Strategy Paper-3

Natural Capital Accounting and Valuation of Lentic Aquatic Ecosystem Services in Karnataka, India

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Karnataka Science and Technology Academy, (KSTA)
Bengaluru
Department of Science and Technology, Government of Karnataka
and
Energy and Wetland Research Group,
Centre for Ecological Sciences,
Indian Institute of Science,
Ranbir and Chitra Gupta School of Infrastructure Design and Management (RCG SIDM),
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Published by
Karnataka Science and Technology Academy (KSTA)
Department of Science and Technology, Government of Karnataka
And
Energy and Wetland Research Group,
Centre for Ecological Sciences,
Environmental Information Systems
Indian Institute of Science, Bengaluru
Ranbir and Chitra Gupta School of Infrastructure Design and Management [RCG SIDM]
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Message

Wetlands (lakes, swamps, etc.) are among the most diverse and productive ecosystems, providing numerous ecological, economic, and social benefits to society. Wetlands provide vital ecosystem services and processes, such as nutrient cycling, water purification, reducing pollution, carbon sequestration, groundwater recharge, flood reduction, erosion control, habitats for aquatic flora/fauna, opportunities for education, aesthetics, and recreation.

Post industrialization and globalization era witnessed a spurt in anthropogenic activities, leading to the degradation and decline of fragile ecosystems. This necessitates the conservation of vital ecosystems through sustainable management tenets, which requires an understanding of the livelihood support of ecosystems. Now, many wetlands are in degraded status due to increasing pollution and a lack of awareness among the public about the economic value of wetland ecosystems.

In this context, the current strategy paper focuses on the valuation of provisioning, regulating, and cultural services through the residual value and resource rent method as well as the benefit transfer method from aquatic ecosystems in Karnataka, India. Appraisal of ecosystem services (ES) 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 toward 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 wise use of natural resources. The natural capital accounting research, involving the quantification of services provided by wetlands, and the insights of economic values, would help in devising prudent policies for wetland restoration, conservation, and management. This will, in turn, aid in the development of a region through the wise use of natural resources to ensure sustainable development.

Date: 21-02-2023
Place: Bengaluru

Prof. S. Ayyappan
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Preface

Wetlands constitute vital components of the regional hydrological cycle. They are highly productive, support exceptionally large biological diversity, and provide a wide range of ecosystem services such as food, fibre, and waste assimilation, water purification, flood mitigation, erosion control, groundwater recharge, and microclimate regulation. They also enhance the aesthetics of the landscape and support many significant recreational, social, and cultural activities, aside from being a part of our cultural heritage. Ecosystem services are broadly categorized as (i) provisioning services are those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems, (ii) regulating and maintenance services are those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical cycles, and thereby maintain environmental conditions beneficial to individuals and society, (iii) cultural services are the experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contributes to a range of cultural benefits.

Ecosystem accounts make the value of ecosystem services visible, allowing them to be internalized into decision-making. Accounting of ecosystem services enables an assessment of trade-offs between economic development and environmental conservation and restoration, resulting in better-informed decisions. It also strengthens the economic case for conserving forests in states in India and developing countries where there can be tremendous pressure to relax forest laws and divert forests to non-forest uses without proper consideration of the sustainability of such actions.

There is an urgent policy need for more comprehensive assessments of the natural capital of ecosystems, which will aid in comparing these aggregate values with the opportunity cost of this land. Policymakers need such information to gain support for conservation funding, engage local communities, and develop market-based instruments for conservation, which necessitates accounting for the natural capital found in ecosystems and incorporating their economic worth added to the measurement of the wealth of a region.

The valuation of ecosystem services of lentic aquatic ecosystems is implemented district-wise for Karnataka State, India, as per the validated statistical framework for natural capital accounting – SEEA: System of Environmental-Economic Accounting (SEEA.un.org). According to SEEA protocol, ecosystem services are defined as the contributions of ecosystems to the benefits that are used in economic and other human activities.

The valuation of ecosystem services (VES) provides an unbiased framework to value unaccounted ecosystem benefits and helps develop meaningful policy interventions. The approach allows for adjusted regional or national accounts which reflect the output of ecosystem services, the depletion of natural resources, and the degradation costs (externalized costs of the loss of ecosystem services) of ecosystems in economic terms. In this perspective, the strategy paper (KSTA- Strategy Paper 3), focusing on the valuation of aquatic ecosystem services in Karnataka, India, will help raise awareness and provide a quantitative tool to evaluate the sustainability of policies. The endeavor toward developing the strategy paper was commissioned by the Karnataka Science and Technology Academy (KSTA), Bangalore. The research towards developing the strategy paper was carried out by the Energy and Wetlands Research Group at CES, Indian Institute of Science, in collaboration with the United Nations Environment Programme (UNEP), the ENVIS division, The Ministry of Environment Forests and Climate Change (MoEFCC), Government of India and Ranbir and Chitra Gupta School of Infrastructure Design and Management (RCG SIDM), Indian Institute of Technology Kharagpur (IIT-KGP) as part of the international, EU-funded Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) project.

The value of provisioning, regulating, and cultural services provided by freshwater lentic ecosystems in Karnataka are 50, 197, and 38 billion rupees/year, respectively. The total ecosystem supply value (TESV) provided by the freshwater ecosystem of Karnataka is 285 billion rupees/year, and the net present value (NPV) amounted to 7321 billion rupees. Similarly, the value of services provided by the estuarine ecosystem in Karnataka are 5, 10, and 1 billion rupees/year from the provisioning, regulating, and cultural services. The TESV provided by the estuarine ecosystem of Karnataka is 16 billion rupees/year, and NPV amounted to 411 billion rupees. The total value of provisioning, regulating, and cultural services considering both freshwater and estuarine ecosystem was 55 billion Rs/yr (1,83,328 Rs/ha/yr), 207 billion Rs/yr (6,91,577 Rs/ha/yr), and 39 billion Rs/yr (1,30,686 Rs/ha/yr), respectively. The total ecosystem supply value of Karnataka aquatic ecosystem was 301 billion Rs/yr (10,05,591 Rs/ha/yr), and the net present value amounts to 7,732 billion rupees, which highlights the ecological, social-cultural, economic, and environmental significance of wetlands.

Date: 21-02-2023
Place: Bengaluru

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Natural capital accounting and valuation of lentic aquatic ecosystem services in Karnataka, India

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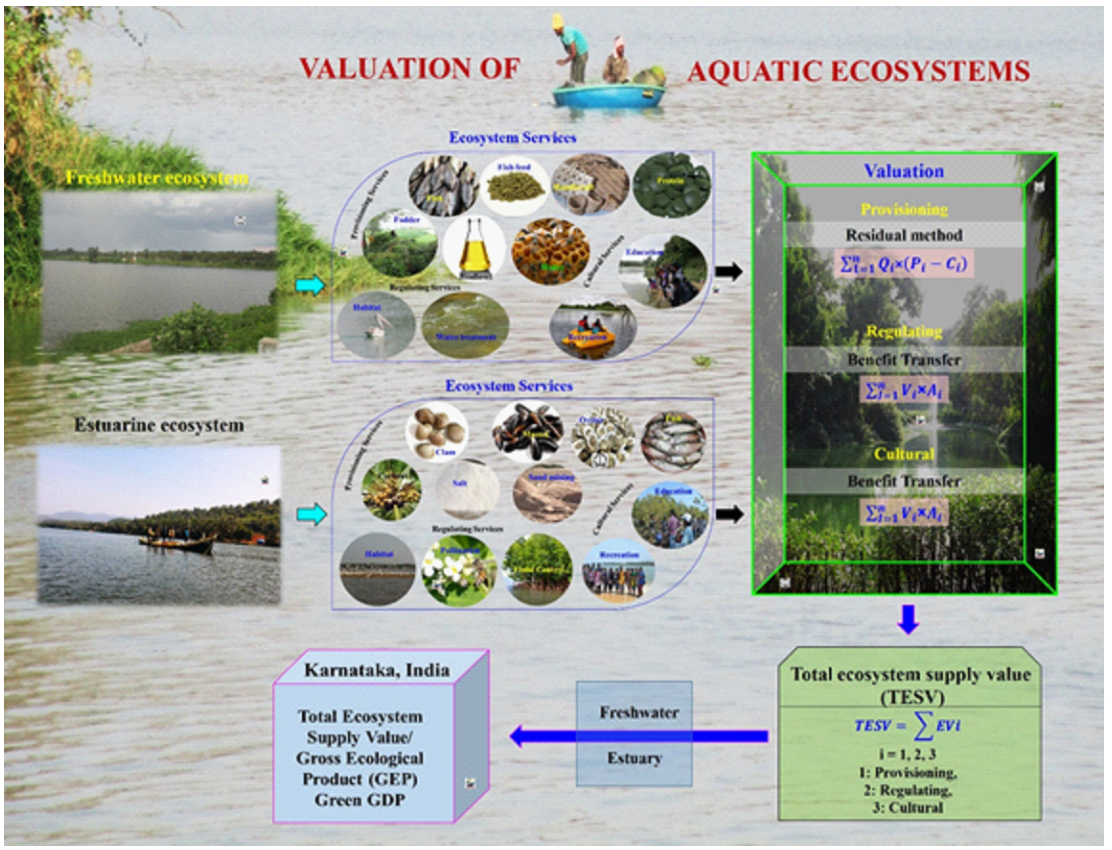
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Natural capital accounting and valuation of lentic aquatic ecosystem services in Karnataka, India

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Natural capital accounting and valuation of lentic aquatic ecosystem services in Karnataka, India

Executive Summary

Wetlands are productive ecosystems providing an array of services that sustain well being of dependent biota. Post industrialization and globalization era witnessed a spurt in anthropogenic activities, leading to the degradation and decline of fragile ecosystems. This necessitates conservation of vital ecosystems through sustainable management tenets, which requires understanding of the livelihood support of ecosystems. Now, many wetlands are in degraded status due to increasing pollution and a lack of awareness among the public about the economic value of wetland ecosystems. Thus, the current study focuses on the valuation of provisioning, regulating, and cultural services through the residual value and resource rent method as well as the benefit transfer method from aquatic ecosystems in Karnataka, India. The value of provisioning, regulating, and cultural services provided by freshwater lentic ecosystems in Karnataka are 50, 197 and 38 billion rupees/year, respectively. The total ecosystem supply value (TESV) provided by the freshwater ecosystem of Karnataka is 285 billion rupees/year and the net present value (NPV) amounted to 7321 billion rupees. Similarly, the value of services provided by estuarine ecosystem in Karnataka are 5, 10, and 1 billion rupees/year from the provisioning, regulating, and cultural services, respectively. The TESV provided by the estuarine ecosystem of the Karnataka is 16 billion rupees/year and NPV amounted to 411 billion rupees. The total value of provisioning, regulating, and cultural services considering both freshwater and estuarine ecosystem was 55 billion Rs/yr (183328 Rs/ha/yr), 207 billion Rs/yr (691577 Rs/ha/yr), and 39 billion Rs/yr (130686 Rs/ha/yr), respectively. The total ecosystem supply value of Karnataka aquatic ecosystem was 301 billion Rs/yr (1005591 Rs/ha/yr) and the net present value amounts to 7732 billion rupees. This highlights the importance of wetlands in ecological, social-cultural, and environmental aspects. Appraisal of ecosystem services (ES) 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 toward 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 wise use of natural resources. The natural capital accounting research, involving quantification of services provided by wetlands, and the insights of economic values would help in devising prudent policies for wetland restoration, conservation, and management. This will in turn aid in the development of a nation through the wise use of natural resources to ensure sustainable development.

Key words: Cultural services, Net present value (NPV), Provisioning services, Regulating services, Total ecosystem supply value (TESV), Wetlands.

1.0 Introduction

Wetlands are among the most diverse and productive ecosystems, providing numerous ecological, economic, and social benefits to society. Wetlands provide vital ecosystem services and processes, such as nutrient cycling, water purification, reducing pollution, carbon sequestration, groundwater recharge, flood reduction, erosion control, and habitats for aquatic flora/fauna, opportunities for education, aesthetics, and recreation (de Groot et al., 2020; Ramachandra et al., 2019; Barbier, 2013; Lambert, 2003; Costanza et al., 1997). The Ramsar convention on wetlands defined wetlands as "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed 6 m". Thus, wetlands refer to locations that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation and other biota typically adapted for life in saturated soil conditions. 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 (Zhang et al., 2015a). 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 et al., 2005). Wetlands also aid in remediation through removal of nutrients (like nitrate, phosphate, etc.) and heavy metals from water (Zedler and Kercher, 2005; Ausseil et al., 2015).

Functions of wetlands include provision of habitat for fish and wildlife, as well as for protecting water quality (remediation), erosion prevention, flood storage and recreation. Wetlands retard water flows, aid in the percolation of rainwater into the ground (vadose and saturated zones) and reduce downstream soil erosion. Some wetlands, particularly those on flood plains and in coastal areas, store excess water during storm events, which helps in flood control and protection from storms. Figure 1 illustrates the functions of wetland ecosystems, which are food production, habitat provision, information provision, and regulation of ecosystem processes. The food web includes complex, dynamic feeding relationships among the organisms inhabiting wetland environments. The combination of shallow water, high levels of inorganic nutrients, and high rates of primary productivity (the synthesis of new plant biomass through photosynthesis) in many wetlands is ideal for the development of organisms (insects, mollusks, and crustaceans)

that form the base of the food web. The primary producers, microalgae are photo synthetic organisms that provide food and energy to higher trophic levels. Consumers at the next level of food chain consume the above-ground live vegetation (herbivore-carnivore food web), while some utilize the dead plant biomass, which breaks down in the water to form small, nutrient-enriched particles of organic material (detritus). As the plant material continues to break down into smaller and smaller particles, it becomes increasingly enriched (nutritious) due to bacterial, fungal, and protozoan activities. The enriched proteinaceous material, including the various microbes that colonize it, feeds many small aquatic invertebrates and small fish, which then serve as food for larger predatory amphibians, reptiles, fish, birds, and mammals.

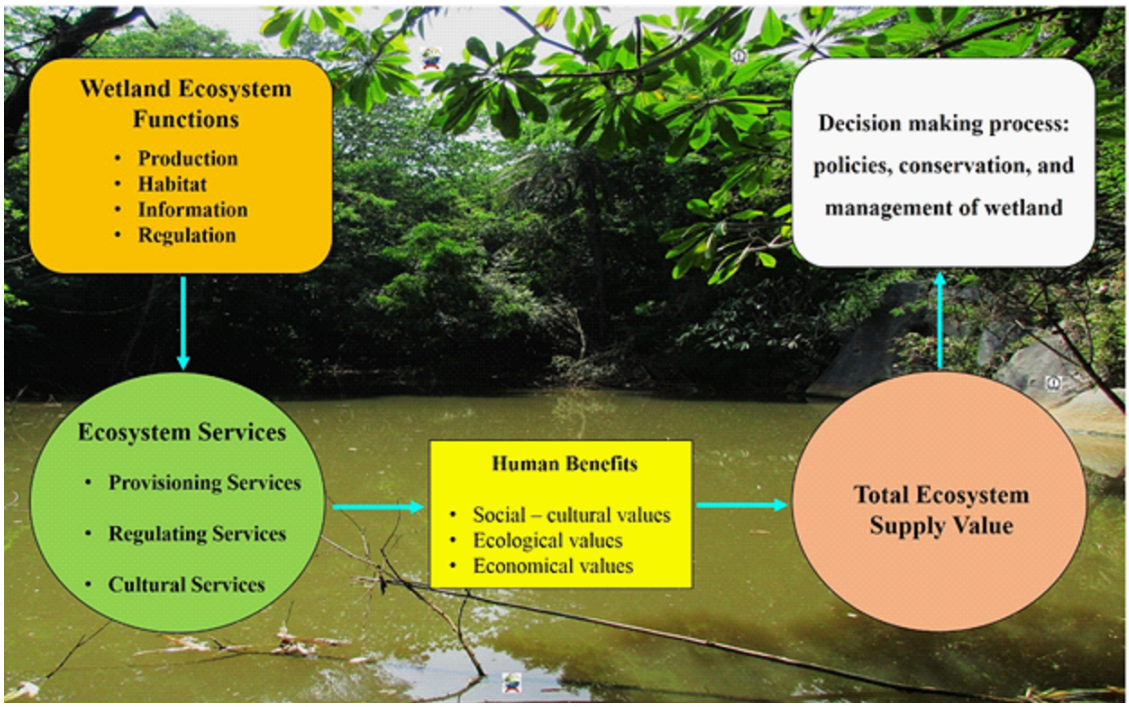


Figure 1.Wetland ecosystem function and service valuation

The diversity of habitats in a watershed of wetlands are vital for biogeochemical cycling, which involves the biological, physical, and chemical transformations of various nutrients within the biota, soils, water, and air. Wetlands are very important with regard to the management of nitrogen, sulfur, and phosphorus. Anaerobic (non-oxygenated) and chemically reduced wetland soils and the muddy sediments of aquatic habitats like estuaries, lakes, and streams, which support microbes that function in nitrogen and sulfur cycling. Upon death and decay, the nitrogen and sulfur in plant and animal biomass are released through mineralization. Much of this is eventually transformed into gaseous forms and released into the atmosphere, where it once again becomes available to certain plants and their associated nitrogen-fixing bacteria in the soil. This is literally a major defense for mud, since it is the anaerobic and chemically reducing conditions in the substrate, in conjunction with various microbes, that ensure the gaseous release of nitrogen and sulfur. On the other hand, phosphorus does not have a gaseous form, but vascular plants in wetlands transform inorganic forms of phosphorus (that might otherwise be shunted into undesirable algal blooms) into organic forms in their biomass as they grow. Thus, wetlands provide the conditions needed for the removal of both nitrogen and phosphorus from surface water, which improves water quality, including that of drinking water, by intercepting surface runoff and removing or retaining inorganic nutrients, processing organic wastes, and reducing suspended sediments before they reach open water.

The pelagic food chain (phytoplankton at the base) was the longest with four trophic transfers, compared to the benthic food chain (based on detritus of planktonic origin), which involved three trophic transfers, and the macrophytic detritus-based food chain involved two trophic transfers (Kulkarni and Ramachandra, 2006; Peel et al., 2019). The oxygenic photosynthesis by microalgae belonging to cyanobacteria led to an increase in oxygen levels on early Earth, initiating aerobic respiration and leading to the evolution of complex multicellular life forms (Sánchez-Baracaldo and Cardona, 2020; Soo et al., 2017). Microalgae provide consumers in the food chain with omega-3 polyunsaturated fatty acids (PUFA) (Ebm et al., 2021). Thus, microalgae provide PUFA such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) to other aquatic organisms for their growth (Ruess and Müller-Navarra, 2019).

Macrophyte provide food and shelter for other aquatic organisms, serve as fodder for livestock, and have medicinal value used for treating diseases. Macrophyte act as substrata for periphyton (Vadeboncoeur, 2006) as well as microhabitats (food and space) for zooplankton (Choi et al., 2014). In aquatic ecosystems, macrophyte aid in nutrient removal, water purification/treatment, and carbon sequestration (Ramachandra et al., 2020a). Fish store nutrients in their tissues, translocate nutrients and excrete dietary nutrients in dissolved forms that are readily available to primary producers, i.e., microalgae in lakes (Vanni, 2002). The feeding activities of fish alter the community structure of phytoplankton, zooplankton, and aquatic insects (Griffiths, 2006). Bioturbation of bottom sediments by fish will cause the release of nutrients into overlying surface water in shallow lakes, thus altering the quality of the water.

Wetlands provide numerous ecosystem services, which include provisioning, regulating, and cultural services, there is a need to quantify the socio-cultural, ecological, and economic value of wetlands (TEEB, 2010) for evolving effective wetland conservation and management strategies (figure 1). Wetland valuation aids in prudent management, conservation, and sustainable use of wetlands and their resources to improve environmental health and biodiversity, to minimize pollution and environmental degradation, and allows decision-makers to develop incentives, policies, and raise financial support for wetland conservation.

1.1 Ecosystem services from wetlands

Ecosystem services are the benefits derived from nature for human wellbeing (figure 2). The Millennium Ecosystem Assessment (MEA) and the Common International Classification of Ecosystem Services (CICES) have identified ecosystem services as provisioning, regulating, and cultural services.

Provisioning services include the products / material benefits obtained from ecosystems such as water, food (fish, algae, etc.), fiber, fuel, genetic resources, biochemical, medicines, and pharmaceuticals. Regulating services include the benefits obtained from various ecosystem processes, such as water regulation, climate regulation, water purification, erosion regulation, and flood control. Cultural services include the nonmaterial benefits from ecosystems through spiritual, recreational, aesthetic, and ecotourism experiences (Magalhães Filho et al., 2021; de Groot et al., 2006).

These benefits may vary in terms of geographical scale, from local to global (Everard et al., 2019). Different researchers have studied wetland ecosystem services globally (table 1). The economic value of a wetland depends on catchment (watershed) integrity or characteristics (hydrology, vegetation, and soil), geographical conditions, socio-economic aspects, and the population of the wetland area (Yiran et al., 2014). The monetary value of global wetland ecosystem services (in 2011) is estimated at US$ 47.4 trillion per year, constituting about 43.5% of the total value of all natural biomes (Davidson et al., 2019). The economic value of Songore wetland was estimated at $142431 (gross financial value) and the wetland income was $20,848 annually (Mahlatini et al., 2020). The total value of ecosystem services from Mabamba Bay wetlands was found to be US$3.6 million/year (Akwetaireho and Getzner, 2010).



Figure 2. Ecosystem services from wetlands

Table 1.Wetland ecosystem services in $/ha/yr

Services	de Groot et al., 2020	Clarkson et al., 2013	de Groot et al., 2012	Costanza et al., 1997	Russi et al., 2013	Quintas-Sorian et al., 2016	Li & Gao, 2016	Zang et al., 2011	Zhang et al., 2015b
Food	6,030	614	1111	256	2090	479		26	14
Water	1,934	408	1217	3800	5189	234	3800		2872
Raw materials	1,682	425	358	106	2430		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			1148	65
Moderation of extreme events	13,320	2986			4430				
Regulation of water flows	3,638	5606		15	9369			2345	
Waste treatment	2,043	3015	162125	4177	4280	175	4177	2376	2562
Erosion prevention		2607	3929	4539		41			
Maintenance of soil fertility		1713	45		4588			112	1
Biological control		948				20	304	326	351
Maintenance of life cycles of migratory species	1,886	1287	10648	304	917				
Maintenance of genetic diversity	3,427	1168	6490		2554				
Aesthetic information	49	1292			3906	109			
Opportunities for recreation and tourism	2,660	2211	2193	574	3700		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			

In India, freshwater lakes provide various ecosystem services to society. For example, the services provided by Rachenahalli lake in Bangalore is 10,435 Rs/ha/day (Ramachandra et al., 2005). The services provided by freshwater lakes in the Kashmir Himalayas include sources of drinking water, irrigation, agriculture, fishery, navigation, recreation, and socioeconomic development (Najar and Khan, 2012). Pandoh Lake water is used for the generation of hydropower, fishing, and agricultural activities (Anshumali and Ramanathan, 2007). Bramhapura Maun in Muzaffarpur city, Bihar provides various services to people, such as food (fish), fodder, ornamental resources, traditional medicine, aquaculture, and water for domestic use (Kumar et al., 2013).

Tourism is a major source of foreign exchange, income, and employment in countries. Neermahal is the "Lake Palace" in East India, situated in the middle of Rudrasagar lake, attracts numerous visitors from India and abroad

(Burman et al., 2007). Rewalsar lake has mythological significance where the pilgrims of Hindu, Sikh, and Buddhist communities perform religious rituals (mass bathing, offering flowers and garlands, offering food for fishes, birds, etc.) during the Baisakhi fair (Harvest festival) in Himachal Pradesh, India (Kashyap et al., 2016). In Pushkar Lake, the festival of Kartik Poornima and the annual cattle fair are held in the month of Kartik (October-November) (Lal and Gardner, 2016). According to an Indian wetland study, states such as Karnataka, Gujarat, and Andhra Pradesh are the richest states in terms of wetland wealth, with a worth of 7896 million US$/yr, 7689 million US$/yr, and 7671 million US$/yr respectively (Pandey et al., 2004).

Several researchers have integrated various geospatial techniques for wetland monitoring and conservation measures, to understand the importance of wetland ecosystem services (table 1). Geospatial techniques play a significant role in wetland inventory, monitoring, habitat suitability analysis, and the preparation of conservation and management plans (Garg, 2015). Geographical Information System (GIS), and temporal remote sensing data can help in mapping of wetland ecosystems, and ecosystem services (Langan et al., 2019). GIS-based tools are useful to incorporate public perception into ecosystem assessments (Shoyama and Yamagata, 2016). The involvement of stakeholders in ecosystem valuation helps to identify the major relevant services, assess the values of ecosystem services, and discuss trade-offs involved in ecosystem service use (Koko et al., 2020). Various GIS based mapping, and modelling tools have been designed to assess ecosystem services include Water World, Artificial Intelligence for Ecosystem Services (ARIES), Integrated valuation of Ecosystem Services and Trade-offs (InVEST), Water Evaluation and Planning System (WEAP), Toolkit for Ecosystem Service Site-based Assessment (TESSA) help in policy and decision making (Pandeya et al., 2016). Geoinformatics with geospatial tools are useful in the valuation of wetland ecosystems.

1.2 Approaches of ecosystem service valuation

In general, market value is used for provisioning services, while non-market values are used for regulating services, as well as cultural services (table 2). Direct valuation (market prices) was applied to estimate the value of provisioning services, while indirect valuation included the avoided cost method and the replacement cost method (Aulia et al., 2020). The value of regulating services provided by wetlands can be obtained through non-market valuation techniques using travel cost (TC), contingent valuation (CV), or hedonic pricing (HP) methods (Woodward and Wui, 2001). The valuation of cultural services is estimated using direct market pricing and travel cost methods (de Groot et al., 2012). The contingent valuation method (CVM) depends on individuals' preferences (willingness to pay for a service) in monetary terms and is used for economic valuation of ecosystem services, including both use values and non-use values (Vo et al., 2012). The willingness to pay (WTP) and benefit-transfer methods are two chief methods of economic valuation (Xu et al., 2020).

Table 2. Various methods adopted for ecosystem services valuation

Wetland	Area	Total value of ecosystem service (ES)	Method used for ecosystem service valuation	Reference
Rachenahalli Lake, Bengaluru, Karnataka	42.09 ha	10435 Rs/ha/day	Market prices method and CVM, socio-economy survey and questionnaire	Ramachandra et al., 2005
Varthur Lake, Bengaluru, Karnataka	220 ha	9554000 Rs/220ha/yr	Market prices method and CVM, socio-economy survey and questionnaire	Ramachandra et al., 2011
Chan-Ba wetland, China	2533 hm^2	7.7462×10^6 ¥/a 3.87×10^8 ¥/a	Market value method, travel cost method, shadow engineering method, ecological method, carbon tax method, afforestation cost method and alternative cost method	Zhou et al., 2018

Begnas watershed system	49 km^2	3.91 US$ million per year, equivalent to 650.67 US$ per household and 799.79 US$/ha	Market price method, TC method, revealed price method, CVM, and benefit transfer method	Thapa et al., 2020
Lake and marsh wetlands in China	3.241 × 10^4 km^2	8.1841 × 10^{10} (USD)	Value transfer method	Yiran et al., 2014
35 national nature reserves in 11 coastal provinces/municipalities in China		331.68 ×10^8USD/yr	Market price method, avoided cost method, and shadow project method	Li et al., 2020
Ga-Mampa wetland, South Africa	1 km^2	Provisioning services: 90,000 $/yr		Adekola et al., 2008
Songore wetland, Zimbabwe	56.25 ha	20,843.31 $/yr	Market price method	Mahlatini et al., 2020
Rural wetland Letseng-la-Letsie, South Africa	819 ha	Provisioning services:220 $/ha/yr	Market price method	Lannas and Turpie, 2009
Peri-urban wetland Mfuleni, South Africa	310 ha	Provisioning services:1765 $/ha/yr	Market price method	
Satajan wetland of North Lakhimpur, Assam, India	95 acre	Provisioning services: Rs 52, 65,600 or 78,591 $/yr	3 types of surveys were conducted: (i)key information interview, (ii) focus group discussion and (iii) household surveys, market cost valuation method and alternate valuation method	Kakoti et al., 2019
Kalyanthakur para lake, Tripura, Northeast India	7.84 ha	Provisioning services: 26263.65 US$/yr Cultural services: 2605.68 US$/yr	CVM	Taran et al., 2016
Kala-oya basin, Sri Lanka	2,870 km^2	Provisioning services: 2972 US$/ha/yr	Participatory appraisal methods and	Vidanage et al., 2005
			market prices method	

Ghodaghodi wetland, Nepal	2563 ha	674,000 US$/yr	Market price method, net revenue method, value transfer method, and CVM	Aryal et al., 2021
KoshiTappu wildlife reserve, Nepal	175 km^2	16 USD million/yr	Market-based and value transfer method	Sharma et al., 2015

The valuation of ecosystem services of lentic aquatic ecosystems (inland wetlands and esturies) is implemented for Karnataka State, India as per the validated protocol - System of Environmental Economic Accounting (SEEA EA; SEEA.un.org), which constitutes the statistical framework for natural capital accounting. According to this protocol, ecosystem services are defined as the contributions of ecosystems to the benefits that are used in economic and other human activities. The valuation of ecosystem services (VES) 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. It provides an unbiased and dependable national framework to value so far unaccounted ecosystem benefits and helps develop meaningful policy interventions.

Ecosystem services encompass all forms of interaction between ecosystems and people, including both in situ and remote interactions. The supply of an ecosystem service is associated with an ecosystem structure or process or a combination of ecosystem structures and processes that reflect the biological, chemical, and physical interactions among ecosystem components. Ecosystem services are broadly categorised as (i) provisioning services, which are those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems; (ii) regulating and maintenance services, which are those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical cycles, and thereby maintain environmental conditions beneficial to individuals and society; and (iii) cultural services, which are experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contributes to a range of cultural benefits. There is a range of other benefits, for example, concerning relational and intrinsic values, that are not captured in the above categories.

A key feature of ecosystem accounting is its capacity to integrate spatially referenced data about ecosystems, i.e., data about the location, size, and condition of ecosystems within a given area and how these are changing over time. Recording these stocks and changes in stocks in a coherent and mutually exclusive manner supports the derivation of indicators. Understanding the size and location of ecosystems also supports the measurement of ecosystem conditions and the quantification and valuation of many ecosystem services, the flows of which will vary from ecosystem to ecosystem.

The total ecosystem supply value (TESV) is the sum of provisioning services, regulating services, and cultural services for a particular ecosystem (figure 3). In the international System of Environmental-Economic Accounting (SEEA, 2014), ecosystem assets are generally valued based on the net present value (NPV) of the expected flow of ecosystem services.

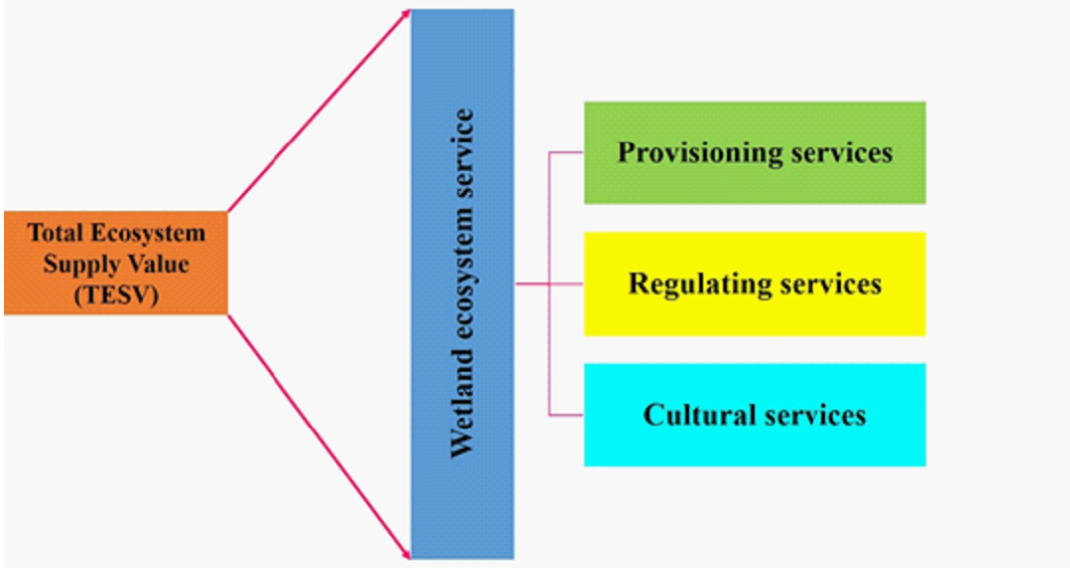


Figure 3. TESV framework for valuation of ecosystem services

There are only a few studies focusing on the valuation of wetland ecosystems in India. For protecting biodiversity, sustainable use of wetland resources, and wetland conservation, the valuation of wetland ecosystems is necessary. The main objectives of this study were to (a) find out the various aquatic ecosystem services provided by algae, fish, macrophyte, and mangroves; (b) estimate the provisioning services, regulating services, and

cultural services provided by wetlands in all the districts in Karnataka; (b) accounting the total ecosystem supply value (TESV) and the net present value (NPV) of wetlands in Karnataka, India.

2.0 Materials and Methods

2.1 Study Area

Karnataka State is endowed with a vast inland water spread that includes lakes, tanks, reservoirs, rivers, and ponds. Karnataka (11°30'N and 18°30'N latitudes and 74°E and 78°30'E longitudes) is the eighth largest state by area and ninth-largest state by population in India. The wetlands of Karnataka are shown in figure 4.1 Size and district wise distribution of wetlands in Karnataka is presented in Figure 4.2.

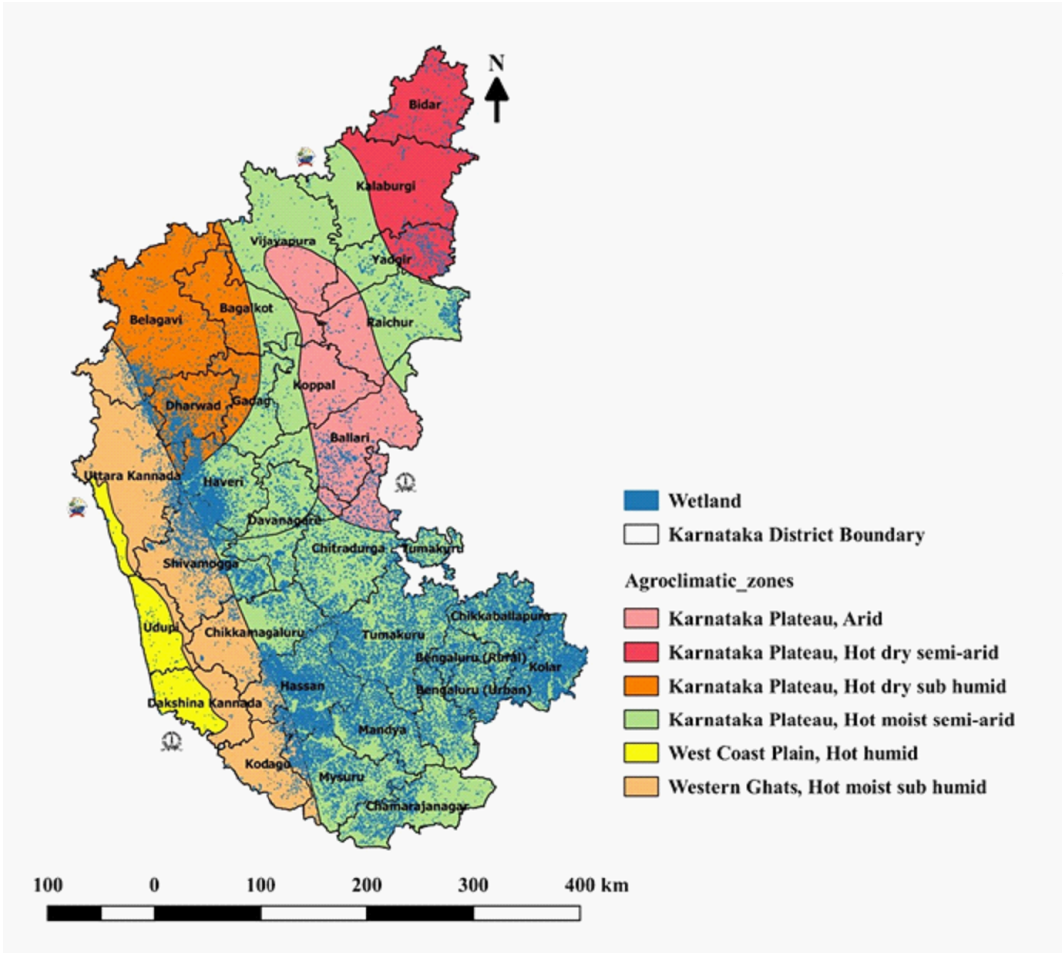
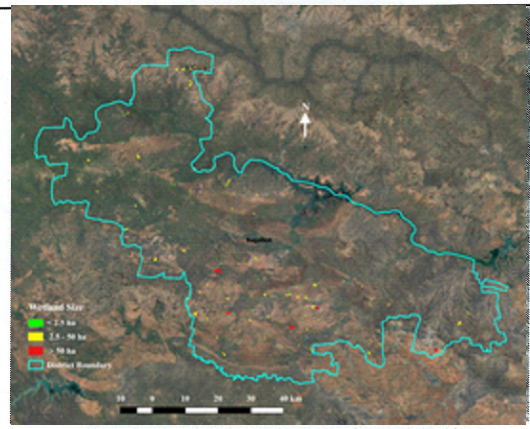
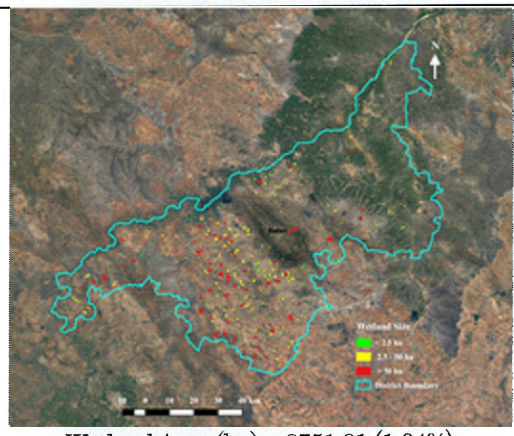
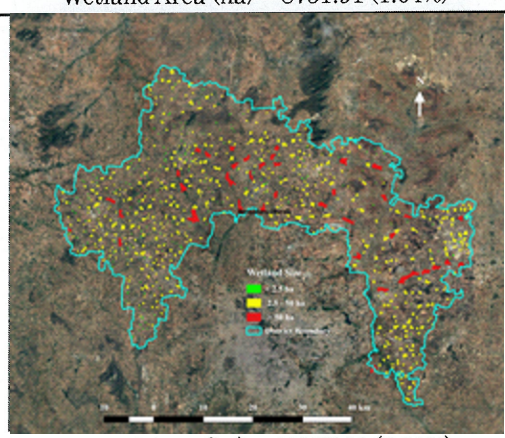
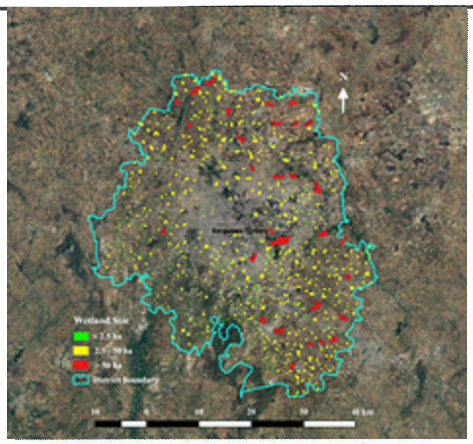
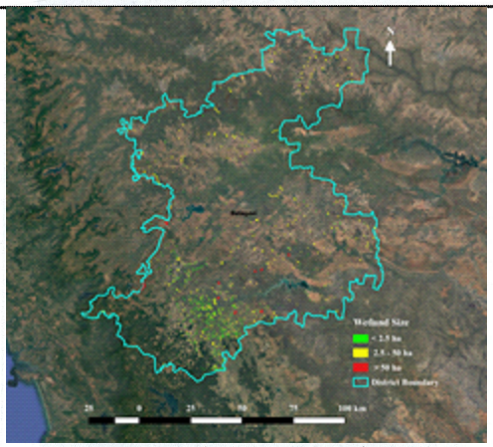
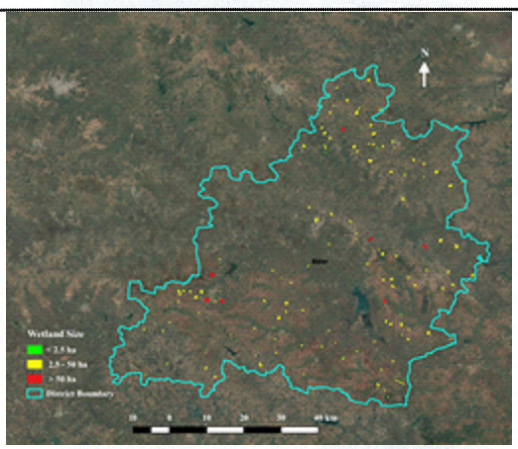


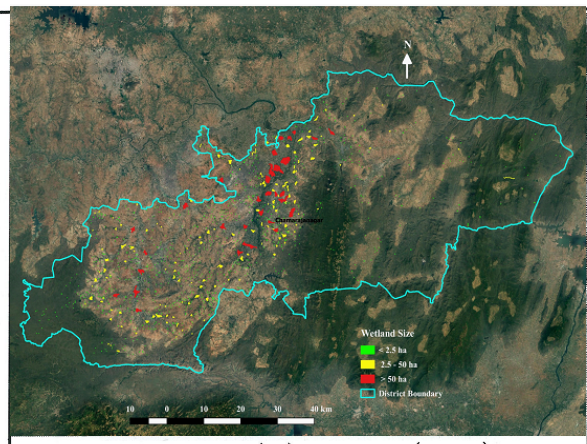
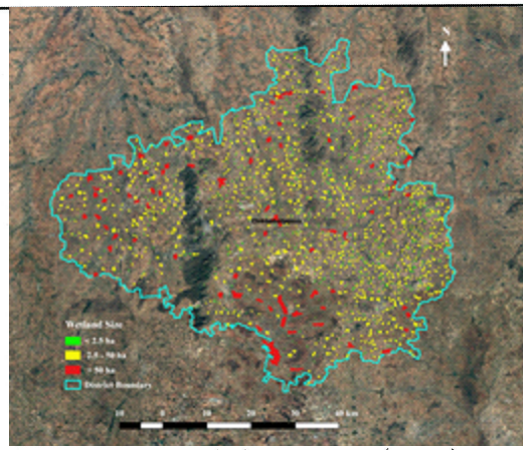
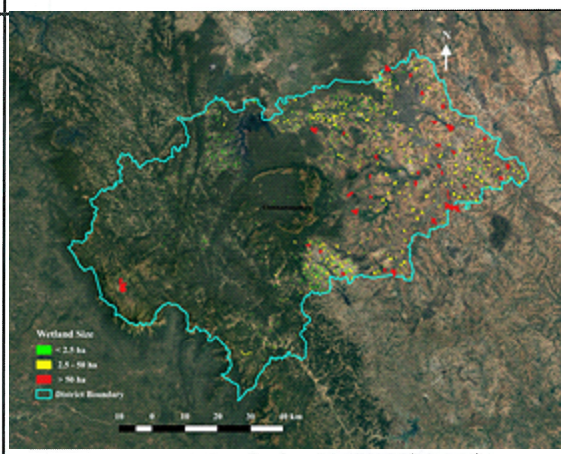
Figure 4.1 Wetlands of Karnataka, India

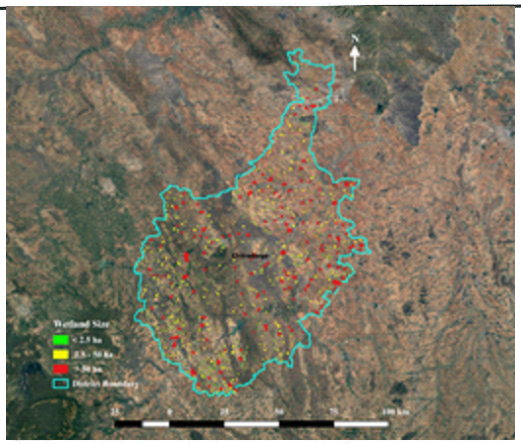
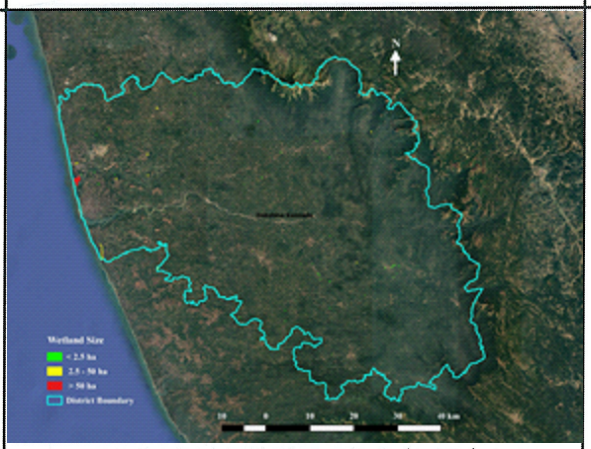
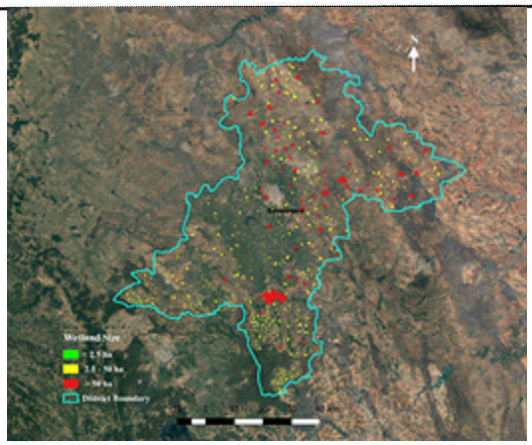
Karnataka state is surrounded by the Arabian Sea to the west, Goa to the northwest, Maharashtra to the north, Telangana to the northeast, Andhra Pradesh to the east, Tamil Nadu to the southeast, and Kerala to the southwest. The state is divided into 30 districts, with Bengaluru as the capital city. The total land area of Karnataka is 191,967 square kilometers (i.e., 5.83 percent of the total land area of India). 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 – 40°C whereas winter temperatures range from 14°C – 32°C. Ragi, jowar, rice, wheat, sugarcane, coconut, groundnut, and cotton are the major crops grown in Karnataka.

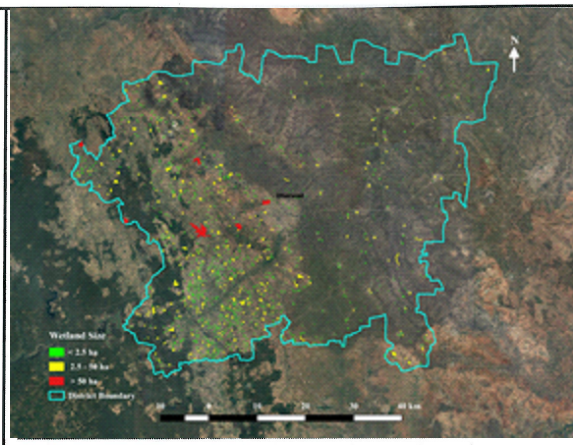
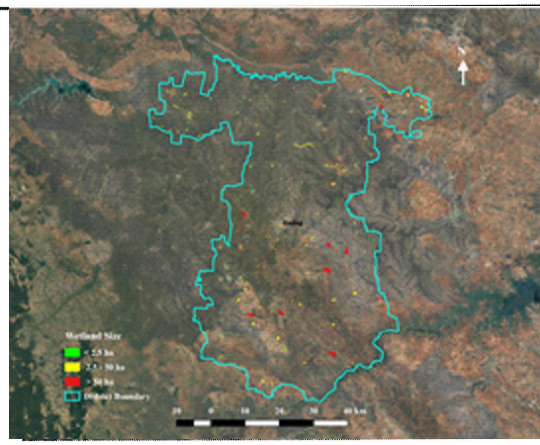
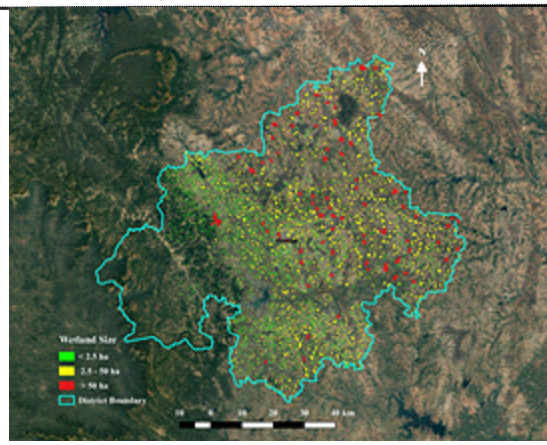
Figure 4.2 Karnataka wetlands: Districtwise distribution, size and numbers

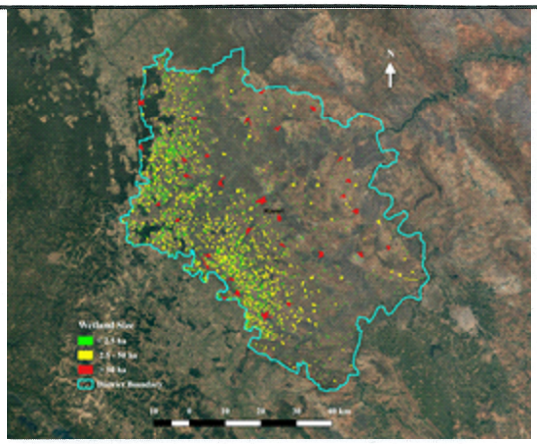
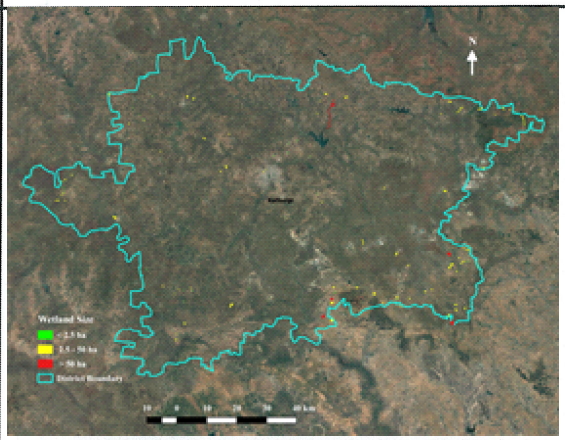
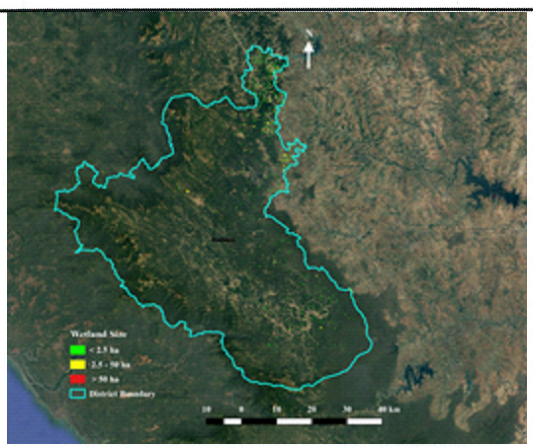
District	Map	Wetland Size (Number)	Wetland size (%)
Bagalkot (Bagalkote) Geographical Area (ha) = 656257.27	 Wetland Area (ha) = 1391.90 (0.21%)	Total Number = 198 < 2.5 ha = 117 2.5–50 ha = 76 > 50 ha = 5	< 2.5 ha = 59.1 2.5–50 ha = 38.4 > 50 ha = 2.5
Ballari (Bellary) Geographical Area (ha) = 845578.94	 Wetland Area (ha) = 8751.91 (1.04%)	Total Number = 515 < 2.5 ha = 280 2.5–50 ha = 182 > 50 ha = 53	< 2.5 ha = 54.4 2.5–50 ha = 35.3 > 50 ha = 10.3
Bengaluru (Rural) (Bangalore Rural) Geographical Area (ha) = 230057.52	 Wetland Area (ha) = 11997.61 (5.22%)	Total Number = 803 < 2.5 ha = 234 2.5–50 ha = 529 > 50 ha = 40	< 2.5 ha = 29.1 2.5–50 ha = 65.9 > 50 ha = 5.0

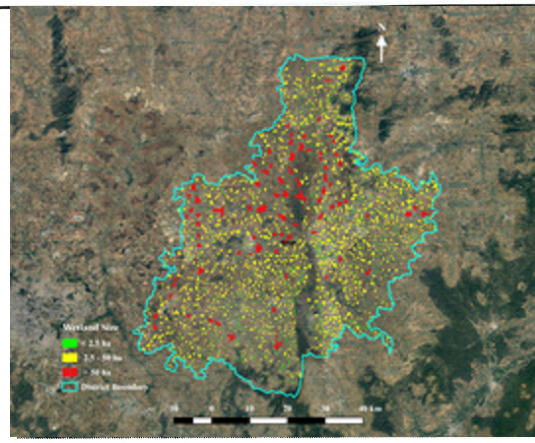
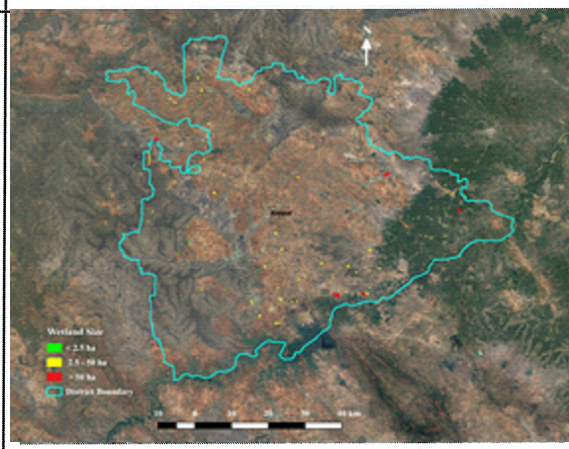
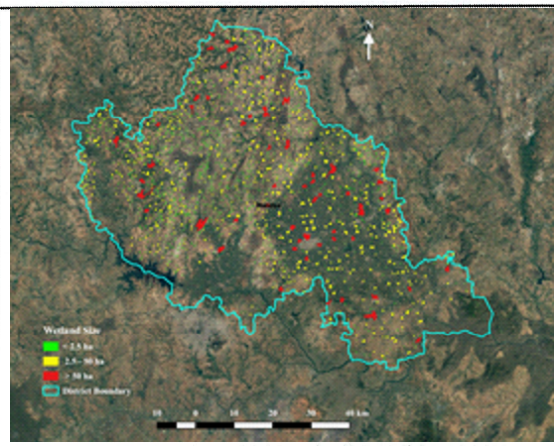
Bengaluru (Urban) (Bangalore Urban) Geographical Area (ha) = 219582.07	 Wetland Area (ha) = 9255.42 (4.22%)	Total Number = 985 < 2.5 ha = 394 2.5–50 ha = 561 > 50 ha = 30	< 2.5 ha = 40.0 2.5–50 ha = 57.0 > 50 ha = 3.0
Belagavi (Belgaum) Geographical Area (ha) = 1338197.42	 Wetland Area (ha) = 4776.00 (0.36%)	Total Number = 1091 < 2.5 ha = 726 2.5–50 ha = 355 > 50 ha = 10	< 2.5 ha = 66.5 2.5–50 ha = 32.5 > 50 ha = 1
Bidar Geographical Area (ha) = 544874.68	 Wetland Area (ha) = 2316.19 (0.43%)	Total Number = 157 < 2.5 ha = 38 2.5–50 ha = 112 > 50 ha = 7	< 2.5 ha = 24.2 2.5–50 ha = 71.3 > 50 ha = 4.5

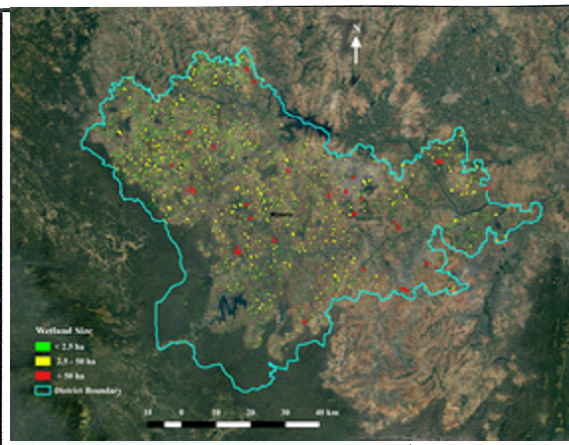
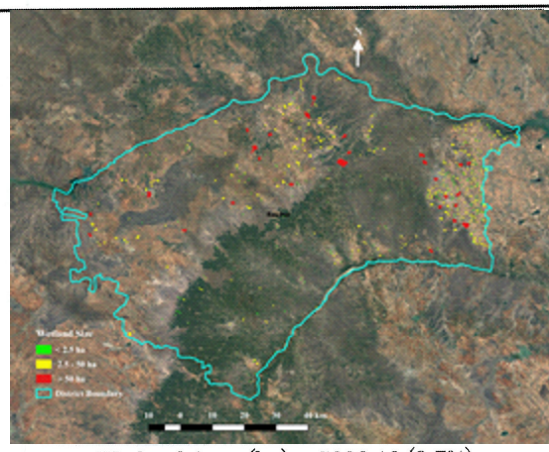
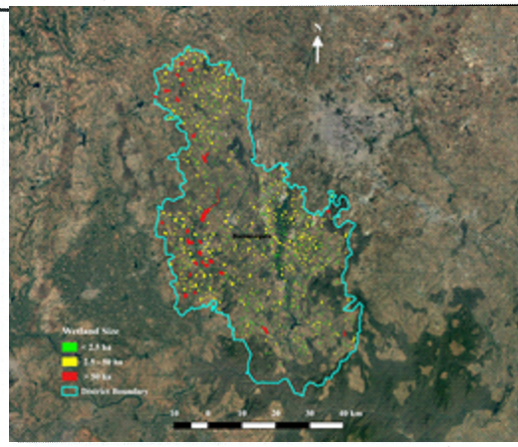
Chamarajanagar Geographical Area (ha) = 563934.54	 Wetland Area (ha) = 6475.18 (1.15%)	Total Number = 1197 < 2.5 ha = 1020 2.5–50 ha = 143 > 50 ha = 34	< 2.5 ha = 85.2 2.5–50 ha = 12 > 50 ha = 2.8
Chikkaballapura Geographical Area (ha) = 425128.80	 Wetland Area (ha) = 20592.46 (4.84%)	Total Number = 2149 < 2.5 ha = 904 2.5–50 ha = 1175 > 50 ha = 70	< 2.5 ha = 42 2.5–50 ha = 54.7 > 50 ha = 3.3
Chikkamagaluru (Chikmagalur) Geographical Area (ha) = 720981.82	 Wetland Area (ha) = 8880.39 (1.23%)	Total Number = 1049 < 2.5 ha = 647 2.5–50 ha = 370 > 50 ha = 32	< 2.5 ha = 61.7 2.5–50 ha = 35.3 > 50 ha = 3

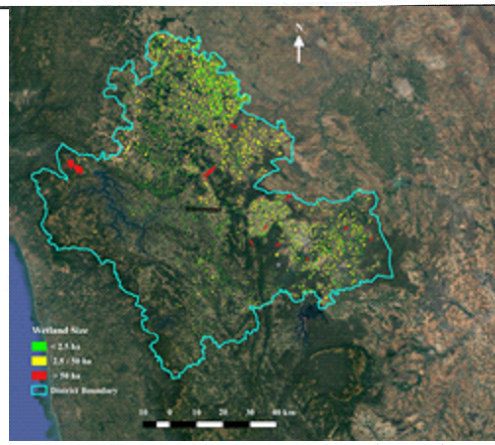
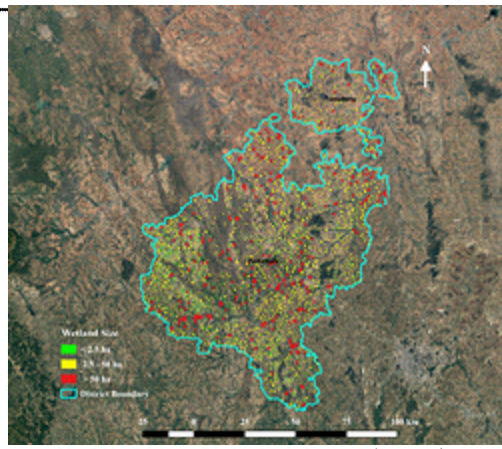
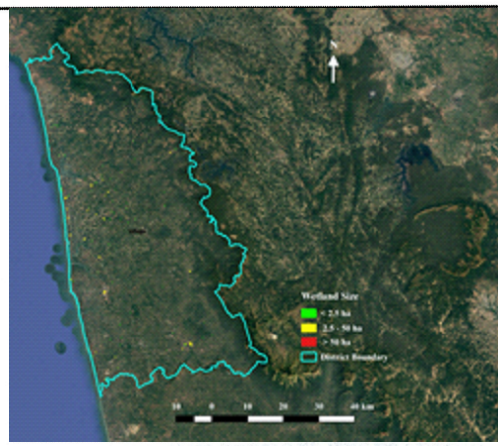
Chitradurga Geographical Area (ha) = 843487.39	 Wetland Area (ha) = 23960.49 (2.84%)	Total Number = 1262 < 2.5 ha = 553 2.5–50 ha = 569 > 50 ha = 140	< 2.5 ha = 43.8 2.5–50 ha = 45.1 > 50 ha = 11.1
Dakshina Kannada Geographical Area (ha) = 484587.84	 Wetland Area (ha) = 253.72 (0.05%)	Total Number = 59 < 2.5 ha = 49 2.5–50 ha = 9 > 50 ha = 1	< 2.5 ha = 83 2.5–50 ha = 15.3 > 50 ha = 1.7
Davanagere Geographical Area (ha) = 591584.24	 Wetland Area (ha) = 12784.48 (2.16%)	Total Number = 648 < 2.5 ha = 268 2.5–50 ha = 326 > 50 ha = 54	< 2.5 ha = 41.4 2.5–50 ha = 50.3 > 50 ha = 8.3

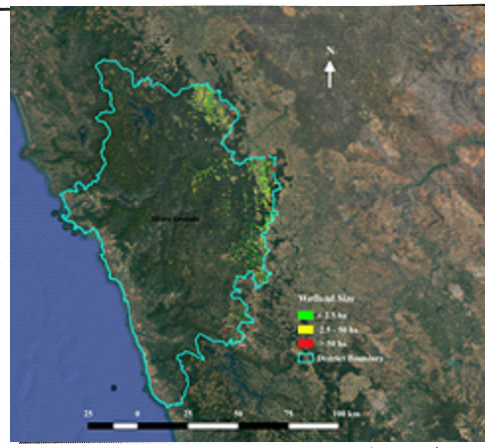
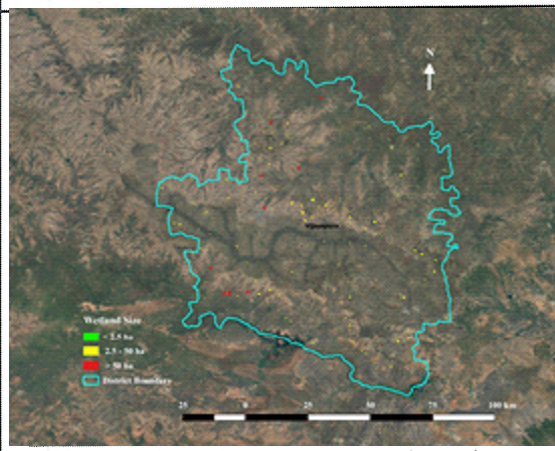
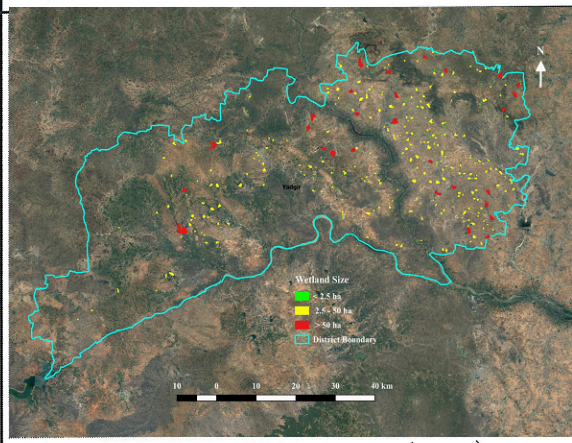
Dharwad Geographical Area (ha) = 425486.58	 Wetland Area (ha) = 3842.48 (0.9%)	Total Number = 1471 < 2.5 ha = 1198 2.5–50 ha = 267 > 50 ha = 6	< 2.5 ha = 81.4 2.5–50 ha = 18.2 > 50 ha = 0.4
Gadag Geographical Area (ha) = 465532.12	 Wetland Area (ha) = 1842.89 (0.4%)	Total Number = 345 < 2.5 ha = 257 2.5–50 ha = 80 > 50 ha = 8	< 2.5 ha = 74.5 2.5–50 ha = 23.2 > 50 ha = 2.3
Hassan Geographical Area (ha) = 681815.33	 Wetland Area (ha) = 22173.96 (3.25%)	Total Number = 5333 < 2.5 ha = 4082 2.5–50 ha = 1178 > 50 ha = 73	< 2.5 ha = 76.5 2.5–50 ha = 22.1 > 50 ha = 1.4

Haveri Geographical Area (ha) = 481781.94	 Wetland Area (ha) = 13645.57 (2.83%)	Total Number = 2850 < 2.5 ha = 1805 2.5–50 ha = 1014 > 50 ha = 31	< 2.5 ha = 63.3 2.5–50 ha = 35.6 > 50 ha = 1.1
Kalburgi (Gulbarga) Geographical Area (ha) = 1096696.39	 Wetland Area (ha) = 1482.88 (0.14%)	Total Number = 109 < 2.5 ha = 31 2.5–50 ha = 73 > 50 ha = 5	< 2.5 ha = 28.4 2.5–50 ha = 67.0 > 50 ha = 4.6
Kodagu Geographical Area (ha) = 410268.75	 Wetland Area (ha) = 445.14 (0.11%)	Total Number = 447 < 2.5 ha = 421 2.5–50 ha = 26 > 50 ha = 0	< 2.5 ha = 94.2 2.5–50 ha = 5.8 > 50 ha = 0.0

Kolar Geographical Area (ha) = 399027.96	 Wetland Area (ha) = 25283.74 (6.34%)	Total Number = 2870 < 2.5 ha = 1197 2.5–50 ha = 1594 > 50 ha = 79	< 2.5 ha = 41.7 2.5–50 ha = 55.5 > 50 ha = 2.8
Koppal Geographical Area (ha) = 557647.83	 Wetland Area (ha) = 1093.30 (0.2%)	Total Number = 144 < 2.5 ha = 84 2.5–50 ha = 55 > 50 ha = 5	< 2.5 ha = 58.3 2.5–50 ha = 38.2 > 50 ha = 3.5
Mandya Geographical Area (ha) = 494723.01	 Wetland Area (ha) = 14013.11 (2.83%)	Total Number = 2089 < 2.5 ha = 1429 2.5–50 ha = 606 > 50 ha = 54	< 2.5 ha = 68.4 2.5–50 ha = 29.0 > 50 ha = 2.6

Mysuru (Mysore) Geographical Area (ha) = 631979.77	 Wetland Area (ha) = 9698.04 (1.53%)	Total Number = 2682 < 2.5 ha = 1931 2.5–50 ha = 727 > 50 ha = 24	< 2.5 ha = 72.0 2.5–50 ha = 27.1 > 50 ha = 0.9
Raichur Geographical Area (ha) = 847033.56	 Wetland Area (ha) = 5928.19 (0.7%)	Total Number = 532 < 2.5 ha = 222 2.5–50 ha = 283 > 50 ha = 27	< 2.5 ha = 41.7 2.5–50 ha = 53.2 > 50 ha = 5.1
Ramanagara Geographical Area (ha) = 352688.67	 Wetland Area (ha) = 8283.97 (2.35%)	Total Number = 1334 < 2.5 ha = 819 2.5–50 ha = 489 > 50 ha = 26	< 2.5 ha = 61.4 2.5–50 ha = 36.7 > 50 ha = 1.9

Shivamogga (Shimoga) Geographical Area (ha) = 847253.81	 Wetland Area (ha) = 13330.17 (1.57%)	Total Number = 3857 < 2.5 ha = 2643 2.5–50 ha = 1203 > 50 ha = 11	< 2.5 ha = 68.5 2.5–50 ha = 31.2 > 50 ha = 0.3
Tumakuru (Tumkur) Geographical Area (ha) = 1060355.93	 Wetland Area (ha) = 46586.68 (4.39%)	Total Number = 3891 < 2.5 ha = 2051 2.5–50 ha = 1634 > 50 ha = 206	< 2.5 ha = 52.7 2.5–50 ha = 42.0 > 50 ha = 5.3
Udupi Geographical Area (ha) = 357045.21	 Wetland Area (ha) = 231.95 (0.06%)	Total Number = 79 < 2.5 ha = 55 2.5–50 ha = 24 > 50 ha = 0	< 2.5 ha = 69.6 2.5–50 ha = 30.4 > 50 ha = 0.0

Uttara Kannada Geographical Area (ha) = 1029816.25	 Wetland Area (ha) = 3409.47 (0.33%)	Total Number = 1290 < 2.5 ha = 1032 2.5–50 ha = 252 > 50 ha = 6	< 2.5 ha = 80.0 2.5–50 ha = 19.5 > 50 ha = 0.5
Vijayapura (Bijapur) Geographical Area (ha) = 1050134.43	 Wetland Area (ha) = 1896.34 (0.18%)	Total Number = 147 < 2.5 ha = 47 2.5–50 ha = 91 > 50 ha = 9	< 2.5 ha = 32.0 2.5–50 ha = 61.9 > 50 ha = 6.1
Yadgir (Yadagiri) Geographical Area (ha) = 528300.05	 Wetland Area (ha) = 6179.23 (1.17%)	Total Number = 339 < 2.5 ha = 63 2.5–50 ha = 248 > 50 ha = 28	< 2.5 ha = 18.6 2.5–50 ha = 73.2 > 50 ha = 8.3

Estuaries in Karnataka

An Estuary is a semi-enclosed coastal body of water that extends to the effective limit of tidal influence, within which seawater entering from one or more free connections with the open sea, or any other saline coastal body of water, is significantly diluted with freshwater derived from land drainage, and can sustain euryhaline biological species for either part or the whole of their life cycle (Gillanders and Kingsford, 2002). The estuary acts as a transitional zone between freshwater and saltwater habitats as well as land and the sea (Thrush et al., 2013).

Estuaries consist of distinct aquatic habitats, comprising seagrass and kelp beds, shellfish beds and coral reefs, hard-bottom communities of sponges and outcrops, soft-bottom communities with mud and sand, rocky inter-tidal zones, fringing mangrove forests, and vegetated marshes/wetlands. Vegetated marshes/wetlands are fundamental estuarine habitats that stabilize shorelines, protect uplands against erosion, and improve water quality by filtering pollutants and trapping fine sediments. They are the same habitats that supply food and shelter for fish, invertebrates, birds, mammals, amphibians, and others. The high productivity of wetlands also plays a vital role in the cycling of food and nutrients within estuaries and in nearby coastal areas (McGlynn, 2009). They are the chief habitats for various marine species and called as the "nurseries of the sea". Estuaries are protected environments supported by mangroves, and organic-rich mudflats contribute to an ideal habitat status for most of the commercially important fish and shellfish species(Bhavan et al., 2021).

Estuaries aid as huge sponges, soaking up excess water during floods and heavy storms. Estuaries stabilize shorelines and protect coastal areas, inland habitats, and human communities. Estuaries contribute diverse living and non-living resources, which offer opportunities for employment, income, amenities, and pleasure to the local community (Ramachandra et al., 2013). Fishing is one of the chief economic activities of the rural coastal communities. Estuaries and inlets act as places for harvesting food and fiber (Ramachandra et al., 2013).

Estuaries are the store house of mangroves biodiversity, which acts as a protective shield for the coastline apart from providing tremendous other benefits. Mangroves are salt tolerant forest ecosystem observed usually in tropical and subtropical intertidal regions where they get organic materials

from estuarine or oceanic ecosystems (Ramachandra et al., 2013). Mangroves support commercial fisheries through the provision of nurseries, breeding, spawning, and hatching habitats for offshore fisheries and exporting organic matter to the marine environment producing nutrients for fauna in both the mangroves themselves and in adjacent marine and estuarine ecosystems. Mangroves play an ideal role in shoreline protection, where they act as natural barriers, handling the destructive energy of waves and reducing the impact of cyclones and storm surges (Salem and Mercer, 2012). Mangrove supplies forestry products (firewood, charcoal, timber, honey, etc.) and sustain fishery products (fish, prawns, crabs, etc.). Due to their high calorific values, mangrove twigs are used for making charcoal and firewood. Mangrove extracts are used in indigenous medicines. Mangrove swamps act as a trap for the sediments and a sink for the nutrients. The root system of plants retains the substrate firm and thus contributes to the lasting stability of the coast (Ramachandra et al., 2013).

This study accounts ecological services of ten different estuaries of Dakshina Kannada, Udupi, and Uttara Kannada namely: Mulky-Pavanje, Netravathi, Udyavara, Sita, Kollur-Chakra-Haladi, Kali, Aghanashini, Gangavali, Sharavathi, and Venkatapura estuaries (figure 5, table 3).

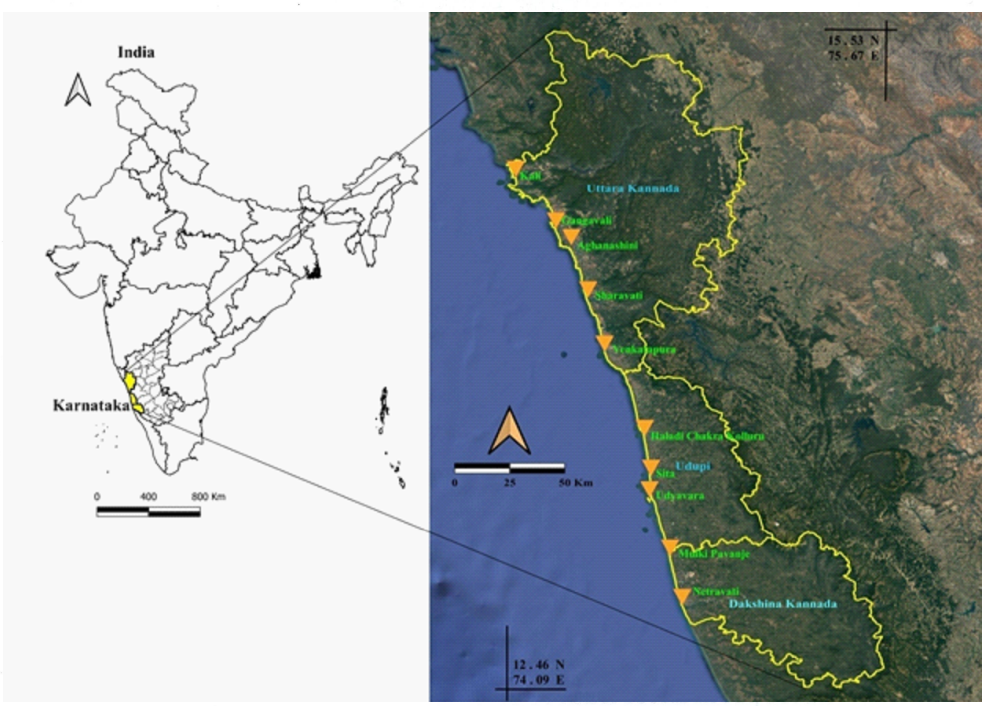


Figure 5. Estuaries in Karnataka

Dakshina Kannada district

The district of South Kanara (Dakshina Kannada) is situated on the Western Coast of India. The South Kanara region is separated from the rest of the South Indian peninsula by the towering heights of the Western Ghats. It spreads from the Western Ghats towards the sea to the west. The length of the coast-line, which is almost straight, but broken at numerous points by rivers, rivulets, creeks, and bays, is 76 nautical miles (140. 85 kilometers). The district lies between 12° 27' and 13° 58' north latitude, and 74° 35' and 75° 40' east longitude. It is about 177 kilometers in length, about 40 kilometers broad at its narrowest and about 80 kilometers at its widest part. In several respects, it shares the geographical and economic characteristics of its contiguous districts of Coorg, Shivamogga, Chikkamagaluru, etc. The district, which is a long and narrow strip of territory, is generally bounded on the north by the North Kanara district, on the east by the districts of Shivamogga, Chikkamagaluru, Hassan, and Coorg, on the south by the Kasaragod taluk, which is at present in Kerala State, and on the west by the Arabian Sea (Dakshina Kannada District Gazetteer, 2011).

Udupi district

Udupi district has a geographical area of 3,880 sq.km. Geographically, the Udupi district is separated from the rest of the South Indian Peninsula by the Western Ghats. It spreads from the Western Ghats towards the sea to the west. The newly formed Udupi district has a coastal line that extends for about 100 km and is broken at numerous points by rivers, rivulets, creeks, and bays. The district lies between 13° 05' and 13° 55' North latitude and 74° 40' and 75° 07' East longitude. The district is bounded by Uttara Kannada district on the north, Shivamogga and Chikkamagaluru districts on the east, Dakshina Kannada on the south, and the Arabian Sea on the west. In its east, the Udupi district is bounded by higher ranges of the Western Ghats. The width of the districts gets narrower as one proceeds from south to north. Swarna, Seetha, Haladi, Chakra, and Kollur are the important rivers of the district. The coast line is generally straight and the backwater areas are ideal for fisheries and boating (Udupi District Gazetteer, 2012).

Uttara Kannada district

The district is located in the mid-western part of the state. It lies between 13°55' to 15° 31' North latitude, 74°9' to 75°10' East longitude, and extends over an area of 10,327 sq km, which is 5.37 percent of the total area of the state. The coast stretches in a long, nearly straight line to the south east, except for the shallow Karwar and Belekeri bays. Though the coast is unbroken by deep or wide mouthed estuaries, it is varied and picturesque with rocky islands and capes, stretches of palm fringed sand beaches, low narrow mouths, and rough bluffs and headlands. The deep, winding valleys, waving wooded hills, and wild background of high peaks stretch behind the coastline boundaries. The district, which is a long and narrow strip of territory, is surrounded by Belgaum district and Goa territory in the north, Dharwad district in the east, Dakshina Kannada, and Shivamogga districts in the south, and the Arabian Sea in the west (Uttara Kannada District Gazetteer, 1985).

Table 3. Location, latitude, longitude and area of study area

Study area	Location	Latitude	Longitude	Area (ha)	Source
Mulki – Pavanje Estuary	Dakshina Kannada	12° 70' N	74°39' E	750	(Dakshina Kannada District Gazetteer, 2011)
Netravathi Estuary	Dakshina Kannada	12°50' N	74°50' E	1920	
Udyavara Estuary	Udupi	13° 00' 00" to 13 ° 45' 00" N	74° 47' 30" to 74 ° 30' 00" E	800	(Udupi District Gazetteer, 2012)
Sita Estuary	Udupi	13°33'972"N	74°71'056"E	980	
Chakra-Haladi-Kollur Estuary	Udupi	13°64'306"N	74°65'861" E	2550	
Kali Estuary	Uttara Kannada	14.816° to 14.917° N	74.125° to 74.267° E	3240	(Uttara Kannada District Gazetteer, 1985)
Gangavali Estuary	Uttara Kannada	14.586° to 14.618° N	74.278° to 74.385° E	700	
Aghanashini Estuary	Uttara Kannada	14.391° to 14.585° N	74.304° to 74.516° E	4801	
Sharavathi Estuary	Uttara Kannada	14.241° to 14.385° N	74.418° to 74.507° E	1600	
Venkatapura Estuary	Uttara Kannada	14.008° to 14.085° N	74.502° to 74.569° E	200	

2.2 Water sample collection and water quality analysis

Water samples were collected from the lakes of Bengaluru, Karnataka in clean and sterile one-litre bottles for laboratory analysis of physicochemical parameters. Physicochemical parameters like water temperature (WT); pH; total dissolved solids (TDS); electrical conductivity (EC); and dissolved oxygen (DO) were measured onsite. The analysis of other physicochemical parameters like chemical oxygen demand (COD); biochemical oxygen

demand (BOD); total alkalinity (TA); chloride (Cl); total hardness (TH); calcium (Ca); magnesium (Mg); nitrate (N); and orthophosphate (OP) were done in the laboratory according to the standard procedures of APHA AWWA WEF (2005).

Microalgae sample collection and quantification

A plankton net (of 50 μm mesh) was used for microalgae sampling. The samples were transferred to clean and sterile bottles for further identification and quantification. Samples were preserved in 5% neutralized formal dehyde solution. Then, cells were counted on a microscope and identified using standard keys (Desikachary, 1959; Prescott, 1970; AlgaeBase, 2021).

Fish sampling and data collection

Fish sampling was carried out in different lakes in Bengaluru, Karnataka. Fishermen used gill nets, cast nets, and dragnets of varying dimensions to catch fish samples from lakes. The fish samples were identified using standard keys (Jayaram, 1999; Talwar, 1991; Fish Base, 2021).

Macrophyte sampling and data collection

In lakes, quadrats were laid at different locations randomly and macrophytes were collected (all species falling in the quadrat were considered). Samples were washed properly to remove adhered sediments and epiphytes, and stored in polythene bags. Then, the samples were identified based on the standard taxonomic literature (Cook, 1996).

2.3 Valuation of ecosystem service from wetlands

The total ecosystem supply value of wetland ecosystems in Karnataka was assessed considering (a) provisioning services, (b) regulating services, and (c) cultural services. The following services were considered for the present study, and this involved data compilation (table 4, 5) from primary (field investigation) and secondary sources (government agencies, published articles in peer-reviewed journals). The study used residual value and resource rent as well as benefit transfer method to estimate the TESV of the total wetlands in Karnataka (table 6).

Provisioning services include the products obtained from wetland ecosystems such as water, algae, macrophyte, fish, raw materials, genetic resources, medicinal resources, ornamental resources, fuelwood, and

irrigation. Regulating services include the benefits obtained from the regulation of ecosystem processes such as air quality regulation, climate regulation, moderation of extreme events, regulation of water flows, waste treatment/water purification, erosion prevention, maintenance of soil fertility, biological control, maintenance of life cycles of migratory species, maintenance of genetic diversity, carbon sequestration, waterborne disease control, pollination, water conservation, flood control, habitat or refugia, and groundwater recharge. Cultural services include the benefits from wetlands through aesthetic information, opportunities for recreation and tourism, inspiration for culture, art and design, spiritual experience, information for cognitive development, existence and bequest values, and education.

2.4 Data and source: Freshwater Ecosystem in Karnataka

Table 4. Data used for computing ecosystem services with the details of data sources.

Provisioning services

Services	Services and monetary benefits	Source
Ecosystems type: Wetland ecosystems		
Provisioning services	Microalgae: Data: Microalgal species; microalgal biomass from different wetlands. Microalgae samples were collected from the surface water of wetlands by plankton net, identified, and counted under compound microscope.	Microalgae species listed through field work to wetlands (of Bengaluru, Uttara Kannada, Mandya; and Kolar district); average microalgal biomass from Bengaluru lakes were considered. Ramachandra et al., 2018; Asulabha et al., 2018; Ramachandra et al., 2016; Ramachandra et al., 2001
	From Bengaluru wetland, harvested microalgae were dried and determined the productivity. Microalgal productivity from wetlands was estimated to be 14 $g/m^2/d$ (51.1 t/ha/yr dry biomass). With a harvesting period of 5-7 days (i.e., 52 cycles per year), the total microalgae harvested was 7.28 t/ha/yr. It was assumed that out of 7.28 t/ha/yr of dried algal biomass, 6 t of microalgal biomass was used for biodiesel production, 280 kg of microalgal biomass was used for fish feed, and 1 t of biomass for protein production.	Ramachandra et al., 2018; Asulabha et al., 2018; Ramachandra et al., 2016; Saranya and Ramachandra, 2020

	Biodiesel ❖ Biodiesel production cost from microalgae was 31.29 Rs/L resulting in a benefit of 25 Rs/L. ❖ Lipid content of dried microalgal biomass is around 20 – 50%. ❖ 6 t of microalgal biomass produces 2069.76 L biodiesel giving a benefit of 51744 Rs.	Chisti, 2007; Nagarajan et al., 2013; Chisti, 2013; Louw et al., 2016; Saranya and Ramachandra, 2020
	Glycerol ❖ During biodiesel production, crude glycerol is produced (10%) as byproduct. Benefit from glycerol amounted to 16 Rs/kg. Benefit from 235.2 kg glycerol was 3763 Rs.	Quispe et al., 2013
	Feed for Fish ❖ 1 kg of feed for fish will give benefit of 15 Rs/kg. 280 kg of microalgal biomass was used as feed for fish, which gives a benefit of 4200 Rs.	Ansari et al., 2020
	Protein ❖ About 540 kg protein could be obtained from one-ton algal biomass. Benefit from one kg of protein was 94 Rs. Thus, benefit from 540 kg of food (protein) was 50760 Rs.	Asiedu, 2015; Mahapatra et al., 2016
	Macrophyte: Data: Types of macrophytes, biomass. Spatial extent of macrophytes	Macrophyte species listed through field work to wetlands (of Bengaluru, Uttara Kannada, Mandya; and Kolar district). Ramachandra et al., 2017; Ramachandra et al., 2016; Ramachandra et al., 2014; Kiran et al., 2007
	Digitized the area of macrophyte cover in entire wetlands of Karnataka; The total macrophyte cover in Karnataka wetlands is 50432.35 ha	Google Earth and QGIS open software

	Macrophyte is used as food, honey, making handicraft materials, and fodder. ❖ Benefits from fodder is 5580 Rs/ha/yr (each person will get a benefit of 1488 Rs/yr for fodder collection). ❖ Benefit from cattle grazing in wetland is estimated to be 1174 Rs/ha/yr. ❖ Benefit from food (leaf vegetables like Ipomea, Marsilea, and Amaranthus) is estimated to be 147 Rs/ha/yr. ❖ Benefit from handicraft made of aquatic plants is 2310 Rs/ha/yr.	Mukherjee, 2008; Ramachandra et al., 2005; Ramachandra et al., 2011 Mukherjee, 2008; Ramachandra et al., 2005; Ramachandra et al., 2011
	❖ The capacity of wetlands to supply honey is 20 to 40 kg/ha/yr. In Karnataka, average benefit from honey in 52 Rs per kg. From wetlands, honey production is estimated to be 2080 Rs/ha/yr.	Affek, 2018; Tejaswi, 2008
	Fish: Data: Fish species (location wise), type, quantity	Fish species listed through field work to wetlands (of Bengaluru, and Mandya district). Ramachandra and Sreekantha, 2006; Sincy et al., 2018; Fish Base, 2021.
	Fish catch data; wetlands of Karnataka studied for determining fish catch, price, and benefit associated with fishing.	District wise inland fish catch from districts, Department of Inland Fisheries, GoK https://fisheries.karnataka.gov.in/english Directorate of Economics and statistics, GoK https://des.karnataka.gov.in/english; District at a glance, GoK
	❖ Total fish catch from Bengaluru wetlands 465 kg/ha/yr. Total fish catch was estimated to be 525 kg/ha/yr from Karnataka fisheries data. So the average fish catch was estimated as 495 kg/ha/yr ❖ The price of fish ranged between 120-300 Rs/kg resulting in a benefit of 65 Rs/kg	District at a glance, GoK; Ramachandra et al., 2005; Ramachandra et al., 2011

	Water: Data: Sector wise water demand, Value of water for domestic consumption, irrigation, livestock use, and industries Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Raw materials: Data: Types of raw materials, quantity, value of raw materials like wood, craftwork materials, and construction materials Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

	Genetic resources: Data: Genetic resources – types, Value of genetic resources (products for materials science, genes for resistance to plant pathogens and crop pests, and ornamental species) Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate.	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Medicinal resources: Data: Fish types, medicinal values of fish species	For checklist of medicinal values of fish species chosen published literature from India (Gogoi and Bora, 2020; Borah and Prasad, 2017; Borah and Prasad, 2016; Gupta and Dey, 2017; Teronpi et al., 2012; Chanu et al., 2016; Prakash and Prakash, 2021).
	Data: Checklist of aquatic plants, medicinal values	For checklist of medicinal values of aquatic plants chosen published literature from India (Kiran et al., 2007; Taran and Deb, 2020; Nandan and Singh, 2004; Sarmah et al., 2013; Misra et al., 2012; Sarma and Saikia, 2010; Mishra et al., 2016; Chai et al., 2015; Banerjee et al., 2012).
	Data: Value of extraction of medicine from biota (e.g. aquatic plants, and fish) Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Clarkson et al., 2013 GDP(PPP) per capita for India https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

	Ornamental resources: Data: considered value of ornamental resources like resources for fashion, handicraft, jewellery, pets, worship, decoration, and souvenirs. Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Clarkson et al., 2013 GDP(PPP) per capita for India https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Fuelwood: Data: About 10% macrophyte cover area of each wetland is considered as annual fuelwood extraction area. Value of fuelwood, and logs from wetland. Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Average value from published Indian literatures (Ramachandra et al., 2005; Ramachandra et al., 2011); other literatures (Schuijt, 2002; Zuze, 2013; Schuyt & Brander, 2008). *In appendix (tableA1) GDP(PPP) per capita for India https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Irrigation: Data: Tank irrigated area for 30 districts in Karnataka as wetland water is used for the cultivation of crops such as paddy, maize and various types of vegetables and fruits	Tank irrigated area from District at a glance (GoK).
	Irrigation service value was estimated as 1826 Rs/ha/yr.	Mukherjee, 2008

Regulating Services

Services	Services and monetary benefits	Source
Ecosystems type: Wetland ecosystems		
Regulating Services	Air quality regulation: Amount of aerosols or chemicals "extracted" - effect on air quality. Data: Leaf area index, and NOx-fixation Air quality regulation service value per hectare Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Climate regulation: Quantity of greenhouse gases, etc., fixed and/or emitted - effect on climate parameters. Data: Greenhouse gas-balance (esp. C-fix), DMS production, Land cover characteristics. Climate regulation service value per hectare Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

	Moderation of extreme events: Data: Ecosystems and living organisms create buffers against natural disasters. They reduce damage from floods, storms, avalanches, landslides, and droughts. The moderation of extreme events service value per hectare. Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Regulation of water flows: Data: Quantity of water stored and influence of hydrological regime. The regulation of water flows service value per hectare Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

	Waste treatment: Data: Denitrification (kg N/ha/y), Accumulation in plants, - kg –BOD/ha/y, chelation (metal binding). Waste treatment service value per hectare Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Erosion prevention: Data: Erosion prevention service value per hectare Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Clarkson et al., 2013 GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Maintenance of soil fertility: Data: Value for maintenance of soil fertility service value per hectare Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Clarkson et al., 2013 GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

	Biological control: Data: Number and impact of pest control species; number & impact of pollinating species. The biological control service value per hectare Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Clarkson et al., 2013 GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Maintenance of life cycles of migratory species: Data: Wetlands serve as feeding and breeding grounds for migratory species. Maintenance of life cycles of migratory species service value per hectare Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

	Maintenance of genetic diversity: Data: Genetic diversity (the variety of genes between, and within, species populations) and a gene pool for developing commercial crops and livestock. Maintenance of genetic diversity service value per hectare Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Carbon sequestration: Data: Wetlands are carbon sinks that contribute towards reducing carbon emissions. Carbon sequestration services value is calculated by considering the social cost of carbon per tonne. The social cost of a tonne of CO_2 is taken as US$ 86. Field studies from Bengaluru wetlands. Determined carbon sequestration from algae, and macrophyte; quantification of algal biomass and macrophyte biomass	Verma et al., 2014

	Microalgae ❖ 1 tC = 3.67 tCO_2 ❖ 1 kg microalgae = 1.83 kg C ❖ Total microalgal biomass: 51.1 t/ha/yr ❖ Total value of carbon sequestration from microalgae: 234404.05 Rs tCO_2/ha/yr	Baral et al., 2016; Chisti, 2008
	Macrophyte ❖ Total macrophyte biomass: 119310 t/ha/y ❖ Total C from macrophyte: 124.44 kg/ha/y ❖ Total value of carbon sequestration from macrophyte: 311.92 Rs $kgCO_2$/ha/yr	Kalita, 2019
	Water borne diseases control: Data: Proper management of wetlands with the use of fish that consume mosquito larvae, or of bacterial larvicides that kill them without affecting other organisms Water borne diseases control service values per ha (average of 71, 5726 and 25 Rs/ha/yr.) from Indian literatures.	Verma et al., 2001; Kant et al., 2013; Ramachandra et al., 2011
	Pollination: Data: Value for pollination service per ha (19 Rs/ha/yr.) from literature. Value adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Schuyt & Brander, 2008 GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

	Water conservation: Data: Water conservation service value per ha (2875 Rs/ha/yr.) from literature. Value adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Li & Gao, 2016 GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Flood control: Data: Flood control service values per ha (ranged between 191 to 13032 Rs/ha/yr.) from literatures. Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Kaul et al., 2016; Zuze, 2013; Schuyt & Brander, 2008. *In appendix (tableA2) GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Habitat/refugia: Data: Critical breeding, feeding and nesting habitat for populations in wetlands Habitat service values per ha (164 and 3486 Rs/ha/yr.) from literature. Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Schuyt & Brander, 2008; Kaggwa et al., 2009 GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

	Groundwater recharge: Data: Water filters down from the wetland into an underground aquifer which stores potable water. Groundwater service values per ha (192000 and 238246 Rs/ha/yr.) from literature. Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ramachandra et al., 2019; Kaggwa et al., 2009 GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

Cultural Services

Services	Services and monetary benefits	Source
Ecosystems type: Wetland ecosystems		
Cultural Services	Aesthetic information: Data: Expressed aesthetic value, e.g., number of houses bordering wetland areas; number of users of "scenic routes" Aesthetic information service value per ha. Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

	Opportunities for recreation and tourism: Data: Value considered for ecotourism, bird-watching, swimming, and outdoor sports. Recreation and tourism service values per ha (ranged between 2 to 101747 Rs/ha/yr.) from literatures. Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Indian literatures (Anitha & Muraleedharan, 2006; Dehlavi & Adil, 2011; Rao, 2018; Verma et al., 2001; Dixit et al., 2016; Mishra, 2014; Venkatachalam & Zareena Begam, 2016; Prasher et al., 2006) and others (Schuijt, 2002; Zuze, 2013; Schuyt & Brander, 2008; Kaggwa etal., 2009; Baral etal., 2016; Li & Gao, 2016; Dehlavi & Adil, 2011). *In appendix (table A3) GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Inspiration for culture, art and design: Data: Presence of culturally important landscape features or species; Number of people "using" ecosystems for cultural heritage and identity. Inspiration for culture, art and design service values per ha (ranged between 302 to 13985 Rs/ha/yr.) from literatures. Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Indian literatures (Ramachandra, 2016; Ramachandra et al., 2019) and others (Zuze, 2013; Schuyt & Brander, 2008; Kaggwa et al., 2009). *In appendix (table A4) GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

	Spiritual experience: Data: Number of people who attach religious significance to ecosystems; number of books, paintings, etc., using ecosystems as inspiration Spiritual experience service value per ha. Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Information for cognitive development: Data: Cognitive development resulting from wetland organisms. Information for cognitive development service value per ha. Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

	Existence and bequest values: Data: Expressed (through, e.g., donations and voluntary work) or stated preference for nature protection for ethical reasons Existence and bequest values service value per ha. Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Ecosystem Services Valuation Database (ESVD), 2020: https://www.es-partnership.org/wp-content/uploads/2020/08/ESVD_Global-Update-FINAL-Report-June-2020.pdf GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019
	Education: Data: Value for use of wetlands for scientific and education Education service value per ha (48000, 34660, and 4773 Rs/ha/yr). Compared with values of global studies, adjusted for GDP (PPP) per capita and corresponding currency exchange rate	Indian literatures (Ramachandra, 2016; Ramachandra et al., 2019) and Li & Gao, 2016 GDP(PPP) per capita for India https://data.worldbank.org/indicator/ NY.GDP.PCAP.PP.CD?locations=IN Currency exchange rate https://www.thehansindia.com/business/ currency-update-today-indian-rupee-against-us-dollar-on-19-november-2021-716019

Data and source: Estuaries in Karnataka

Table 5. Data used for computing ecosystem services from estuaries with the details of data sources

Ecosystem services	Variables	Data sources	Approach
Provisioning sources	Fishery resources (Fish, Clams, Oysters and Mussels) provide the major livelihood opportunities of the estuarine dependent communities in the coastal villages.	Indian case studies – Ramachandra et al., 2013; CMFRI Annual Report, 2014-15 (http://eprints.cmfri.org.in/id/eprint/10461); CMFRI Annual Report, 2017-18 (http://eprints.cmfri.org.in/id/eprint/13044); CMFRI Annual Report, 1999-2000 (http://eprints.cmfri.org.in/id/eprint/6336); CMfRI Annual Report, 2010-11 (http://eprints.cmfri.org.in/id/eprint/8676); Indian Journal of Fisheries, 1985 (http://eprints.cmfri.org.in/id/eprint/407)	Residual Value Method $\sum_{i=1}^{n} Q_i (P_i - C_i)$ Where Qi represents quantity, Pi is the price, Ci is the cost involved in the harvest.
	Agricultural activities (Coconuts and Gazani paddy) – which provide a significant source of income for the local communities.	Indian case study - Ramachandra et al., 2013; Google earth pro is used for estimating total area (ha) of coconut plantation http://earth.google.com.	Residual Value Method $\sum_{i=1}^{n} Q_i (P_i - C_i)$ Where Qi represents quantity, Pi is the price, Ci is the cost

	Mining activity (Sand production) – which provides economic benefits to the estuarine dependent communities in the coastal villages.	Indian case study - (Ramachandra et al., 2013)	Residual Value Method $\sum_{i=1}^{n} Q_i(P_i - C_i)$ Where Qi represents quantity, Pi is the price, Ci is the cost involved in the harvest.
	Mangrove products (charcoal, fodder, timber and thatch) - which provides major livelihoods to the local communities.	Indian case study - Ramachandra et al., 2013 Google earth pro software is used to estimate total area (ha) of Mangrove plantation http://earth.google.com.	Residual Value Method $\sum_{i=1}^{n} Q_i(P_i - C_i)$ Where Qi represents quantity, Pi is the price, Ci is the cost involved in the harvest
	Salt production - which provides main livelihood option to the local communities	Indian article https://www.whatshot.in/bangalore/producing-brown-salt-since-300-years-this-tiny-village-is-karnatakas-rann-of-kutch-c-28641	Residual Value Method $\sum_{i=1}^{n} Q_i(P_i - C_i)$ Where Qi represents quantity, Pi is the price, Ci is the cost involved in the harvest
Regulating services	Gas regulation	Gas regulation service value per hectare is based on the Indian case study (Ramachandra et al., 2019).	Benefit transfer method

	Climate regulation	Climate regulation service values per hectare are based on Indian case study (Ramachandra et al., 2019). Compared with the values of International case studies (de Groot et al., 2020; Costanza et al., 2012). Adjusted for GDP (PPP) per capita for India (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN). and corresponding currency exchange rate https://www.xe.com/currencyconverter/.	Benefit transfer method
	Disturbance regulation	Disturbance regulation service values per hectare is based on Indian case study (Ramachandra et al., 2019). Compared with the values of International case study (Costanza et al., 2012). Adjusted for GDP (PPP) per capita for India (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN). and corresponding currency exchange rate https://www.xe.com/currencyconverter/.	Benefit transfer method

	Soil fertility	A soil fertility service value per hectare is based on International case study (de Groot et al., 2020). Adjusted for GDP (PPP) per capita for India (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN). and corresponding currency exchange rate https://www.xe.com/currencyconverter/.	Benefit transfer method
	Water regulation	Water regulation service values per hectare is based on Indian case study (Ramachandra et al., 2019). Compared with the values of International case studies (Taye et al., 2021; de Groot et al., 2020). Adjusted for GDP (PPP) per capita for India (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations =IN). and corresponding currency exchange rate https://www.xe.com/currencyconverter/.	Benefit transfer method
	Air quality	Air quality service value per hectare is based on International case studies (Taye et al., 2021; de Groot et al., 2020). Adjusted for GDP (PPP) per capita for India (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN). and corresponding currency exchange rate https://www.xe.com/currencyconverter/.	Benefit transfer method

	Erosion control	Erosion control service value per hectare is based on the Indian case study (Ramachandra et al., 2019). Compared with the values of International case studies (de Groot et al., 2020; Costanza et al., 2012). Adjusted for GDP (PPP) per capita for India (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN). and corresponding currency exchange rate https://www.xe.com/currencyconverter/	Benefit transfer method
	Nutrient cycling	Nutrient cycling service value per hectare is based on the Indian case study (Ramachandra et al., 2019). Compared with the values of International case study (Costanza et al., 2012). Adjusted for GDP (PPP) per capita for India (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN). and corresponding currency exchange rate https://www.xe.com/currencyconverter/	Benefit transfer method

	Pollination	Pollination service value per hectare is based on the International case study (de Groot et al., 2020). Adjusted for GDP (PPP) per capita for India (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN). and corresponding currency exchange rate https://www.xe.com/currencyconverter/	Benefit transfer method
	Carbon sequestration	Carbon sequestration service value per hectare is based on the Indian case study (Ramachandra et al., 2019) Compared with the values of International case study (Salem and Mercer, 2012). Adjusted for GDP (PPP) per capita for India (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN). and corresponding currency exchange rate https://www.xe.com/currencyconverter/	Benefit transfer method

Cultural services	Recreation services	Recreation services value per hectare is based on the Indian case study (Ramachandra et al., 2019). Compared with the values of International case studies (de Groot et al., 2020; Costanza et al., 2012). Adjusted for GDP (PPP) per capita for India (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN). and corresponding currency exchange rate https://www.xe.com/currencyconverter/	Benefit transfer method
	Aesthetic Information	Aesthetic Information services value per hectare is based on the Indian case study (Ramachandra et al., 2019). Compared with the value of International case study (de Groot et al., 2020). Adjusted for GDP (PPP) per capita for India (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN). and corresponding currency exchange rate https://www.xe.com/currencyconverter/	Benefit transfer method
	Education, scientific and research services	Education, scientific and research services value per hectare is based on the Indian case study (Ramachandra et al., 2019).	Benefit transfer method

2.5 Method

The SEEA Central Framework provides concepts, definitions and classifications to support integrated accounting for physical flows (natural inputs from and residual flows to the environment such as water, energy, air emissions, and solid waste); environmental transactions and transfers (e.g., environmental taxes, environmental subsidies, and environmental protection expenditure); and individual environmental assets (e.g., mineral and energy resources, timber, fish, land, soil, and water).

Residual value and resource rent methods: The residual value and resource rent methods estimate the value of an ecosystem service by taking the gross value of the final marketed good to which the ecosystem service provides an input and then deducting the cost of all other inputs, including labour, produced assets, and intermediate inputs (SEEA, 2021).

The equation for Residual value method used for provisioning services is as follows:

$$\sum_{i=1}^{n} Q_i(P_i - C_i)$$

where Qi represents quantity, Pi is the price, Ci is the cost involved in the harvest

Benefit transfer method: The benefit transfer method involves transferring monetary values of ecosystem services from previous studies or literature that focused on a different region to our area of interest (Ramachandra et al., 2019; Adekola, 2007).

The equation for Benefit transfer method:

$$\sum_{i=1}^{n} V_i \times A_i$$

where Vi represents the monetary values per hectare and Ai represents the area

Ecosystem accounting needs to be performed by adjusting GDP for the PPP (purchasing power parity) value. This adjustment converts nominal GDP into a number, which helps in easy comparison between countries with different currencies. The per capita income gap between the countries is reduced under PPP exchange rates. The exchange rate of the US dollar to the Indian rupee is now Rs 74.22. Based on PPP, the GDP per capita of India is projected at 7333 international dollars in 2021. GDP per capita (US$ PPP) for the US is projected at 68309.

Table 6. **Method for computing goods and services from wetland ecosystems**

Provisioning services

Services	Variables	Data source	Approach
Provisioning services	Microalgae (*PSi*)	Microalgae services: for biofuel production, serve as food (protein) and feed for fish ❖ Biodiesel (*Bi*): 51744 Rs/ha/yr ❖ Glycerol (*Gl*): 3763 Rs/ha/yr ❖ Feed for fish (*Ff*): 4200 Rs/ha/yr ❖ Food (Protein) (*P*): 50760 Rs/ha/yr Benefits from Microalgae (*BMA*) $BMA = \sum Bi + Gl + Ff + P$ $PS_1 = BMA * A$ Where, *A*= area of wetlands in districts of Karnataka (in ha)	Residual Method

	Macrophyte (PS_2)	Macrophyte services: as food, honey, making handicraft materials, and fodder. Total macrophyte cover in Karnataka wetlands is 50432.35 ha ❖ Fodder (Fr): 5580 Rs/ha/yr ❖ Honey (Ho): 2080 Rs/ha/yr ❖ Grazing (G): 1174 Rs/ha/yr ❖ Food (F): 147 Rs/ha/yr ❖ Handicraft material (Hm): 2310 Rs/ha/yr Benefits from Macrophyte (BM) $BM = \sum Fr + Ho + G + F + Hm$ $PS_2 = BM * A_m$ Where, A_m= Macrophyte covered area of wetlands in districts of Karnataka (in ha)	Residual Method
	Fish (PS_3)	Fish as food ❖ Benefit: 65 Rs/kg ❖ Average fish catch: 495 kg/ha/yr ❖ Benefit from Fish (BF): 32175 Rs/ha/yr Benefits from Fish (BF) $PS_3 = BF * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Residual Method
	Water (PS_4)	Value for water service per hectare: 15359 Rs/ha/yr $PS_4 = 15359 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies (ESVD, 2020)

	Raw materials (PS_5) Genetic resources (PS_6)	Value for raw materials per hectare: 13358 Rs/ha/yr $PS_5 = 13358 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha) Value for genetic resources per hectare: 476 Rs/ha/yr $PS_6 = 476 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies (ESVD, 2020) Benefit transfer methodbased on case studies (ESVD, 2020)
	Medicinal resources (PS_7)	Value for medicinal resources per hectare: 786 Rs/ha/yr $PS_7 = 786 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case study (Clarkson et al., 2013)
	Ornamental resources (PS_8)	Value for ornamental resources service per hectare: 905 Rs/ha/yr $PS_8 = 905 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case study (Clarkson et al., 2013)
	Fuelwood (PS_9)	Fuelwood extraction from- 10% of macrophyte covered area of wetlands in districts of Karnataka Value for fuelwood service per hectare: 5833 Rs/ha/yr $PS_9 = 5833 * A_f$ Where, A_f= Area of fuelwood in wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies from India (Ramachandra et al., 2005; Ramachandra et al., 2011)

	Irrigation (PS_{10})	Data on irrigation and agricultural crops grown in each district of Karnataka obtained from government reports (District at a Glance). Value for irrigation service per hectare: 1826 Rs/ha/yr $$PS_{10} = 1826 * A_i$$ Where, A_i= Tank irrigated area in districts of Karnataka (in ha)	Benefit transfer method based on case studies from India (Mukherjee, 2008)

Regulating Services

Services	Variables	Data source	Approach
Regulating Services	Air quality regulation (RMS_1)	Value for air quality regulation service per hectare: 270 Rs/ha/yr $RMS_1 = 270 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies (ESVD, 2020)
	Climate regulation (RMS_2)	Value for climate regulation service per hectare: 1191 Rs/ha/yr $RMS_2 = 1191 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies (ESVD, 2020)
	Moderation of extreme events (RMS_3)	Value for moderation of extreme events service per hectare: 105781 Rs/ha/yr $RMS_3 = 105781 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies (ESVD, 2020)
	Regulation of water flows (RMS_4)	Value for regulation of water flow service per hectare: 28891 Rs/ha/yr $RMS_4 = 28891 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies (ESVD, 2020)
	Waste treatment (RMS_5)	Value for waste treatment service per hectare: 16225 Rs/ha/yr $RMS_5 = 16225 * A$ Where, A= Area of wetlands in	Benefit transfer method based on case studies (ESVD, 2020)

		districts of Karnataka (in ha)	
	Erosion prevention (RMS_6)	Value for erosion prevention service per hectare: 20704 Rs/ha/yr $RMS_6 = 20704 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case study (Clarkson et al., 2013)
	Maintenance of soil fertility (RMS_7)	Value for maintenance of soil fertility service per hectare: 13604 Rs/ha/yr $RMS_7 = 13604 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case study (Clarkson et al., 2013)
	Biological control (RMS_8)	Value for biological control service per hectare: 7529 Rs/ha/yr $RMS_8 = 7529 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case study (Clarkson et al., 2013)
	Maintenance of life cycles of migratory species (RMS_9)	Value for maintenance of life cycles of migratory species service per hectare: 14978 Rs/ha/yr $RMS_9 = 14978 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies (ESVD, 2020)
	Maintenance of genetic diversity (RMS_{10})	Value for maintenance of genetic diversity service per hectare: 27216 Rs/ha/yr $RMS_{10} = 27216 * A$ Where, A= Area of wetlands in	Benefit transfer method based on case studies (ESVD, 2020)

		districts of Karnataka (in ha)	
	Carbon sequestration (RMS_{11})	Microalgae ❖ Total value of carbon sequestration from microalgae: 234404.05 Rs tCO_2/ha/yr Macrophyte ❖ Total value of carbon sequestration from macrophyte: 311.92 Rs $kgCO_2$/ha/yr Value for carbon sequestration service per hectare (summation of carbon sequestration from microalgae and macrophyte): 234716 Rs/ha/yr $RMS_{11} = 234716 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies from India (Verma et al., 2014; Kalita, 2019), Baral et al., 2016
	Water borne disease control (RMS_{12})	Value for water borne disease control service per hectare: 1941 Rs/ha/yr $RMS_{12} = 1941 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies from India (Verma et al., 2001; Kant et al., 2013; Ramachandra et al., 2011)
	Pollination (RMS_{13})	Value for pollination service per hectare: 19 Rs/ha/yr $RMS_{13} = 19 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case study (Schuyt & Brander, 2008)
	Water conservation (RMS_{14})	Value for water conservation service per hectare: 2875 Rs/ha/yr	Benefit transfer method based

		$RMS_{14} = 2875 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	on case study (Li & Gao, 2016)
	Flood control (RMS_{15})	Value for flood control service per hectare: 7053 Rs/ha/yr $RMS_{15} = 7053 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies from India (Kaul et al., 2016), Zuze, 2013; Schuyt & Brander, 2008
	Habitat/refugia (RMS_{16})	Value for habitat/refugia service per hectare: 1825 Rs/ha/yr $RMS_{16} = 1825 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies (Schuyt & Brander, 2008; Kaggwa et al., 2009)
	Groundwater recharge (RMS_{17})	Value for Groundwater recharge service per hectare: 215123 Rs/ha/yr $RMS_{17} = 215123 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies from India (Ramachandra et al., 2019), Kaggwa et al., 2009

Cultural services

Services	Variables	Data source	Approach
Cultural services	Aesthetic information (CS_1)	Value for aesthetic information service per hectare: 389 Rs/ha/yr $CS_1 = 389 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies (ESVD, 2020)
	Opportunities for recreation and tourism (CS_2)	Value for opportunities for recreation and tourism service per hectare: 12111 Rs/ha/yr $CS_2 = 12111 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies from India (Anitha & Muraleedharan, 2006; Dehlavi& Adil, 2011; Rao, 2018; Verma et al., 2001; Dixit et al., 2016; Mishra, 2014; Venkatachalam & Zareena Begam, 2016; Prasher et al., 2006), Schuijt, 2002; Zuze, 2013; Schuyt & Brander, 2008; Kaggwa et al., 2009; Baral et al., 2016; Li & Gao, 2016; Dehlavi & Adil, 2011
	Inspiration for culture, art and design (CS_3)	Value for inspiration for culture, art and design service per hectare: 3346 Rs/ha/yr $CS_3 = 3346 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies from India (Ramachandra, 2016; Ramachandra et al., 2019), Zuze, 2013; Schuyt & Brander, 2008; Kaggwa et al., 2009

	Spiritual experience (CS_4)	Value for spiritual experience service per hectare: 8 Rs/ha/yr $CS_4 = 8 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies (ESVD, 2020)
	Information for cognitive development (CS_5)	Value for information for cognitive development service per hectare: 953 Rs/ha/yr $CS_5 = 953 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies (ESVD, 2020)
	Existence and bequest values (CS_6)	Value for existence and bequest values service per hectare: 91312 Rs/ha/yr $CS_6 = 91312 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies (ESVD, 2020)
	Education (CS_7)	Value for education service per hectare: 29144 Rs/ha/yr $CS_7 = 29144 * A$ Where, A= Area of wetlands in districts of Karnataka (in ha)	Benefit transfer method based on case studies from India (Ramachandra, 2016; Ramachandra et al., 2019), Li & Gao, 2016

Macrophyte

Macrophyte covered ~18% of the Karnataka wetland area. The total macrophyte cover in Karnataka wetlands is 50432.35 ha (figure 6, table 7).

The total benefit from macrophyte was computed considering fodder, honey production, food, grazing, and handicraft making through the residual value method for calculating provisioning services.

Table 7. Karnataka macrophyte cover

District	Macrophyte Cover (ha)
Bengaluru Urban	1316.63
Bengaluru Rural	1448.9
Chamarajanagar	3032.63
Mysuru	3052.41
Bidar	137.59
Raichur	656.74
Yadgir	949.19
Dharwad	284.54
Belagavi	200.61
Gadag	348.18
Vijayapura	29.82
Kalaburgi	171.98
Shivamogga	865.73
Bagalkot	103.86
Dakshina Kannada	15.06
Chikkamagaluru	1330.86
Chikkaballapura	1741.72
Kolar	2733.96
Ramanagara	1253.06
Udupi	41.99
Uttara Kannada	316.46
Mandya	3968.29
Chitradurga	5734.12
Davanagere	2599.28
Kodagu	86.49
Hassan	4291.89
Haveri	2266.65
Koppal	263.74
Ballari	1782.32
Tumakuru	9407.65

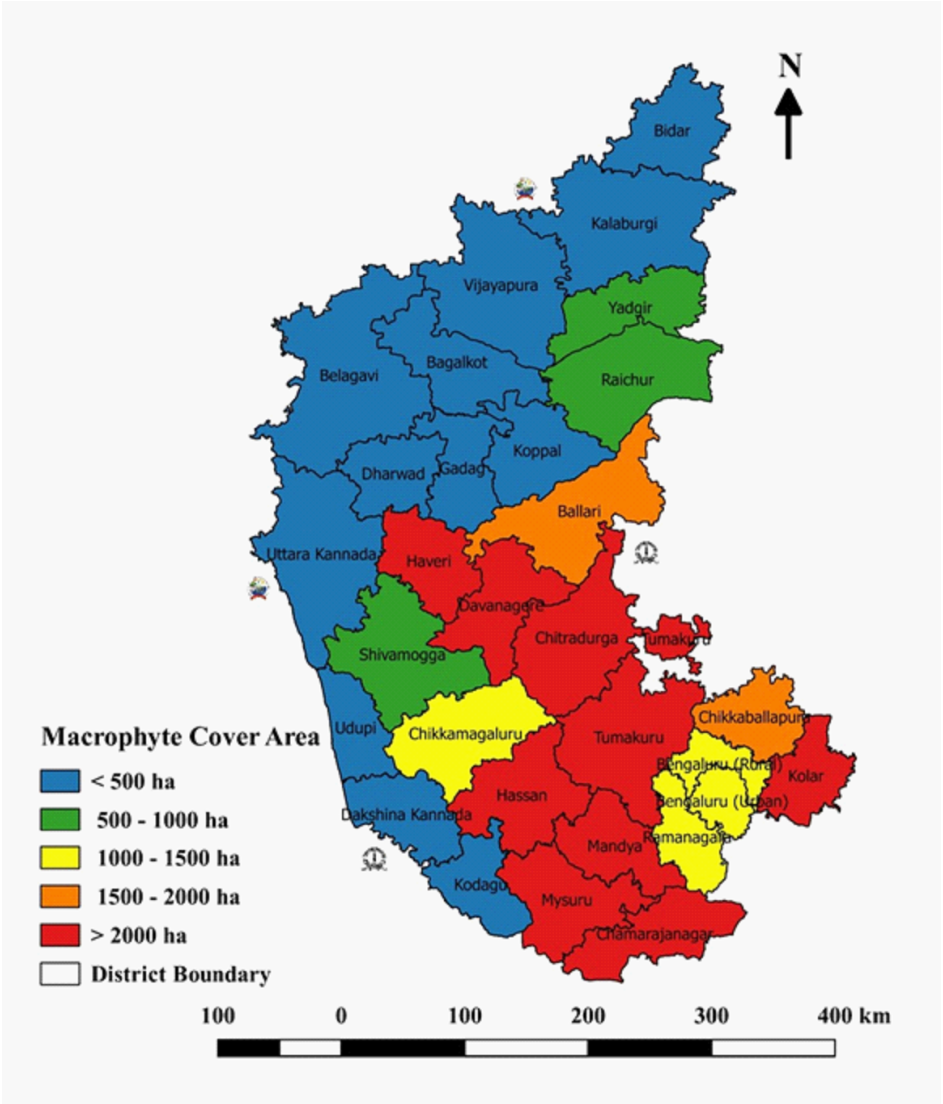


Figure 6. Macrophyte covered area in wetlands of districts of Karnataka

Fuelwood

Wetland trees provide materials such as timber and fuel wood. The households near the lakes collect fuelwood as cooking energy. Fuelwood quantity is quantified considering 10% of the macrophyte spread area in wetlands (table 8).

Table 8. Fuelwood - area in hectare from wetlands

Sl.No.	District	Fuelwood area in ha
1	Bagalkot	10.39
2	Ballari	178.23
3	Bengaluru Rural	144.89
4	Bengaluru Urban	131.66
5	Belagavi	20.06
6	Bidar	13.76
7	Chamarajanagar	303.26
8	Chikkaballapura	174.17
9	Chikkamagaluru	133.09
10	Chitradurga	573.41
11	Dakshina Kannada	1.51
12	Davanagere	259.93
13	Dharwad	28.45
14	Gadag	34.82
15	Hassan	429.19
16	Haveri	226.67
17	Kalaburgi	17.20
18	Kodagu	8.65
19	Kolar	273.40
20	Koppal	26.37
21	Mandya	396.83
22	Mysuru	305.24
23	Raichur	65.67
24	Ramanagara	125.31
25	Shivamogga	86.57
26	Tumakuru	940.77
27	Udupi	4.20
28	Uttara Kannada	31.65
29	Vijayapura	2.98
30	Yadgir	94.92

Irrigation

Wetland water is used for irrigation of agriculture and horticulture fields. The data on irrigation (figure 7, table 9) and agricultural crops grown in each district of Karnataka was obtained from government reports (District at a Glance, GoK).

Table 9. Tank irrigated area in hectare

Sl.No.	District	Tank irrigated area in ha
1	Bagalkot	839
2	Ballari	1139
3	Bengaluru Rural	624
4	Bengaluru Urban	1449
5	Belagavi	307
6	Bidar	688
7	Chamarajanagar	1646
8	Chikkaballapura	251
9	Chikkamagaluru	9124
10	Chitradurga	5041
11	Dakshina Kannada	2172
12	Davanagere	914
13	Dharwad	238
14	Gadag	1379
15	Hassan	17407
16	Haveri	20768
17	Kalaburgi	1069
18	Kodagu	171
19	Kolar	3368
20	Koppal	2984
21	Mandya	14654
22	Mysuru	4335
23	Raichur	789
24	Ramanagara	1688
25	Shivamogga	48572
26	Tumakuru	5377
27	Udupi	453
28	Uttara Kannada	6155
29	Vijayapura	945
30	Yadgir	3525

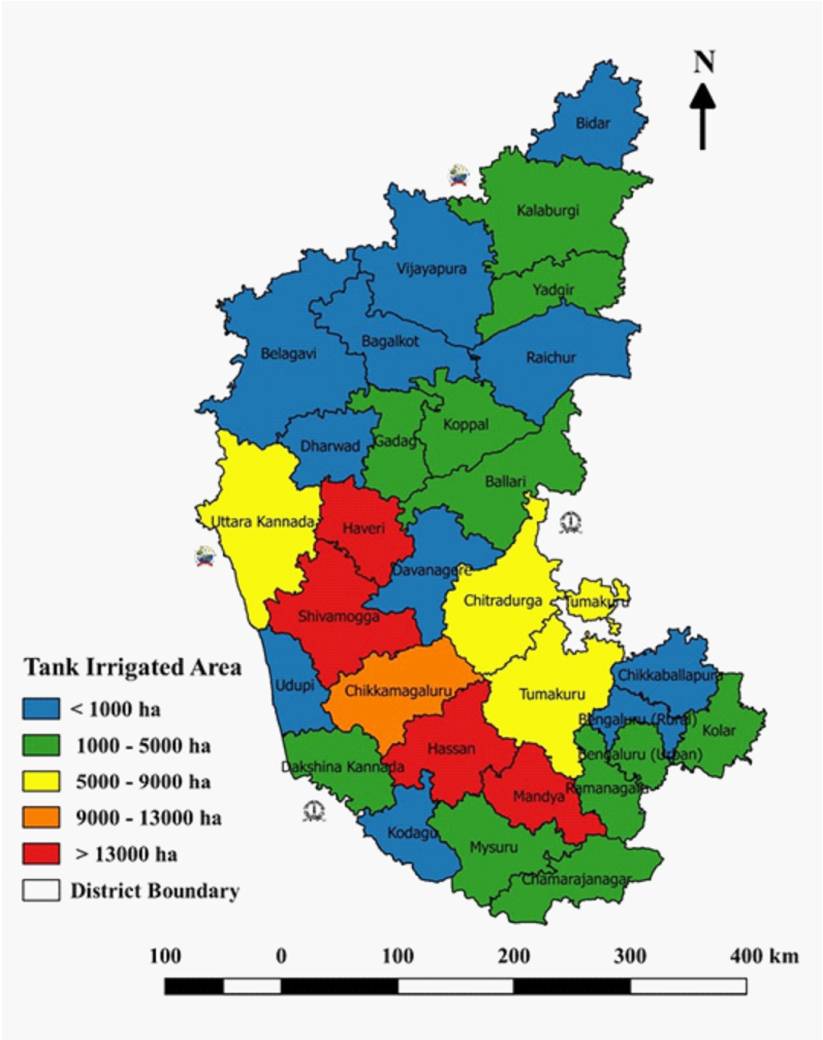


Figure 7.Tank irrigated area in districts of Karnataka

In this study, the residual value method and the benefit transfer method is used for ecosystem service valuation. Values used for the valuation of ecosystem service are listed in table 10.

Table 10. Values used for wetland ecosystem valuation

Symbol	Services	Unit Value (Rs/ha/yr)
	Provisioning Services	
PS1	Algae	110467
PS2	Macrophyte	11291
PS3	Fish	32175
PS4	Water	15359
PS5	Raw materials	13358
PS6	Genetic resources	476
PS7	Medicinal resources	786
PS8	Ornamental resources	905
PS9	Fuelwood	5833
PS10	Irrigation	1826
	Regulating Services	
RMS1	Air quality regulation	270
RMS2	Climate regulation	1191
RMS3	Moderation of extreme events	105781
RMS4	Regulation of water flows	28891
RMS5	Waste treatment	16225
RMS6	Erosion prevention	20704
RMS7	Maintenance of soil fertility	13604
RMS8	Biological control	7529
RMS9	Maintenance of life cycles of migratory species	14978
RMS10	Maintenance of genetic diversity	27216
RMS11	Carbon sequestration	234716
RMS12	Water borne disease control	1941
RMS13	Pollination	19
RMS14	Water conservation	2875
RMS15	Flood control	7053
RMS16	Habitat/refugia	1825
RMS17	Groundwater recharge	215123
	Cultural Services	
CS1	Aesthetic information	389
CS2	Opportunities for recreation and tourism	12111
CS3	Inspiration for culture, art and design	905
CS4	Spiritual experience	8
CS5	Information for cognitive development	953
CS6	Existence and bequest values	91312
CS7	Education	29144

The values adopted for the valuation of ecosystem services are shown in table 10. For wetland valuation, provisioning service was calculated by equation (1). PSn 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), An 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 10% of the macrophyte area). The regulating service (RMS) 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 NPV (net present value) of a wetland ecosystem (SEEA, 2014, 2021).

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

$$RMS_n = \sum_{i=1}^{17} RMS_i \times A_n \quad \text{..... (2)}$$

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

$$TESV = \sum_{n=1}^{30} PS_n + RMS_n + CS_n \quad \text{..... (4)}$$

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

where, NPV = net present value; R = net cash flow (TESV) in year t; T = discount period (50 year); and r = discount rate (3%).

The NPV reflects the monetary value of an asset on the basis of its cash flow during a discount period and a discount rate. Macrophyte spatial extent is quantified using Google Earth, and QGIS open-source GIS software is used for visualization of ecosystem services provided by wetlands.

3.0 Results and Discussion

3.1 Water Quality of Lakes

Water quality of aquatic ecosystems depends on the climate, geology, topography, and soil properties of a region. In the case of Bengaluru lakes in Karnataka, 79% of lakes belong to class E, 19% belong to classes D and E, and 2% belong to class A as per CPCB standards (figure 8). The loss and degradation of wetlands in Karnataka occurred due to urbanization, industrial development, agriculture expansion, water extraction for domestic and industrial usage, encroachment, and pollution of water bodies due to domestic sewage as well as industrial effluents (Ramachandra et al., 2021; Ramachandra et al., 2020b; Ramachandra and Aithal, 2016; Ravikumar et al., 2013). The sustained inflow of untreated domestic sewage and industrial effluents enhance nutrients in water bodies, which allows invasive exotic species to proliferate, leading to a decline of native species, which alters the community structure and composition of aquatic biota (Ramachandra et al., 2014).

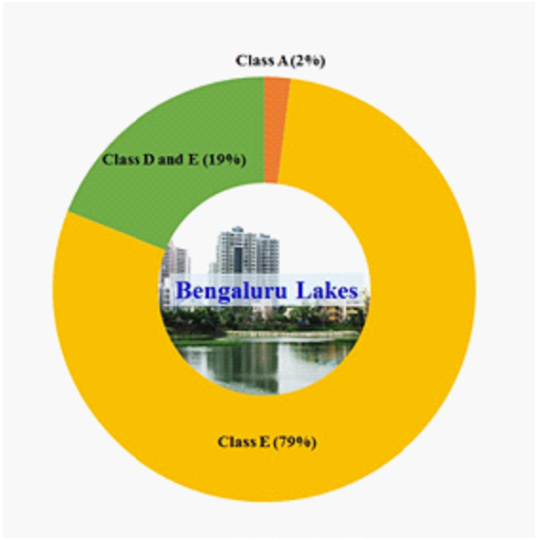


Figure 8. Classification of lakes as per CPCB standards

Degradation of wetlands occurs due to urbanization, industrialization, agricultural intensification, water extraction for domestic use and industries, and pollution (Singh et al., 2013). The physical, chemical, and geomorphological variables of an aquatic ecosystem strongly influence

freshwater biodiversity (Oikonomou and Stefanidis, 2020). The current study highlights that among Bangalore wetlands, 24 lakes are less polluted (with low ionic as well as nutrient content), 22 lakes are moderately polluted, and 34 lakes are highly polluted (with high ionic, organic, and nutrient content) in Bengaluru, Karnataka (figure 9).

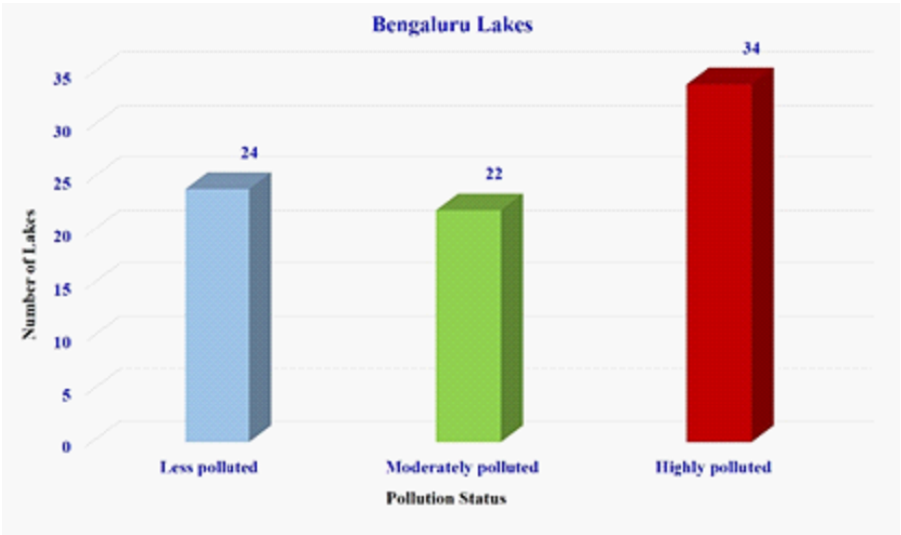


Figure 9. Pollution status of lakes in Bengaluru (based on water quality data)

The study on 105 wetlands in Bengaluru district (figure 10) revealed that about 90% of the lakes were under threat due to (i) the sustained inflow of untreated domestic sewage and industrial effluents, (ii) dumping of organic wastes, (iii) dumping of construction and demolition wastes, (iv) encroachment of lake bed and storm water drains (Ramachandra et al., 2016), (v) narrowing and concretising storm water drains, and (vi) dumping of waste (solid and liquid waste) in storm water drains.

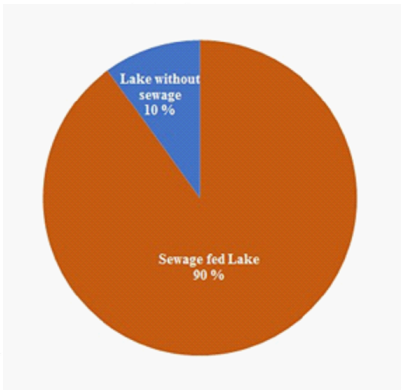


Figure 10. Sewage fed lakes in Bengaluru

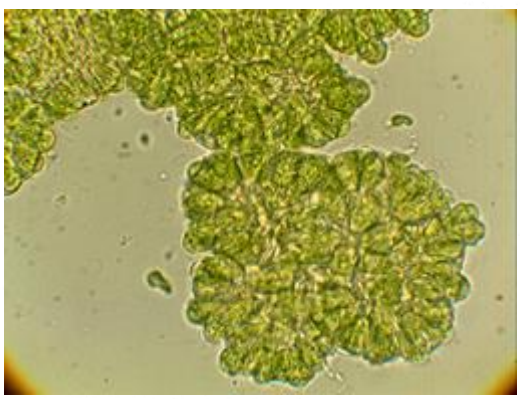
Nutrient enrichment in a waterbody leads to eutrophication, stimulating the profused growth of invasive species of algae and aquatic plants, and results in dissolved oxygen depletion (Tang et al., 2020), which affects the native species of aquatic biota. It was observed that benthic algal production is higher in clear-water than in turbid lakes (McGowan et al., 2005). High densities of cyanobacteria (blue-green algae) can impair lake ecosystem services such as poor-quality drinking water, recreational activity, and biodiversity (Schallenberg et al., 2013). This is aggravated by the recent trends of changes in climate affecting ecosystems and their related services (Marquès et al., 2013). The alarming decline in the quality and quantity of wetland resources is likely to affect the livelihoods of various stakeholders who depend either directly or indirectly on these wetland resources.

Wetland loss and conversion to other land uses with unplanned urbanization due to the expansion of built-up areas, agricultural extension, water abstraction, and flow modification (Pal and Talukdar, 2018). Unplanned urbanization, industrialization, and waste disposal practices impose negative effects on wetland ecosystem services (Alam et al., 2017). The major threats to wetlands are eutrophication, sewage, solid waste, overfishing, detergent usage, and agricultural sources (Biswasroy et al., 2011). Over-exploitation of wetland resources and anthropogenic activities deteriorated the Kuttanad wetland ecosystem, causing an ecological imbalance (Rao and Balasubramanian, 2019). Even though inhabitants depended on Loktak lake's bio-resources such as fishes, prawns, eels, vegetable items, fuelwood, thatching materials, handicraft materials, medicinal plants, and oysters for livelihood and income generation, various anthropogenic pressures resulting in pollution and ecological degradation led to the poor socio-economic condition of the people (Laishram and Dey, 2013). Unplanned developmental activities drivers such as habitat loss, habitat degradation, and fragmentation, overharvesting of biological resources, illegal hunting and poaching, monoculture plantation, agricultural intensification, loss of genetic resources, shifting cultivation with insufficient fallow period, human-wildlife conflict, invasive alien species, and atmospheric pollution have an adverse impact on conservation and sustainable use of biodiversity and ecosystem services (Xu et al., 2019). The driving forces for decline in ecosystem services such as food supply (rice production, and fish production), and biodiversity in China's Poyang lake and Bangladesh's Tanguar Haor wetland from 2000 to 2012 were land use policies, population increase, and economic development (Sun et al., 2017).

The problems of encroachment of lakes and wastewater discharges into lakes with an increase in urbanization need to be addressed with strict enforcement of acts, and regulations (Merugu and Seetharaman, 2013). A reduction of nutrient input into lakes from point and nonpoint sources and the banning of anthropogenic activities is necessary to protect lakes (Kumar et al., 2006).

3.2 Ecosystem services provided by microalgae

Microalgae are ubiquitous photosynthetic microorganisms that generally thrive in freshwater as well as saltwater ecosystems. They have chlorophyll and produce atmospheric oxygen through the process of photosynthesis, which converts water and carbon dioxide into carbohydrates with the help of solar energy. Wetland primary production is influenced by a variety of factors such as vegetation type, hydrology, climate, geographic location, light intensity, water temperature, and the nutrient status of water and sediment. Microalgae provide many essential ecosystem services and are widely used for commercial applications as food and nutritional supplements (Asulabha et al., 2018). Recently, several studies have been carried out on the utilization of microalgae for carbon dioxide sequestration and wastewater remediation. The microalgae help in bioremediation (purification of water/wastewater) since they have the ability to accumulate nutrients, heavy metals, inorganic and organic toxic substances, pesticides, and other pollutants in their tiny cells. Microalgae help in the reduction of greenhouse gas (GHG) emissions, wastewater treatment, nutrient removal/recycling, and the production of carbon-neutral biofuels (Silva et al., 2021).



Botryococcus sp. used for biofuel production



Spirulina sp. as feed

Figure 11. Microalgae images under microscope

3.2 Ecosystem services provided by microalgae

Microalgae biomass (table 11, figure 11) 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).

Table 11. Review of algal biomass productivity

Reference	Area ha	Cultivation	Biomass productivity	Lipid content	USD per kg algal biomass	USD per L algal lipid or biodiesel
Amer et al., 2011	500	Pond	24 g m^{-2} day^{-1}	40%		4–7.50
Davis et al., 2011	1950.58	Pond	25 g m^{-2} day^{-1}	25%		2.25
Norsker et al., 2011	100	Pond	21 t ha^{-1} $year^{-1}$		6.57	
Delrue et al., 2012	333.3	Pond	20–30 g m^{-2} day^{-1}	20–50 %		1.3–2.53
Nagarajan et al., 2013	400	Pond	30 g m^{-2} day^{-1} or 60 g m^{-2} day^{-1}	50%		0.42–0.97

Some species of microalgae produce bioactive compounds and commercially valuable pigments such as chlorophyll, phycobiliproteins, carotenoids, and astaxanthin (Khan et al., 2018a). For example, *Chlorella* sp. containing large amounts of proteins, carbohydrates, lipids, vitamins, micronutrients, and carotenoids, is directly used in animal feed. Microalgae are rich sources of proteins and can produce 2.5 to 7.5 tons/ha/yr of proteins (Khan et al., 2018a). In order to produce 160 MT/day of protein commercially, 336 MT/day of dry algae (with 54 wt.% protein) is required (Asiedu, 2015). Polyunsaturated fatty acids, including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), extracted from microalgae have been marketed by numerous algae-based or biotechnological companies worldwide.

Microalgae is the most preferred source for biofuel production due to several advantages: (i) higher productivity than other crops; (ii) higher photosynthesis efficiency (3-8%) than terrestrial plants (0.5%), (iii) shorter doubling time; (iv) higher lipid content; (v) no competition with resources needed for food supply; (vi) ability to grow in wastewaters and nutrient removal; (viii) reduced land requirements; (ix) ability for CO_2 sequestration and; (x) ability to accumulate other products of commercial value (Silva et al., 2021; Amit et al., 2021).

The total oil content of third generation feedstocks (biofuels from microalgae) was higher than the first generation (biofuels from edible food crops such as rapeseed, oil seeds, sunflower, soybean, potato, barley, wheat, and sugarcane) and second generation (biofuels from non-edible crops like jatropha, jojoba, pongamia, and lignocellulosic biomass) feedstocks (Chhandama et al., 2021). The production of microalgal biodiesel begins with the harvesting of microalgal biomass, followed by drying and lipid extraction, and then the transesterification process. During the transesterification process, the fatty acids of one molecule triacylglyceride (TAG) react with alcohol to form fatty acid methyl esters (FAMEs) and glycerol (Schlagermann et al., 2012). Techniques for harvesting microalgae biomass include filtration, centrifugation, flocculation, and flotation (Tan et al., 2020). Table 12 lists the cost and benefits of microalgae byproducts.

Table 12. Costs and benefits of algae derived byproducts

Algal Product	Cost	Selling price	Benefit	Reference
Biodiesel	0.42 $/L or 31.29 Rs/L	56 Rs/L	25 Rs/L	Nagarajan et al., 2013; Chisti, 2013; Louw et al., 2016
Glycerol			16.39 Rs/kg	Quispe et al., 2013
Protein	$2.86/kg	$4.13/kg	$ 1.27/kg	Asiedu, 2015
Algal fuel	$0.45/L to $7.93/L	$1.32/L to $5.94/L	0.87$/L to1.99 $/L	Gu et al., 2020
Biodiesel	0.33 €/L			Amit et al., 2021
	0.33 €/L	0.75 €/L	0.42 €/L	Branco-Vieira et al., 2020
Biofuel	$0.44/L to $8.76/L			Chowdhury & Loganathan, 2019
Biofuel	$ 0.43/L ($ 1.64/gal) $ 7.92/L ($ 30.00/gal)	$ 1.82/L ($ 7/gal)		Roles et al., 2021

Microalgae play a significant role in wastewater treatment and produce valuable biomass in large quantities that can be used for biofuel production (Randrianarison and Ashraf, 2017). Microalgae-based biofuels (third-generation of biomass energy) are a renewable and sustainable source of energy required to meet the global energy demand for the transportation sector. Microalgal biodiesel is an alternative to reduce the unsustainable utilization of fossil fuels that causes global warming. Microalgal biodiesel showed reduced emissions of carbon monoxide (CO), unburned hydrocarbon (HC), and oxide of nitrogen (NOx) compared to petroleum diesel (Ali et al., 2017). Microalgal biodiesel can displace petroleum-derived diesel since it has properties similar to petroleum-derived diesel and can be directly used in conventional diesel engines (Chisti, 2008). The calorific value of biodiesel is about 39 MJ/kg. Pure biodiesel can be used directly in a diesel engine or it may be blended with conventional diesel before use (Pandey et al., 2018). About 20 kg of wet de-oiled biomass can produce one cubic meter of biogas/day, which is equivalent to generating about 6 kWh of power. This is sufficient to light three 100-watt incandescent bulbs for 20 hours (Ali et al., 2017). Biofuels derived from algae biomass include hydrogen, methane, syngas (gaseous), ethanol, jet fuel, diesel, butanol (liquid), and charcoal (solid fuel) through different methods such as photobiological method, gasification, fermentation, anaerobic digestion, liquefaction, transesterification, and pyrolysis (Chowdhury and Loganathan, 2019; Aliyu et al., 2021). Biodiesel complies with the three key aspects of sustainability, i.e., economic (lower production cost and high profit), environmental (lower environmental load) and social (ensure food security, livelihood, and employment) sustainability (Mizik and Gyarmati, 2021). The provisioning service provided by microalgae from the wetlands of Karnataka amounts to 1,10,467 Rs/ha/yr (table 13).

Table 13. Provisioning service provided by microalgae

Microalgae	Provisioning services
Biodiesel	51744 Rs/ha/yr
Glycerol	3763 Rs/ha/yr
Protein/Food	50760 Rs/ha/yr
Fishmeal	4200 Rs/ha/yr
Total Benefit	110467 Rs/ha/yr

3.3 Ecosystem services provided by fish

Fisheries sector provides livelihoods, income, and nutritious food to society (Sincy et al., 2018). Fish excretion contributes to nutrient recycling and nutrient translocation, which influences microalgal biomass production and community composition in aquatic ecosystems (Williamson et al., 2018). Physical habitat variables (stream channel width and depth, and organic matter) and water quality variables (conductivity, pH, water temperature, chlorophyll, turbidity, and dissolved oxygen) play a decisive role in the fish species assemblage (Vieira and Tejerina-Garro, 2020). The vertical distribution of fish in lakes is determined by water temperature and oxygen stratification. Vertical migration of fish along with diel periodicity helps in avoiding predation and reducing competition (Perivolioti et al., 2020). Fish for their growth, development, and reproduction, require long-chain polyunsaturated fatty acids (PUFA), such as eicosapentaenoic acid (EPA, 20:5n-3), docosahexaenoic acid (DHA, 22:6n-3), and arachidonic acid (AA, 20:4n-6) (Sargent et al. 1999). Figure 12 shows some of the commercially important fish species in Karnataka.



Fish as food source **Fish in wetland**

Figure 12. Commercially important fish species

Ctenopharyngodon idella feeds on numerous aquatic weeds such as species of Lemna, Potamogeton, Elodea, Ceratophyllum, Vallisneria, Hydrocharis, and Myriophyllum (Lancar and Krake, 2002) and has been useful in weed control. The introduction of planktivorous fish alters plankton communities in food webs (Izaguirre et al., 2018). Fish rich in protein, essential fatty acids, and micronutrients (Fe, Zn, Ca, and vitamin A) constitute an important

component of the human diet and serve as medicine (table 14). Crude protein (% ww) content in *Catla catla, Cirrhinus mrigala, Clarias batrachus,* and *Labeo rohita* ranges from 16.2 ± 0.51, 15.5 ± 0.51, 16.4 ± 0.31, and 15.9 ± 0.41 respectively. The DHA and EPA (mg/100 g wet wt.) content in freshwater fish species *Amblypharyngodon mola, Puntius sophore, Tor putitora* was found as 133.3 ± 6.8 and 94.6 ± 5.4; 161.7 ± 7.6 and 303.8 ± 8.3; 115.5 ± 12.2 and 201.9 ± 13.1 respectively (Mohanty et al., 2016). The blood, bile, fat, and meat of eel fish were used as traditional medicine to treat obesity, alcoholism, gout, mental disorders, and during pregnancy (Svanberg and Locker, 2020). The Indian major carps (IMC) *Labeo rohita, Catla catla, Cirrhinus mrigala,* and the exotic carps *Cyprinus carpio, Ctenopharyngodon idella,* and *Hypothalmichthys molitrix* with high market value fetches good revenue to fishermen in India (Dasgupta and Panigrahi, 2014). Fishing tourism (relating to fishing activity for tourist and educational services) helps in local development as it integrates both socio-economic and cultural activities. Hence, sustainable management of resources, with habitat maintenance/conservation, aids in sustaining the fish species, which provide employment and income to the dependent fishing communities (Tursi et al., 2015). In the present study, the value of the provisioning service provided by fish from wetlands in Karnataka accounts to 32,175 Rs/ha/yr.

Table 14. Fish species being used for medicinal purpose

Species	Part used	Medicinal use for curing diseases	Application
Amblypharyngodon mola	Whole fish	Premenstrual pain	Fish is boiled and consumed
		Pox, pain, asthma	Cooked fish
Anabas testudineus	Whole fish	Dysmenorrhoea	Fish head, Tal tree leaf (*Borassus flabellifer*), and chilly are boiled together and eaten.
Anguilla bengalensis	Fats	Rheumatoid-arthritis	Fat is applied and massaged into the affected parts to relieve pain
	Whole body	Piles and meningitis	Fish is cooked with *Stellaria media* and orally taken as soup once daily for 2 weeks
	Body mucous	Burns	Mucous is applied to the affected parts
Bagarius bagarius	Fat	Rheumatism, gout and joint pain	Fat is applied to the joints and massaged
Chaca chaca	Whole body	Polio	Dried fish is cooked with spices and taken orally

Channa gachua	Whole body	Gall bladder stone	Flesh is cooked and consumed
		Abdominal pain	Boiled fish is consumed
Channa punctatus	Whole fish	Tuberculosis	The fish is boiled with black pepper and consumed
		Diarrhoea	Boiled fish is consumed
	Bile	Malaria	Bile is taken thrice a day till recovery
Channa stewartii	Whole body	Diabetes, pain, high pressure	Boiled in water and consumed
Clarias batrachus	Whole body	Body ache, wound healing	Cooked with black pepper and consumed
		Small pox	Cooked fish is consumed to cure small pox
		Weakness after delivery	Boiled fish is taken regularly
Eutropiichthys vacha	Flesh	Tuberculosis, brain health	Used as curry two times a week for one month
Heteropneustes fossilis	Whole body	Pain, wound healing	Cooked with black pepper and prescribed to eat
		Anemia	Boiled fish taken as a tonic
	Brain	Sting by the fish itself	Brain is consumed raw when stung by the fish, as analgesic
Hilsa ilisha	Body oil	Arthritis, cracked heels, scurvy	Used as ointment for hands, heels and legs
Labeo pangusia	Flesh	Weakness after delivery	Boiled fish is consumed regularly
Labeo pangusia	Bile	Stomach ache	Bile is taken orally to relieve stomach pain
Labeo rohita	Gall bladder (Bile)	Gastric problem, gastric ulcer, intestinal cancer	The fish is ground with water and consumed orally
Mystus bleekeri	Whole body	Dysentery	Fish is boiled with *Portulacaoleracea*, and curry taken 2 times daily for 3 days
Mystus sp.	Whole fish	Small pox	Cooked fish is consumed to cure small pox
Notopterus notopterus	Whole fish	Delivery pain, abdominal pain	The burned fish is cooked with mustard oil and black pepper and consumed
Osteobramacotio cotio	Whole body	Ringworm infection	Sundried fish is crushed into a powder and consumed
Puntius sp.	Whole body	Eye problem	Fish is cooked and consumed
		Blood purifier	Fish is cooked with bamboo shoots and taken orally to purify the blood
		Common cold	Fish is cooked with chilly and consumed
	Head	Night blindness	The cooked head part of fish is taken regularly
		Memory	A boiled head of the fish is taken to increase memory
Wallago attu	Head	Liver tonic	Boiled head is consumed regularly to improve liver function
	Barbels	Treatment of diarrhoea	Roasted barbel is mixed with powdered tender leaves of *Psidiumguajava*
Xenentodon cancila	Whole fish	Joint pain, swelling	Cooked and consumed. Spine and bone is used to prick out the clotted blood

Source: Gogoi and Bora, 2020; Borah and Prasad, 2017; Borah and Prasad, 2016; Gupta and Dey, 2017; Teronpi et al., 2012; Chanu et al., 2016; Prakash and Prakash, 2021

Fish in wetlands provide income and employment to society (table 15). The revenue from fish products from the Sundarbans amounted to US$ 158,368 in 2014–2015 (Islam and Hossain, 2017). The reservoirs of small and medium categories had a fish yield of 200 kg/ha/yr and those under large category had fish yield of 100 kg/ha/yr (Rao et al., 2002). Stocking of fingerlings and adopting improved management practices in reservoirs (Sarkar et al., 2018) would enhance fish production. Overexploitation, including killing of juvenile and brood fish in flood plain wetland fisheries (Sarkar and Borah, 2018), has been a major factor responsible for depletion of fish stock in wetlands.

Table 15. Economic value of fishing from wetlands

Water body	Area (ha)	Value (USD/yr)	Reference
Kuttanad wetlands, Kerala, India	162125	82949309	Rao, 2018
Bhoj wetland, Bhopal, India	3229	113103.4	Verma et al., 2001
Wular lake, Jammu & Kashmir, India	13000	686166.7	Kaul et al., 2016
Nakivubo Urban wetland, Uganda	529	3300	Schuijt, 2002
Hadejia Nguru wetland, Nigeria	350000	3465100	
Chilwa wetland, Malawi	240000	18675500	
Zambezi basin wetland, Southern Africa	2982900	78620700	
Chilwa wetland, Malawi	240000	18675478	Zuze, 2013
That Luang wetland, Laos	2000	1092092	
Muthurajawela wetland, Sri Lanka	6000	64904	
Mfolozi flood plain, South Africa	20886	149543.8	
Muthurajawela wetland, Sri Lanka	3068	64904	Schuyt & Brander, 2008
Whangamarino wetland, New Zealand	10320	10518	
Rachenahalli lake, Bangalore, Karnataka, India	42.09	7449	Ramachandra et al., 2005
Varthur lake, Bangalore, Karnataka, India	220	51642	Ramachandra et al., 2011
Pong Dam wetland, India	15500	54160	Prasher et al., 2006
Ulluru tank, Karnataka, India	3.99	4384	Ramachandra and Sreekantha, 2006
Kaspadi tank, Karnataka, India	1.7	1047	
Nagara tank, Karnataka, India	3.58	2835	

3.4 Ecosystem services provided by macrophyte

Aquatic plants are generally referred as macrophytes, which are either emergent, submergent, or floating types. Ecological significance of macrophytes include cover for fish and acts as substrate for aquatic invertebrates, produce oxygen and serve as food for some fish and other wildlife.

Macrophyte provides numerous ecosystem services to society, including food production, medicine, water purification/treatment, carbon sequestration, and recreational opportunities. The charophytes (Chara, Nitella, and Nitellopsis) play a vital role in maintaining a clear-water state (Poikane et al., 2018). *Ceratophyllum demersum* and *Potamogeton pectinatus* are dominant in nutrient-enriched water (Stefanidis et al., 2019). Submerged macrophytes provide food and refugia for aquatic fauna ranging from microscopic crustaceans to large fish (Gopal, 2016). Symbiotic association between macrophyte (Azolla) and algae belonging to cyanobacteria (*Anabaena* sp.) aid in fixing atmospheric nitrogen (Slembrouck et al., 2018). Macrophytes (figure 13) provide (i) food for other aquatic organisms, (ii) fodder for livestock, (iii) medicine for treating animal and human diseases, (iv) fiber, (v) green manure, (vi) industrial raw materials (manufacture of essential oils), and (vii) pesticide for killing pests/insects, and some species are useful as ornamental plants (Zhang et al., 2014). Macrophytes like *Alternanthera sessilis, Eleocharis dulcis,* and tubers of *Colocasia esculenta* are used as vegetables, while *Fimbristylis dichotoma, Cyperus iria,* and *C. pangorie* are used for making mats (Rao et al., 2008). Table 16 lists the commercially important aquatic macrophytes with use values.



Trapa natans



Nelumbo nucifera



Nymphaea sp.



Alternanthera sp.

Figure 13. Commercially important aquatic macrophytes

Table 16. Value of commercially important aquatic macrophytes (INR/kg)

Macrophytes – Scientific Name	Common Name	INR/kg
Euryale ferox	Prickly waterlily	300
Trapa natans	Water chestnut	170
Colocasia esculenta	Taro/elephant ear	30
Nelumbo nucifera	Lotus	230
Centella asiatica	Indian pennywort	250
Ipomoea aquatc	Water spinach	25
Acorus calamus	Sweet flag	72
Bacopa monnieri	Brahmi	150
Eclipta alba	Bhringraj	150
Source: Raut et al., 2020		

Grasses like *Saccharum spontaneum* and *Sporobolus maderaspatanus* aid in mitigating floods and soil erosion. Macrophytes are used as human food, fodder *(Cynodon dactylon)*, carpet grass *(Axonopus compressus)*, medicine, roofing materials, and as raw materials for making household products like mats, ropes, toys, and hats (Kalita, 2019, Sukumaran and Jeeva, 2011). Some species of Nymphoides are used for treating injuries, jaundice, dysentery, convulsions, and snake bites (Khan et al., 2018b). Aquatic plants store carbon and enhance the carbon sequestration capacity of wetlands. The total carbon sequestered by the twelve macrophytes of Hokersar wetland was 0.85 kg $C/m^2/yr$, which varied with season and habitat (Lolu et al., 2019). Table 17 shows the beneficial uses of different species of macrophyte. In the present study, the value of the provisioning service provided by macrophytes in the wetlands of Karnataka was 11291 Rs/ha/yr.

Table 17. Benefits of macrophytes

Species	Family	Uses
Alternanthera philoxeroides	Amaranthaceae	Consumed as a vegetable, used as animal feed. The juice of younger twigs is consumed to treat worm problems, and its paste is applied to cattle wounds
Azolla pinnata	Azollaceae	Used to treat urinary problems
Bacopa monnieri	Plantaginaceae	Its juice is used to cure fevers
Ceratophyllum demersum	Ceratophyllaceae	Use to relieve pain from insect and scorpion bites; fruit is fed to domestic ducks
Cynodon dactylon	Poaceae	It is a good source of food for aquatic molluscans. This plant is used to cure skin diseases. People utilizes this plant for rituals. Juice is used in the treatment of piles and on cuts and wounds
Cyperus corymbosus	Cyperaceae	Its stem is used for making mats
Cyperus iria and *Cyperus difformis*	Cyperaceae	The plant is a source of fiber, fuel, and food
Eichhornia crassipes	Pontederiaceae	It is used as a fertilizer, to reduce oil in lake water, and as manure in potato fields
Euryale ferox	Nymphaeaceae	Used as a vegetable, it has medicinal value
Hydrilla verticillata	Hydrocharitaceae	Used as fish food, aquarium plants, and fertilizer. It is used by fish farmers to breed *Cyprinus carpio* since their eggs are attached to this plant
Ipomoea aquatica	Convolvulaceae	Its young leaves and stems are used as vegetables and serve as animal feed
Ludwigia adscendens	Onagraceae	Aerial parts are used to make poultices for treating skin problems. Its shoots are used as vegetables

Ludwigia perennis	Onagraceae	The plant is boiled with coconut oil and applied externally to reduce fever
Monochoria vaginalis	Pontederiaceae	Used as cattle feed, liquid extracts from the plant improved the seed viability rate and increased the seedling vigour of some crops
Nymphaea pubescens	Nymphaeaceae	Young stems and unopened flower buds can be boiled and served as a vegetable
Nymphaea rubra	Nymphaeaceae	Flowers are used for religious purposes. Its rhizomes are used for curing dyspepsia and dysentery. It is also cultivated as an ornamental plant
Nymphaea stellata	Nymphaeaceae	Used for the treatment of diabetes, liver disorders, inflammation, urinary disorders, menstruation problem
Nymphoides indica	Menyanthaceae	Used to reduce fevers, its young leaves, stems, fruits, and unopened flower buds can be boiled and served as a vegetable
Pistia stratiotes	Araceae	Its root is used as a pain killer for hemorrhoids. Its leaf juice is boiled with coconut oil and used for treating skin diseases. Its juice mixed with sugar is recommended for curing asthma and cough
Polygonum barbatum	Polygonaceae	Roots and seeds are used for medicinal purposes
Polygonum hydropiper	Polygonaceae	Medicinal value
Salvinia cucullata	Salviniaceae	Used as fodder
Spirodela polyrrhiza	Araceae	Plants are used as organic manures with high nitrogen content (6-7%); used as fodder for cattle; plants are also consumed by herbivorous fish, ducks, goose, and swans; a source of animal feed due to high protein content; used for wastewater purification (phytoremediation).
Trapanatans var. bispinosa	Trapaceae	Used as edible fruit, raw fruits are used for treating diarrhoea and dyspepsia.
Utricularia aurea	Lentibulariaceae	Edible as it is rich in nutrients and is used to treat urinary diseases
Vallisneria spiralis	Hydrocharitaceae	Used as fish food, it helps to clean the water and is used for ornamental purposes
Wolffiaglobosa	Araceae	Leaves are cooked as vegetables
Source: Kiran et al., 2007; Taran and Deb, 2020; Nandan and Singh, 2004; Sarmah et al., 2013; Misra et al., 2012; Sarma and Saikia, 2010; Mishra et al., 2016; Chai et al., 2015; Banerjee et al., 2012		

3.5 Ecosystem services from wetlands in Karnataka

Wetlands play several important roles, including the cycling of water, carbon, and nutrients; food and fiber production; water purification; regulation of flows; provision of habitat for aquatic organisms; and tourism and recreation services (figure 14).



Water storage and recharge



Cattle grazing



Habitat for birds



Washing activities



Wetland as grazing ground



Habitat for macrophyte



Fishing activities



Habitat for fishes



Water used for domestic purpose



Wetland water used for irrigation



Crop cultivation near wetland



Temple near wetland



Performing religious rituals/pooja



Recreation



Lake view apartment



Habitat for migratory birds



Recreation



Ornamental use



Wetland survey



Wetland research

Figure 14. Wetland ecosystem services in Karnataka

The spatial distribution of wetlands in Karnataka is provided in figure 15. The spatial analyses reveal that about 61% of wetlands had an area of <2.5 ha, 36% of wetlands had an area of 2.5–50 ha, and 3% of wetlands had an area of >50 ha.

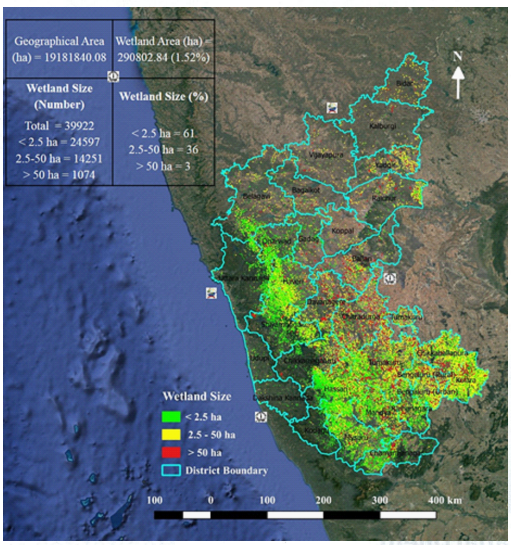


Figure 15. Classification of wetlands of Karnataka based on size

Accounting of provisioning services, shows that the major share is from microalgae (57%), fish (17%), water provision (8%), raw materials (7%), macrophyte (6%), and other services (5%). Other services in the provisioning service include genetic resources, medicinal resources, ornamental resources, and fuelwood. The percentage composition of each service under the regulating service is carbon sequestration (33%), ground water recharge (31%), moderation of extreme events (15%), other services (10%), regulation of water flows (4%), erosion prevention (3%), and maintenance of genetic diversity (4%). Other services include air quality regulation, climate regulation, waste treatment/water purification, maintenance of soil fertility, biological control, maintenance of life cycles of migratory species, waterborne disease control, pollination, habitat or refugia, water conservation, and flood control. In the case of cultural services, existence, and bequest values (68%), have the highest contribution, followed by education (21%), recreation and tourism (9%), and other services (2%). Other services in cultural service include aesthetic information, inspiration for culture, art, and design, spiritual experience, and information for cognitive development (figure 16).

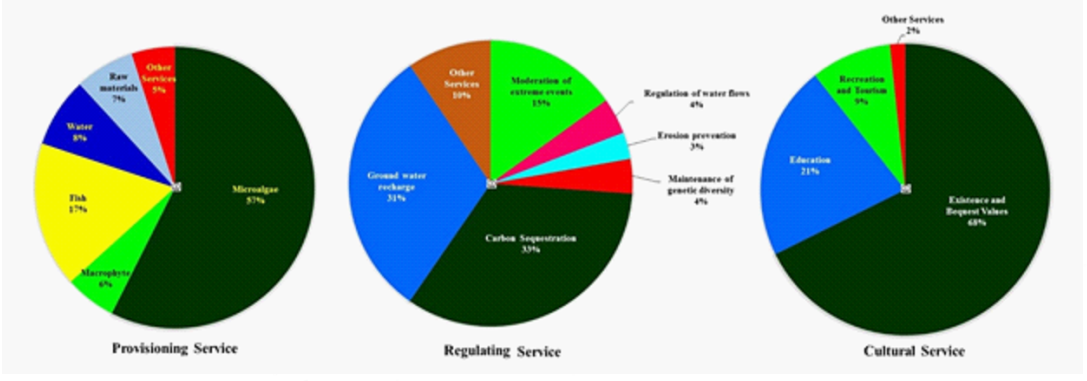


Figure 16: Contribution of different freshwater wetland ecosystem services

Figure 17 illustrates share of ecosystem services — provisioning, regulating, and cultural services contributed about 18%, 69%, and 13%, respectively, to the total ecosystem supply value.

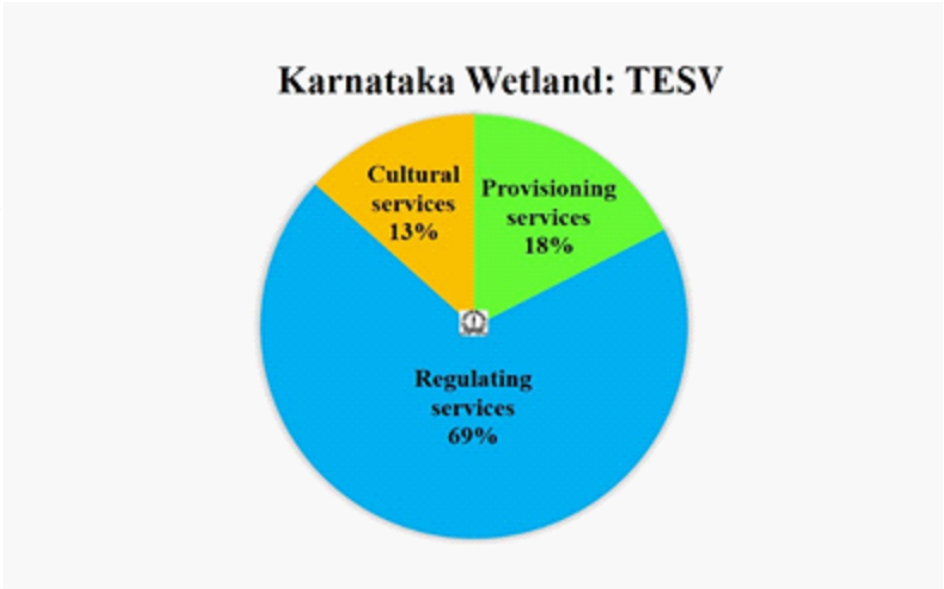


Figure 17. Contribution of ecosystem services provided by freshwater wetlands of Karnataka

The value of provisioning, and regulating services provided by freshwater wetlands in Karnataka was 49.70 and 196.89 billion Rs/yr, respectively. Figures 18 and 19 depict the district-wise share of provisioning and regulating services, respectively. The value of provisioning services for the Ga-Mampa wetland is about $90,000 per year (Adekola et al., 2008). The value of Satajan wetland and bird sanctuary provisioning services in Assam was Rs 52, 65,600 or $78,591 when wild edible plants, fodder, firewood, fish, fresh water, and wild medicinal plants were considered (Kakoti et al., 2019). The total provisioning value of the Kalyanthakur para lake considering aquatic plants, fishes, molluscs, crabs, domestic uses, collection of timber, and fuelwood was US$ 26263.65/year while total cultural value accounted to US$ 2605.68/year (Taran et al., 2016). The average net monetary value of wetlands provisioning services when material collection, fishing, crop production, hunting, and logging are considered is $11,508 per household per year (Adekola et al., 2015).

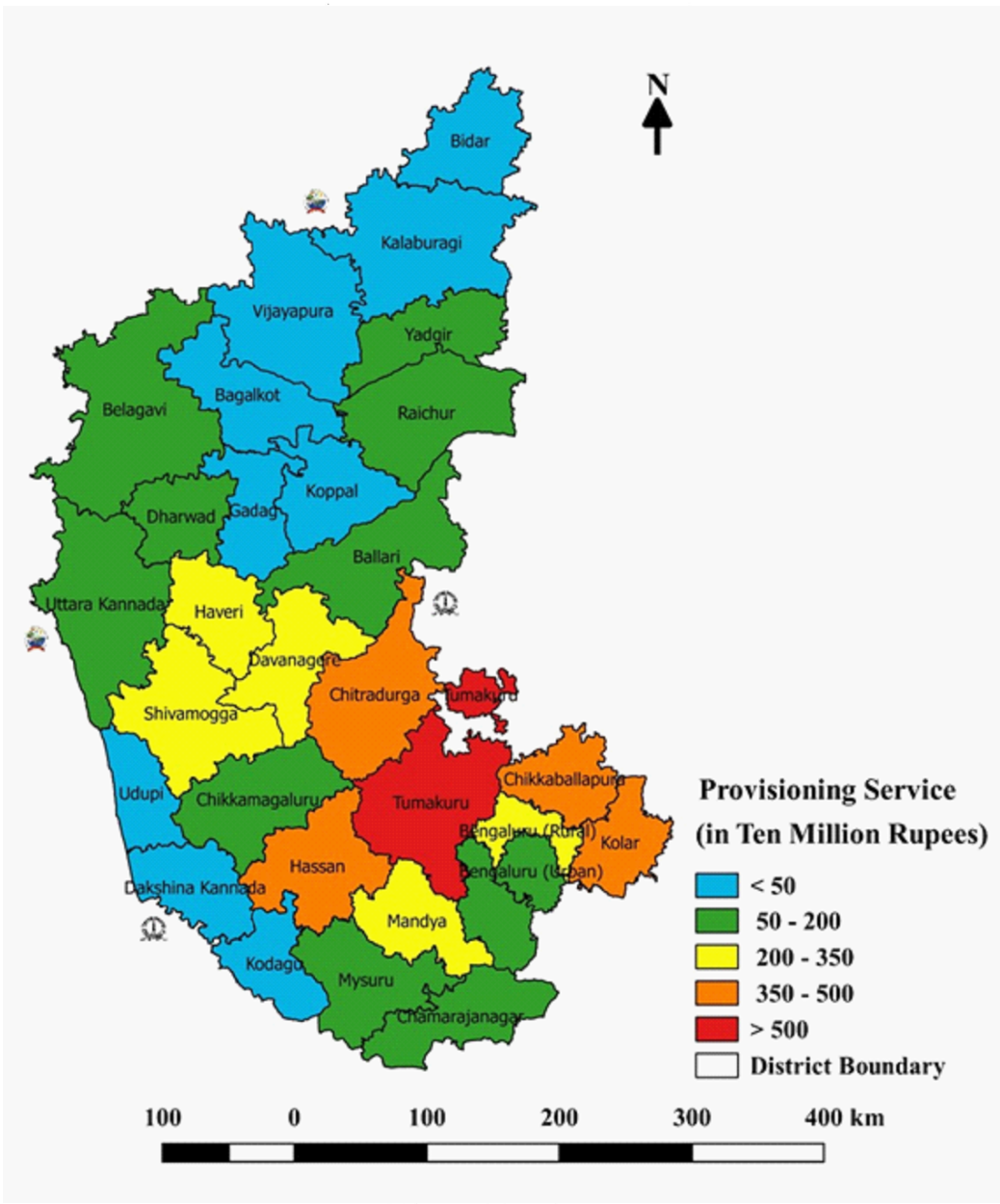


Figure 18. Provisioning service of freshwater wetlands of Karnataka

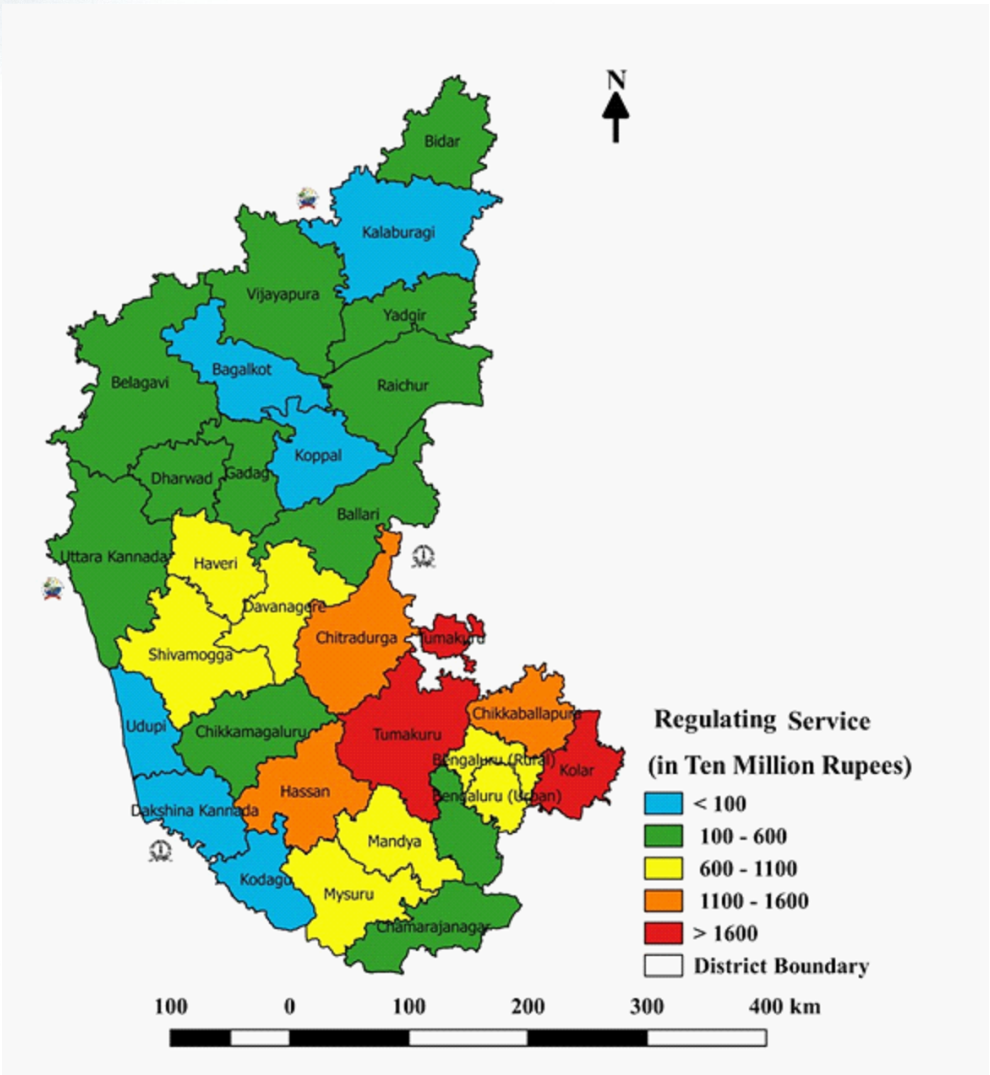


Figure 19. Regulating service of freshwater wetlands of Karnataka

Recreational benefits from the wetlands of Karnataka include scenic beauty, swimming, boating, botanical gardening, an amusement park, and picnic spots. For example, Lalbagh lake, situated in the famous Lalbagh Botanical Gardens of south Bangalore, is a prime attraction for nature lovers, bird watchers as well as tourists as it supports a variety of flora and fauna. Thonnur lake in Mysore is an attractive spot for bird watching, boating, and swimming. A beautiful butterfly park has been built over a small island within the lake. The Regional Museum of Natural History, which is also located on the banks of Karanji lake, provides information on the natural environment of South India

and on nature conservation. Lakes in Karnataka have cultural significance, evident from Pampa Sarovar, a sacred lake in the Koppal district near Hampi in Karnataka. A special pooja is conducted in the Honnamanakere (Honnama lake) in Kodagu district during the Gowri festival, during which people offer bagina (puja items along with flowers and bangles placed in a bamboo sieve) to the lake and visitors pray for good rain. Ganesh Chaturthi is mainly celebrated in Karnataka, during which thousands of Ganesh idols are immersed in Kalyani near the lakes. Visitors come to the lakes during festivals such as Durga puja, Jagadhatri puja, Lakshmi puja, and Ganesh Chaturthi to perform puja (Bhattacharya et al., 2014; Bengani et al., 2020).

Cultural services provided by freshwater wetlands in Karnataka amount to 37.93 billion Rs/yr (figure 20). The annual economic value of the cultural ecosystem service of the Pateira de Fermentelos freshwater wetland in Portugal is estimated at 3087 €/ha/yr (Roebeling et al., 2016). About 90% of people are willing to pay (WTP) for recreational activities in the Kanibrazan wetland, with an average estimate of 38217 Rials per person (Zarandi et al., 2019). In 2014 – 2015, the revenue from tourism (96949 native and 3868 foreign tourists) amounted to US$ 144,832 from the Sundarbans (Islam and Hossain, 2017). The average WTP for the recreational benefits provided by Pilikula lake through the travel cost method (TCM) is 238 INR (Jala and Nandagiri, 2015).

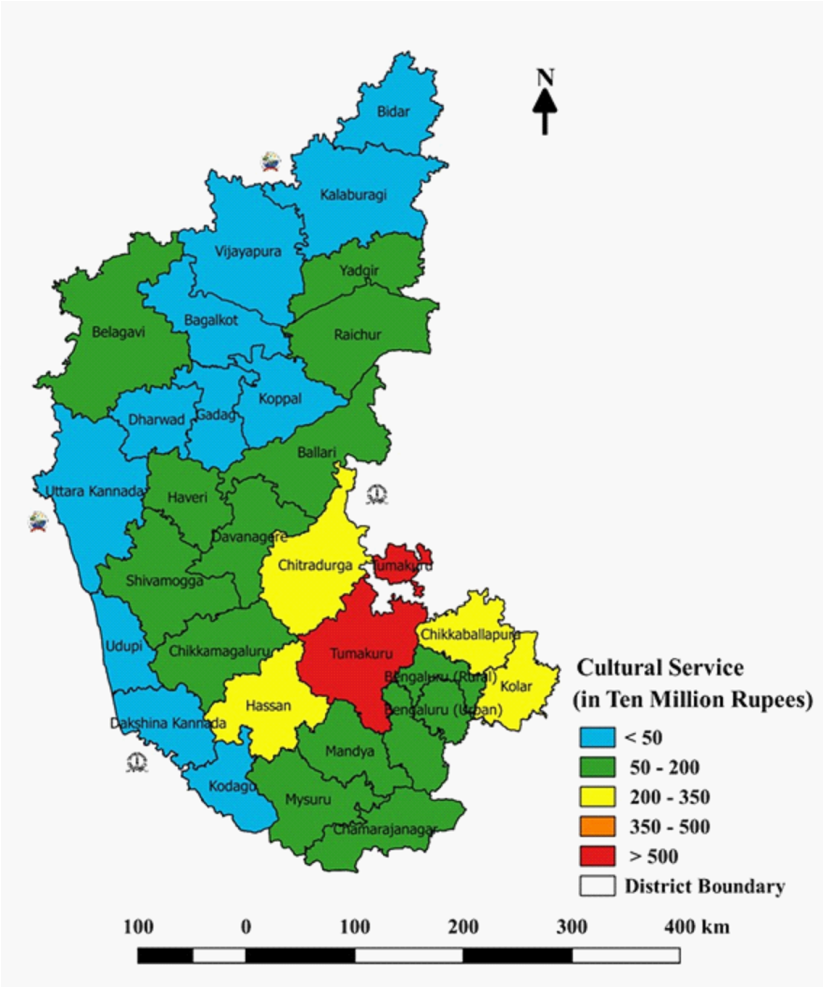


Figure 20. Cultural service of freshwater wetlands of Karnataka

Tumakuru district has the largest wetland spatial extent with the highest values for ecosystem services compared to other districts. It was found that Tumakuru has the highest wetland area (46633.36 ha), followed by Kolar, Chitradurga, Hassan, Chikkaballapura, Mandya, Shivamogga, etc. In Karnataka, Tumakuru district had the highest ecosystem service potential, whereas Udupi district had the lowest values of ecosystem services (figure 21). The value of provisioning, regulating, and cultural services provided by wetlands in Tumakuru district was 8214, 32641, and 6287 million Rs/yr respectively. Udupi district had the lowest values for wetland ecosystem services than other districts in Karnataka because of its smaller wetland area (223.63 ha). The value of provisioning, regulating, and cultural services provided by wetlands in Udupi district was 40; 157; and 30 million Rs/yr respectively.

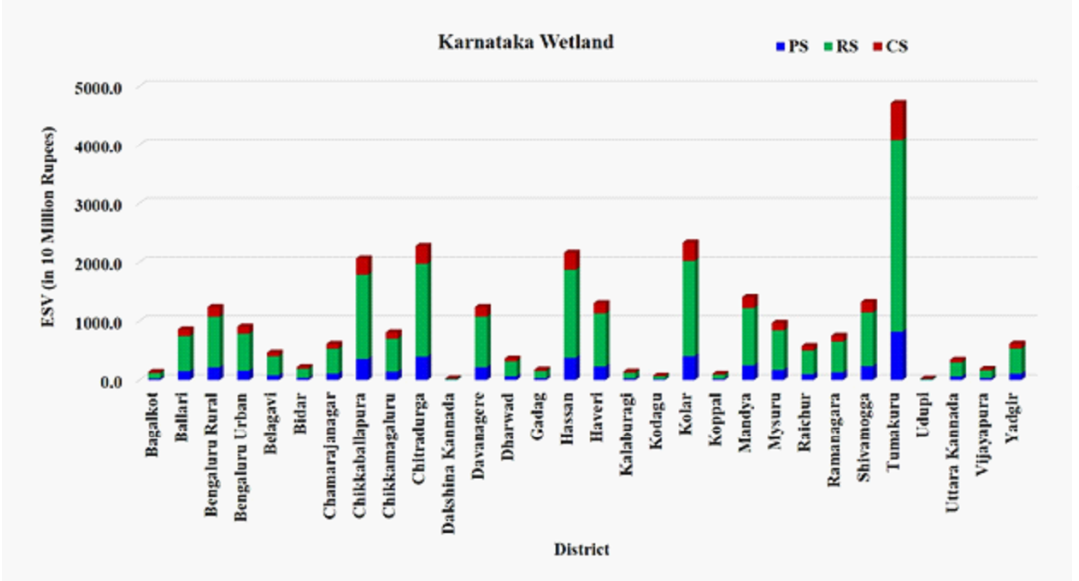


Figure 21. District wise ecosystem supply value of freshwater wetlands of Karnataka

3.6 Total ecosystem supply value (TESV) and net present value (NPV) of freshwater wetlands in Karnataka

Total ecosystem supply value is the summation of provisioning, regulating, and cultural services provided by the freshwater wetland in Karnataka. The total ecosystem supply value of Karnataka freshwater wetland was 284.52 billion Rs/yr, with the highest value recorded in Tumakuru district at 47.14 billion Rs/yr (figure 22). Total ecosystem supply value differs with the various ecosystem services considered and the ecosystem conditions of each wetland. The annual economic value of Ghodaghodi wetland is estimated to be about USD 6,74,000 with the highest contribution from use value (96%) compared to non-use value (4%) of wetland (Aryal et al., 2021). Overall, wetlands dominated by vegetation (13,852 $/ha/yr) and open water (4,042 $/ha/yr) had a total ecosystem service value of 17,894 $/ha/yr (Patterson et al., 2018). The average total economic value for food, water provisioning, and wastewater treatment in the Boeng Cheung Aek wetland is 30.12 million USD/yr, ranging from 15.71–48.96 million USD/yr (Ro et al., 2020).

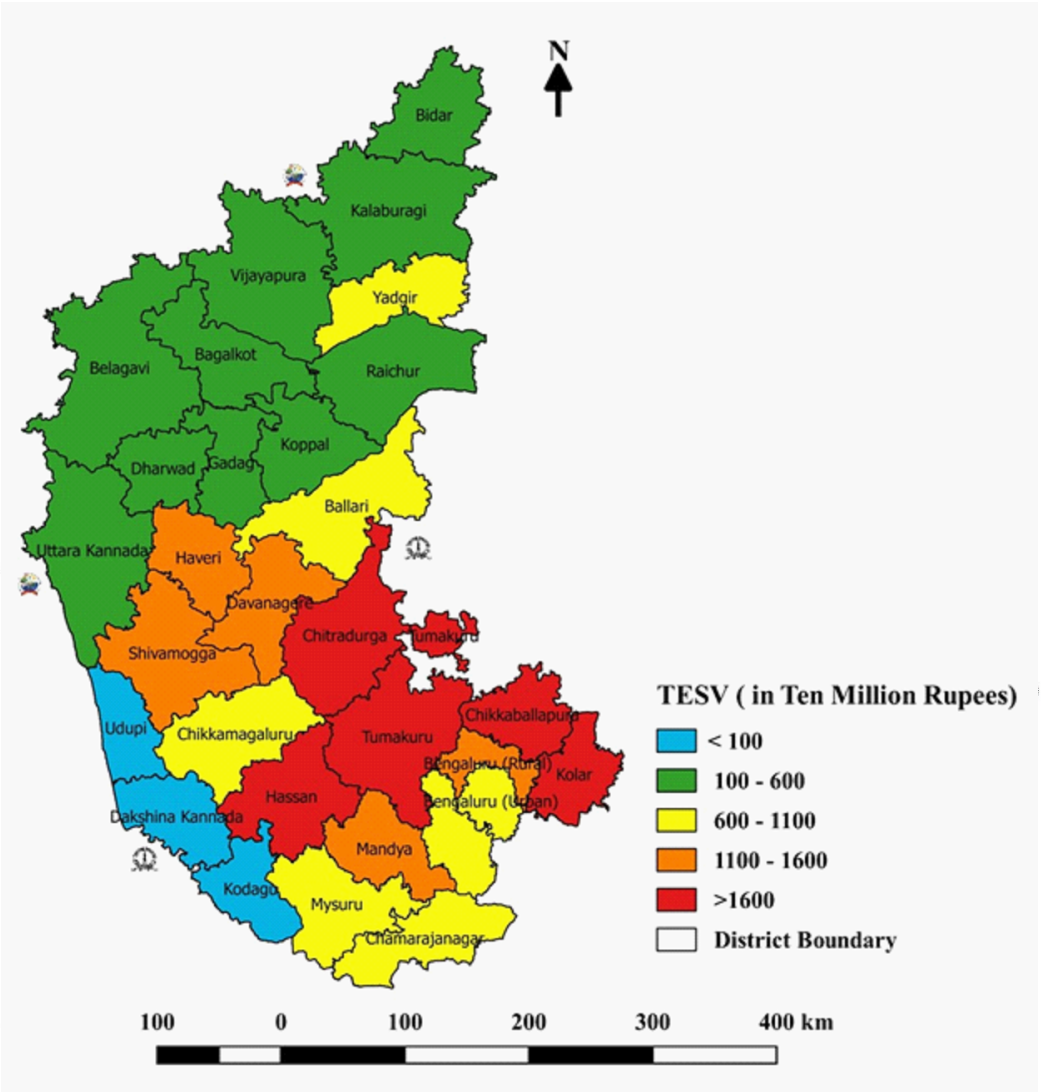


Figure 22. TESV of freshwater wetlands of Karnataka

NPV of freshwater wetlands in Karnataka is 7320.6 billion rupees. The highest NPV value was recorded in the Tumakuru district, with 1212.9 billion rupees. NPV ranged from 450 – 650 billion rupees in districts like Chitradurga, Chikkaballapura, Hassan, and Kolar, whereas it ranged from 250 – 450 billion rupees in Davanagere, Haveri, and Shivamogga (figure 23). In earlier studies, the net present value of revenue (benefits) earned from Sukhna lake in Chandigarh city during the last ten years was estimated at Rs. 451 million

(Chaudhry et al., 2013). The net present value of three mangrove ecosystems in Thailand ranges from 10158 to 12392 US$/ha (Barbier, 2011).

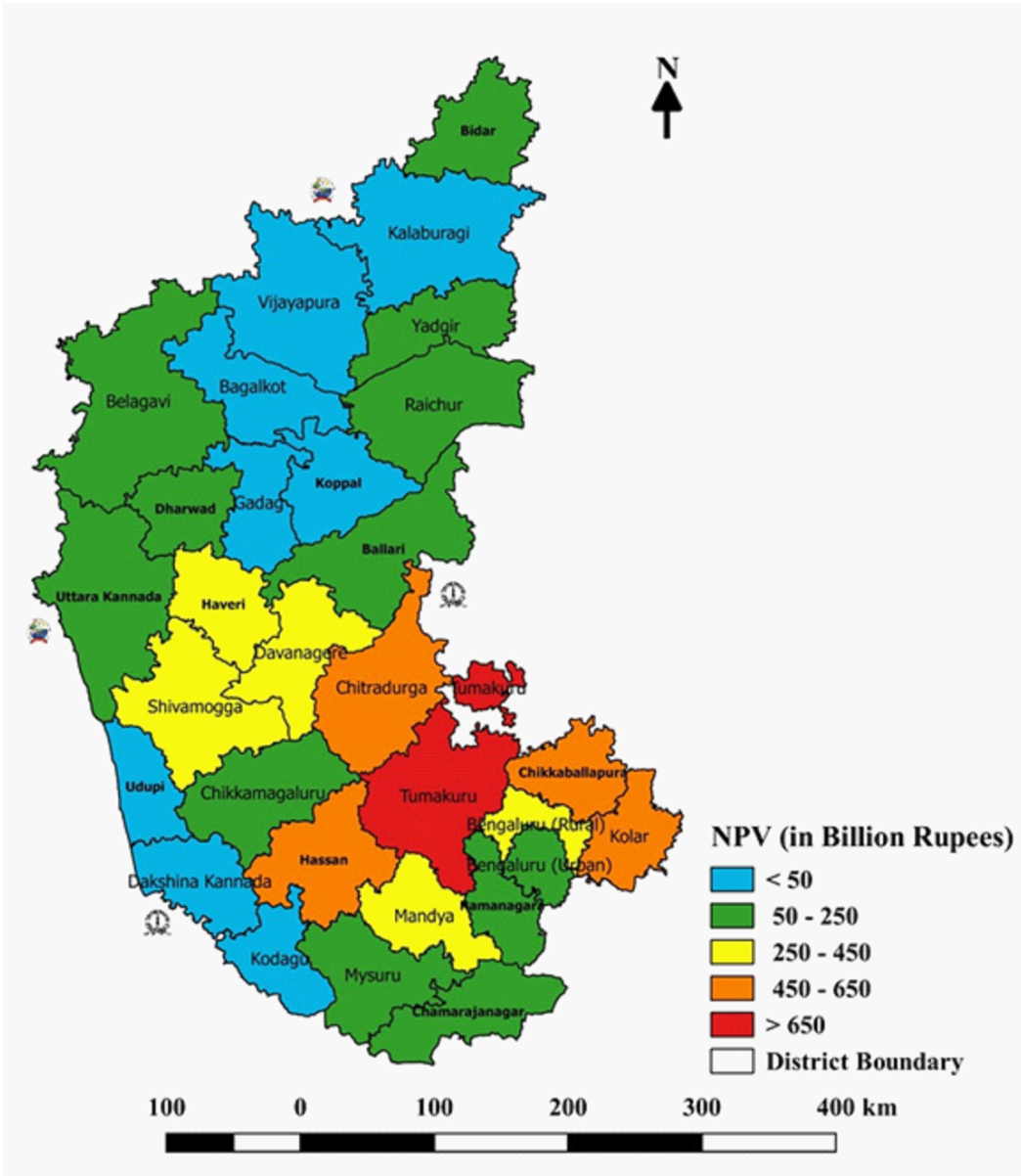


Figure 23. NPV of freshwater wetlands of Karnataka

Wetlands are fundamental to the economic, social, and cultural wellbeing of the population in India. The total benefit from wetland fisheries, fodder collection, and jute retting was 5.51 lakh Rs/yr, 2.23 lakh Rs/yr, and 1.24 lakh Rs/yr, respectively, from Kalobaur beel (Mukherjee, 2008). In the case of Koshi Tappu Wildlife Reserve, the total net benefit value from wetland fodder was estimated at USD 42,51,919 (Sharma et al., 2015). In Karnataka, wetlands cover an area of 281299.5 ha. Karnataka freshwater wetlands provided a provisioning service worth 1.8 lakh rupees per hectare per year, a regulating service worth 7 lakh rupees per hectare per year, and a cultural service worth 1.3 lakh rupees per hectare per year. TESV of Karnataka freshwater wetlands is 284.52 billion Rs/yr and the NPV amounted to 7320.6 billion rupees (table 18). Wetland restoration would improve wetland habitats, the wetland ecosystem's functioning and biodiversity, and would also improve water quality (Ramachandra et al., 2020b).

Table 18. Total ecosystem supply value of Karnataka freshwater wetlands

Services	Details	Value
	Wetland: Total area (ha) based on grid	281299.5
Provisioning Service	Total Rs/yr (in billion Rupees)	49.70
	Production Rs/ha/yr (in Lakhs)	1.8
	% distribution	18
Regulating Service	Total Rs/yr (in billion Rupees)	196.89
	Production Rs/ha/yr (in Lakhs)	7
	% distribution	69
Cultural Service	Total Rs/yr (in billion Rupees)	37.93
	Production Rs/ha/yr (in Lakhs)	1.3
	% distribution	13
TESV	Total Rs/yr (in billion Rupees)	284.52
	Production Rs/ha/yr (in Lakhs)	10.1
NPV	NPV in Billion Rupees	7320.6

4.0 Estuarine Ecosystem in Karnataka

4.1 Provisioning services

Provisioning services from estuarine ecosystem include fishery (fish, clam, oyster, and mussel), agricultural products (saline paddy and coconut), mining products (sand), mangrove resources, and salt production. The residual value method is used for valuing provisioning services.

Estuarine Fishery

The fishery sector provides the major livelihood opportunities of the estuarine dependent communities in the coastal villages. It includes the common estuarine fishes, clams, oysters, mussels, etc. The market price of fishery resources and the quantity obtained for each category of fish resources are given in table 19.

The annual income generated from utilization of estuarine fish resources (fishes, clams, oysters, and mussels) from Mulki-Pavanje estuary is 18,61,52,000 Rs/year. The annual income from estuarine fish resources is 42,18,32,000 Rs/year in the Netravathi estuary, 18,51,58,000 Rs/year in Udyavara estuary, 36,35,10,600 Rs/year in Sita estuary, 56,71,76,800 Rs/year in Haladi-Chakra-Kollur estuary, 33,48,97,140 Rs/year in Kali estuary, 5,00,01,740 Rs/year in Gangavali estuary, 2,43,31,56,920 Rs/year in Aghanashini estuary, 45,65,09,200 Rs/year in Sharavathi estuary, and 1,48,30,040 Rs/year in Venkatapura estuary (figure 24).

Table 19. Estuarine fisheries

Estuary	Area of Estuary (ha)	Resource	Total fish catch (ton)	Price/Ton	Cost/Ton	Residual value (Price - Cost)	Total benefit Rs/year	Total benefits Rs/ha/year
Mulki-Pavanje estuary	750	Clam	304	2,40,000	1,44,000	96,000	29184000	38912
		Oyster	36	1,40,000	84,000	56,000	2016000	2688
		Mussel	6	4,80,000	2,88,000	1,92,000	1152000	1536
		Fish	769	5,00,000	3,00,000.00	2,00,000.00	153800000	205066.6667
		Total					186152000	248202.6667
Netravathi estuary	1920	Clam	292	2,40,000	1,44,000	96,000	28032000	14600
		Oyster	0	1,40,000	84,000	56,000	0	0
		Mussel	0	4,80,000	2,88,000	1,92,000	0	0
		Fish	1969	5,00,000	3,00,000.00	2,00,000.00	393800000	205104.1667
		Total					421832000	219704.1667
Udyavara	800	Clam	195	2,45,000	1,47,000	98,000	19110000	23887.5

estuary		Oyster	24	1,45,000	87,000	58,000	1392000	1740
		Mussel	0	4,85,000	2,91,000	1,94,000	0	0
		Fish	820	5,02,000.00	3,01,200	2,00,800.00	164656000	205820
		Total					185158000	231447.5
Sita estuary	980	Clam	1565	2,45,000	1,47,000	98,000	153370000	156500
		Oyster	124	1,45,000	87,000	58,000	7192000	7338.77551
		Mussel	5.9	4,85,000	2,91,000	1,94,000	1144600	1167.959184
		Fish	1005	5,02,000.00	3,01,200	2,00,800.00	201804000	205922.449
		Total					363510600	370929.1837
Haladi-Chakra-Kollur estuary	2550	Clam	383	2,45,000	1,47,000	98,000	37534000	14719.21569
		Oyster	75	1,45,000	87,000	58,000	4350000	1705.882353
		Mussel	0	4,85,000	2,91,000	1,94,000	0	0
		Fish	2616	5,02,000.00	3,01,200	2,00,800.00	525292800	205997.1765
		Total					567176800	222422.2745
Kali estuary	3240	Clam	55	2,50,000	1,50,000	1,00,000	55,00,000	1,697
		Oyster	0.459	1,50,000	90,000	60,000	27,540	8.5
		Mussel	20	4,90,000	2,94,000	1,96,000	39,20,000	1,209
		Fish	1624	5,01,000.00	3,00,600.00	2,00,400.00	32,54,49,600	1,00,447
		Total					33,48,97,140	1,03,363
Gangavali estuary	700	Clam	11	2,50,000	1,50,000	1,00,000	11,00,000	1,571
		Oyster	0.069	1,50,000	90,000	60,000	4,140	5
		Mussel	0	4,90,000	2,94,000	1,96,000	0	0
		Fish	244	5,01,000.00	3,00,600.00	2,00,400.00	4,88,97,600	69,853
		Total					5,00,01,740	71,431
Aghanashini estuary	4801	Clam	76	2,50,000	1,50,000	1,00,000	76,00,000	1,583
		Oyster	0.642	1,50,000	90,000	60,000	38,520	8
		Mussel	28	4,90,000	2,94,000	1,96,000	54,88,000	1,143
		Fish	12076	5,01,000.00	3,00,600.00	2,00,400.00	2,42,00,30,400	5,04,067
		Total					2,43,31,56,920	5,06,802
Sharavathi estuary	1600	Clam	10	2,50,000	1,50,000	1,00,000	10,00,000	625
		Oyster	0	1,50,000	90,000	60,000	0	0
		Mussel	0	4,90,000	2,94,000	1,96,000	0	0
		Fish	2273	5,01,000.00	3,00,600.00	2,00,400.00	45,55,09,200	2,84,693
		Total					45,65,09,200	2,85,318
Venkatapura estuary	200	Clam	2	2,50,000	1,50,000	1,00,000	200000	1000
		Oyster	0.014	1,50,000	90,000	60,000	840	4
		Mussel	0	4,90,000	2,94,000	1,96,000	0	0
		Fish	73	5,01,000.00	3,00,600.00	2,00,400.00	1,46,29,200	73,146
		Total					1,48,30,040	74,150

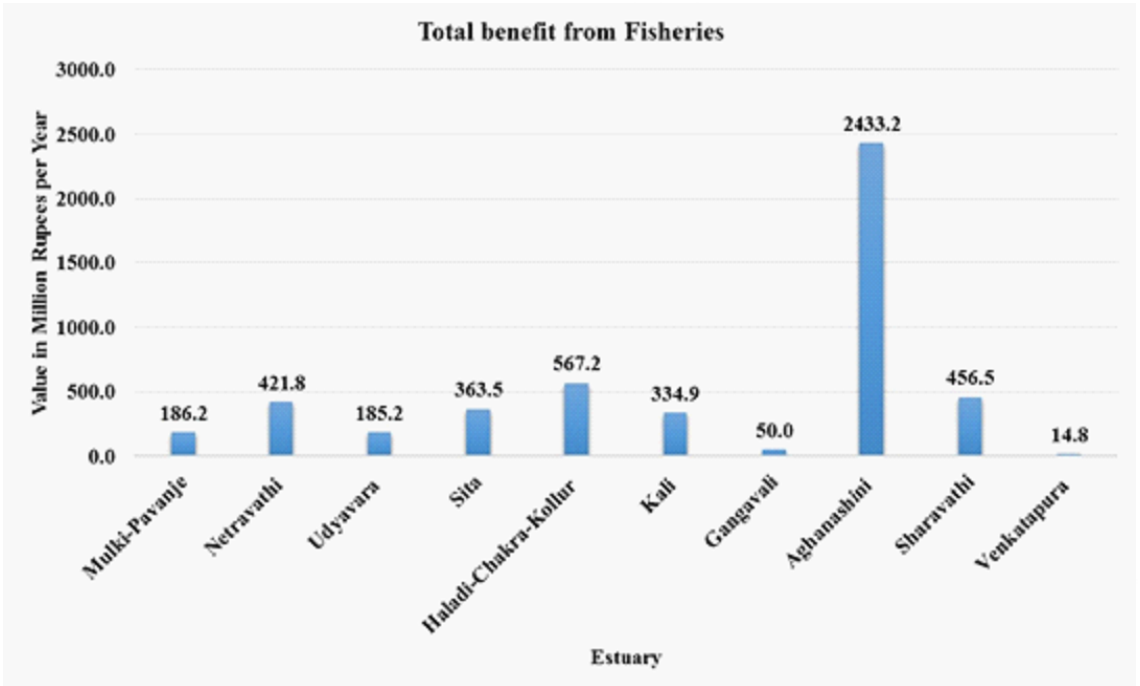


Figure 24. Total benefit from fisheries in estuaries of Karnataka

Agricultural Products

The estuarine belt of Dakshina Kannada, Udupi, and Uttara Kannada districts supports saline-tolerant paddy (gazani) and coconut cultivation. The market price and total quantity of production of coconut and paddy are given in table 20. The annual income provided from coconut plantations is 7,84,350 Rs/year in the Mulki-Pavanje estuary, 19,98,640 Rs/year in the Netravathi estuary, 8,35,200 Rs/year in Udyavara estuary, 10,23,120 Rs/year in Sita estuary, and 26,62,200 Rs/year in Haladi-Chakra-Kollur estuary. The annual income from coconut and paddy plantations is 1,50,07,500 Rs/year in Kali estuary, 51,68,430 Rs/year in Gangavali estuary, 1,83,09,420 Rs/year in Aghanashini estuary, 80,80,560 Rs/year in the Sharavathi estuarine belt, and 10,36,264 Rs/year in Venkatapura estuary. Variations in the ecosystem benefits from paddy and coconut plantations are depicted in figure 25.

Table 20. Paddy and coconut from estuaries in Karnataka west coast

Estuary	Area of estuary (ha)	Area of coconut plantation (ha)	Annual production (tons)	Price/Ton	Cost/Ton	Residual value (Price - Cost)	Total benefit Rs/yr
Mulki-pavanje	750	20.23	67.5	29,050	17,430	11,620	7,84,350
Netravathi	1920	16.9	172	29,050	17,430	11,620	19,98,640
Udyavara	800	15.7	72	29,000	17,400	11,600	8,35,200
Sita	980	26.12	88.2	29,000	17,400	11,600	10,23,120
Haladi-Chakra-Kollur	2550	49.5	229.5	29,000	17,400	11,600	26,62,200
Kali	Gazani	3240	2,036	18,000	10,800	7,200	1,46,59,200
	Coconut		30	29,025	17,415	11,610	348,300
	Total						1,50,07,500
Gangavali	Gazani	700	713	18,000	10,800	7,200	51,33,600
	Coconut		3	29,025	17,415	11,610	34,830
	Total						51,68,430
Aghanashini	Gazani	4801	2443	18,000	10,800	7,200	1,75,89,600
	Coconut		62	29,025	17,415	11,610	7,19,820
	Total						1,83,09,420
Sharavathi	Gazani	1600	0	18,000	10,800	7,200	0
	Coconut		696	29,025	17,415	11,610	80,80,560
	Total						80,80,560
Venkatapura	Gazani	200	143	18,000	10,800	7,200	10,29,600
	Coconut		0.574	29,025	17,415	11,610	6,664
	Total						10,36,264

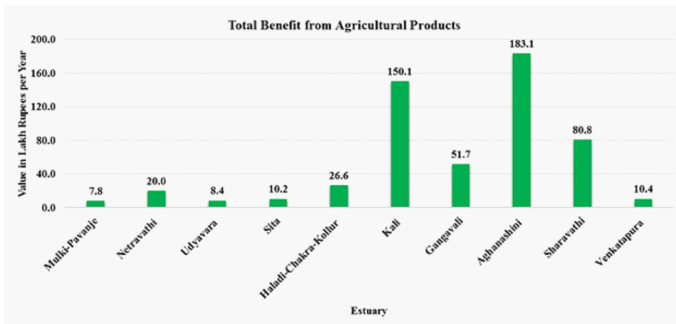


Figure 25. Total benefit from paddy and coconut products in estuaries of Karnataka

Mining Product

Mining and dredging activities are prevalent significant level in the estuaries of Dakshina Kannada, Udupi, and Uttara Kannada districts. The quantity and price of mining products from estuaries are given in table 21.

Mining provides an annual income of 540 Rs/year in Mulki-Pavanje estuary, 1,382 Rs/year in Netravathi estuary, 598 Rs/year in Udyavara estuary, 764 Rs/year in Sita estuary, 1,989 Rs/year in Chakra-Haladi-Kolluru estuary, 7,896 Rs/year in Kali estuary, 532 Rs/year in Gangavali estuary, 476 Rs/year in Aghanashini estuary, 672 Rs/year in Sharavathi estuary, and 106 Rs/year in Venkatapura estuary (figure 26).

Table 21. Income generated from mining activities

Estuary	Area (ha)	Component	Annual production (in tonnes)	Price/ton	Cost/ton	Residual value (Price - Cost)	Total benefit Rs/year
Mulki-pavanje	750	Sand	22.5	60	36	24	540
Netravathi	1920	Sand	57.6	60	36	24	1,382
Udyavara	800	Sand	23	65	39	26	598
Sita	980	Sand	29.4	65	39	26	764
Haladi-Chakra-Kollur	2550	Sand	76.5	65	39	26	1,989
Kali	3240	Sand	282	70	42	28	7,896
Gangavali	700	Sand	19	70	42	28	532
Aghanashini	4801	Sand	17	70	42	28	476
Sharavathi	1600	Sand	24	70	42	28	672
Venkatapura	200	Sand	3.8	70	42	28	106

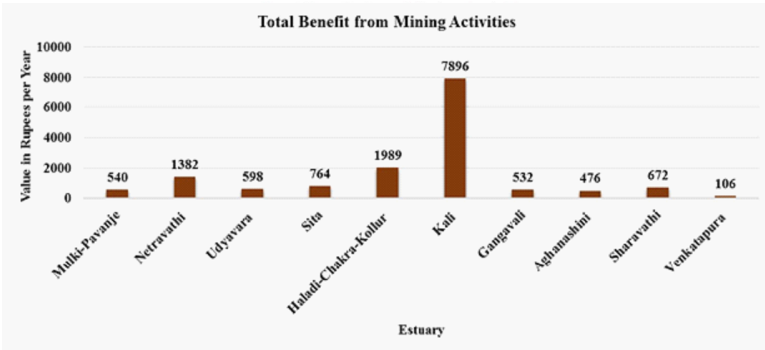


Figure 26. Total benefit from mining activities in estuaries of Karnataka

Mangrove products

The mangrove forest is being used by the local inhabitants for fodder, timber, firewood, and construction activities. The market price and quantity of mangrove resources are given in table 22. The annual income generated from mangrove product extraction is 8,30,290.5 Rs/year in Mulki-Pavanje estuary, 21,25,891.2 Rs/year in Netravathi estuary, 8,85,788 Rs/year in Udyavara estuary, 10,85,090.3 Rs/year in Sita estuary, 2823328.75 Rs/year in Haladi-Chakra-Kollur estuary, 2090780 Rs/year in Kali estuary, 2160 Rs/year in Gangavali estuary, 2,002,340 Rs/year in Aghanashini estuary, 21,02,180 Rs/year in Sharavathi estuary, and 4,14,780 Rs/year in Venkatapura estuary (figure 27).

Table 22. Estimation of annual income from Mangrove product harvesting

Estuary.	Area (ha)	Area of mangrove plantation (ha)	Mangrove product	Total Mangrove production (in tons)	Price/ton	Cost/ton	Residual value (Price - Cost)	Total benefit Rs/Year
Mulki-Pavanje estuary	750	16.03	Fodder	3337	602	361	241	804217
			Timber	26	152	91	61	1586
			Charcoal	7.5	152	91	61	457.5
			Thatch	30	2,002	1,201	801	24030
			Total					830290.5
Netravati estuary	1920	4.8	Fodder	8544	602	361	241	2059104
			Timber	67.2	152	91	61	4099.2
			Charcoal	19.2	152	91	61	1171.2
			Thatch	76.8	2,002	1,201	801	61516.8
			Total					2125891.2
Udyavara estuary	800	0.5	Fodder	3560	601	360	241	857960
			Timber	28	151	90	61	1708
			Charcoal	8	151	90	61	488
			Thatch	32	2,001	1,200	801	25632
			Total					885788
Sita estuary	980	6.5	Fodder	4361	601	360	241	1051001
			Timber	34.3	151	90	61	2092.3
			Charcoal	9.8	151	90	61	597.8
			Thatch	39.2	2,001	1,200	801	31399.2
			Total					1085090.3

Haladi-Chakra-Kollur estuary	2550	10.2	Fodder	11347	601	360	241	2734627
			Timber	89.25	151	90	61	5444.25
			Charcoal	25.5	151	90	61	1555.5
			Thatch	102	2,001	1,200	801	81702
			Total					2823328.75
Kali estuary	3240	100	Fodder	7,920	600	360	240	19,00,800
			Timber	148	150	90	60	8,880
			Charcoal	45	150	90	60	2,700
			Thatch	223	2,000	1,200	800	178,400
			Total					2090780
Gangavali estuary	700	43.2	Fodder	0	600	360	240	0
			Timber	36	150	90	60	2160
			Charcoal	0	150	90	60	0
			Thatch	0	2,000	1,200	800	0
			Total					2160
Aghanashini estuary	4801	101.6	Fodder	7200	600	360	240	1728000
			Timber	215	150	90	60	12900
			Charcoal	64	150	90	60	3840
			Thatch	322	2,000	1,200	800	2,57,600
			Total					2,002,340
Sharavathi estuary	1600	5	Fodder	8640	600	360	240	20,73,600
			Timber	23	150	90	60	1,380
			Charcoal	0	150	90	60	0
			Thatch	34	2,000	1,200	800	27,200
			Total					21,02,180
Venkatapura estuary	200	8.64	Fodder	1728	600	360	240	4,14,720
			Timber	1	150	90	60	60
			Charcoal	0	150	90	60	0

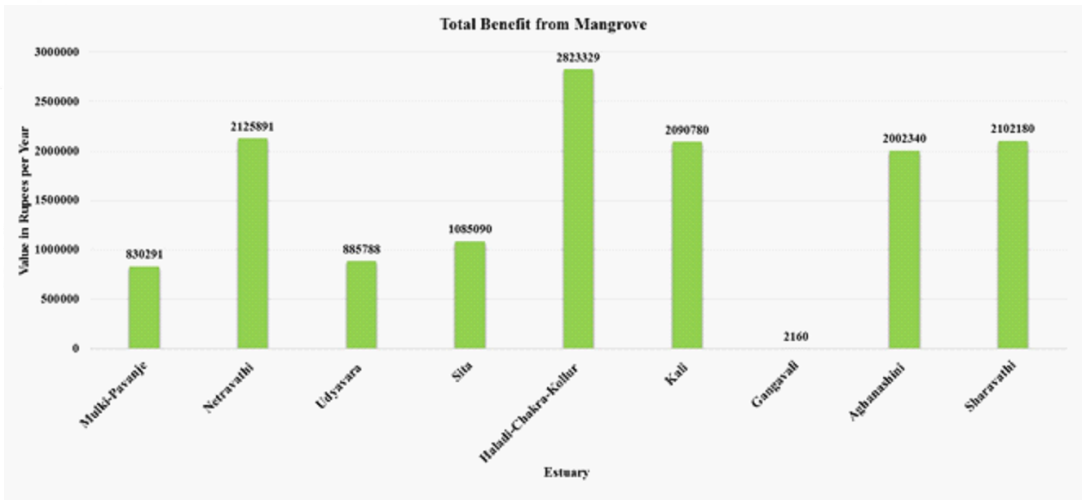


Figure 27. Total benefit from mangrove products in estuaries of Karnataka

Salt production

Market price and quantity of salt production is given in table 23. The annual income generated by salt production in the Aghanashini estuary is 31,20,000 Rs/year.

Table 23. Salt production in estuarine catchment

Estuary	Area (ha)	Item	Quantity extracted (ton)	Price (Rs/ton)	Cost (Rs/ton)	Residual value (Price - Cost)	Income generated Rs/year
Kali	3240	Salt	0	0	0	0	0
Gangavali	700	Salt	0	0	0	0	0
Aghanashini	4801	Salt	12,000	650	390	260	31,20,000
Sharavathi	1600	Salt	0	0	0	0	0
Venkatapura	200	Salt	0	0	0	0	0

Total Provisioning Service

Table 24 lists estuary-wise provisioning services and the total provisioning service amounts to 18,77,67,180 Rs/year in Mulki-Pavanje estuary, 42,59,57,913 Rs/year in Netravathi estuary, 18,68,79,586 Rs/year in Udyavara estuary, 36,56,19,574 Rs/year in Sita estuary, 57,26,64,317 Rs/year in Haladi-Chakra -Kollur estuary, 35,20,03,316 Rs/year in Kali estuary, 5,51,72,862

Rs/year in Gangavali estuary, 2,45,65,89,156 Rs/year in Aghanashini estuary, 46,66,92,612 Rs/year in Sharavathi estuary, and 1,62,81,190 Rs/year in Venkatapura estuary.

Table 24. Total provisioning services from estuaries of Dakshina Kannada, Udupi and Uttara Kannada districts.

Estuary	Mulki - Pavanje	Netravathi	Udyavara	Sita	Haladi Chakra Kollur estuary
Area (in ha)	750	1,920	800	980	2,550
Fishery Resources (Rs/year)	186152000	421832000	185158000	363510600	567176800
Agriculture activities (Rs/year)	7,84,350	19,98,640	8,35,200	10,23,120	2662200
Mining activity (Rs/year)	540	1382	598	764	1989
Mangrove products (Rs/year)	830290	2125891	885788	1085090	2823328
Total Provisioning service value (Rs/year)	18,77,67,180	42,59,57,913	18,68,79,586	36,56,19,574	57,26,64,317

Estuary	Kali estuary	Gangavali estuary	Aghanashini estuary	Sharavathi estuary	Venkatapura estuary
Area (ha)	3,240	700	4,801	1,600	200
Fishery Resources (Rs/year)	33,48,97,140	5,00,01,740	2,43,31,56,920	45,65,09,200	14,830,040
Agricultural activities (Rs/year)	1,50,07,500	51,68,430	1,83,09,420	80,80,560	1,036,264
Sand	7,896	532	476	672	106
Mangrove Products (Rs/year)	20,90,780	2,160	20,02,340	21,02,180	4,14,780
Salt (Rs/year)	0	0	31,20,000	0	0
Total Provisioning service value (Rs/year)	35,20,03,316	5,51,72,862	2,45,65,89,156	46,66,92,612	1,62,81,190

4.2 Regulating services

Regulating services provided by estuarine ecosystems include gas regulation, climate regulation, disturbance regulation, soil fertility, water regulation, air quality, erosion control, nutrient cycling, pollination, and carbon sequestration are given estuary wise in table 25. The regulating services provided by estuarine ecosystems are computed through benefit transfer method considering the spatial extent of an estuary.

The regulating services amount to 41,86,91,347 Rs/year in Mulki-Pavanje estuary, 1,06,55,86,339 Rs/year in Netravathi estuary, 44,35,22,429 Rs/year in Udyavara estuary, 54,44,08,037 Rs/year in Sita estuary, 1,41,53,25,562 Rs/year in Haladi-Chakra-Kollur estuary, 1,81,44,55,680 Rs/year in Kali estuary, 39,60,21,325 Rs/year in Gangavali estuary, 2,67,99,94,740 Rs/year in Aghanashini estuary, 88,77,87,490 Rs/year in Sharavathi estuary, and 11,24,61,485 Rs/year in Venkatapura estuary.

Table 25. Regulating services from estuaries of Dakshina Kannada, Udupi and Uttara Kannada districts.

Estuary		Mulki-Pavanje estuary Rs/yr	Netravathi estuary Rs/yr	Udyavara estuary Rs/yr	Sita estuary Rs/yr	Chakra-Haladi-Kollur Rs/yr
Total Area of mangroves (ha)		16.03	7.3	0.5	6.5	10.2
Total Area of estuary (ha)		750	1920	800	980	2550
Regulating services	Average value Rs/ha/year					
Gas regulation	9,600	72,00,000	1,84,32,000	76,80,000	94,08,000	2,44,80,000
Climate regulation	4,710	35,32,500	90,43,200	37,68,000	46,15,800	1,20,10,500
Disturbance regulation	32,556	5,21,872	2,37,658	16,278	2,11,614	3,32,071
Soil fertility	31,072	4,98,084	2,26,825	15,536	2,01,968	3,16,934
Water regulation	73,726	1,181,827	5,38,199	36,863	4,79,219	7,52,005
Air quality	20,968	3,36,117	1,53,066	10,484	1,36,292	2,13,873
Erosion control	65,061	4,87,95,750	12,49,17,120	5,20,48,800	6,37,59,780	16,59,05,550

Nutrient cycling	4,74,916	35,61,87,000	91,18,38,720	37,99,32,800	46,54,17,680	1,21,10,35,800
Pollination	19,203	3,07,824	1,40,181	9,601	1,24,819	1,95,870
Carbon sequestration	8,133	1,30,371	59,370	4,066	52,864	82,956
Total Regulating services value (Rs/year)		41,86,91,347	1,06,55,86,339	44,35,22,429	54,44,08,037	1,41,53,25,562
Estuary		Kali (Rs/year)	Gangavali (Rs/year)	Aghanashini (Rs/year)	Sharavathi (Rs/year)	Venkatapura (Rs/year)
Total Area of mangroves (ha)		100	43.2	101.6	5.0	8.64
Total Area of estuary (ha)		3240	700	4801	1600	200
Regulating services	Average value (Rs/ha/year)					
Gas regulation	9,600	3,11,04,000	67,20,000	4,60,89,600	1,53,60,000	19,20,000
Climate regulation	4,710	1,52,60,400	32,97,000	2,26,12,710	75,36,000	9,42,000
Disturbance regulation	32,556	32,55,600	14,06,419	33,07,689	1,62,780	2,81,283
Soil fertility	31,072	31,07,200	13,42,310	31,56,915	1,55,360	2,68,462
Water regulation	73,726	73,72,600	31,84,963	74,90,561	3,68,630	6,36,992
Air quality	20,968	20,96,800	9,05,817	21,30,348	1,04,840	1,81,163
Erosion control	65,061	21,07,97,640	4,55,42,700	31,23,57,861	10,40,97,600	1,30,12,200
Nutrient cycling	4,74,916	1,53,87,27,840	33,24,41,200	2,28,00,71,716	75,98,65,600	9,49,83,200
Pollination	19,203	19,20,300	8,29,569	19,51,024	96,015	1,65,913
Carbon sequestration	8,133	8,13,300	3,51,345	8,26,312	40,665	70,269
Total Regulating service value (Rs/year)		1,81,44,55,680	39,60,21,325	2,67,99,94,740	88,77,87,490	11,24,61,485

4.3 Cultural services

The cultural services provided by estuaries include science and education, recreation, and aesthetic information, which are accounted through benefit transfer method considering spatial extent and estuary-wise culture services are listed in table 26.

The cultural services amount to 4,82,67,750 Rs/year in Mulki-Pavanje estuary, 12,35,65,440 Rs/year in Netravathi estuary, 5,14,85,600 Rs/year in Udyavara estuary, 6,30,69,860 Rs/year in Sita estuary, 16,41,10,350 Rs/year in Haladi-Chakra-Kollur estuary, 20,85,16,680 Rs/year in Kali estuary, 4,50,49,900 Rs/year in Gangavali estuary, 30,89,77,957 Rs/year in Aghanashini estuary, 10,29,71,200 Rs/year in Sharavathi estuary, and 1,28,71,400 Rs/year in Venkatapura estuary.

Table 26. Cultural services from estuaries of Dakshina Kannada, Udupi and Uttara Kannada districts.

Estuary		Mulki-Pavanje estuary Rs/year	Netravathi estuary Rs/year	Udyavara estuary Rs/year	Sita estuary Rs/year	Chakra-Haladi-Kollur Rs/year
Total Area of estuary (ha)		750	1920	800	980	2550
Cultural services	Average value Rs/ha/year					
Science and education	34,660	2,59,95,000	6,65,47,200	2,77,28,000	3,39,66,800	8,83,83,000
Recreation	21,603	1,62,02,250	4,14,77,760	1,72,82,400	2,11,70,940	5,50,87,650
Aesthetic Information	8,094	60,70,500	1,55,40,480	64,75,200	79,32,120	2,06,39,700
Total Cultural service value (Rs/year)		4,82,67,750	12,35,65,440	5,14,85,600	6,30,69,860	16,41,10,350
Estuary		Kali (Rs/year)	Gangavali (Rs/year)	Aghanashini (Rs/year)	Sharavathi (Rs/year)	Venkatapura (Rs/year)
Total Area of estuary (ha)		3240	700	4801	1600	200
Cultural services	Average value (Rs/ha/year)					
Science and education	34,660	11,22,98,400	2,42,62,000	16,64,02,660	5,54,56,000	69,32,000
Recreation	21,603	6,99,93,720	1,51,22,100	10,37,16,003	3,45,64,800	43,20,600
Aesthetic	8,094	2,62,24,560	56,65,800	3,88,59,294	1,29,50,400	16,18,800
Total Cultural service value (Rs/year)		20,85,16,680	4,50,49,900	30,89,77,957	10,29,71,200	1,28,71,400

Ecosystem services provided by estuaries in Karnataka are depicted in figure 28, which highlights that Aghanashini estuary provides highest value compared to other estuaries in Karnataka. Share of provisioning, regulating and cultural services of estuaries in Karnataka is depicted in figure 29, which shows that 32% by provisioning services, 61% by regulating services and 7% by cultural services. The highest contribution is from regulating services. Provisioning services 27%, regulating services 65%, and cultural services 8% in the Dakshina Kannada district. Uttara Kannada district provides provisioning services 34%, regulating services 59%, and cultural services 7% whereas Udupi district provides provisioning services 30%, regulating services 63%, and cultural services 7%.

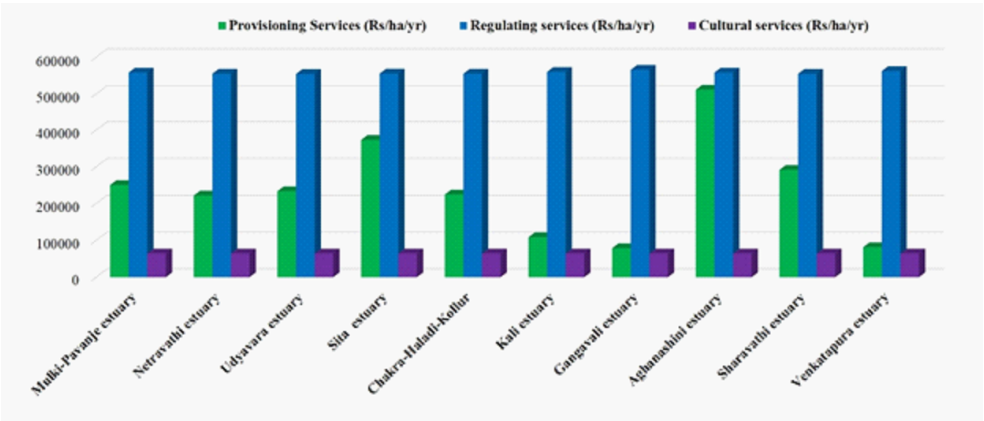


Figure 28. Ecosystem services provided by estuaries of Karnataka

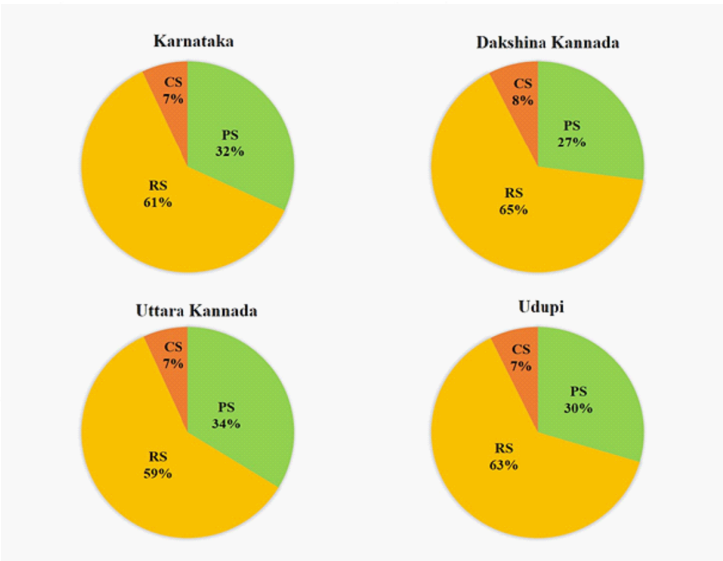


Figure 29. District wise ecosystem services from estuaries of Karnataka

4.4 Ecosystem Services of estuaries in the West Coast, Karnataka, India (districtwise analyses)

Dakshina Kannada

The total provisioning services provided by estuaries in Dakshina Kannada district ranged from 18,77,67,180 Rs/year (Mulki-Pavanje estuary) to 42,59,57,913 Rs/year (Netravathi estuary). The annual value per hectare of Mulki-Pavanje estuary is 2,50,356 Rs/ha/year and Netravathi estuary is 2,21,853 Rs/ha/year.

Regulating services value provided by estuaries of Dakshina Kannada ranged from 41,86,91,347 Rs/year (Mulki-Pavanje estuary) to 1,06,55,86,339 Rs/year (Netravathi estuary).

Cultural services value ranged from 4,82,67,750 Rs/year (Mulki-Pavanje estuary) to 12,35,65,440 Rs/year (Netravathi estuary).

Udupi district

The total provisioning services provided by estuaries in Udupi district ranged from 18,68,79,586 Rs/year (Udyavara estuary) to 57,26,64,317 Rs/year (Chakra-Haladi-Kollur estuary). The Sita estuary gives a value of 36,56,19,574 Rs/year. The annual value per hectare of Udyavara estuary is 2,33,599 Rs/ha/year, Sita estuary is 3,73,081 Rs/ha/year and Chakra -Haladi - Kollur estuary is 2,24,574 Rs/ha/year.

Regulating services provided by Udyavara estuary ranged from 44,35,22,429 Rs/year (Udyavara estuary) to 1,41,53,25,562 Rs/year (Chakra -Haladi-Kollur estuary) and Sita estuary gives the regulating services of 54,44,08,037 Rs/year.

Cultural services range from 5,14,85,600 Rs/year (Udyavara estuary) to 16,41,10,350 Rs/year (Chakra-Haladi-Kollur estuary) and Sita estuary provides cultural services of 6,30,69,860 Rs/year.

Uttara Kannada district

The total provisioning services provided by estuaries in Uttara Kannada district ranged from 1,62,81,190 Rs/year (Venkatapura estuary) to 2,45,65,89,156 Rs/year (Aghanashini estuary). The total provisioning services

provided by the Kali estuary is 35,20,03,316 Rs/year, Gangavali estuary is 5,51,72,862 Rs/year, and Sharavathi estuary is 46,66,92,612 Rs/year. The annual value per hectare of Kali estuary is 1,08,642 Rs/ha/year, Gangavali estuary is 78,818 Rs/ha/year, Aghanashini estuary is 5,11,682 Rs/ha/year, Sharavathi estuary is 2,91,682 Rs/ha/year, and Venkatapura estuary is 81,405 Rs/ha/year.

Regulating services provided by the estuaries of Uttara Kannada district range from 11,24,61,485 Rs/year (Venkatapura estuary) to 2,67,99,94,740 Rs/year (Aghanashini estuary). The regulating services provided by Kali estuary is 1,81,44,55,680 Rs/year, Gangavali estuary is 39,60,21,325 Rs/year, and Sharavathi estuary is 88,77,87,490 Rs/year.

Cultural services provided by estuaries of Uttara Kannada district ranges from 1,28,71,400 Rs/year (Venkatapura estuary) to 30,89,77,957 Rs/year (Aghanashini estuary). The cultural services provided by Kali estuary is 20,85,16,680 Rs/year, Gangavali estuary is 4,50,49,900 Rs/year, and Sharavathi estuary is 10,29,71,200 Rs/year.

4.5 Total Ecosystem Supply Value (TESV)

Total ecosystem supply value is the aggregation of provisioning, regulating, and cultural services. The total ecosystem supply value (TESV) calculated for 10 estuaries in Dakshina Kannada, Udupi, and Uttara Kannada districts is given in table 27.

The total ecosystem supply value is 65,47,26,277 Rs/year in Mulki-Pavanje estuary, 1,61,51,09,692 Rs/year in Netravathi estuary, 68,18,87,615 Rs/year in Udyavara estuary, 97,30,97,471 Rs/year in Sita estuary, 2,15,21,00,229 Rs/year in Haladi-Chakra-Kollur estuary, 2,37,49,75,676 Rs/year in Kali estuary, 49,62,44,087 Rs/year in Gangavali estuary, 5,44,55,61,853 Rs/year in Aghanashini estuary, 1,45,74,51,302 Rs/year in Sharavathi estuary, and 14,16,14,075 Rs/year in Venkatapura estuary (figure 30).

Table 27. Total Ecosystem Supply Value of estuaries of Dakshina Kannada, Udupi and Uttara Kannada

Estuary	Mulki-Pavanje estuary	Netravathi estuary	Udyavara estuary	Sita estuary	Chakra-Haladi-Kollur
Area (in ha)	750	1,920	800	980	2,550
Provisioning services (Rs/yr)	18,77,67,180	42,59,57,913	18,68,79,586	36,56,19,574	57,26,64,317
Regulating services (Rs/yr)	41,86,91,347	1,06,55,86,339	44,35,22,429	54,44,08,037	1,41,53,25,562
Cultural services (Rs/yr)	4,82,67,750	12,35,65,440	5,14,85,600	6,30,69,860	16,41,10,350
Total ecosystem supply value (Rs/yr)	65,47,26,277	1,61,51,09,692	68,18,87,615	97,30,97,471	2,15,21,00,229
Total ecosystem supply value (Rs/ha/yr)	8,72,968	8,41,202	8,52,359	9,92,956	8,43,960
Estuary	Kali estuary	Gangavali estuary	Aghanashini estuary	Sharavathi estuary	Venkatapura estuary
Area (ha)	3240	700	4801	1600	200
Provisioning services (Rs/yr)	352003316	55172862	2456589156	466692612	16281190
Regulating services (Rs/yr)	1,81,44,55,680	39,60,21,325	2,67,99,94,740	88,77,87,490	11,24,61,485
Cultural services (Rs/yr)	208516680	4,50,49,900	30,89,77,957	10,29,71,200	1,28,71,400
Total ecosystem supply value (Rs/yr)	2,37,49,75,676	49,62,44,087	5,44,55,61,853	1,45,74,51,302	14,16,14,075
Total ecosystem supply value (Rs/ha/yr)	7,33,017	7,08,920	11,34,255	9,10,907	7,08,070

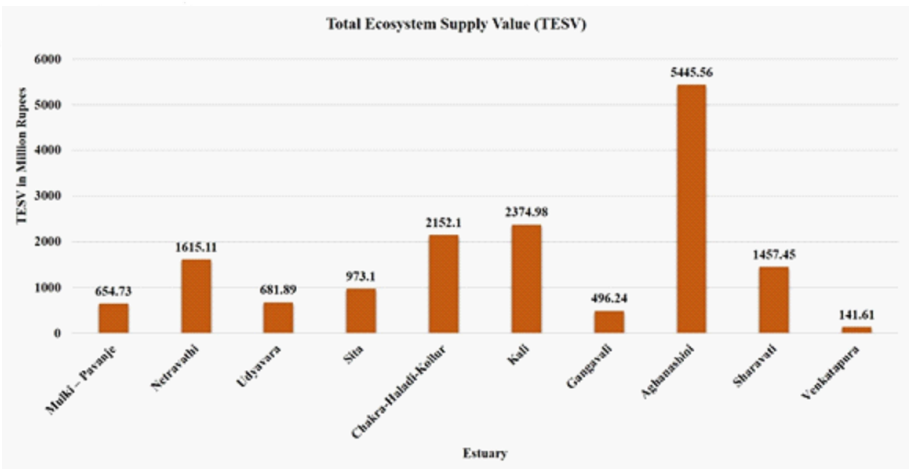


Figure 30. TESV from estuaries of Karnataka

Estuary-wise TESV is depicted in figure 31, which reveals that Aghanashini estuary (13%) of Karnataka has the highest contribution, followed by Sita (12%), Sharavathi (11%), etc.

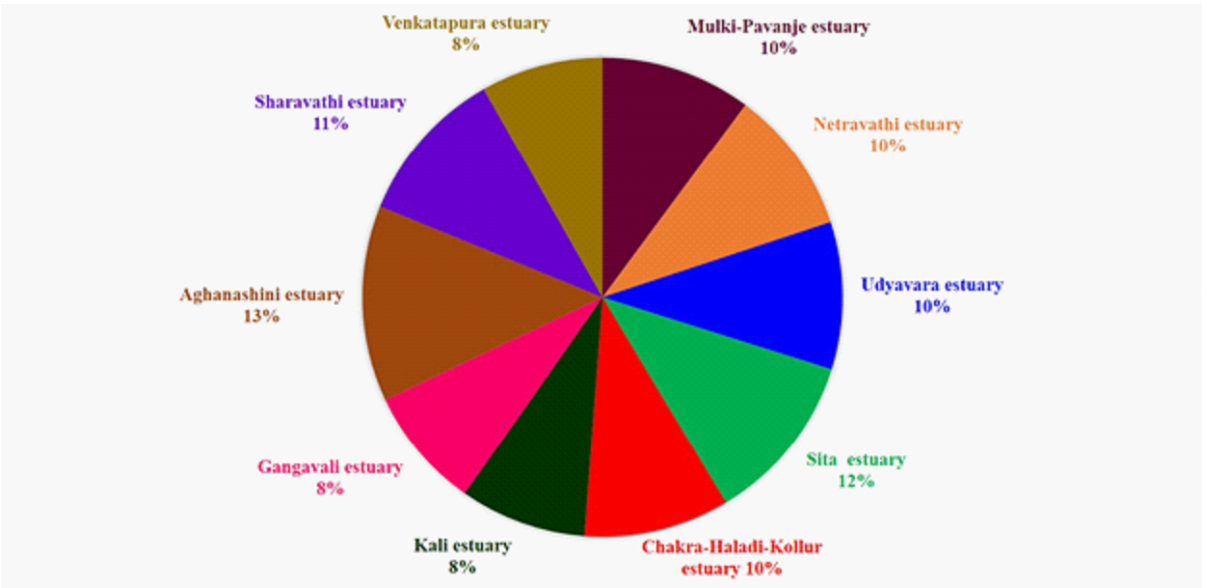


Figure 31. Contribution of estuaries of Karnataka towards TESV

4.6 Net Present Value (NPV)

NPV of estuaries asset is computed by considering annual flows of ecosystem services (TESV), 3% social rate of discount for capital returns, and time period of 50 years. Table 28 lists district wise NPV of estuaries. The analysis reveals that NPV of Mulki-Pavanje estuary is 16.84 billion Rs, Netravathi estuary is 41.55 billion Rs, Udyavara estuary is 17.54 billion Rs, Sita estuary is 25.03 billion Rs, Chakra-Haladi-Kollur estuary is 55.36 billion Rs, Kali estuary is 61.10 billion Rs, Gangavali estuary is 12.76 billion Rs, Aghanashini estuary is 1,40 billion Rs, Sharavathi estuary is 37.49 billion Rs/year, and Venkatapura estuary is 3.64 billion Rs. Figure 32 depicts NPV of estuaries in the west coast of Karnataka.

Table 28. Net Present Value (NPV) of Estuaries of Dakshina Kannada, Udupi and Uttara Kannada districts.

District	Estuary	Net Present Value	Total (Estuary wise)
Dakshina Kannada	Mulki – Pavanje	16,84,40,77,455	
	Netravathi	41,55,17,65,535	
	Total		58,39,58,42,990
Udupi	Udyavara	17,54,28,54,482	
	Sita	25,03,47,81,326	
	Haladi – Chakra – Kollur	55,36,68,67,381	
	Total		97,94,45,03,189
Uttara Kannada	Kali	61,10,07,61,718	
	Gangavali	12,76,68,22,001	
	Aghanashini	1,40,09,74,25,235	
	Sharavathi	37,49,57,03,901	
	Venkatapura	3,64,32,91,146	
	Total		2,55,10,40,04,001
Karnataka State	Total Net Present Value of all selected estuaries	4,11,44,43,50,180	

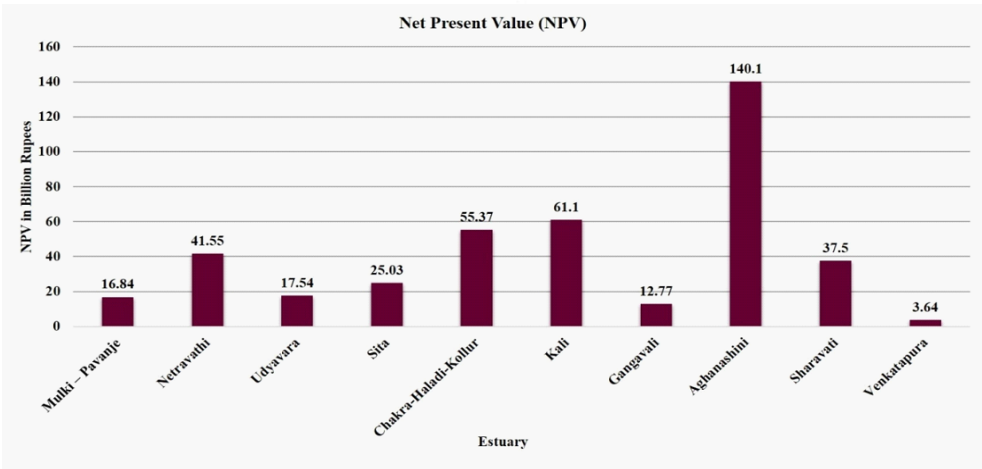


Figure 32. NPV of estuaries in Karnataka State, India

5.0 Framework for accounting aquatic (inland, estuaries) ecosystems

Ecosystem	Provisioning Services (Rs/ha/yr)	Regulating Services (Rs/ha/yr)	Cultural Services (Rs/ha/yr)	TESV (Rs/ha/yr)
Freshwater	**1,76,681**	**6,99,941**	**1,34,822**	**10,11,444**
Estuarine	**2,89,928**	**5,57,451**	**64,357**	**9,11,736**
Aquatic	**1,83,328**	**6,91,577**	**1,30,686**	**10,05,591**

5.0 Accounting of Aquatic Ecosystem in Karnataka, India

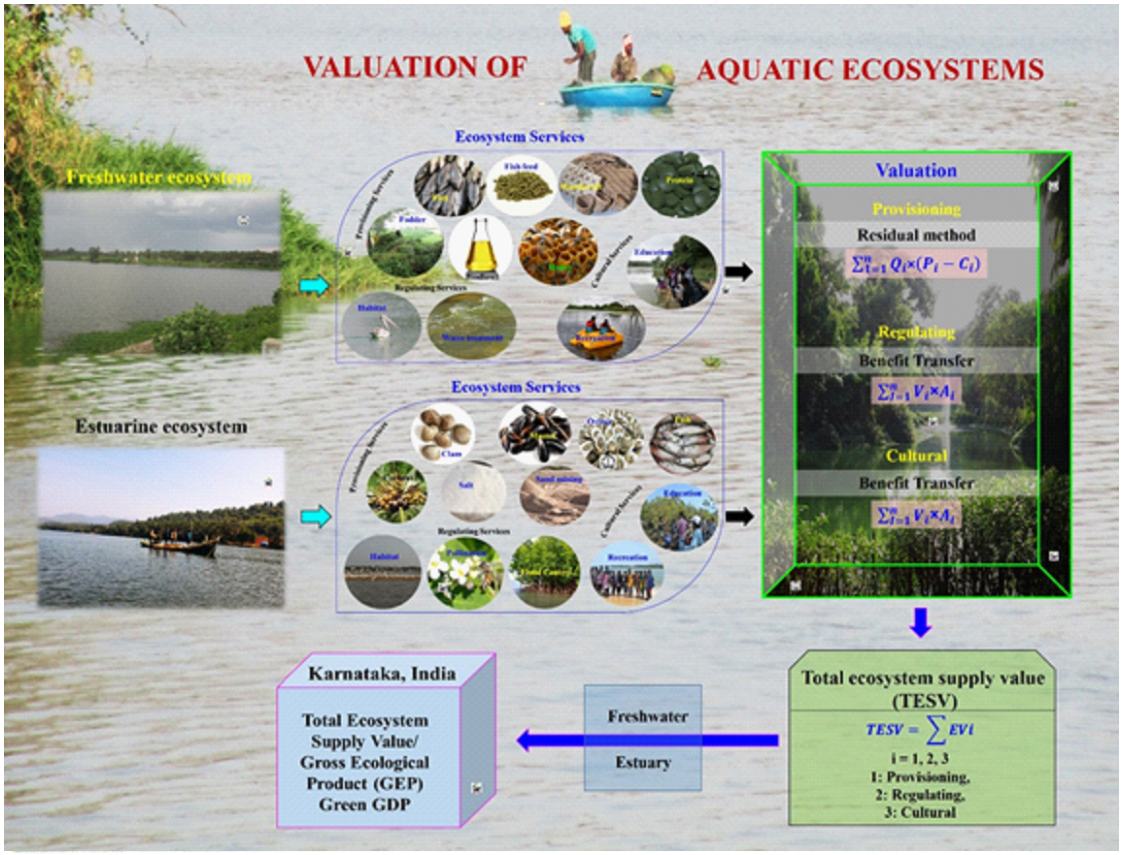


Figure 33. Framework for valuation ecosystem services of aquatic ecosystems in Karnataka

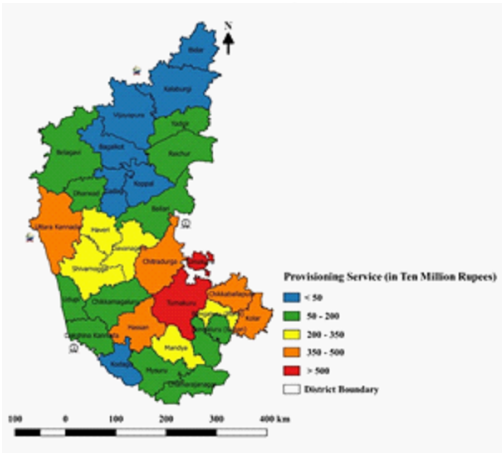


Figure 34. Provisioning service of aquatic ecosystems in Karnataka

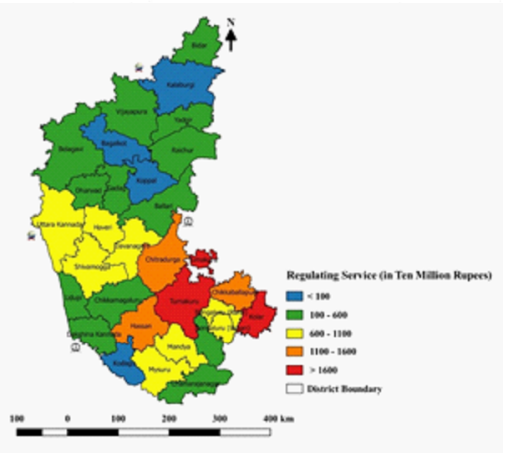


Figure 35. Regulating service of aquatic ecosystems in Karnataka

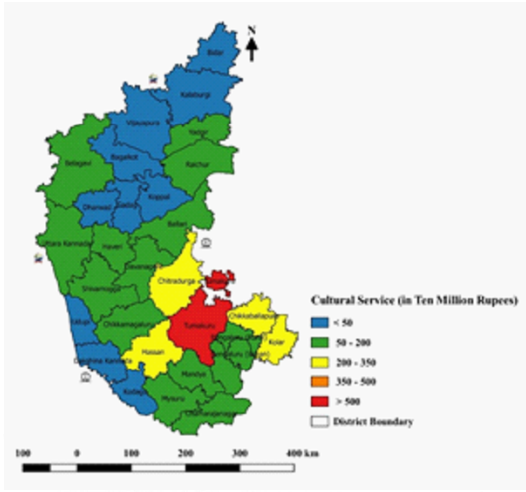


Figure 36: Cultural service of aquatic ecosystems in Karnataka

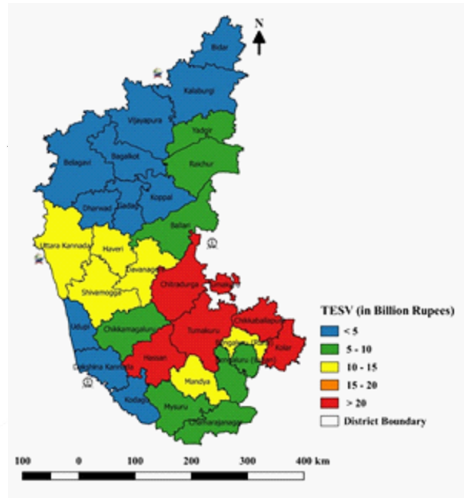


Figure 37: TESV of aquatic ecosystems in Karnataka

Provisioning service ranges from 129 – 8214 million rupees per year (figure 34). In Karnataka, aquatic ecosystem provides a total provisioning service value of 55 billion rupees per year.

Regulating service ranges from 515 – 32641 million rupees per year (figure 35). In Karnataka, aquatic ecosystem provides a total regulating service value of 207 billion rupees per year.

Cultural service ranges from 99 – 6287 million rupees per year (figure 36). In Karnataka, aquatic ecosystem provides a total regulating service value of 39 billion rupees per year.

Natural capital accounting and valuation of ecosystem services reveal that aquatic ecosystem in Karnataka provides TESV of 301 billion rupees per year. Kodagu has lowest TESV, whereas Tumakuru has the highest TESV. Total ecosystem supply value ranges from 0.7– 47.1 billion rupees per year (figure 37).

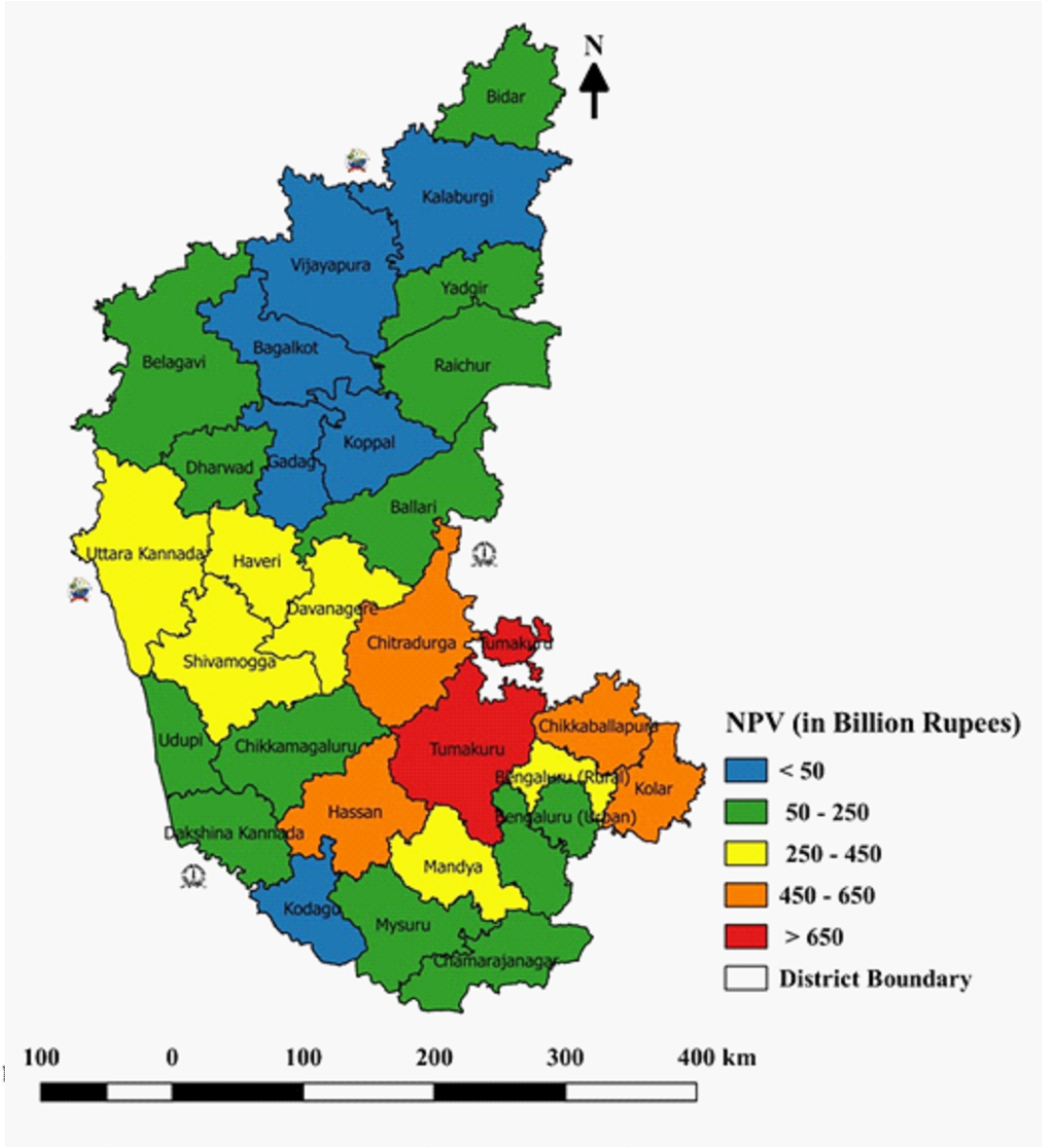


Figure 38. NPV of aquatic ecosystems in Karnataka

Net present value of aquatic ecosystem ranges from 19.1–1212.9 billion rupees (figure 38). In Karnataka, NPV of aquatic ecosystem assets amounts to 7732 billion rupees.

6.0 Conclusion

Natural capital accounting and valuation of ecosystem services reveal significant direct and indirect contributions to the district and state economies and human welfare. The evaluation of ecosystem services would aid in formulating policy and legislation that can provide protection and sustainable management of aquatic ecosystems to fully capitalize on the most significant ecosystem services. Among the districts of Karnataka, the Udupi district had the lowest values of ecosystem services, whereas the Tumakuru district had the highest ecosystem service potential. The value of provisioning, regulating, and cultural services ranged from 40 – 8214 million Rs/yr, 157 – 32641 million Rs/yr, and 30 – 6287 million Rs/yr, respectively. The total ecosystem supply value of Karnataka wetlands was 285 billion Rs/yr, while the NPV value of Karnataka wetlands was 7321 billion rupees. The valuation of wetland services underlines the fact that wetlands are highly productive and economically viable ecosystems, provides crucial information on wetland resources and services, which will help policy makers and stakeholders with wetland conservation / management, and stresses the need for sustainable and wise use of wetland resources.

NPV of estuaries of Dakshina Kannada district is 58.39 billion Rs. Similarly, NPV of three estuaries in Udupi district is 97.94 billion Rs and five estuaries in Uttara Kannada district is 255 billion Rs.

The total value of provisioning, regulating, and cultural services considering both freshwater and estuarine ecosystems are 1,83,328 Rs/ha/yr, 6,91,577 Rs/ha/yr, and 1,30,686 Rs/ha/yr, respectively. The total ecosystem supply value of Karnataka aquatic ecosystem was 10,05,591 Rs/ha/yr. Aquatic ecosystems and their resources need to be conserved to sustain ecosystem services which benefits millions of local people. This entails (i) regular monitoring of water quality by involving a network of local education institutions (schools, colleges), (ii) documenting diversity of aquatic species, (iii) regular desilting or dredging of wetlands to enhance water storage capacity (and also the silt provides valuable nutrients to agricultural lands in the command area of wetlands, (iv) discouraging the disposal of solid waste in the catchment, drains and in wetlands, (v) treatment of liquid waste through constructed wetlands (for optimal nutrient removal) before allowing to aquatic ecosystems, (vi) maintaining riparian vegetation of native species, (vii) protecting flood plains

(buffer regions) integrity by maintaining vegetation cover, (viii) regulating the introduction of exotic species, (ix) public awareness through seminars, workshops, and media, (x) encouraging research on wetlands, educational institutions can adopt a lake and monitor it regularly, (xi) involving local stakeholders in the maintenance and sustainable management of wetlands and (xii) constituting an advisory committee of experts from diverse subjects (ecologists, hydrologists, social scientists) domain including environmental scientists and policy makers for wetland protection.

Considering the ecological significance (breeding area, habitat) there shall be no activity that would alter the physical and chemical integrity of estuaries in a region upto 500 m from HTL. Regions that get affected by tides up to 500 metres from the high tide line (HTL) and the land area between the low tide line (LTL) and the high tide line are declared as coastal regulation zone (CRZ). Ecologically sensitive and vulnerable areas need to be mapped for conservation with the no development zone in each estuary.

The Environment Ministry came up with the Coastal Regulation Zone rules (CRZ rules) in February 1991, under the Environment Protection Act in 1986. The rules were notified in 2011. In 2018, the government issued the Coastal Regulation Zone Notification 2018 to remove restrictions on building, streamlining the clearance process and increasing tourism in the coastal areas.

As per the CRZ rules, the coastal areas of creeks, seas, bays, rivers and backwaters that get affected by tides up to 500 metres from the high tide line (HTL) and the land area between the low tide line (LTL) and the high tide line are declared as coastal regulation zone (CRZ). The CRZ rules and regulations have been formulated with the objective of protecting coastal ecosystems, by regulating human and industrial activities near the coastline. CRZ norms (https://mczma.gov.in/sites/default/files/CRZ%20Notification%202019.pdf) prohibits major developmental activities such as new industries, disposal of hazardous materials, large scale fish processing units, land reclamation, discharge of untreated waste, ports, mining of sand, altering sand dunes, disposal of plastic waste. Wetlands are to be conserved and managed in

accordance with the principle of 'wise use' as per Wetlands Authority (Wetlands (Conservation and Management) Rules 2017, Government of India) with stringent restrictions on the (i) conversion for non-wetland uses including encroachment of any kind; (ii) discharge of untreated wastes and effluents from industries, cities, towns, villages and other human settlements; (iii) construction of a permanent nature except for boat jetties within fifty meters from mean high flood level.

Acknowledgement

We thank the ENVIS Division, The Ministry of Environment, Forests and Climate Change, Government of India and Indian Institute of Science (IISc) for the sustained support to ecological research.

The valuation of ecosystem services of ecosystems is implemented for Karnataka State, India as per the validated protocol - System of Environmental Economic Accounting (SEEA EA; SEEA.un.org), which constitutes the statistical framework for natural capital accounting. We are grateful to the European Union (EU), United Nations Statistics Division (UNSD) and United Nations Environment Programme (UNEP) for supporting the study in Karnataka State, India. Thanks to (i) Dr Prabhuraj, Director, Karnataka State Remote Sensing Centre (KSRSAC), Government of Karnataka (GoK), Bangalore, for providing spatial data of the district administrative boundaries, stream and river network, population data; (ii) Dr Hemanth Kumar, Executive Secretary, Karnataka State Council for Science and Technology (KSCST), GoK for providing spatial data related to geology, lithology, etc. (iii) Director, National Remote Sensing Centre, Department of Space, GoI, Hyderabad and (iii) Director, Department of Agriculture, GoK for providing soil health data – district wise for Karnataka.

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Appendix

Table A1: Provisioning services - Fuelwood

Water body	Area (ha)	Value (USD/yr)	Value per Unit Area (USD/ha/y)	Adjustment for GDP (PPP) per capita	Value in INR	Reference
HadejiaNguru wetland, Nigeria	350000	1601700	4.58	0.49	36	Schuijt, 2002
Lake Chiuta, Malawi	31000	28561.71	0.92	0.10	7	Zuze, 2013
Muthurajawela wetland, Sri Lanka	6000	82530	13.76	1.47	109	
Muthurajawela wetland, Sri Lanka	3068	82530	26.9	2.88	214	Schuyt & Brander, 2008
Rachenahalli lake, Bengaluru, Karnataka, India	42.09	113218	2690	287.83	21363	Ramachandra et al., 2005
Hebbal lake, Bengaluru, Karnataka, India	60.7	139014	2290	245.03	18186	
Varthur lake, Bengaluru, Karnataka, India	220	25284	115	12.31	913	Ramachandra et al., 2011
Average Value					5833	

Table A2: Regulating services - Flood control

Water body	Area (ha)	Value (USD/yr)	Value per Unit Area (USD/ha/y)	Adjustment for GDP (PPP) per capita	Value in INR	Reference
Wular lake, Jammu & Kashmir, India	13000	17500000	1346	144.02	10689	Kaul et al., 2016
That Luang wetland, Laos	2000	2842000	1421	152.05	11285	Zuze, 2013
Muthurajawela wetland, Sri Lanka	6000	5033800	839	89.77	6663	
Mfolozi flood plain, South Africa	20886	504605.76	24	2.57	191	
Muthurajawela wetland, Sri Lanka	3068	5033800	1641	175.59	13032	Schuyt & Brander, 2008
Whangamarino wetland, New Zealand	10320	601037	58	6.21	461	
Average Value					7053	

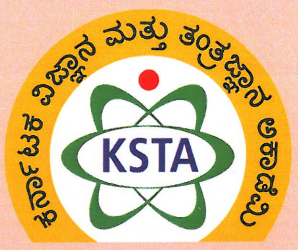
Table A3: Cultural services - Opportunities for recreation and tourism

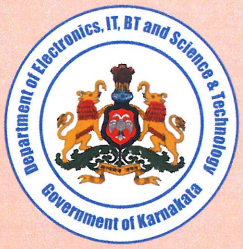
Water body	Area (ha)	Value ($/yr)	Value per Unit Area ($/ha/y)	Adjustment for GDP (PPP) per capita	Value in INR	Reference
Jagadishpur Ramsar site, Nepal	19600	90769.5	5	0.54	40	Baral et al., 2016
Lakeside wetland Park, Hefei, China	1072	13734310.34	12812	1370.88	101747	Li & Gao, 2016
Athirapally-Vazhachal, Kerala, India	133	1123646	8448	903.94	67090	Anitha and Muraleedharan, 2006
Keenjhar lake, Pakistan	14000	42200000	3014	322.50	23936	Dehlavi and Adil, 2011
Kuttanad wetlands, Kerala, India	162125	3609831.029	22	2.35	175	Rao, 2018
Bhoj wetland, Bhopal, India	3229	1114229	345	36.92	2740	Verma et al., 2001

Little Rann of Kachchh, Gujarat, India	357000	4600000	13	1.39	103	Dixit et al., 2016
Zambezi Basin wetland, Southern Africa	2982900	813800	0.27	0.03	2	Schuijt, 2002
Muthurajawela wetland, Sri Lanka	6000	54743	9	0.96	71	Zuze, 2013
Mfolozi flood plain, South Africa	20886	167505.72	8	0.86	64	
Pantanal wetland, Brazil	13,800,000	423640000	31	3.32	246	Schuyt & Brander, 2008
Muthurajawela wetland, Sri Lanka	3068	54743	18	1.93	143	
Whangamarino wetland, New Zealand	10320	2022720	196	20.97	1557	
Wetlands in Bushenyi	18300	8985300	491	52.54	3899	Kaggwa et al., 2009
Hussain Sagar lake, Hyderabad, India	550	210929	384	41.09	3050	Mishra, 2014
Ousteri wetland, Puducherry, India	800	95333	119	12.73	945	Venkatachalam &Zareena Begam, 2016
Pong Dam wetland, India	15500	133547	9	0.96	71	Prasher et al., 2006
Average Value					12111	

Table A4: Cultural services - Inspiration for culture, art and design

Ecosystem	Area (ha)	Value ($/yr)	Value per Unit Area	Adjustment for GDP (PPP) per capita	Value in INR	Reference
Mfolozi flood plain, South Africa	20886	803484.42	38 $/ha/yr	4.07	302	Zuze, 2013
Pantanal wetland, Brazil	13800000	1144490000	83 $/ha/yr	8.88	659	Schuyt & Brander, 2008
Uttara Kannada, Central Western Ghats, India			480 Rs/ha/yr		480	Ramachandra, 2016
Wetlands in Bushenyi	18300	32226300	1761 $/ha/yr	188.43	13985	Kaggwa et al., 2009
Aghanashini, Karnataka, India			1305 Rs/ha/yr		1305	Ramachandra et al., 2019
Average Value					3346.2	





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