Accounting of Ecosystem Services of Wetlands in Karnataka State, India

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Abstract

Wetlands are productive ecosystems, providing an array of services that sustain the well-being of dependent biota. Post industrialization and globalization era witnessed a spurt in the anthropogenic activities, leading to the degradation and decline of fragile ecosystems. This necessitates the conservation of vital ecosystems through sustainable management tenets, this requires an understanding of the livelihood support of ecosystems. The focus of the study, discussed in this article, is to understand the worth of wetlands through the accounting of provisioning, regulating, and cultural services. The provisioning services through accounting of tangible benefits (fish, fodder, water, etc.) considering residual values indicate an annual revenue of INR49.70 billion. Similarly, accounting of non-use values of ecosystems through the benefit transfer method indicates regulating and cultural services support of INR196.89 billion and INR37.93 billion per year, respectively. The annual flow of the total ecosystem supply value accounts for INR284.52 billion per year and the net present value (NPV) amounts to INR7320.6 billion, signifying the ecological, socio-cultural, and environmental support wetland provides to ecosystems in Karnataka. Appraisal of ecosystem services allows for adjusted national accounts, which reflect the output of ecosystem services as well as the depletion of natural resources and the degradation costs (externalized costs of the loss of ecosystem services) of ecosystems in economic terms, which will help raise awareness and provide a quantitative tool to evaluate the sustainability of policies towards prudent management and conservation of fragile livelihood-supporting ecosystems. The monetary valuation of ecosystem services can help in building a better understanding of their influence on well-being and can further facilitate information-driven decisions and policy reforms that align with the Sustainable Development Goals (SDGs) through the judicious use of natural resources.

Keywords: Wetlands, Microalgae, Fish, Macrophyte, SEEA, Ecosystem service, Provisioning service, Cultural service, Regulating service, Total ecosystem supply value (TESV), Net present value (NPV), Karnataka

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Introduction

Wetlands include lentic and lotic waterbodies and constitute the most diverse and productive ecosystem, providing numerous ecological, economic, and social benefits to the society. Wetlands provide vital ecosystem services and processes, such as the provision of food (fish, fodder, etc.), groundwater recharge, water purification, remediation, nutrient assimilation, carbon sequestration, moderating micro-climate, habitat for flora and fauna, flood reduction, erosion control, opportunities for education, aesthetics, and recreation (de Groot, Brander, and Solomonides 2020; Ramachandra, Raj, and Aithal 2019; Barbier 2013; Lambert 2003; Costanza, d'Arge, de Groot, *et al.* 1997). Wetlands help to conserve biodiversity by providing habitat for fish, planktons, aquatic plants, insects, and crustaceans, as well as feeding and resting areas for water birds (Ramachandra, Asulabha, Sincy, *et al.* 2016). Food chains/food webs describe the structure of communities inhabiting a particular ecosystem, and the associated energy as well as nutrient flows, and the interactions between species (Ramachandra, Rajinikanth, and Ranjini 2005). Wetlands aid in removing nutrients like nitrate, phosphate, etc., from water (Ramachandra, Asulabha, and Sincy 2021; Ramachandra, Sincy, and Asulabha 2020a).

Ecosystem functions of wetlands are summarized graphically in Figure 1, which include food production, habitat provision, information provision, and regulation of ecosystem processes. Microalgae are primary producers that sequester carbon and synthesize food and energy for higher trophic levels (Kulkarni and Ramachandra 2006; Peel, Hill, Taylor 2019). Enhanced oxygen levels

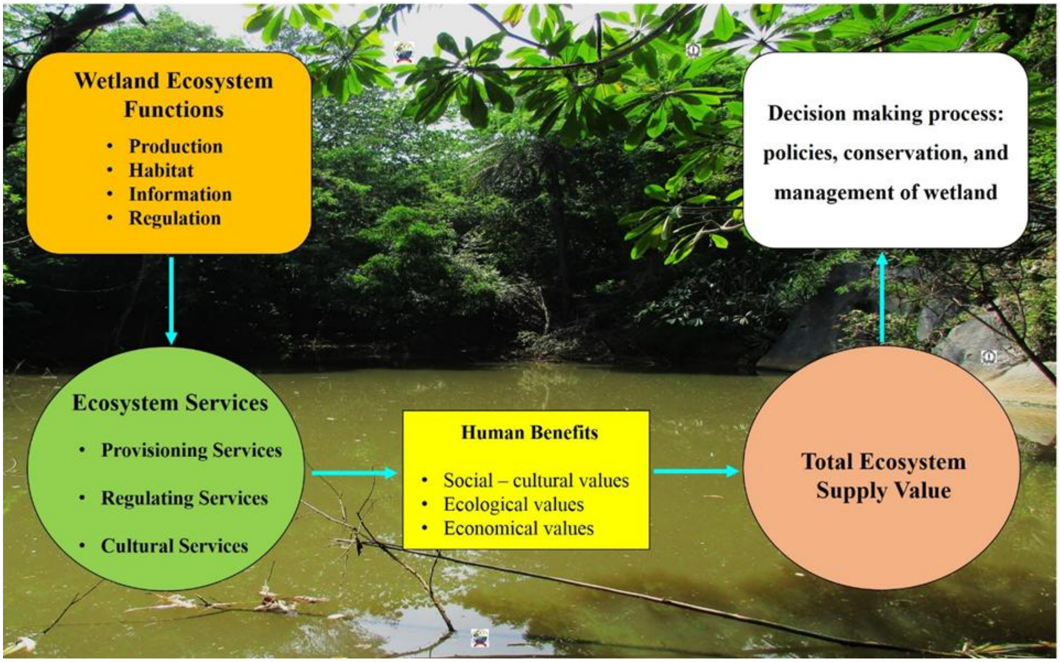

Figure 1 Wetland ecosystems—functions and services

on the early Earth, triggering aerobic respiration and the evolution of complex multicellular life forms are due to photosynthesis carried out by microalgae (cyanobacteria) and the release of oxygen (Sánchez-Baracaldo and Cardona 2020). Wetlands provide food and shelter for diverse aquatic organisms (zooplankton, fish, and birds), fodder (livestock and other grazers), medicine, water purification/treatment (remediation), and carbon sequestration (Ramachandra, Sudarshan, Vinay 2020b; Ramachandra, Asulabha, and Lone 2014). Fish store nutrients in their tissues, translocate nutrients, and excrete dietary nutrients in dissolved forms that are readily available to primary producers (Vanni 2002). Fish feeding alters the community structure of phytoplankton, zooplankton, and insects (Griffiths 2006).

Wetlands provide numerous ecosystem services, sustaining the livelihoods of dependent populations with the provisioning, regulating, and cultural services, and hence there is a need to quantify the socio-cultural, ecological, and economic value of the wetlands (TEEB 2010) for appropriate management strategies by policymakers, and other stakeholders (Figure 1) with incentives, and financial support for conservation. Prudent management with the sustainable use of wetlands would aid in maintaining biodiversity, mitigating pollution, and changes in the climate.

Ecosystem Services from Wetlands

Ecosystem services are the benefits derived from nature for human well-being (Figure 2).

Figure 2 Ecosystem services from wetlands

Ecosystem services are principally categorized into provisioning services, regulating services, and cultural services [SEEA 2021; Millennium Ecosystem Assessment (MEA); Common International Classification of Ecosystem Services (CICES)].

Provisioning services are the tangible benefits that include products obtained from ecosystems such as water, food, fibre, fuel, genetic resources, biochemical, medicines, and pharmaceuticals. Regulating services include the benefits obtained from various ecosystem processes, for instance, water regulation, climate regulation, water purification, erosion regulation, and flood control. Cultural services include the non-material benefits from ecosystems through spiritual, recreation, aesthetics experiences, and ecotourism (Magalhães Filho, Roebeling, Bastos, *et al.* 2021). These benefits vary depending on the geographical scale, from local to global. Table 1 lists wetland ecosystem services based on global studies. The economic value of a wetland depends on the ecosystem process, including catchment characteristics (hydrology, vegetation, and soil), geographical conditions, and socio-economic aspects (Yiran, Demin, Zhenguo, *et al.* 2014).

Table 1 Wetland ecosystem values based on global studies (in $/ha/year)

Services	**de Groot, Brander, and Solomonides 2020**	**Clarkson, Ausseil, and Gerbeaux 2013**	**de Groot, Brander, and Van Der Ploeg, *et al.* 2012**	**Costanza, d'Arge, de Groot, *et al.* 1997**	**Russi, Brink P, Farmer, *et al.* 2013**	**Quintas-Sorian, Martín-López, Santos-Martín, *et al.* 2016**	**Li and Gao 2016**	**Zang, Wu, Liu, *et al.* 2011**	**Zhang, He, Fan, *et al.* 2015**
Food	6,030	614	1,111	256	2,090	479		26	14
Water	1,934	408	1,217	3,800	5,189	234	3,800		2,872
Raw materials	1,682	425	358	106	2,430		106	5	1
Genetic resources	60		10						
Medicinal resources		99	301						
Ornamental resources		114							
Air quality regulation	34						133	118	
Climate regulation	150	488	65	330	351			1,148	65
Moderation of extreme events	13,320	2,986			4,430				
Regulation of water flows	3,638	5,606		15	9,369			2,345	
Waste treatment	2,043	3,015	162,125	4,177	4,280	175	4,177	2,376	2,562
Erosion prevention		2,607	3,929	4,539		41			
Maintenance of soil fertility		1,713	45		4,588			112	1
Biological control		948				20	304	326	351
Maintenance of life cycles of migratory species	1,886	1,287	10,648	304	917				

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Table 1 *Contd...*

Maintenance of genetic diversity	3,427	1,168	6,490		2,554				
Aesthetic information	49	1,292			3,906	109			
Opportunities for recreation and tourism	2,660	2,211	2,193	574	3,700		574	646	612
Inspiration for culture, art, and design	114	700		881	793		881		
Spiritual experience	1								
Information for cognitive development	120								
Existence and bequest values	11,498					8			

Freshwater lakes provide various services, supporting the livelihoods of dependent communities, which include the provision of fish (food), fodder (livestock), water (drinking and irrigation), navigation, recreation, and socio-economic development (Najar and Khan 2012), generation of hydropower, etc. (Anshumali and Ramanathan 2007). Recreation services of wetlands are evident as tourism is a major source of income, and employment in Rudrasagar lake (Burman, Cajee, and Laloo 2007). The wetland ecosystem supply values range from 7670 (Andhra Pradesh), 7689.4 (Gujarat) to 7896.5 (Karnataka) million US$ per year (Pandey, Joseph, and Kaul 2004). Table 2 lists the computation of ecosystem services, wherein provisioning services were accounted based on the market value method, while regulating and cultural services were based on the benefit transfer method.

Table 2 Various methods adopted for ecosystem service valuation

Name of the wetland	Area	Total value of ecosystem service	Method used for ecosystem service valuation	Reference
Rachenahalli Lake, Karnataka	42.09 ha	INR10,435/ha/day	Market prices method and CVM (contingent valuation method), socio-economic survey and questionnaire	Ramachandra, Rajinikanth, and Ranjini 2005
Varthur Lake, Karnataka	220 ha	INR9,554,000/220 ha/year	Market prices method and CVM, socio-economic survey and questionnaire	Ramachandra, Alakananda B, Ali Rani, *et al.* 2011
Begnas watershed system	49 km^2	\$3.91 million/year	Market price method, TC method, CVM, and benefit transfer	Thapa, Wang L, Koirala 2020
Lake and marsh wetlands, China	3.241×10^4 km^2	8.1841×10^{10} (\$)	Value transfer method	Yiran, Demin, Zhenguo, *et al.* 2014

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Table 2 *Contd...*

Songore wetland, Zimbabwe	56.25 ha	$20,843.31/year	Market price method	Mahlatini, Hove A Maguma, *et al.* 2020
Rural wetland Letseng-la-Letsie, South Africa	819 ha	Provisioning services: $220·ha/year	Market price method	Lannas and Turpie 2009
Peri-urban wetland Mfuleni, South Africa	310 ha	Provisioning services: $1765 ha/year		
Kalyanthakur para lake, Tripura	7.84 ha	Provisioning services: $26,263.65/year Cultural services: $2605.68/year	CVM	Taran, Deb, and Roy 2016
Ghodaghodi wetland, Nepal	2563 ha	$674,000 year	Market price method, net revenue method, value transfer method, and CVM	Aryal, Ojha, and Maraseni 2021
Koshi Tappu wildlife reserve, Nepal	175 km^2	$16 million/year	Market-based and value transfer method	Sharma, Rasul G, and Chettri 2015

The total ecosystem supply value (TESV) is the sum of provisioning, regulating, and cultural services, illustrated in Figure 3 (SEEA 2021). The value of an asset is determined by estimating the net present value (NPV) based on the stream of income expected to be earned in the future and then discounting the future income back to the present accounting period (SEEA 2021).

Valuation of wetland ecosystem services would aid in formulating strategies for wetland conservation to protect biodiversity, and sustainable use of wetland resources. The main objectives of this study were to assess TESV and NPV of wetlands in Karnataka, India. This entails accounting provisioning services, regulating services, and cultural services, considering services provided by algae, fish, and macrophytes.

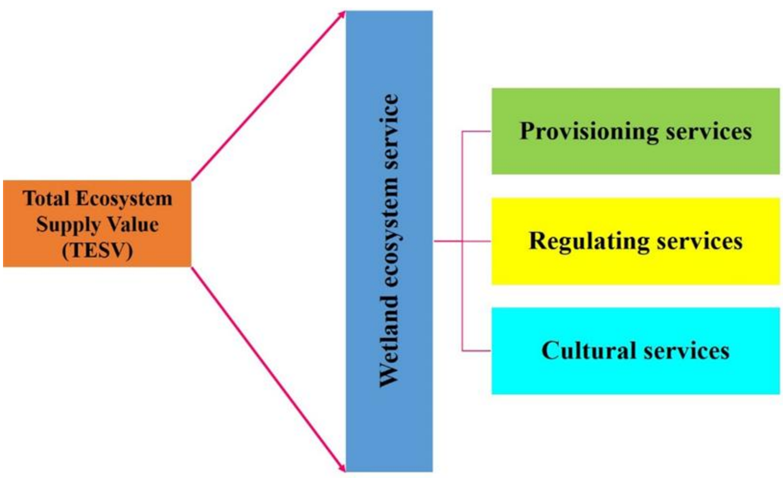

Figure 3 TESV framework for valuation of ecosystem services

Materials and Methods

Study area

Karnataka state is endowed with a vast inland water spread that includes lakes, tanks, reservoirs, rivers, and ponds. Figure 4 depicts the spatial distribution of wetlands in Karnataka. The state is located at 11°30'N and 18°30'N latitudes, 74°E and 78°30'E longitudes, and is the eighth largest state by area and the ninth largest state by population in India. Karnataka state is surrounded by the Arabian Sea to the west, Goa to the northwest, Maharashtra to the north, Telangana to the northeast, Andhra Pradesh to the east, Tamil Nadu to the southeast, and Kerala to the southwest. The state is divided into 30 districts, with Bengaluru as the capital city. Karnataka has a total land area of 191,967 km^2 (or 5.83% of India's total land area). Rainfall ranges from 500 mm to over 4000 mm. Agumbe in the Sahyadris receives the second heaviest annual rainfall (7600 mm) in India. Summer temperatures range from 18°C to 40°C, while winter temperatures range from 14°C to 32°C. Ragi, jowar, rice, wheat, sugarcane, coconut, groundnut, and cotton are the major crops grown in Karnataka.

Valuation of Ecosystem Service from Wetlands

The total ecosystem supply value of wetlands in Karnataka was assessed considering:
(a) provisioning services, (b) regulating services, and (c) cultural services. Ecosystem services are

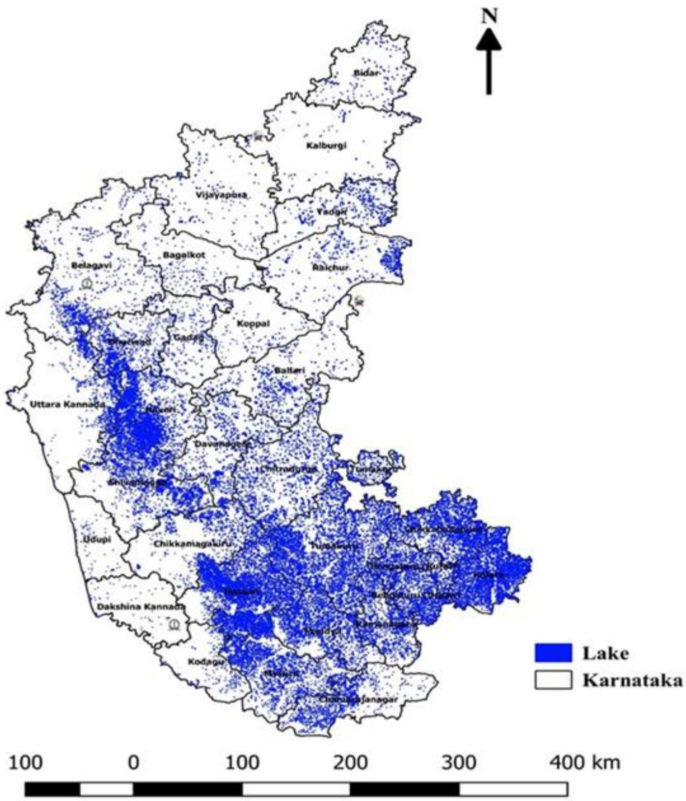

Figure 4 Wetlands of Karnataka, India

accounted through (i) residual value method and (ii) benefit transfer method. This involved data compilation from primary (field investigation) and secondary sources (government agencies, published articles in peer-reviewed journals). Provisioning services of ecosystems are accounted for through the residual value (or resource rent) method. The residual value method has been utilized to estimate the value of an ecosystem service by taking the gross value of the final marketed goods (to which the ecosystem service provides input) and then deducting the cost of all non-ecosystem inputs, including labour, produced assets, and intermediate inputs (SEEA 2021). Benefit transfer involves transferring monetary values of ecosystem services from previous studies or literature that focused on a different region or time period to our area of interest (Ramachandra, Raj, and Aithal 2019). Regulating and cultural service values are based on case studies from India, which are compared with the global ecosystem service valuation database (ESVD)[1] and published literature (of case studies from India) considering GDP (PPP) per capita for India[2] and the currency exchange rate.[3] The provisioning services considered are microalgae, fish, and macrophytes. Microalgae have a relatively shorter cycling period (5–7 days), and the microalgal productivity is 51.1 tonnes per hectare per year (t/ha/y). Microalgal biodiesel production will be economically viable with the economic valorization of residual biomass and extraction of value-added products such as glycerol, colloids, etc. (Branco-Vieira, Mata, Martins, *et al.* 2020; Yang, Hanna, and Sun 2012). In the current study, the total benefit (in INR/ha/y) from microalgae was computed by considering biodiesel, glycerol, food/protein, and feed for fish. Microalgae, being producers in the aquatic food chain, sequesters efficiently to the

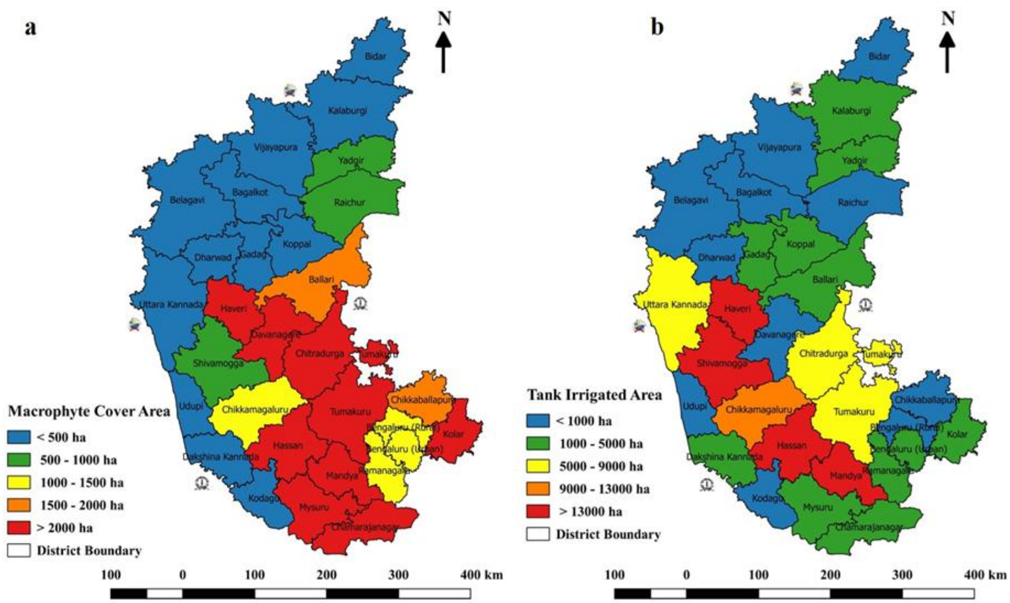

Figure 5 (a) Macrophyte covered area in wetlands and (b) tank irrigated area in districts of Karnataka

1 Details available at <https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf>

2 Details available at <https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD? locations=IN>

3 Details available at <https://www.xe.com/currencyconverter/convert/?Amount=1&From=USD&To =INR>

extent of 1.83 kg of carbon dioxide by 1 kg of algae (Chisti 2008). The carbon sequestration service is accounted for by considering the social cost of $80 per tonne of carbon dioxide removal (Verma, Negandhi, Wahal, *et al*. 2014) and molecular weight ratio (1 tC equals 3.67 tCO_2). The total value of carbon sequestration is INR234,404 tCO_2/ha/y.

Macrophytes covered 50,432.35 ha, which is ~18% of the Karnataka wetland area. The spatial extent of macrophytes in wetlands is shown district-wise in Figure 5 (a). Benefit from macrophytes was computed by considering services such as fodder, honey production, food, grazing, and handicrafts. The total value for carbon sequestration by macrophyte is INR311.92 kgCO_2/ha/y.

Fish is a rich source of easily digestible protein, polyunsaturated fatty acids, vitamins, and minerals for human nutrition (Elaigwu, Oladele, and Umaru 2019). The average fish catch based on field investigations is 495 kg/ha/y and benefit (residual value) from fish (as food) is 65INR/kg. The data on irrigation [Figure 5 (b)] and agricultural crops grown in each district of Karnataka was obtained from government reports, notably District at a Glance. The values adopted for the valuation of ecosystem services are listed in Table 3.

Table 3 Values used for wetland ecosystem valuation

Symbol	Service(s)	Unit value (INR/ha/y)	Reference(s)
	Provisioning services		
PS1	Microalgae	110,467	Field study
PS2	Macrophyte	11,291	Field study
PS3	Fish	32,175	Field study
PS4	Water	15,359	ESVD 2020
PS5	Raw materials	13,358	
PS6	Genetic resources	476	
PS7	Medicinal resources	786	Clarkson, Ausseil, and Gerbeaux 2013
PS8	Ornamental resources	905	
PS9	Fuelwood	5,833	Ramachandra, Rajinikanth, and Ranjini 2005, 2011; Schuijt 2002; Zuze 2013; Schuyt and Brander 2008
PS10	Irrigation	1,826	Mukherjee 2008
	Regulating services		
RMS1	Air quality regulation	270	ESVD 2020
RMS2	Climate regulation	1,191	
RMS3	Moderation of extreme events	105,781	
RMS4	Regulation of water flows	28,891	
RMS5	Waste treatment	16,225	
RMS6	Erosion prevention	20,704	Clarkson, Ausseil, and Gerbeaux 2013
RMS7	Maintenance of soil fertility	13,604	
RMS8	Biological control	7,529	

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Table 3 *Contd...*

Symbol	Service(s)	Unit value (INR/ha/y)	Reference(s)
RMS9	Maintenance of life cycles of migratory species	14,978	ESVD 2020
RMS10	Maintenance of genetic diversity	27,216	
RMS11	Carbon sequestration	234,716	Verma, Negandhi, Wahal, *et al*. 2014; Baral, Basnyat, Khanal, *et al*. 2016; Chisti 2008; Kalita 2019
RMS12	Water-borne diseases	1,941	Verma, Bakshi, and Nair 2001; Kant, Haq, Srivastava 2013; Ramachandra, Alakananda, Ali Rani, *et al*. 2011
RMS13	Pollination	19	Schuyt and Brander 2008
RMS14	Water conservation	2,875	Li and Gao 2016
RMS15	Flood control	7,053	Kaul, Masoodi, Rasool, *et al*. 2016; Zuze 2013; Schuyt and Brander 2008
RMS16	Habitat/refugia	1,825	Schuyt and Brander 2008; Kaggwa, Hogan, and Hall 2009
RMS17	Groundwater recharge	215,123	Ramachandra, Raj, and Aithal 2019; Kaggwa, Hogan, and Hall 2009
	Cultural services		
CS1	Aesthetic information	389	ESVD 2020
CS2	Opportunities for recreation and tourism	12,111	Anitha and Muraleedharan 2006; Rao 2018; Verma, Bakshi, and Nair 2001; Dixit, Bandyopadhyaya, and Kumar 2016; Mishra 2014; Venkatachalam and Zareena Begam 2016; Prasher, Negi, and Kumar 2006; Schuijt 2002; Zuze 2013; Schuyt and Brander 2008; Kaggwa Kaggwa, Hogan, and Hall 2009; Baral, Basnyat, Khanal, *et al*. 2016; Li and Gao 2016; Dehlavi and Adil 2011
CS3	Inspiration for culture, art and design	905	Ramachandra 2016; Ramachandra, Raj, and Aithal 2019; Zuze 2013; Schuyt and Brander 2008; Kaggwa, Hogan, and Hall 2009
CS4	Spiritual experience	8	ESVD 2020
CS5	Information for cognitive development	953	
CS6	Existence and bequest values	91,312	
CS7	Education	29,144	Ramachandra 2016; Ramachandra, Raj, and Aithal 2019; Li and Gao 2016

Note: The values are adjusted for GDP (PPP) per capita and corresponding currency exchange rate.
Sources: GDP (PPP) per capita for India. Details available at <https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN>
Currency exchange rate. Details available at <https://www.thehansindia.com/business/currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019>

The provisioning services of wetlands are calculated by Equation (1). The regulating service (RS) is calculated by Equation (2), and the cultural service (CS) is calculated by Equation (3). The total ecosystem supply value (TESV) is calculated using Equation (4), which is the sum of provisioning, regulating, and cultural services. The Equation (5) is used to calculate the net present value (NPV) of a wetland ecosystem (SEEA 2014; 2021), considering a social discount rate of 3% and the life of an ecosystem asset of 50 years.

$$PS_n = \sum_{i=1}^{10} PS_i \times A_n \qquad (1)$$

Where, PS_n is the total provisioning service district wise. n is Karnataka's 1–30 districts, i is the various provisioning services (i = 1 to 10 services), A_n is the wetland area of each district, but the area is different for the macrophyte (considered macrophyte cover area), irrigation (considered tank irrigated area), and fuelwood service (considered annual fuelwood extraction from 10% of the macrophyte area).

$$RS_n = \sum_{i=1}^{17} RS_i \times A_n \qquad (2)$$

$$CS_n = \sum_{i=1}^{7} CS_i \times A_n \qquad (3)$$

$$TESV = \sum_{n=1}^{30} PS_n + RS_n + CS_n \qquad (4)$$

$$NPV = \sum_{t=1}^{T} \frac{R_t}{(1+r)^t} \qquad (5)$$

where, NPV = net present value; R = net cash flow from an ecosystem in year t; T = discount period (50 years); and r = discount rate (3%). District-wise spatial extent of macrophyte is assessed using remote sensing data (Google Earth) and QGIS open-source GIS for mapping various wetland ecosystem services.

Results and Discussion

Ecosystem services provided by microalgae

Microalgae are photosynthetic microorganisms sequestering carbon during photosynthesis in the presence of solar energy, converting to carbohydrates and oxygen (Asulabha, Sincy, and Jaishanker, *et al.* 2018; 2022). Microalgae biomass is composed of carbohydrates, lipids, and proteins has been widely used in industries to produce fuel (biodiesel, bioethanol, methane, biobutanol, and biogas), feed (spirulina, and chlorella powder), biofertilizers, and medicines (pharmaceuticals and nutraceuticals). Select microalgal species are rich in proteins and produce proteins of 2.5–7.5 tonnes per hectare per year (Khan, Shin, and Kim, *et al.* 2018a). The provisioning services provided by microalgae from wetlands accounts to INR110,467 per hectare per year.

Ecosystem services provided by fish

Fisheries sector provides livelihoods, income, and economically nutritious food to the society (Sincy, Asulabha, Jaishanker, *et al.* 2018; 2022). Fish compose protein, essential fatty acids, and micronutrients (Fe, Zn, Ca, and vitamin A) and form an important component of the human diet and serve as medicine (Table 4) apart from supporting livelihoods of fishing communities. Major carps such as *Labeo rohita*, *Catla catla*, *Cirrhinus mrigala*, and the exotic carps *Cyprinus carpio*, *Ctenopharyngodon idella*, and *Hypothalmichthys molitrix* with high economic value constitute a vital component of local economy in India (Dasgupta and Panigrahi 2014). Ecotourism integrates both socio-economic and cultural activities, involving fishing activities has been providing recreation and education services that are aiding in the decentralized development (Tursi, Maiorano, Sion, *et al.* 2015) based on fish resources. The provisioning service provided by fish from wetlands in Karnataka accounts to INR32,175 per hectare per year.

Table 4 Fish species used in the treatment of ailments

Species	Part used	Medicinal use: curing diseases
Amblypharyngodon mola	Whole fish	Premenstrual pain; pox, pain, asthma
Anabas testudineus	Whole fish	Dysmenorrhoea
Anguilla bengalensis	Fats	Rheumatoid-arthritis
	Whole body	Piles and meningitis
	Body mucous	Burns
Bagarius bagarius	Fat	Rheumatism, gout and joint pain
Channa punctatus	Whole fish	Tuberculosis; diarrhoea
	Bile	Malaria
Channa stewartii	Whole body	Diabetes, pain, high pressure
Clarias batrachus	Whole body	Body ache, Small pox
Eutropiichthys vacha	Flesh	Tuberculosis, brain health
Heteropneustes fossilis	Whole body	Pain, wound healing; anaemia
Hilsa ilisha	Body oil	Arthritis, scurvy
Labeo pangusia	Bile	Stomach ache
Labeo rohita	Gall bladder (Bile)	Gastric ulcer, intestinal cancer
Mystus bleekeri	Whole body	Dysentery
Notopterus notopterus	Whole fish	Delivery pain, abdominal pain
Osteobrama cotio	Whole body	Ringworm infection
Puntius sp.	Whole body	Eye problem; blood purifier; common cold
	Head	Night blindness; memory loss
Wallago attu	Head	Liver tonic
	Barbels	Treatment of diarrhoea
Xenentodon cancila	Whole fish	Joint pain, swelling

Sources: Gogoi and Bora 2020; Borah and Prasad 2016; Gupta and Dey 2017; Prakash and Prakash 2021

Fish supports the livelihoods of fishing communities with regular income and employment (Table 5). The estimate indicates of $158,368, the revenue from fish products at Sundarbans (Islam and Hossain 2017).

Table 5 Economic value of fishing from wetlands

Waterbody	Area (ha)	Value ($/y)	Reference(s)
Kuttanad Wetlands, India	162,125	82,949,309	Rao 2018
Bhoj Wetland, India	3,229	113,103.4	Verma, Bakshi, and Nair 2001
Wular Lake, India	13,000	686,166.7	Kaul, Masoodi, Rasool, *et al.* 2016
Nakivubo Urban Wetland, Uganda	529	3,300	Schuijt 2002
Hadejia Nguru Wetland, Nigeria	350,000	3,465,100	
Chilwa Wetland, Malawi	240,000	18,675,500	
Zambezi Basin Wetland, Southern Africa	2,982,900	78,620,700	
Chilwa Wetland, Malawi	240,000	18,675,478	Zuze 2013
That Luang Wetland, Laos	2,000	1,092,092	
Muthurajawela Wetland, Sri Lanka	6,000	64,904	
Mfolozi Flood Plain, South Africa	20,886	149,543.8	
Muthurajawela Wetland, Sri Lanka	3,068	64,904	Schuyt and Brander 2008
Whangamarino Wetland, New Zealand	10,320	10,518	
Rachenahalli Lake, India	42.09	7,449	Ramachandra, Rajinikanth, and Ranjini, *et al.* 2005
Varthur Lake, India	220	51,642	Ramachandra, Alakananda, Ali Rani, *et al.* 2011
Pong Dam Wetland, India	15,500	54,160	Prasher, Negi, and Kumar 2006
Ulluru Tank, India	3.99	4,384	Ramachandra and Sreekantha 2006
Kaspadi Tank, India	1.7	1,047	
Nagara Tank, India	3.58	2,835	

Ecosystem services provided by macrophyte

Macrophyte provides food, fodder, medicine, and aid in water purification (remediation), carbon sequestration, while providing recreation opportunities (Ramachandra, Sincy, and Asulabha 2018). Macrophyte serves as food for other aquatic organisms, fodder for livestock, medicine for treating animal and human diseases, fibre, green manure, industrial raw materials (manufacture of essential oils), pesticides, and ornamental plants (Zhang, Xu, Chen, *et al.* 2014). *Alternanthera sessilis*, *Eleocharis dulcis*, and tubers of *Colocasia esculenta* are being used as vegetables, while *Fimbristylis dichotoma*, *Cyperus iria*, and *C. pangorie* are used for making mats (Rao, Mesta, and Chandran 2008). Table 6, lists the ecosystem services provided by diverse species of macrophyte. Value of the provisioning services provided by macrophyte amounts to INR11,291 per hectare per year.

Table 6 Benefits of macrophyte

Species	Uses
Alternanthera philoxeroides	Consumed as vegetable, animal feed
Azolla pinnata	Treats urinary problems
Bacopa monnieri	Cures fever
Ceratophyllum demersum	Reduce pain from insect/scorpion bites; fruit for domestic ducks
Cyperus sp.	Source of fibre, fuel, making mats, and food
Eichhornia crassipes	Used as fertilizer
Hydrilla verticillata	Used as fish food, aquarium plant, and fertilizer
Ipomoea aquatica	Used as vegetable and animal feed
Ludwigia perennis	Reduces fever
Nymphaea rubra	Flowers are used for religious purposes, an ornamental plant
Nymphoides indica	Reduces fever
Polygonum barbatum	Medicinal value
Salvinia cucullata	Used as fodder
Spirodela polyrrhiza	Used as organic manures, fodder, phytoremediation
Trapanatans var. bispinosa	Edible fruit, treats diarrhoea and dyspepsia
Vallisneria spiralis	Used as fish food, ornamental purposes
Wolffia globosa	Leaves used as vegetable

Sources: Kiran, Hamsa, and Puttaiah 2007; Taran and Deb 2020; Nandan and Singh 2004; Misra, Panda A and Sahu 2012; Sarma and Saikia 2010; Chai, Ooh, Quah, et al. 2015; Khan, Chowdhury N S, Sharmin 2018b

Ecosystem service value from wetlands in Karnataka

The benefits provided by wetlands of Karnataka can range from tangible products (such as food, fodder, fuelwood, medicine, and water) to intangible products (such as habitat, climate regulation, flood control, erosion control, water and air quality regulation, recreation, and aesthetics). The spatial analyses of wetlands in Karnataka using remote-sensing data, presented in Figure 6, highlight that about 61% of wetlands had an area of <2.5 hectares, 36% of wetlands had an area of 2.5–50 hectares, and 3% of wetlands had an area of >50 hectares.

The provisioning, regulating, and cultural services provided by wetlands in Karnataka constitute about 18%, 69%, and 13%, respectively, of the total ecosystem supply value (Figure 7).

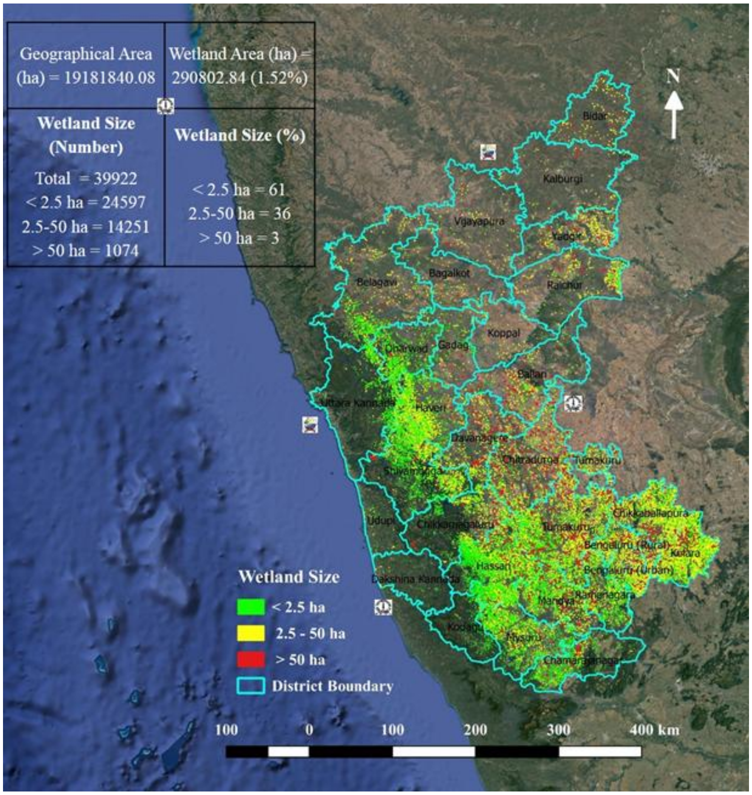

Figure 6 Classification of wetlands of Karnataka based on size

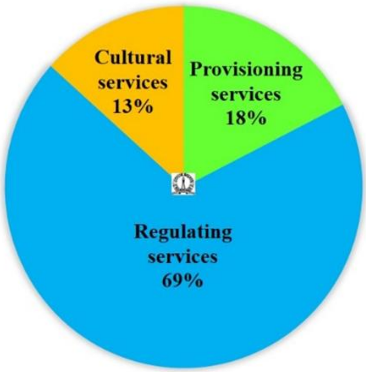

Figure 7 Contribution of ecosystem service provided by wetlands of Karnataka

The review of ecosystem services across wetlands reveals that the provisioning services of the Ga-Mampa wetland are about $90,000 per year (Adekola, Morardet, de Groot, *et al.* 2008). Similarly, Satajan wetland and bird sanctuary in Assam provided provisioning services (wild edible plants, fodder, firewood, fish, fresh water, and wild medicinal plants) of INR5,265,600 per year, or $78,591 per year (Kakoti, Phukan, and Devi 2019). Kalyanthakur Para Lake provides aquatic plants, fishes, molluscs, crabs, domestic uses, collection of timber, and fuelwood, worth $26,263.65 per year, while cultural services amounted to $2605.68 per year (Taran, Deb, and Roy 2016). The average provisioning services of wetlands considering material collection, fishing, crop production, hunting, and logging are about $11,508 per household per year (Adekola, Morardet, de Groot, *et al.* 2015). Figure 8 depicts district-wise provisioning, and regulating services provided by wetlands in Karnataka, which amount to INR49.70 and INR196.89 billion per year, respectively.

Recreational services of wetlands include swimming, boating, jogging, gardening, amusement parks, and as picnic spots for scenic beauty. The lakes in Karnataka have cultural significance, for example, Lalbagh Lake inside the Lalbagh Botanical Gardens supports a variety of flora and fauna and attracts nature lovers, bird watchers, and tourists. Nagavara Lake in Bengaluru has the water-front leisure park, Gardens, adjacent to it. The amusement park for children, and musical fountains, are popular amongst the visitors. Thonnur Lake in Mysore is an attractive spot for bird watching, boating, and swimming. Researchers are attracted to Karanji Lake in Mysore as it has the largest walk-through aviary in India and a butterfly park. The Regional Museum of Natural History on the banks of Karanji Lake provides information on the natural environment of South India and nature conservation. Pampa Sarovar is a sacred lake in Koppal district, Karnataka. A special pooja is conducted in the Honnamana Kere (Honnama Lake) in Kodagu during the Gowri festival. People

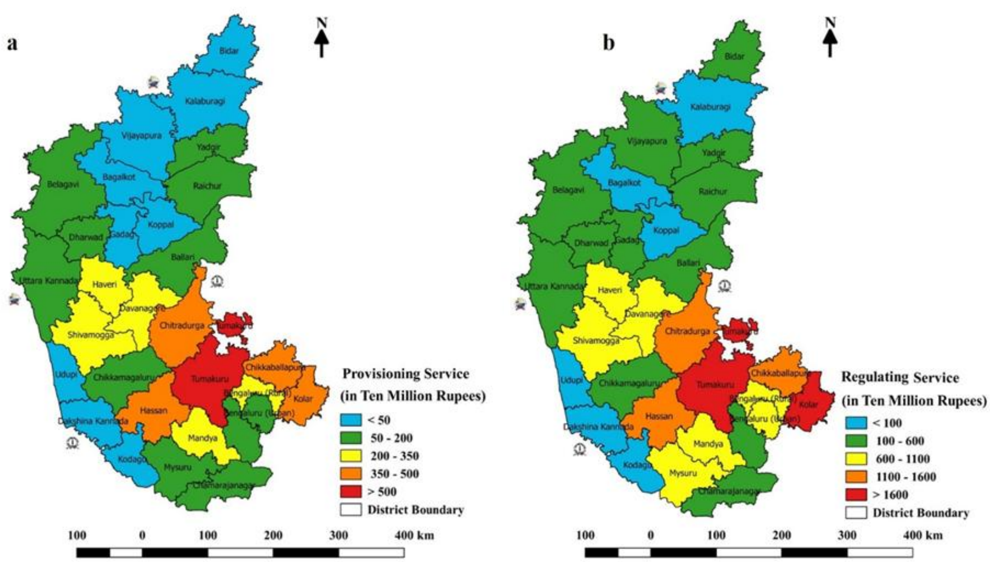

Figure 8 (a) Provisioning service and (b) regulating service of wetlands of Karnataka

offer *bagina* (puja items along with flowers and bangles placed in a bamboo basket) to the Lake and pray for good rain. In Karnataka, during Ganesh Chaturthi, Ganesh idols are immersed in *Kalyani* near the lakes. During festivals such as Durga puja, Jagadhatri puja, Lakshmi puja, and Ganesh Chaturthi, visitors perform puja in lakes (Bhattacharya, Bera, Dutta, *et al.* 2014; Bengani, Ujjania, Sangani, *et al.* 2020).

The cultural services provided by wetlands in Karnataka amount to INR37.93 billion per year, the district-wise share is presented in Figure 9. The annual economic value of the cultural service of the Pateira de Fermentelos wetland is estimated at 3087 €/ha/y (Roebeling, Abrantes, Ribeiro, *et al.* 2016). About 90% of people are willing to pay (WTP) for recreation in the Kanibrazan Wetland, with an average estimate of 38,217 Rials/person (Zarandi, Abesht, Abedi, *et al.* 2019). The cultural services of wetlands are evident from the revenue of $144,832 from the Sundarbans from tourism with 96,949 native and 3,868 foreign tourists (Islam and Hossain 2017).

Figure 10 illustrates the ecosystem services provided by wetlands, district-wise in Karnataka, and the analyses reveal that the Tumakuru district with the larger spatial extent of wetlands, contributes significantly (INR 47,142 million per year) through ecosystem services, followed by Kolar, Chitradurga, Hassan, Chikkaballapura, Mandya, and Shivamogga. The values of provisioning, regulating, and cultural services provided by wetlands in Tumakuru district are INR8214, INR32,641, and INR6287 million per year, respectively. Udupi district had the lowest values of INR40, INR157, and INR30 million per year in provisioning, regulating, and cultural services, respectively.

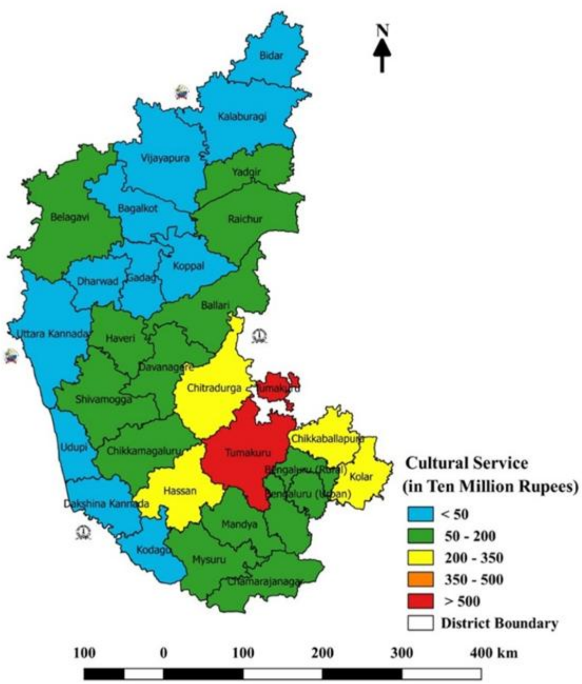

Figure 9 Cultural service of wetlands of Karnataka

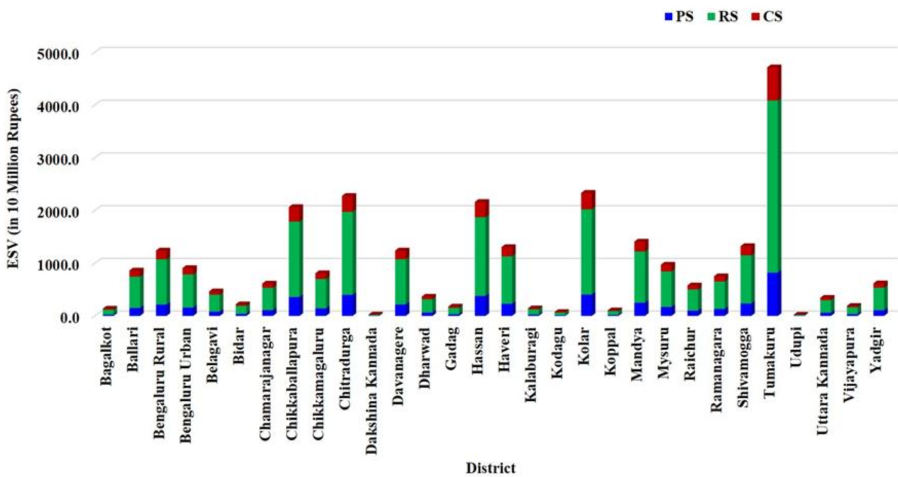

Figure 10 District-wise ecosystem service value of wetlands of Karnataka

Total Ecosystem Supply Value and Net Present Value of the Wetlands in Karnataka

Total ecosystem supply value is the summation of provisioning, regulating, and cultural services. TESV depends on the spatial extent and condition of the ecosystem. The TESV of Karnataka wetlands presented district-wise in Figure 11(a) reveals that Tumakuru district tops among all districts with INR47.14 billion per year of the total INR284.52 billion per year from wetlands in Karnataka. The average total economic value for food, water provisioning, and wastewater treatment in the Boeng Cheung Aek wetland is $30.12 million per year, ranging in $15.71–48.96 million per year (Ro, Sovann, Bun, *et al*. 2020).

Net present value computed, based on the annual flow of TESV shows that the worth of ecosystem assets of wetlands in Karnataka amounts to INR7321 billion. Figure 11 (b) depicts district-wise variability of NPV, with the highest NPV of INR1213 billion being in the Tumakuru district. The NPV ranged between INR450 and INR650 billion in districts like Chitradurga, Chikkaballapura, Hassan, and Kolar, whereas it ranged in INR250–450 billion in Davanagere, Haveri, and Shivamogga. Similar studies done across the globe indicate the NPV of revenue (benefits) earned during the last 10 years from Sukhna Lake in Chandigarh was estimated at INR451 million (Chaudhry, Bhargava, Sharma, *et al*. 2013). In the case of Koshi Tappu Wildlife Reserve, the total net benefit value from wetland fodder was estimated at $4,251,919 (Sharma, Rasul, and Chettri 2015).

Wetlands are fundamental to the economic, social, and cultural well-being of the population in India. Table 7 lists provisioning, regulating, cultural services, TESV, and NPV of wetlands in Karnataka. Wetlands cover an area of 281,300 hectares in Karnataka and provide provisioning services worth INR1.8 lakh per hectare per year, regulating services worth INR7 lakh per hectare per year, and cultural services worth INR1.3 lakh per hectare per year. The TESV of wetlands in Karnataka amounts to INR285 billion per year (or INR10.1 lakh per hectare per year) and the NPV of wetland assets is about INR7321 billion (Table 7).

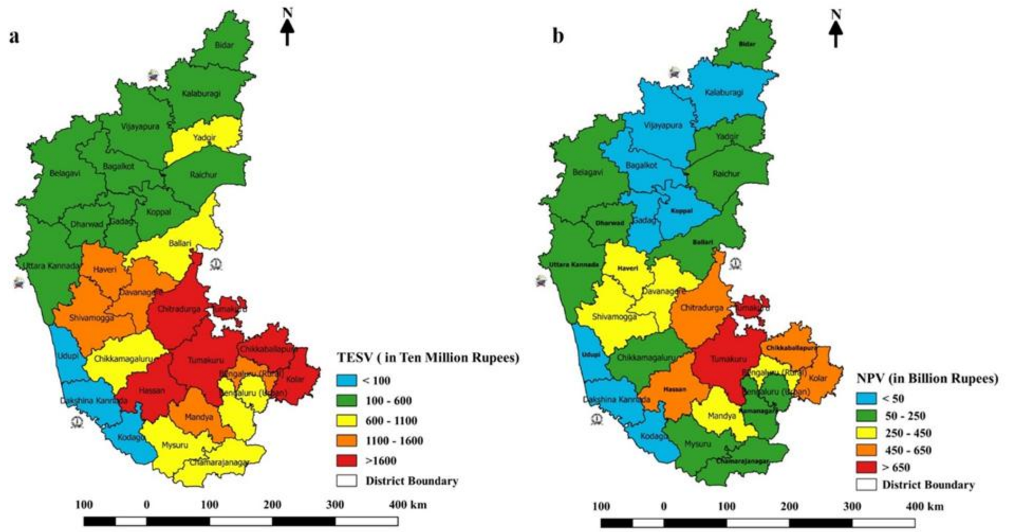

Figure 11 (a) TESV and (b) NPV of wetlands of Karnataka

Table 7 Total ecosystem value of Karnataka wetlands

Service(s)	Details	
	Wetland: Total area (in hectare) based on grid	281,299.5
Provisioning service	Total INR per year (in billion rupees)	49.70
	Production: INR per hectare per year (in lakh)	1.8
	Percentage distribution	18
Regulating service	Total INR per year (in billion rupees)	196.89
	Production: INR per hectare per year (in lakh)	7
	Percentage distribution	69
Cultural service	Total INR per year (in billion rupee)	37.93
	Production: INR per hectare per year (in lakh)	1.3
	Percentage distribution	13
TESV	Total INR per year (in billion rupees)	284.52
	Production: INR per hectare per year (in lakh)	10.1
NPV	NPV (in billion rupees)	7,320.6

Conclusion

The valuation of ecosystem services of wetland ecosystems, district-wise for Karnataka state, India was implemented as per the validated protocol—System of Environmental Economic Accounting (SEEA 2021). Services of the ecosystem were quantified by considering only the contribution of the ecosystem to the benefit, through the residual value method by taking the gross value of the final marketed goods to which the ecosystem service provides input and then deducting the cost of all other inputs, including labour, produced assets, and intermediate inputs.

The value of wetland ecosystem services, helps in developing appropriate policies towards the conservation and sustainable management of ecosystems. The value of provisioning, regulating, and cultural services ranged from INR4–821.4 ten million per year, INR15.7–3264.1 ten million per year, and INR3–628.7 ten million per year, respectively. Amongst the districts, the Tumakuru district contributes significantly with TESV of INR47.14 billion per year. TESV of Karnataka wetlands amounts to INR285 billion per year and the NPV is INR7321 billion. The valuation of ecosystem services underlines the fact that wetlands are highly productive and economically viable ecosystems, and the accounting of ecosystem services provides crucial information for optimal decision-making towards the judicious use of wetland resources.

Conservation of wetland ecosystems entails regular monitoring of water quality, recording of aquatic species, regular removal of accumulated silt, maintaining riparian vegetation, prevention of untreated wastewater inflow, regulating the introduction of exotic species, implementation of constructed wetlands and algal pond at inlets for nutrient removal, awareness among stakeholders, including public through regular seminars, workshops, and media, encouraging research on wetlands, adoption of wetlands by the local educational institutions for regular monitoring and environmental education programmes, and constituting a functional working committee of subject experts, local people, and decision-makers for regular auditing, effectively to provide valuable inputs to the wetland custodians.

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