. In addition, various non-timber forest products (NTFPs) harvested from the wetland were used for subsistence during both seasons. The total annual value of provisioning ES in harvesting paddy, fish, NTFPs, and soil extraction was estimated as USD 387,487. Our study confirms that the change in structural components of the wetland driven by the annual flooding ensures the delivery of provisioning ES that facilitates livelihood sustainability. We suggest that national and international policies focus on the conservation and wise use of such seasonal wetlands to ensure a sustainable future for the wetland-dependent population in the tropics.

Keywords Ecosystem services · Economic valuation · Structural components · Livelihood sustainability

1 Introduction

Wetland ecosystems comprising bogs, fens, swamps, marshes, floodplains, and lakes are among Earth's most productive ecosystems. Covering only 6% of the earth's surface, the global inland and coastal wetland area is estimated as 12.1 million km^2, an area almost as large as Greenland (Ramsar Convention on Wetlands 2018). Of these 12 million km^2 areas covered by diverse wetland types, 46% can be grouped under seasonal wetlands such as marshes, floodplains, and intermittent wetland/lakes (Ramsar Convention on Wetlands 2018). Davidson et al. (2019) reported that wetlands deliver ecosystem services (ES) worth $47.4 trillion per year. This value accounts for 43.5% value of all natural biomes, exceeding the contributions of terrestrial forests. The 2021 Global Wetlands Outlook highlighted that globally the well-being and livelihood of four billion people are dependent on wetland ES. In developing countries, wetland ES are the only source of livelihood for the poor (WMD et al. 2009). In this regard, the provisioning ES i.e., tangible products such as food, fodder, fuel wood, timber, fiber, and water, harvested

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directly from the wetlands, significantly contributes to the rural economy (Ramsar Convention Secretariat 2007). Provisioning ES provide immediate returns either in cash or use (Hartel et al. 2014; Bhatta et al. 2016). Floodplains covering ~ 2 million km^2 (Sutfin et al. 2016) and accounting for ~ 1.4% of the global land surface area contribute to more than 25% of all the terrestrial ES (Tockner and Stanford 2002). Nevertheless, most of the seasonal wetlands in the floodplains are not included under the standard protected area format, though they tenably play important ecological and socio-economic role (Downing 2010; Blackwell and Pilgrim 2011; Van Meter and Basu 2015). The general perception is that large permanent wetlands and lakes provide the bulk of the services compared to the smaller seasonal ecosystems (Schwartz and Jenkins 2000; Downing et al. 2006; Adekola et al. 2012). Therefore, national and international policies emphasizing conserving larger, permanent wetlands/lakes ensuingly downplays the potential ecological and socio-economic role played by the seasonal wetlands located mostly amidst the human-dominated landscapes (Downing 2010; Blackwell and Pilgrim 2011; Van Meter and Basu 2015; Biggs et al. 2017). Local communities have been dependent on seasonal wetlands (Tockner and Stanford 2002; Wantzen et al. 2008; Adekola et al. 2012; Sarkar et al. 2020). However, expansion of cities, construction of roads, buildings, dams & dikes, modification of river channels, over-exploitation of wetland resources, and conversion to agriculture or other land use types have contributed to the degradation and shrinkage of such wetlands, particularly in the tropics (Tockner and Stanford 2002; Hamilton 2009; Sakane et al. 2011; Tomaselli et al. 2012; Mwita et al. 2013; Rogger 2013). Consequently, the health and well-being of the dependent communities are potentially compromised, pushing them further towards "socio-economic bankruptcy" (MEA 2005), where a wetland-dependent socio-economy heavily suffers due to dwindling wetland resources. Such a scenario of a resource-bankrupt society can potentially disrupt a nation's overall sustainability and economic growth, thus highlighting the importance of their conservation (Kapur 2016). Therefore, it is essential to improve our understanding of the role of seasonal floodplain wetlands in providing economically valuable provisioning ES in the form of harvestable goods that ensures sustainable livelihood for the wetland-dependent communities. Here, sustainable livelihood refers to the ability to resist and deal with the harsh and seasonally changing environment (Wantzen et al. 2008), which minimizes livelihood risks and maximizes the benefits offered by natural ecosystems. Considering the high human dependency on provisioning ES and direct contribution of provisioning ES on livelihood sustenance, in particular in developing countries (Adekola et al. 2012; Hartel et al. 2014; Bhatta et al. 2016; Sarkar et al 2019; Sarkar et al 2020), the present study focused on assessing the contribution of the provisioning ES only.

We hypothesize that periodic change in structural components in seasonal wetlands driven by annual flood events determine the provisioning ES type and quantity, providing opportunities for practicing diverse livelihood activities. We elucidate this hypothesis using the case study of a seasonal floodplain wetland located in the Barak River basin of Northeast India. The specific objectives of this study were to (i) assess the different structural components of the wetland during the dry and wet seasons, (ii) quantify the provisioning ES of the wetland available during dry and wet seasons, and (iii) estimate the equivalent economic values of the wetland provisioning ES for both the seasons.

2 Methods

2.1 Study Area

The present study was conducted in Chatla—a seasonal floodplain wetland in the Barak River basin of Assam in northeast India (Fig. 1). Topographically, Chatla is a fenland dotted with varied structural components, such as numerous water bodies, and hillocks within it, covering an area of 1600 ha (Kar et al. 2008). Chatla is connected by small inlet tributaries, namely, Jalengachhara, Baluchhara, and Salganga, and an outlet tributary, i.e., river Ghagra, drains into river Barak from the northern boundary of the wetland. River Barak is a part of the Surma-Meghna river system, a river complex in the Indian subcontinent.

Chatla retains water from April to October, representing pre-monsoon to post-monsoon seasons, and appears like a lake. However, it experiences a dry phase from November to March, representing winter to the beginning of the pre-monsoon season. The total rainfall during the study period varied from 2121 to 2228 mm, while the total rainfall during the flooding phase (April to October) ranged between 2093 and 2190 mm. The average atmospheric temperature varied from 20 to 32 °C, and relative humidity varied from 51 to 76%. Chatla wetland is dominated by tree species such as *Barringtonia acutangula* (L.) Gaertn, *Lagerstroemia speciosa* (L.) Pers., *Vitex negundo* L. and grasses such as *Chrysopogon zizaniodes* (L.) Nash, and *Saccharum ravennae* (L.) L. About 52 villages are located on numerous hillocks within the wetland as well as at a varying distance from the wetland periphery (Rao and Purakayastha 2003). For generations, most of the communities residing in these riparian villages have depended on the various wetland resources for their livelihood sustenance (Plate 1).

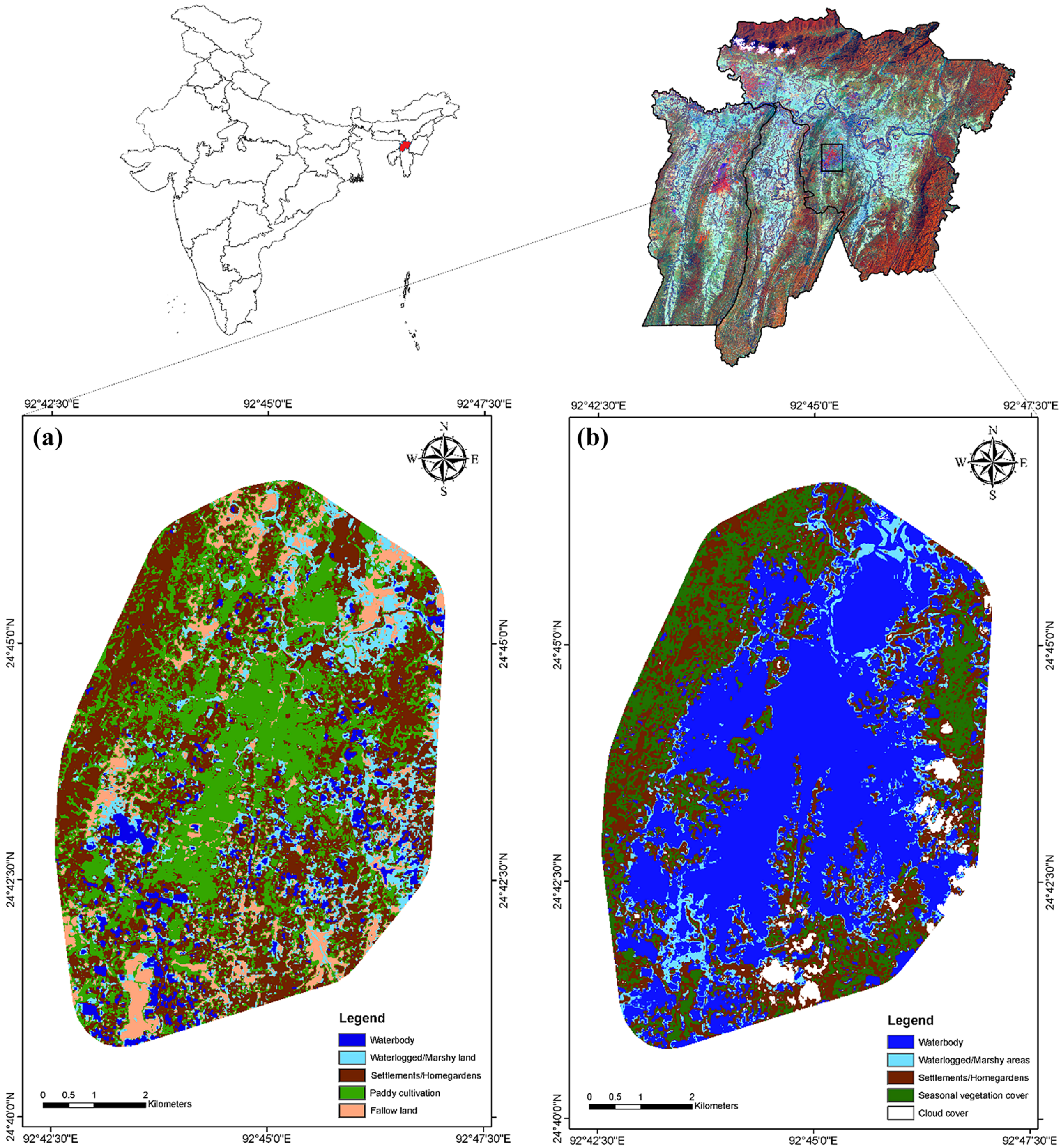

Fig. 1 Variations in structural components of Chatla wetland during dry **a** and wet **b** seasons

2.2 Methodological Approaches

In the present study, we used two methodologically contrasting albeit complementary approaches involving the use of (i) spatially explicit data of the different structural components of wetland area derived from satellite images for the study period, and (ii) social-ecological information obtained through household- and market surveys conducted in and around the wetland (Plate 2a, b).

Plate 1 Photographs representing utilization of various provisioning ES delivered by Chatla wetland by the riparian communities (where, **a**—paddy cultivation during dry season; **b**—culture fishery during dry season; **c**—capture fishery during wet season; **d**, **e**, **f**—extration of fuelwood, fodder, and sand; **g**, **h**—utilization of wetland soil in plastering of house and preparing pottery items; **i**—display of handicraft item prepared using wetland products)

2.2.1 Mapping of Different Structural Components

We mapped and estimated the area under different structural components of Chatla for its dry and wet phases using Landsat 8 satellite data. Satellite images of the study area (Path 136/Row 43) for March (dry phase) and October (wet phase) for the year 2014 were downloaded from the United States Geological Survey (USGS) website (http://landsatlook.usgs.gov). False-color composite (FCC) images for the dry and wet seasons were generated by combining the bands 5, 6, and 4 in red, green, and blue (RGB) format. The composite images (~ 30 m pixels) were then re-sampled to a spatial resolution of ~ 15 m using a panchromatic image (Band 8) of the same area from the Landsat 8 product bundle. Ancillary data, namely administrative boundary files of Barak valley, particularly the Cachar, Karimganj, and Hailakandi districts, were downloaded from www.divagis.org. The geographical boundary of Chatla and its adjoining areas were generated by drawing a convex polygon by connecting the GPS (Global Positioning System) coordinates of the outer

Plate 2 Photographs showing household survey (**a**), market survey (**b**), and collection of GPS coordinates for preparation of study area map (**c**) in Chatla wetland

peripheral villages. A buffer of 1 km was added to the polygon to include a small portion of the catchment of Chatla. The area of interest (AOI) was extracted from the re-sampled image using the polygon. To map different structural components of the wetland, we first grouped the elements under different arbitrary classes using an unsupervised classification approach. Here, the ISO (Iterative Self-Organizing) data clustering algorithm was run to generate 50 unsupervised classes of the various structural components of Chatla. These classes were later grouped under five major classes of structural components through on-screen image inspection. Inspection of the image to identify different structural components of Chatla were done by super-imposing the map on the Google Earth image. Also, extensive field surveys were conducted in the study area (Plate 2c) during the dry- (March 2014) and wet phases (October 2014). The GPS coordinates for the major structural components existing during the corresponding period were recorded for on-screen image inspection as well as for accuracy assessment (Fig. 2). Accuracy assessment of the maps for two seasons were done using a theoretical error matrix. The overall classification accuracy was calculated as:

$$\text{Overall classification accuracy} = \frac{\text{Number of correct points}}{\text{Total number of points}}. \tag{1}$$

2.2.2 Household Surveys for Identification and Quantification of Provisioning ES

Initially, reconnaissance surveys were conducted to understand the resource-use pattern and the socio-economic conditions of the communities residing in the riparian villages of Chatla. Based on the reconnaissance surveys, 26 villages covering 50% of the total riparian villages of Chatla were selected for detailed household surveys. Household surveys were conducted following the systematic random sampling method from 2013 to 2015 (Plate 2a). The sample size for households surveys was calculated using the following equation (adapted from Cochran 1979) with a 95% confidence interval, standard error of 5%, and a sample fraction of 60%:

$$n = \frac{Z^2 \times \pi(1-\pi)}{\left[S.E.(p)\right]^2}, \tag{2}$$

where n is the required sample size,

S.E (p) is the standard error of a proportion.

π is the proportion of the population.

Z (i.e., 1.96) is the coefficient of 95% confidence interval.

The sample size obtained using the above equation was 368 households.

Information on the usage of various wetland resources was collected from 10 to 30% of the total households in each village, thus covering 368 households from 26 villages. For uniform representation of resident communities during the systematic random sampling, 10% of households were surveyed in villages with ≥ 100 households; whereas, for villages with ≤ 100 households, 30% of the households were surveyed. For this, a set of approaches, namely questionnaire surveys, focused group discussions, key informant interviews, and direct field observations, were employed (Haines–Young and Potschin 2009; Springate–Baginski et al. 2009), and the information was recorded using a semi-structured schedule (Appendix-1). The schedule comprised of three sections to collect information on the (i) demographic and socio-economic characteristics of the riparian communities, (ii) type and quantity of wetland resources harvested/collected/extracted by the riparian communities, and (iii) economic

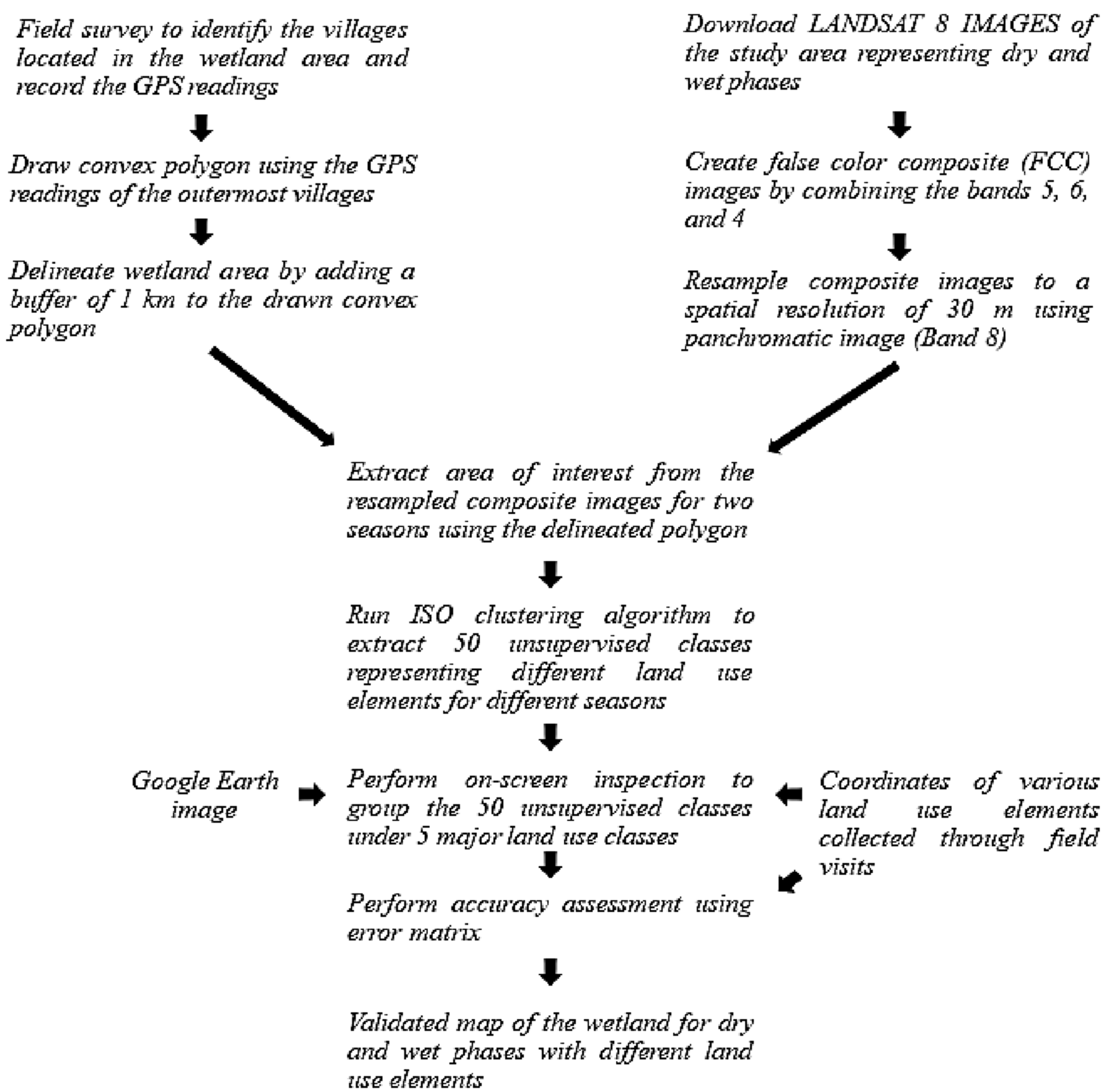

Fig. 2 Flowchart showing major steps of the land use classification

value of the wetland resources based on surveys conducted in the local markets. Household surveys were conducted in the local (Bengali and Hindi) language, and responses were recorded on the schedule in English. The quantities and values for the information on the quantity of various resources harvested/collected/extracted and their associated costs expressed in local units were converted into standard units. The monetary values estimated in Indian Rupees (INR) were converted into US dollars (USD) based on an average exchange rate of USD 1 = INR 61.22 for the years 2013 (INR 58.55), 2014 (INR 60.99) and 2015 (INR 64.13) (source: Exchange Rates UK, https://www.exchangerates.org.uk).

Data on the type and quantity of resources used by the riparian communities collected through schedule surveys were validated through field visits during dry and wet seasons. Fish species harvested by the riparian communities as recorded during the surveys were identified following standard literature (Jayaram 1999; Menon 1999; Das et al. 2010) and the online database on fishes, FishBase– https://www.fishbase.de/. The non-timber forest products (NTFPs) were identified following standard literature (Kanjilal et al. 1934, 1936; Balakrishnan 1981). Besides the herbarium of the Botanical Survey of India, Shillong was also consulted to identify plant species and further confirmed following the Plant List database (http://www.theplantlist.org/).

2.2.3 Economic Valuation of Provisioning ES

Economic valuation of the recorded provisioning ES was done following the market price method (TEEB 2010). For this, scheduled surveys (Appendix-1) were conducted in the local markets (Plate 1f) located in and around the wetland, such as Dorgakona, Irongmara, Silcoorie camp, Roskandy, and Machghat areas, following Russi et al. (2013). Household surveys and interactions with the vendors in local markets were done in the local (Bengali and Hindi) language, and responses were recorded on the schedule in English. We calculated the gross economic value and the opportunity cost of time and labor spent in collecting & producing these wetland products following Barbier (1991). Economic valuation of each of the harvested/cultivated resources during the dry and wet seasons was done using the following equation (Peh et al. 2014):

$$\text{Economic value of a partiular}PES = A \times (B - C), \quad (3)$$

where

'A' represents the annual gross harvested/cultivated amount of a particular provisioning ES (tonne year^{-1}).

'B' represents the unit price of the particular provisioning ES (USD tonne^{-1}).

'C' represents the unit cost for harvesting/cultivating of the particular provisioning ES (USD tonne^{-1}).

It is important to mention that while estimating the net benefit from the provisioning ES harvested directly from the wetland, the unit cost of harvesting was considered zero as no cost was incurred while harvesting those goods, as stated by the respondents. Besides, the cost of family labor was not taken into account as the opportunity cost was considered minimal as the family members were unable to engage in other jobs due to high unemployment rate in the market or due to old age where people were unable to work for other jobs (Adekola et al. 2012; Peh et al. 2014).

The total economic value of the major provisioning ES of the wetland was estimated using the equation as follows:

$$\text{Total economic value of provisioning ES} \\ = \text{Economic value of}\left(\text{pes}_1 + \text{pes}_2 + \ldots + \text{pes}_n\right), \quad (4)$$

where pes_1, pes_2,..... pes_n represent the different provisioning ES recorded during the survey.

Finally, the contribution of the major provisioning ES in terms of its economic value (%) was estimated for each season using the following equation:

$$\text{Economic contribution of each provisioning ES}(\%) \\ = \frac{\text{Economic value of a particular provisioning service}}{\text{Total economic value of all provisioning ES}} \times 100, \quad (5)$$

3 Results

3.1 Seasonal Changes in the Structural Components of *Chatla* Wetland

Structural components of Chatla during the dry season were grouped under five major categories, namely, (1) settlements/home gardens (riparian villages), (2) fallow lands, (3) paddy cultivation, (4) water bodies, and (5) marshy areas. On the other hand, during the wet season, it was grouped under four major categories, namely (1) settlements/home gardens (riparian villages), (2) seasonal vegetation cover, (3) water bodies, and (4) marshy areas (Table 1). The theoretical error matrix showed high degrees of overall classification accuracy of the land use maps for the dry (81.51%) and wet (80.58%) seasons (Table 2).

The area under different structural components of Chatla showed considerable variations across the seasons (Fig. 1, Table 1). During dry season, maximum area (2158.06 ha; 34.44%) of Chatla was under paddy cultivation, followed by the areas under fallow lands (1664.39 ha; 26.56%), settlements/home gardens (1358.03 ha; 21.67%), and marshy areas (731.93 ha;

Table 1 Areas under different structural components of Chatla wetland and its adjoining areas during dry and wet seasons

Types of structural components	Areas (ha)	
	Dry season (March)	Wet season (October)
Settlements/home gardens (Riparian villages)	1358.03 (21.67%)	1170.42 (18.68%)
Fallow land	[a], [aa]1664.39 (26.56%)	0 (0%)
Paddy cultivation	2158.06 (34.44%)	0 (0%)
Seasonal vegetation cover	0 (0%)	[aa] 1277.78 (20.39%)
Water body	[aaa]354.01 (5.65%)	[aaaa]3199.22 (51.05%)
Marshy areas	[aa]731.93 (11.68%)	[aa]511.42 (8.16%)
Total area	6266.42 (100%)	* 6158.84 (98.28%)

Numbers within parenthesis show the % of area covered under different structural components of the wetland during dry and wet seasons

[a]Indicates the area from where wetland soil is extracted

[aa]Indicates the area under NTFPs during the dry and wet seasons

[aaa]Indicates the area under fish ponds during dry season; [aaaa] indicates the area under capture fishery during wet season

*107.58 ha (1.72%) of the wetland area was under cloud cover during the study period

Table 2 Theoretical error matrix of land use classification in the Chatla wetland for the dry and wet phases

Phase	Classified	Water body	Water-logged/ Marshy area	Settlements/ Homegardens	Paddy cultivation	Fallow land	Total	Correct Sampled	Overall accuracy
Dry	Water body	25	2	0	0	0	27	25	**81.51%**
	Waterlogged/Marshy area	2	22	1	3	5	33	22	
	Settlements/Homegardens	0	1	21	0	0	22	21	
	Paddy cultivation	4	5	0	32	1	42	32	
	Fallow land	0	1	2	0	19	22	19	
	Total	31	31	24	35	25	146	119	
Phase	Classified	Water body	Water-logged/ Marshy area	Settlements/ Homegardens	Seasonal vegetation cover		Total	Correct Sampled	Overall accuracy
Wet	Water body	35	2	0	0		37	35	**80.58%**
	Waterlogged/Marshy area	1	15	1	3		20	15	
	Settlements/Homegardens	0	1	18	2		21	18	
	Seasonal vegetation cover	0	5	5	15		25	15	
	Total	36	23	24	20	0	103	83	

11.68%). While, only ~ 6% of wetland area (354.01 ha) was covered by water bodies in the dry season. On the other hand, during the wet season, ~ 51% of the total area (3199.22 ha) was inundated by water, followed by areas under seasonal vegetation cover (1277.78 ha; 20.39%), settlements/home gardens (1170.42 ha; 18.68%) and marshy areas (511.42 ha; 8.16%). During the wet season, cloud cover constituted 1.72% (107.58 ha) of the total mapped area.

Overall, mapping of the structural components of Chatla revealed remarkable changes for some of its types across wet and dry seasons. For example, areas under water bodies increased from ~ 6% in the dry season to ~ 51% in the wet season, causing a change of ~ 45% for that particular structural component. For other types of structural components e.g., (i) areas under fallow land decreased from ~ 27% in the dry season to 0% in the wet season; (ii) areas under paddy cultivation decreased from ~ 34% in the dry season to 0% in the wet season; (iii) areas under settlements/home gardens (riparian villages) decreased from ~ 22% in the dry season to ~ 19% in the wet season; and, (iv) areas under marshy areas decreased from ~ 12% in the dry season to 8% in the wet season (Fig. 1, Table 1). On the other hand, areas under seasonal vegetation cover were recorded only during wet season covering ~ 20% of the total wetland area. Here, area under seasonal vegetation represents the growth/flourish/appearance of seasonal free-floating and rooted macrophytes & aquatic vegetation, such as *Chrysopogon zizaniodes*, *Eichhornia crassipes*, *Eleocharis acicularis*, *Fimbristylis bisumbellata*, *Imperata cylindrica*, and *Saccharum ravennae* among others, in the floodwater covered barren/fallow areas in the wet season. Thus, during the study period, some types of structural components, such as fallow lands that prevailed in the dry season, were replaced by a new structural component in the wet season, i.e., seasonal vegetation cover (Fig. 1, Table 1).

3.2 Types of Provisioning ES Provided by *Chatla*

Household surveys in 26 riparian villages revealed that Chatla provides different wetland resources: fish, paddy, soil, surface water, and non-timber forest products (NTFPs) such as fuelwood, fodder, and cane, & common donax. The supply of these provisioning ES differed across wet and dry phases of the wetland. We recorded six local varieties of paddy grown in Chatla, of which *Boro* paddy (summer rice) was cultivated to a greater extent within the wetland (Table 3). Both *Boro* (summer rice) and *Sali* (winter rice) paddies were harvested during the dry season. During the dry season, a total of 31 fish species were recorded from the fishponds, i.e., culture fishery source within Chatla (Table 4); whereas, during the wet season, 49 species, including fishes and shrimps, were recorded from the capture fishery source, i.e., area inundated by seasonal flooding (Table 4). The major provisioning ES of Chatla during the dry season comprised of the production of paddy, fishery resources (from fish ponds), supply of fuelwood, fodder, cane, common donax, and wetland soil (clay) (Tables 5 and 6). During the wet season, capture fishery followed by harvest/collection of fodder, mining of soil (sand), and surface water availability comprised the major provisioning ES of Chatla (Tables 5 and 6).

Table 3 Rice varieties cultivated in the wetland by its riparian communities during the paddy growing season and the purpose of their cultivation

Purpose	Variety of summer rice (*Boro* paddy) (Cropping: November–December; Harvesting: March–April)	Variety of winter rice (*Sali* paddy) (Cropping: June-July; Harvesting: November–December)
Subsistence use and selling of surpluses to local market for income generation	*Bashful*, *Buciboruah*, *Khoiboruah*, *Moircha*	*Birain*, *Lathma*

Amongst NTFPs, the dried- bole and branches, including leaves of plant species such as *Barringtonia acutangula*, *Ipomoea carnea*, *Lagerstroemia speciosa,* and *Melastoma malabathricum* were used as fuelwood (Table 5). Sources of fodder for livestock comprised tree species' leaves (*Barringtonia acutangula*) and grasses (*Alternanthera sessilis*, *Chrysopogon zizaniodes*, *Digitaria ciliaris*, *Eleusine indica*, *Eragrostis unioloides*, *Imperata cylindrica, Ludwigia hyssopifolia*, *Pseudoraphis spinescens*, and *Sacciolepis interrupta*). Cane species (*Calamus tenuis*) was used to make furniture, various handicraft items, and fishing gears; while fibre extracted from Common donax (*Schumannianthus dichotomus*) was used to make handcrafted mats that are used as bedspread or for sitting.

During the dry season, the dependency of the riparian communities was highest for fuelwood (68.48%), followed by wetland soil (68.21%), paddy (65.49%), culture fishery (62.77%), fodder (33.57%), cane (2.99%) and common donax (1.36%) (Table 6). Whereas, during the wet season, dependency was highest for capture fishery resources (68.75%), followed by fodder (33.57%), and soil (sand) (2.45%). For income generation, most (~55%) of the surveyed households depended on fishing and paddy cultivation. In comparison, a few were involved in craft making (1.53%) and pottery (1.09%) by utilizing cane & common donax, and wetland soil, respectively (Sarkar et al. 2019).

An estimated 279.16 tonnes of paddy were produced during the dry season from 34.44% of the total area in Chatla (Table 1, Fig. 3, Online Resource 1). About 25.65 tonnes of fishery resources were harvested from culture fishery practiced in 5.65% of the total wetland area (Table 1, Fig. 3, Online Resource 2). In addition, the riparian communities also harvested 43.9 tonnes of NTFPs from 38.24% of wetland area (comprising fallow lands and marshy area) (Table 1, Online Resource 4, 5, 7, and 8). Fuelwood accounted for 16.76 tonnes, fodder was 26.38 tonnes, and common donax & cane was 0.38 tonnes each). Also, an estimated 18.7 tonnes of wetland soil were extracted from 26.56% wetland area during the dry season (Table 1, Fig. 3, Online Resource 9).

During the wet season, an estimated 60.81 tonnes of fish were harvested from 51.05% of the inundated area in Chatla (Table 1, Fig. 3, Online Resource 3), which served as a capture fishery source. In addition, 15.83 tonnes of fodder were extracted from ~29% area (area under seasonal vegetation cover and marshy areas) of the wetland (Table 1, Online Resource 6). Moreover, during the early wet season, 26.4 tonnes of sandy soil was extracted from the confluence points of the inlet tributaries of Chatla (Fig. 3, Online Resource 9).

3.3 Economic Valuation of Provisioning ES of *Chatla*

During the dry season, Chatla provided provisioning ES in the form of paddy cultivation and culture fishery resources with an estimated economic worth of USD 50,153 and USD 67,027, respectively, which respectively contributed to 12.94% and 17.30% of the total economic value of provisioning ES of Chatla annually (Table 7, Online Resource 1 and Online Resource 2). While, the economic value of NTFPs, namely fuelwood, fodder, common donax, and cane, was estimated to be USD 766, USD 431, USD 1651, and USD 3675, respectively, which all together contributed to 1.68% of the total economic value of provisioning ES (Table 7, Online Resources 4, 5, 7, 8). The economic value of wetland soil was estimated to be USD 107, contributing to 0.03% of the total economic value of provisioning ES (Table 7, Online Resource 9). Thus, the monetary value of provisioning ES provided by Chatla during the dry season was estimated as USD 1,23,811, contributing to ~32% of the total economic value of provisioning ES provided by Chatla annually.

During the wet season, Chatla provided provisioning ES in the form of capture fishery resources with an estimated worth of USD 263,210, contributing to 67.93% of the total economic value of provisioning ES of Chatla per annum (Table 7, Online Resource 3). In comparison, the monetary value of fodder and soil was estimated to be USD 207 and USD 259, respectively, contributing to 0.12% of the total economic value of provisioning ES of Chatla (Table 7, Online Resource 6 and 9). Thus, during the wet season, Chatla provided provisioning ES worth USD 263,676, which accounted for 68.05% of the total economic value of provisioning ES of Chatla per annum (Table 7). Overall, the total

Table 4 Culture- and capture fishery resources of the wetland during dry and wet seasons respectively and the purpose of their culture/capture by the riparian communities

Purpose	Culture fishery resources harvested during dry season (November-March)	Capture fishery resources harvested during wet season (May–October)
Subsistence consumption and selling of surpluses to local market for income generation	*Anabas testudineus* (Bloch, 1792)	*Acanthocobitis botia* (Hamilton, 1822)
	Bangana ariza (Hamilton, 1807)	*Ailia coila* (Hamilton, 1822)
	Chanda nama (Hamilton, 1822)	*Anabas testudineus* (Bloch, 1792)
	Channa punctata (Bloch, 1973)	*Badis badis* (Hamilton, 1822)
	Channa striata (Bloch, 1973)	*Bangana ariza* (Hamilton, 1807)
	Cirrhinus mrigala (Hamilton, 1822)	*Botia dario* (Hamilton, 1822)
	Clarias batrachus (Linnaeus, 1758)	*Chanda nama* (Hamilton, 1822)
	Ctenopharyngodon idella (Valenciennes, 1844)	*Channa punctata* (Bloch, 1973)
	Cyprinus carpio (Linnaeus, 1758)	*Channa striata* (Bloch, 1973)
	Gibelion Catla (Hamilton, 1822)	*Chitala chitala* (Hamilton, 1822)
	Heteropneustes fossilis (Bloch, 1794)	*Cirrhinus mrigala* (Hamilton, 1822)
	Hypophthalmichthys molitrix (Valenciennes, 1844)	*Clarias batrachus* (Linnaeus, 1758)
	Labeo bata (Hamilton, 1822)	*Ctenopharyngodon idella* (Valenciennes, 1844)
	Labeo boga (Hamilton, 1822)	*Esomus danrica* (Hamilton, 1822)
	Labeo calbasu (Hamilton, 1822)	*Gibelion Catla* (Hamilton, 1822)
	Labeo gonius (Hamilton, 1822)	*Glossogobius giuris* (Hamilton, 1822)
	Labeo rohita (Hamilton, 1822)	*Gudusia chapra* (Hamilton, 1822)
	Macrobrachium cacharense (Tiwari, 1952)	*Heteropneustes fossilis* (Bloch, 1794)
	Macrobrachium gangeticum (Spence Bate, 1868)	*Hypophthalmichthys molitrix* (Valenciennes, 1844)
	Monopterus cuchia (Hamilton, 1822)	*Labeo bata* (Hamilton, 1822)
	Mystus tengara (Hamilton, 1822)	*Labeo boga* (Hamilton, 1822)
	Mystus vittatus (Bloch, 1794)	*Labeo calbasu* (Hamilton, 1822)
	Notopterus notopterus (Pallas, 1769)	*Labeo gonius* (Hamilton, 1822)
	Oreochromis mossambicus (Peters, 1852)	*Labeo rohita* (Hamilton, 1822)
	Parambassis baculis (Hamilton, 1822)	*Lepidocephalichthys guntea* (Hamilton, 1822)
	Parambassis lala (Hamilton, 1822)	*Macrobrachium cacharense* (Tiwari, 1952)
	Parambassis ranga (Hamilton, 1822)	*Macrobrachium gangeticum* (Spence Bate, 1868)
	Pethia conchonius (Hamilton, 1822)	*Macrognathus aral* (Bloch and Schneider, 1801)
	Puntius chola (Hamilton, 1822)	*Macrognathus pancalus* (Hamilton, 1822)
	Systomus sarana (Hamilton, 1822)	*Mastacembelus armatus* (Lacepede, 1800)
	Trichogaster fasciata (Bloch & Schneider, 1801)	*Monopterus cuchia* (Hamilton, 1822)

Table 4 (continued)

Purpose	Culture fishery resources harvested during dry season (November-March)	Capture fishery resources harvested during wet season (May–October)
		Mystus tengara (Hamilton, 1822)
		Mystus vittatus (Bloch, 1794)
		Notopterus notopterus (Pallas, 1769)
		Ompok bimaculatus (Bloch, 1794)
		Oreochromis mossambicus (Peters, 1852)
		Parambassis baculis (Hamilton, 1822)
		Parambassis lala (Hamilton, 1822)
		Parambassis ranga (Hamilton, 1822)
		Pethia conchonius (Hamilton, 1822)
		Puntius chola (Hamilton, 1822)
		Rasbora daniconius (Hamilton, 1822)
		Rita rita (Hamilton, 1822)
		Salmostoma bacaila (Hamilton, 1822)
		Sperata seenghala (Sykes, 1839)
		Systomus sarana (Hamilton, 1822)
		Trichogaster fasciata (Bloch and Schneider, 1801)
		Wallago attu (Bloch and Schneider, 1801)
		Xenentodon cancila (Hamilton, 1822)

economic value of provisioning ES provided by Chatla in both seasons was estimated at USD 387,487 per annum.

4 Discussion

Seasonal wetlands play an important role in providing crucial ecological services such as hydrological regulation, flood abatement, wetland goods, habitats for endemic species, recreational opportunities, and enhancing the aesthetic value of the local landscape (Downing 2010). Some ecological factors that potentially facilitate the provisioning ES by such wetlands include the period of inundation, their position within the landscape, topographic heterogeneity due to the hydrogeologic setting of the specific landscape, and hydrologic connections with other aquatic bodies (Blackwell and Pilgrim 2011).

Our study integrating the spatially explicit data of structural components of Chatla wetlands with its socio-ecological information elucidated that periodic episodes of inundation and recession of water greatly influenced the availability of provisioning ES. This facilitated livelihood sustainability and risk aversion strategies of the riparian communities. For example, during the dry season, the topographic heterogeneity of Chatla makes it suitable for paddy cultivation and culture fishery within the wetland, both of which are major sources of income generation for most households. During this season, paddy cultivation and culture fishery within Chatla respectively contributed towards ~ 13% and ~ 17% of the total economic value of provisioning ES generated per annum; thus, sustaining the livelihoods of ~ 65% and ~ 63% of riparian households, respectively through paddy production and culture fishery. Given such intensive paddy cultivation in ~ 34% of the wetland area, diminution of nutrients in the agricultural plots at the end of each cropping season is very likely. In this regard, the annual flood event potentially maintains soil fertility through the deposition of alluvial soil during the flood phase. These natural processes prepare the land for the next round of cultivation, having higher productivity with minimal input of synthetic fertilizers (Das et al. 2014), thus reducing the farmers' investment costs for paddy production. Likewise, the flood pulse in Chatla potentially rejuvenates the culture fishery systems within the wetland through the inflow of oxygenated and nutrient-rich floodwater. This natural annual phenomenon further helps in clearing the accumulated waste feed, and metabolic residuals of fishes along with the impure water. Besides, it also helps maintain a rich depository of diverse planktonic and algal communities in the fishponds that enhances productivity by minimizing the total investment/management costs for fish production by the fishermen (Parven et al. 2018). On the other hand, during the wet season, Chatla acts as a source of capture fishery as the flood pulse brings in a variety of fish species with high economic value such as *Ailia coila*, *Chitala chitala*, *Gudusia chapra*, *Ompok bimaculatus*, *Sperata seenghala* and *Wallago attu* within the wetland. Taking advantage of this natural phenomenon, the riparian communities harvest the fishery resources worth USD 263,210,

Table 5 NTFPs available in the wetland during dry and wet seasons and the purpose of their collection by the riparian communities of the wetland

Purpose	NTFPs harvested during dry season (November-March)	NTFPs harvested during wet season (April–October)
Fodder for livestock	*Alternanthera sessilis* (L.) R. Br.ex DC	*Alternanthera sessilis* (L.) R. Br.ex DC
	Barringtonia acutangula (L.) Gaertn	No collection
	Chrysopogon zizaniodes (L.) Roberty	*Chrysopogon zizaniodes* (L.) Roberty
	Digitaria ciliaris (Retz.) Koeler	*Digitaria ciliaris* (Retz.) Koeler
	Eleusine indica (L.) Gaertn	*Eleusine indica* (L.) Gaertn
	Eragrostis unioloides (Retz.) Nees ex Steud	*Eragrostis unioloides* (Retz.) Nees ex Steud
	Imperata cylindrica (L.) Raeusch	*Imperata cylindrica* (L.) Raeusch
	Ludwigia hyssopifolia (G.Don) Exell	*Ludwigia hyssopifolia* (G.Don) Exell
	Pseudoraphis spinescens (R.Br.) Vickery	*Pseudoraphis spinescens* (R.Br.) Vickery
	Sacciolepis interrupta (Willd.) Stapf	*Sacciolepis interrupta* (Willd.) Stapf
Fuel wood for cooking	*Barringtonia acutangula* (L.) Gaertn	No collection
	Ipomoea carnea Jacq	
	Lagerstroemia speciosa (L.) Pers	
	Melastoma malabathricum L	
Cane for making [a]furniture and various [a]handicrafts items and fishing gears	[a]*Calamus tenuis* Roxb	No collection
Common donax for making [a]mats	[a]*Schumannianthus dichotomus* (Roxb.) Gagnep	No collection

[a]Indicates surplus resources and/or the surplus manufactured goods prepared out of the resources are sold in the local market by the riparian communities

which accounted for 67.93% of the total economic value of provisioning ES provided by Chatla per annum.

The varying structural components of Chatla due to the periodic inundation also supply different types of NTFPs, including fuelwood, fodder, cane, common donax across both seasons. While some of these goods help in daily sustenance, others help generate additional income for a smaller section of riparian communities. For example, NTFPs like cane and common donax harvested only during the dry season are used for making fishing gears, handicraft items, furniture & mats, and the surplus goods are sold in the local markets for income generation. The equivalent economic value of harvesting cane and common donax was estimated to be USD 3675 and USD 1651. On the other hand, NTFPs like fuelwood are collected during the dry season for subsistence use worth USD 766. Whereas fodder is harvested during both seasons, with an equivalent economic value of USD 431 and USD 207 during wet season. Besides NTFPs, the riparian communities also extract wetland soil for subsistence and commercial purposes. For example, during the

Table 6 Households (%) of the riparian villages involved in harvest/collection/extraction of wetland provisioning ecosystem services during dry and wet seasons

Types of wetland provisioning ecosystem services		Households involved (%)	
		Dry season (November–March)	Wet season (April–October)
Paddy		65.49	–
Fishery resource	Culture fishery	62.77	–
	Capture fishery	–	68.75
NTFPs	Fuel wood	68.48	–
	Fodder	33.57	33.57
	Common donax	1.36	–
	Cane	2.99	–
Soil		68.21	2.45

'–'Indicates no involvement in harvest/collection/extraction of wetland provisioning ecosystem services during that season

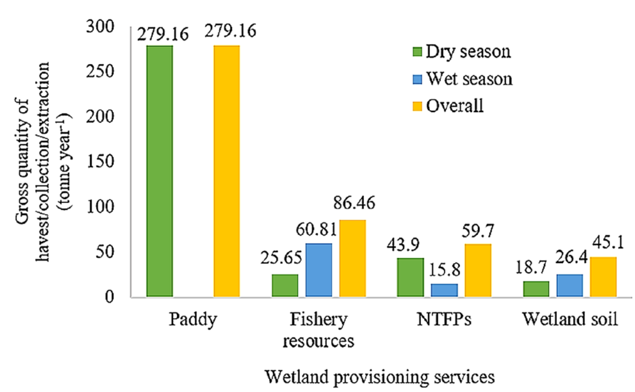

Fig. 3 Harvest/collection/extraction (tonnes year^{-1}) of various provisioning ecosystem services (ES) of Chatla wetland by its riparian communities

Table 7 Economic value of the wetland provisioning services and its contribution (%) in terms of its total economic value to the riparian communities of the wetland during dry and wet seasons

Types of wetland provisioning services		Economic value (USD)		Contribution (%)	
		Dry season (November-March)	Wet season (April–October)	Dry season (November-March)	Wet season (April–October)
Paddy		USD 50,153 (INR 3,070,760)	-	[a]12.94	-
Fishery resource	Culture fishery	USD 67,027 (INR 4,103,888)	-	[a]17.30	-
	Capture fishery	-	USD 263,210 (INR 16,115,631)	-	[a]67.93
NTFPs	Fuel wood	USD 766 (INR 46,914)	-	[a]0.20	-
	Fodder	USD 431 (INR 26,380)	USD 207 (INR 12,662)	[a]0.11	[a]0.05
	Common donax	USD 1651 (INR 99,750)	-	[a]0.42	-
	Cane	USD 3675 (INR 225,000)	-	[a]0.95	-
Soil		USD 107 (INR 6570)	USD 259 (INR 15,840)	[a]0.03	[a]0.07
Total economic value and contribution of the wetland provisioning services (%) across seasons		USD 123,811 (INR 7,579,262)	USD 263,676 (INR 16,144,133)	[aa]31.95	[aa]68.05
Grand total economic value of the wetland provisioning services		USD 387,487 (INR 23,723,395)			

Values in parenthesis represent corresponding INR values @USD 1 = INR 61.2273

'–'Represents absence of PES during that season

[a]Indicates that the values are based on the total economic value of the wetland provisioning ES across dry and wet seasons

[aa]Indicates that the values are based on the total economic value of the wetland provisioning ES per annum

dry season, most riparian households use wetland soil for wall plastering and polishing mud houses and earthen stoves. In contrast, a smaller section of riparian households prepare pottery items. As a result, the monetary value of wetland soil was estimated as USD 107 during the dry season. At the same time, mining sand during the early wet season from the inlet tributaries of Chatla incurred an economic gain of USD 259.

Furthermore, riparian communities also use surface water for bathing and washing during the wet season. Thus, the diversity of the provisioning ES of Chatla was higher during the dry season. However, when the season-wise economic value of provisioning ES was compared, the contribution was higher (68.05%) during the wet season. This could be ascribed to the entry of diverse and abundant fishery resources through the inlet tributaries during flood. Thus, the seasonal changes in structural components of Chatla wetland significantly contribute toward the livelihood sustainability and well-being of the riparian communities by providing a suite of provisioning ES worth USD 387,487 annually i.e., ~ USD 242 ha^{-1} year^{-1}. The study, therefore, highlights the role of provisioning ES of Chatla in maintaining sustainability through providing paddy, fish (culture fishery), soil, and supply of NTFPs (fuel wood, fodder, cane & common donax) in dry season; and, fish (capture fishery), soil, water and NTFPs (e.g., fodder) in wet season. Previous studies also highlighted the role of seasonal wetlands in the livelihood sustainability of the local stakeholders through providing diverse provisioning ES (Adekola et al. 2012; Sarkar et al. 2019). In terms of economic value, previous studies also highlighted high economic value of provisioning ES delivered by the seasonal wetlands. For example, Adekola et al. (2012) estimated the economic value of provisioning ES of Ga-Mampa, a seasonal wetland in South Africa, as USD 900 ha^{-1} year^{-1}. The high economic value of provisioning ES of seasonal wetlands are nearly equal to the permanent wetlands. For instance, the monetary value of provisioning ES delivered by Letseng-la-Letsie, a permanent wetland located in Lesotho was estimated as USD 220 ha^{-1} year^{-1} (Lannas and Turpie 2009). Also, the economic value of provisioning ES of Lake Rotorua—one of the oldest permanent lakes in New Zealand—was estimated to be a minimum of 788 ha^{-1} year^{-1} (Mueller et al. 2016). This proves that irrespective of the type, wetland ecosystems play an equally important role in sustaining the livelihood of local stakeholders by providing economically valuable provisioning ES.

Overall, the present study highlighted the role of Chatla wetland in helping riparian communities cope with seasonal variations by minimizing the associated risks to the loss of livelihood. At the same time, it maximizes the benefits offered by Chatla in providing provisioning ES and maintaining a sustainable livelihood. This is reflected in the riparian communities' per capita monthly income, which was lower than the monthly per capita net national income (Sarkar et al. 2019). This signifies that despite the riparian communities' substantially lower monthly income, the annual flood event in Chatla ensures livelihood sustainability by providing diverse provisioning ES 'free of cost' or at minimal investments. High dependency of local communities on wetland provisioning ES has also been reported elsewhere, for example, GaMampa wetland in South Africa (Adekola et al. 2012), Ghodaghodi lake in Western Nepal (Lamsal et al. 2015), and Maguri-Motapung beel in Northeast India (Bhatta et al. 2016). Therefore, urgent policy interventions for the conservation and wise use of seasonal wetlands and their resources is imperative for their sustainable management which would ultimately secure diverse sustainable livelihood options. We believe that formal interventions such as establishing institutions duly empowered to implement and coodinate management activities in and around the ecosystem are vital. In addition, encouraging the active participation of wetland-dependent communities could be constructive. Also, on-site awareness campaign about the benefits of seasonal wetlands and the causes, indicators, and consequences of wetland degradation would underscore the urgency of the situation. Lack of awareness often lead to overexploitation and unsustainable utilization of wetland resources which ultimately threatens the natural integrity of wetlands (Sarkar et al. 2022). In this regard, the local communities could act as caretakers of wetlands, given their key position in terms of their physical proximity to wetlands and their potential role in implementing government policies for effective management and conservation of wetlands (Biswas et al. 2010; Sarkar et al. 2020). Previous studies highlight how wetland resources could be properly managed through community particicpation. For example, in Finland, a conservation project, Life + Return of Rural Wetlands, aiming at wetland-restoration and management, engaged the local stakeholders and demonstrated meaningful outcomes in safeguarding the wetlands and associated ES over a few years. Thus, engagement of locals could yield the best conservation results by assisting in formulating long-term policy measures & implementing site-specific management practices (Kibwage et al. 2008; Lamsal et al. 2015).

We believe that the efforts to change the attitude of local stakeholders and government authorities toward wetland protection is the most fundamental intervention toward wetland conservation. In this regard, organizing capacity-building programs at regular intervals to develop and strengthen the relevant skills and abilities of the locals in preserving the ecosystems and associated ES is imperative (Kibwage et al. 2008; Gopal 2013; Lamsal et al. 2015). It is important to mention that the supporting ES, e.g., biomass production, soil formation, and habitat provision, underpins the perpetual delivery of livelihood-sustaining provisioning ES. Therefore, to maintain the flow of provisioning ES, maintaining the natural integrity of the ecosystem is imperative, which is often vulnerable to increasing anthropogenic pressure. In this regard, attempting to assess the degree of anthropogenic pressure on seasonal wetlands is crucial to identify the provisioning ES vulnerable to over-extraction and prioritize them for adopting necessary management actions. Here, the frequency-based protocol suggested by Sarkar et al. (2022) could be helpful in objectively assessing the level of anthropogenic pressure on seasonal wetlands. Also, given the interlinkage between provisioning ES with other ES, e.g., supporting, regulating, cultural, it is crucial to assess and integrate the economic value of other ES, which is a limitation of the present study.

Studies acknowledge that promoting sustainable livelihood options could be a practical approach toward wise-use of wetlands and yielding better conservation results (Lamsal et al. 2015). However, lack of skills and financial support cause hindrance to adopting alternative livelihood options (Sarkar et al. 2020). In this regard, the local government, private agencies, and NGOs could facilitate the riparian people adopting alternate livelihood options. For example, institutional support in terms of (i) providing proper training in market-driven skills (e.g., preparing handicraft items using wetland vegetation such as *Eichhornia crassipes*, *Chrysopogon zizanioides*, etc. growing abundantly within the wetland), (ii) creating markets for selling handicraft products, and (iii) providing financial incentives at the initial stage to implement the newly learned skills. To mention a success story, a group of six women from fishing community residing around Deepor Beel (a Ramsar site in Assam, Northeast India), with technical help from NECTAR (an autonomous body under the Department of Science and Technology, India), produced biodegradable yoga mats from water hyacinth (*Eichhornia crassipes*) using traditional Assamese loom and different combinations of tools and techniques. Also, community-based ecotourism could also be one of the sustainable livelihood options in the areas owned and managed by riparian communities (Bhattacharya 2003). Considering this, encouraging community-based eco-tourism initiatives with boating facilities in Chatla could attract more visitors during the wet season, a potent source of income generation for the riparian people. The trained communities preparing handicraft items could utilize this opportunity to sell their products to the visitors. All of these practices, which complement the socio-ecological complexity in seasonal wetlands, would ultimately enhance their capacity for the perpetual delivery of economically valuable provisioning ES.

5 Conclusion

The present study highlights that seasonal wetlands are at par with the permanent wetlands in terms of their role in providing economically valuable provisioning ES, which supports sustainable livelihoods, especially in developing countries. Therefore, we suggest that national and international policies focus on the conservation and wise use of such seasonal wetlands and their resources. We believe that such collective case studies on seasonal wetlands would help gather valuable scientific data for formulating adequate management actions. Additionally, given the high importance of wetlands and the global trend of increasing anthropogenic pressure on them, as discussed above, we also emphasize the need for constant effort for the economic valuation of wetlands irrespective of their size, type, and location. Therefore, a compendium of such case studies would further assist in developing appropriate management strategies for conserving and judicious use of wetlands. Such interventions are essential to sustain the ecological integrity of wetlands, which is indispensable for the uninterrupted flow of ES and thus maintaining sustainability.

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Data Availability All data generated or analysed during this study are included in this published article [and its supplementary information files].

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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