Seminar Proceedings

Agriculture and Ecosystem Services

Edited by

Suresh Pal

भाकृअनुप – राष्ट्रीय कृषि आर्थिकी एवं नीति अनुसंधान संस्थान

ICAR–National Institute of Agricultural Economics and Policy Research

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FOREWORD

The Sustainable Development Goals in the context of agriculture underscore the significance of interdependence between agricultural production systems, people and environment. This interdependence is increasing with rising population and intensification of the production systems. As a result, there are adverse ecological impacts of the intensification process, which may further accentuate due to climate change. Therefore, it is necessary to understand ecological functions of agricultural systems and quantify their economic significance. These functions can broadly be classified as ecosystem services, which vary considerably across the production systems. There is considerable attention from researchers to assess these ecosystem services so that suitable interventions can be made to enhance these services, or check their further deterioration.

Globally, some efforts have been made to assess ecosystem services, but a few studies are conducted in India, and no evidence on agriculture. There are both positive as well as adverse impacts of agriculture on ecosystem services. Therefore, their understanding becomes important to restore and enhance ecosystem services. Important among them are soil formation and carbon sequestration, cropping diversity in semi-arid and arid regions, solar radiation and temperature regulation, reclamation of land and water and many more. Forest and wetlands have even much stronger ecosystem services. This volume is an outcome of a national seminar on this topic, which has discussed ecosystem services in the context of Indian agriculture. More importantly, the volume has discussed the role of technological interventions in reducing the disservices and addressing the problems like desertification, soil erosion and moderating the impacts of natural hazards like floods and droughts.

The volume has presented an overview of global assessment of ecosystem services and analytical methods used. There are contributions on watershed development, wetland and coastal ecosystems, agro-forestry, biodiversity and soil amendments. These contributions are made by the researchers from different disciplines with established research work in the area. The volume has also discussed the possibilities of mainstreaming payment of ecosystem services in the development process. This could be possible when there is understanding of economic and social values of ecosystem services and a mechanism to collect charges from the beneficiaries and transfer them to the people generating the services. Further research on these lines shall take the concept forward and incentivise the people generating ecosystem services. It is hoped that this volume shall encourage research in this area.

Chhabilendra Roul
Special Secretary,
Department of Agricultural Research and Education &
Secretary, Indian Council of Agricultural Research
New Delhi-110001

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There is increasing interaction between biophysical, economic, environmental and social systems in the context of agriculture. These dimensions, particularly production system and environmental linkages, are important for ensuring sustainability of agriculture and addressing the trade-offs at an early stage. This is possible when environmental or ecosystem services are assessed and prioritized for interventions. With this background, a national seminar on ‘Agriculture and Ecosystem Services’ was organised by ICAR-National Institute of Agricultural Economics and Policy Research on 28-29 May, 2018 and this volume is an outcome of the seminar. We sincerely thank all the paper contributors, panelists and keynote speakers for their invaluable contribution to the discussion. We particularly thank Sh. Chhabilendra Roul, Special Secretary, DARE and Secretary ICAR, and Dr. R.B. Singh, Former President, National Academy of Agricultural Sciences (NAAS) for their support and valuable guidance during the inaugural session. Dr. Kanchan Chopra, former Director, Institute of Economic Growth, Dr. Meine van Noordwijk, World Agro-Forestry Centre, Dr. A.K. Singh, Secretary, NAAS and Dr. P.K. Joshi, Director South Asia, International Food Policy Research Institute, and Dr. V.P. Singh, World Agro-Forestry Centre enriched the discussion with valuable insights. We are grateful to them. We are also grateful to all the paper contributors and colleagues at NIAP, particularly Sulakshana Rao, for their efforts to bring out this volume. Special thanks to Mrs. Aruna T. Kumar for her skills in editing the manuscript.

Suresh Pal
Editor

October, 2018

ACRONYMS AND ABBREVIATIONS

AEZ	Agroecological Zones
CV	Coefficient Variation
CA	Conservation Agriculture
CAFRI	Central Agroforestry Research Institute
CAZRI	Central Arid Zone Research Institute
CBD	Centre for Biodiversity Development
CDM	Clean Development Mechanism
CEC	Cation Exchange Capacity
CRP	Conservation Reserve Program
CSP	Carbon Sequestration Potential
CVM	Contingent Valuation Method
DAP	Diammonium Phosphate
DUV	Direct Use Values
EDS	Ecosystem Disservices
EEZ	Exclusive Economic Zone
e-NAM	e-National Agricultural Market
ES	Ecosystem Services
ESV	Ecosystem Services Valuation
FAO	Food and Agricultural Organisation
FGDs	Focused Group Discussions
FYM	Farm Yard Manure
GDP	Gross domestic product
GHG	Greenhouse Gases
GIS	Geographic Information System
ICAR	Indian Council of Agricultural Research
IPBES	Intergovernmental Science-Policy Platform on Biodiversity & Ecosystem Services

ISRO	Indian Space Research Organization
IUV	The Indirect Use Values
KSB	Potassium Solubilizing Bacteria
kWh	Kilo Watt Hours
LPG	Lachhaputraghati
LR test	Likelihood ratio test
LULUCF	Land Use, Land-Use Change and Forestry
MEA	Millenium Ecosystem Assessment
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MOP	Muriate of Potash
MPAs	Marine Protected Areas
MSP	Minimum Support Price
N_2O	Nitrous Oxide
NA	Not Available
NAAS	National Academy of Agricultural Sciences
NABARD	National Bank for Agriculture and Rural Development
NAPCC	National Action Plan on Climate Change
NBSS&LUP	National Bureau of Soil Survey and Land Use Planning
NGO	Non-Governmental Organisation
NICRA	National Innovations on Climate Resilient Agriculture
NMSA	National Mission for Sustainable Agriculture
NPK	Nitrogen Phosphorus Potassium
NPP	Net Primary Production
NRSC	National Remote Sensing Centre
NUV	Non-Use Value
OECD	Organization for Economic Co-operation and Development
OV	Option Value
PES	Payment for Ecosystem Services
PPP	Public Private Partnership
PSA	Pago por Servicios Ambientales

PSM	Propensity Score Matching
RDI	Restricted Deficit Irrigation
REDD	Reducing Emissions from Deforestation and Forest Degradation
SAT	Semi-Arid Tropics
SDGs	Sustainable Development Goals
SDI	Sub Surface Irrigation
SOC	Soil Organic Carbon
SSP	Sardar Sarovar Project
SWC	Soil and Water Conservation Measures
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Value
THI	Temperature Humidity Index
UNDP	United Nations Development Programme
UNEP	United Nations Environmental programme
USD	US Dollar
VS	Volatile Solids
WEY	Wheat Equivalent Yield
WHS	Water Harvesting Structures
WTA	Willingness to Accept
WTP	Willingness To Pay
WWF	World Wide Fund for Nature

CHAPTER 1

AGRICULTURE AND ECOSYSTEM SERVICES: INTRODUCTION AND SYNTHESIS OF THE ISSUES

Suresh Pal, Sulakshana Rao, and Prem Chand

Introduction

The contributions of Indian agriculture in ensuring national food security, improving livelihood of rural poor and reducing poverty are well documented. Of late, there have been concerns about rising environmental costs of agricultural development, mainly because of indiscriminate use of natural resources like groundwater, erosion of soil and biodiversity. Therefore, sustainability and resilience of agricultural production systems have gained importance for future growth. The linkages between production systems, natural resources, environment and social system have now become more prominent to reduce environmental footprints of agricultural development. In particular, understanding of agriculture-ecosystem interactions and trade-offs is essential for considering agriculture and ecosystems in a holistic manner and corrections of those processes, which contribute to negative environmental footprints.

Agriculture as a manmade ecosystem provides as well as relies upon services of natural ecosystems. These ecosystem services, for well-being of people (health, livelihood, survival) and sustaining life on earth are getting increasing attention of researchers for their assessment. The Millennium Ecosystem Assessment (MEA, 2005) has analysed provisioning services from agriculture such as provision of food, fibre and fuel. The other services from agriculture such as soil conservation, water quality, carbon sequestration, biodiversity conservation, etc. also gained importance later. At the same time, agriculture also generates ecosystem disservices (EDS) in terms of nutrient leaching, groundwater depletion, pesticide pollution, etc. It is, therefore, important to understand ecosystem services provided by different agro-ecosystems and quantify them for prioritising investment decisions and development of institutional frameworks for incentivising the people who are generating these services. Also, appropriate institutional arrangements can be designed to incorporate investment and incentives for increasing the ecosystem services in economic development framework.

Understanding of ecosystem services and their incorporation into development process is rather absent in developing countries and India is no exception to this. At the most, the concept is confined to few studies in the domain of environmental sciences. But Indian agriculture has reached a stage where further neglect of ecosystem services will impair the development process and cost significantly to the economy in terms of cost associated with the mitigation process. Air and water pollution, pesticide residue, natural resource degradation and green-house emission are some of the notable ecosystem dis-services with heavy toll on human health and environment, and their corrective measures would need significant resources. With this background, a national seminar was organized to discuss and document ecosystem services from different agro-ecosystems in India. This volume contains a summary of discussions and presentations at the seminar. The main issues discussed were nature of ecosystem services and their valuation methods, technologies and practices (biological amendments, conservation agriculture), investments and agricultural policies for increasing the flow of services. This chapter provides a synthesis of evidences, followed by a detailed review of global studies on ecosystem services and valuation methods in the next chapter. The subsequent chapters contain case studies on biodiversity, wetland ecosystems, and services from soil and water conservation programs, soil amendments, and agro-forestry systems. It is hoped that the volume would contribute to the understanding of ecosystems services from agriculture and convince for the development of an institutional mechanism to channelize investment to improve these services and quality of life.

Ecosystems and Ecosystem Services

An ecosystem can be defined as a natural unit of living things (animals, plants and micro-organisms) and their physical environment (Wallace, 2007). Ecosystems provide a range of services for human well-being and sustaining life. They also offer goods for consumption (ecosystem functions), and contribute to their attributes (system structure, diversity, etc.) for their sustenance (de Groot *et al.,*2002). The concept of ecosystem services gained attention after a study by MEA (2005) on ecosystems and their linkages with human welfare. The benefits people derive from the ecosystems were defined as ecosystem services (ES) and MEA identified four major types of ecosystem service, viz. provisioning services, regulating services, supporting services, and cultural services. These ecosystem services are illustrated in Table 1. As evident from this table, agriculture largely provides provisioning services and other ecosystem services are rather nominal. But in case of forestry, wetlands and coastal systems, provisioning, supporting and regulating services are almost balanced. Considering the vastness of some of these ecosystems, e.g. coastal, value of all services shall be significant. The length of coastal wetland in India is around 43,000 km^2 (Bassi *et al*, 2014). Similarly, mangrove ecosystems are spread across West Bengal, Gujarat, Andaman & Nicobar Islands, Andhra Pradesh, Odisha and Maharashtra. However, these ecosystems are degrading at an alarming rate (MEA, 2005), primarily because these ecosystems are common property resources with unrestricted exploitation by the users. The valuation of ecosystem services would attract attention of the government for restoration of these systems.

Table 1. Ecosystems, their services and relative importance

Ecosystem services	**Ecosystems**					
	Crop land (Arid eco-system)	Forest	Agro-forestry	Coastal wetlands	Marine	Mangroves
Provisioning services						
Freshwater		*	*	*		
Food	***	*	**	**	**	
Timber, fuel, and fiber	*	***	***			*
Supporting services						
Biodiversity regulation	*	***	**	**	***	**
Regulating services						
Carbon sequestration	**	***	**	*		**
Nutrient cycling	*	***	***	*	*	*
Air quality and climate	*	***	**	*	*	**
Natural hazard regulation	*	**	**	**	*	***
Cultural services						
Cultural and amenity	**	**	*	***	**	*

Note: Number of asterisk indicate strength of the service.
Source: Millennium Ecosystem Assessment (2005).

The first step in the valuation of ecosystem services is preparation of an inventory of all ecosystem services. The inventory of ecosystem services from different ecosystems (Table 2) revealed that agriculture largely provides provisioning services, which are well-documented. In addition, there are regulating services in the forms of soil and water conservation, diversity of cropping systems, and support for animal and other life on earth. Cropping diversity, groundwater recharge, and soil and water conservation are significant for irrigation tank ecosystems. Arid ecosystem though puts pressure on land and water resources, but helps in sustaining life, improving diversity and controlling desertification. These ecosystem services outweigh the disservices like exploitation of groundwater, pollution of air and water, and effect of pesticide residue etc.

Table 2. Inventory of ecosystem services from different systems

Ecosystems	Provisioning services	Regulating services	Supporting services	Cultural services
Mangroves	Fish, firewood, timber, medicinal plants, fodder	Carbon sequestration, bio-shield and storm protection, shore-line protection, waste assimilation, nutrient recycling	Fish breeding nursery (ground)	Ecotourism
Wetlands	Paddy, fish, freshwater, ducks, vegetables, medicinal plants	Control of soil erosion, protection from storm and flood, pollution control and detoxification, groundwater recharge, climate regulation	Biodiversity conservation, nutrient cycling	Aesthetic, educational, recreational services
Agro-forestry	Food, timber, fibre, medicinal plants	Carbon sequestration, air quality, natural hazard regulation, bio-drainage	Biodiversity conservation, nutrient cycling,	Cultural and amenity
Agro-ecosystem	Food, fibre, bio-energy, medicinal plants	Air quality and climate regulation, soil conservation	Biodiversity conservation, wildlife habitat, soil fertility, soil enrichment	Agro-tourism, aesthetic landscapes
Tank ecosystem	Food, fibre and silt collection	Soil and water conservation, flood control, surface and groundwater recharge	Cropping diversity	Festivals and other recreational services
Forest	Food, timber, firewood, freshwater, fibre, medicinal plants	Climate regulation, air quality, carbon sequestration, waste treatment, biological control	Biodiversity conservation, wildlife, genetic material	Eco tourism

Source: Compiled from various presentations at the seminar.

Three ecosystems, viz. wetland, forest and mangroves, generate provisioning, regulating and supporting services. Important among these are conservation of biodiversity, carbon sequestration, soil and water conservation, nutrient recycling, freshwater, bioremediation, and protection against natural hazards like flood, and climate regulation. In addition, there are aesthetic and cultural services from these ecosystems. Some studies indicated that value of regulating and supporting services from these ecosystems are much higher than the value of provisioning services (de Groot *et al.*, 2012 and Costanza *et al.,* 2012). Thus, valuation of these ecosystem services, particularly for the neglected ecosystems, deserves high priority for seeking higher allocation of public resources for their restoration.

Ecosystem services have two other important dimensions. First, aesthetic and cultural services help build social and intellectual capital. Cross-cultural interactions and learning of sustainable practices, understanding of ecosystems, collective social responsibility, and intellectual and spiritual development of people have far greater impact on sustainable practices, social cohesiveness and economic development. These services must be preserved and promoted even at a higher level of investment. The second important characteristic of ecosystem services is that these services have spatial and temporal dimensions. Benefits of ecosystem services are spread over to far off places. For example, people from other countries come for ecotourism, fresh air and water flow unrestricted, and benefits of climate regulation flow across the borders. Similarly, existence and option value of biodiversity and soil formation are available for future generations also. Therefore, spatial and temporal disaggregation of benefits of ecosystem services should be understood for mobilization of resources for strengthening these services and assessing value of these services in a larger context.

The foregoing discussion indicates interdependence of economic, ecological and social dimensions of ecosystems and their role in sustainable development. It is, therefore, important that any attempt to comprehend ecosystem services is understanding science of sustainability and building social and ecological capital for development. Developing countries can build on their strength in terms of regulating and supporting ecosystem services and can bargain with developed countries for payment of these services. Finally, unrestricted flow of ecosystem services calls for global alliance to strengthen mechanism to mobilise resources and transfer them to the people who are generating these services.

Valuation of Ecosystem Services

Valuation of ecosystem services is useful for understanding their economic significance and prioritisation of investment options for restoring economic and ecologically important ecosystem services. The valuation also helps in assessing incentives and compensation for enhancement of ecosystem services, or charging those who are using or degrading these services. Provisioning services are best valued at market prices and in the process producers are automatically rewarded. However, most of the regulating, supporting and cultural services are non-market goods, and therefore, their assessment is rather challenging. Their valuation can be done either indirectly using revealed preference of the users or through stated preference methods by eliciting choice or option value of non-use services, or option value of existence like biodiversity (Table 3). The revealed preference methods are useful for use goods and services like clean air and flood control (Liu *et al.,* 2010). Important among these methods are avoided or replacement cost, travel cost and Hedonic Pricing method. In Hedonic pricing method, special attributes of market goods or services, e.g. high fertility land, house facing scenic landscape or closeness to public services, the value can be estimated through difference in the prices, as market goods with preferred attributes are valued high and buyers are willing to pay for these attributes (Brown *et al.,* 2007). The Contingent Valuation method is useful to value society attaches to a non-use good, e.g. biodiversity, or a use good which shall be created in future. This method assesses the willingness to pay (WTP) for a particular good or service. The WTP is arrived at using choice experiments with different choices options and associated prices relating to a particular ecosystem service (*see* Chapter 2).

Table 3. Summary of valuation methods of ecosystem services

Method	Description	Examples
Direct market valuation(market price, factor income method)	The exchange value that ecosystem services have in trade	Mainly applicable to the "goods" (e.g., fish)
Indirect market valuation (avoided cost; replacement cost; travel cost; Hedonic Pricing)	When there are no explicit markets for services	Avoided cost method (flood control), replacement cost method (groundwater recharge), Hedonic Pricing (clean air or aesthetic views)
Contingent Valuation (CVM)	Survey based method to express WTP for the services	Non-use values (e.g. biodiversity conservation)
Benefit transfer	Uses results from other, similar area to estimate the value of a given.	(e.g. regulating services)

Source: Compiled from various presentations at the seminar and literature.

In India, most of the studies on valuation of ecosystem services were conducted for wetlands and forests, perhaps because these ecosystems are overexploited and their ecological contributions are less conducted. The studies on agro-ecosystems and tank irrigation are rather limited, but their contribution in water scarce regions through watershed development are enormous in terms of soil and water conservation and improving cropping diversity and land cover. A summary of the values of different ecosystem services is given in Table 4. In most of the studies, methods like averted (or replacement) cost, and travel cost have been used. Travel cost is mainly used for ecotourism and Contingent Valuation method is used for assessing the value of biodiversity or sacred groves. Few studies have estimated the value of carbon sequestration by using carbon price available in the studies in developed countries (*see* Chapter 10).

Value of the ecosystem services from wetlands and mangroves is quite significant (Table 4). In fact, the regulating and supporting services provided by these systems also contribute to provisioning services in the adjacent agro-ecosystem and forest. The study on mangroves showed that they provide protection against natural calamity and contribute to reduction in crop losses. Mangroves are natural protection of people against cyclone and there was 54 per cent reduction in deaths in the east coast (Das, 2018). The intervention for sand dune stabilization has reduced the frequency of sand storms from 17 in 1966 to 2.5 in 2000. Also, there is sequestration of carbon to the extent of four metric tonne in four lakh hectares treated area so far (*see* Chapter 5). Similarly, the value of nutrient cycling and bioremediation through microbial processes are to the order of 17.5 - 27.5 kg/ha of added biofertilizer. Agro-forestry system is of great economic significance to farmers and it also reduces carbon emission. The value of carbon sequestration in soil by agro-forestry ranges from US$ 1,778 to US$ 4,673 depending upon nature, density and age of plantation. The value of services from traditional conservation methods like sacred groves is estimated at US$ 14 for use and US$ 1.74 for existence value (Table 4).

Table 4. Quantification of ecosystem services

Ecosystem	Ecosystem services	Method	Monetary or physical value	Reference
Mangrove	Storm protection (regulating)	Averted deaths	US$ 4335/ha (2009 prices) in Kendrapada district (Odisha)	Das (2015)
Wetland	Coastal protection (regulating)	Benefit transfer	Rs. 2.89 million/km^2/year (Gulf of Kuchh, India) -2007 price	Dixit *et al.* (2010)
	Protection against salinity ingression (regulating)	Productivity change & preventive expenditure measure	Rs. 0.10 million/km^2/year (Gulf of Kuchh, India) 2007 price level	
	Biodiversity conservation (supporting)	Contingent valuation method	Rs.11 lakhs/ha/annum (Kuttanad wetlands, Kerala, 2012 price)	Rao (2018)

Table 4 contd...

Ecosystem	Ecosystem services	Method	Monetary or physical value	Reference
Forest	Ecotourism & biodiversity (recreational and supporting)	Travel cost & CVM	Ecotourism Rs. 30,000/ha Option value for biodiversity Rs. 44,000/ha Athirapally-Vazhachal area, Kerala (2002 price)	Anitha and Muraleedharan (2006)
	Water quality and quantity improvements	Hedonic Cost function	Savings of \$0.40-\$1.20/household/year	Pattanayak (2004)
Arid-ecosystem	Soil fertility, soil erosion control, water conservation, carbon sequestration	Value in physical terms	• Soil fertility- One tree adds 0.70 kg N, 0.04 kg P and 0.20 kg K per year • Soil erosion control- Tree having 20m^2 crown area saves 15 kg soil from erosion • Water conservation- 26% reduction in run off • Carbon sequestration- 9 kg/tree/year	Chapter 5
	Nutrient recycling and carbon storage	Discounted net present value	• Soil nutrient value Rs 15,600 ha^{-1} • Soil carbon value Rs 1,300 ha^{-1}	Chapter 4
Agro-forestry	Carbon sequestration (regulating)	Market value	US\$ 1,778 and US\$ 4,673 for poplar trees in seven years of rotation in boundary and agri-silvi-culture system, respectively	Chapter 10
	Carbon sequestration (tonnes)	Amount of carbon stored	Carbon sequestration: 355.79 tonnes/ha	Chapter 4
	Soil retention (kg)	Annual sediment yield	Soil retention : 505.40 kg/ha (2013 value) Lachhaputraghati (LPG) watershed, Odisha	
Tank ecosystem	Groundwater re-charge (Regulating)	Benefit transfer	Economic value of US\$ 2972/ha/year (2003 price)	Vindanage *et al.* (2005)
Sacred groves	Use value and existence value (all services)	Contingent valuation method	Use value US\$ 14/person/year, existence value US\$ 1.74/person/year	Chapter 8

Source: Compiled from various presentations at the seminar.

Ecosystem Services from Agriculture

Understanding of the ecosystem services provided by agriculture is complex as the interaction between agriculture and its ecosystem is bidirectional. However, these interactions and contributions to ecosystem services vary considerably because of wide diversity in agricultural ecosystems, arising mainly due to differences in cropping systems and environment. Therefore, purpose of the analysis should be to reward ecosystem services and take suitable measures to reduce the dis-services. Understanding of these issues becomes easier when multi-functionality characteristics of agro-ecosystems are taken into consideration, and economic, ecological and social dimensions are given due emphasis. The following discussion captures some of these dimensions with emphasis on soil and role of technologies in enhancing ecosystem services (Table 5) from agriculture and associated activities.

Soil: The main ecosystem service associated with soil is carbon sequestration and nutrient cycling. The Sustainable Development Goals of the United Nations, Zero Hunger, Climate Action and Life on Earth, are indirectly related to carbon sequestration. Incorporation of residues of cereal in soil, cultivation of horticultural and pulse crops, green manuring and several similar practices promote carbon sequestration and nutrient recycling. However, multi-functionality of agro-ecosystem is not accounted for and agro-ecosystem is always pointed out for the amount of methane emission and overuse of water. Multi-functionality of the major agro-ecosystem of rice includes groundwater recharge, flood control, improved water quality, biodiversity (wetlands), moderating climate, etc.

Climate: Another important ecosystem service provided by agriculture is climate regulation. Land cover with crops and trees absorbs direct radiation and moderate temperature. Negative radiation is retained within soil and plant ecology and only useful sun light is reflected back in the environment. This not only maintains temperature but also controls rainfall. Local deforestation leads to vulnerability and increased atmospheric GHG content (Coe *et al.,* 2013).

Technological interventions for ecosystem services

Sand dune stabilization

Indian arid zone area is 38.9 million ha which is 12 per cent of the national geographic area. The main hot arid areas are Rajasthan, Gujarat and Haryana, and the major challenges are desertification and land degradation, wind erosion, poor soils (low organic matter, poor water holding capacity, low fertility), salinization, and scarcity of irrigation water. ICAR-CAZRI made interventions for sand dune stabilization, which include techniques such as fencing, fixing barriers, afforestation and planting of grass slips. Four lakh hectare area in Western Rajasthan was adopted for the purpose. Major benefits due to sand dune stabilization (Table 5) are reduction of sand dunes spread from 54 per cent of total geographical area in 1990s to 48 per cent in 2013, reduction in dust storms from 17 in 1966 to 2.5 in 2000, decrease

Table 5. Interventions for enhancing ecosystem services

Interventions for enhancing the services	Quantification	Institutional Aspect
Biological amendments	• Rhizobium in legumes: Rs. 190-225 per ha increase in ecosystem services • Azotobacter in cereals, fodder, oilseeds and vegetables, Rs. 145-200 per ha • BGA/cyanobacteria paddy, wheat, maize, legumes, vegetables, Rs. 260-315 per ha • P-solubilizer for all crops Rs. 600 per ha	• Production and distribution of biofertilizers and other agriculturally important micro-organisms • Payment for ecosystem services, nutrient saving
Sand dunes stabilization	• Net sown area increased by 119% in last four decades • Ecosystem services of trees in sand dune stabilization **Provisioning service** • Fodder - average green fodder (leaf + pod) yield :14-16 kg/ha/year • Fuel - average fuel wood production: 20-50 kg/year (calorie value 4,400 kcal/kg) • Timber - yearly production – 1.06 cu.ft/ tree **Supporting and regulating services** • Soil fertility- one tree adds 0.70 kg N, 0.04 kg P and 0.20 kg K per year • Soil erosion control- tree having 20m^2 crown area saves 15 kg soil from erosion • Water conservation- 26% reduction in run off • Carbon sequestration- 9 kg/tree/year	• ICAR-CAZRI adopted 4 lakh hectare in Rajasthan for sand dunes stabilization • Need for partnership with CAZRI, forest department, state line department
Conservation agriculture	• Improved soil health (SOC 0.5 t/ha/year) • Reduced weather risks (high adaptability and low crop yield variability) • Reduce chemical load (20-25 kg N/ha, less herbicide) • Saving of irrigation water, rice-wheat-mungbean: 40-50 ha-cm/year • More profit: lower costs and higher yields (Rs.12,000-15,000/ha/year) • Lower GHGs emission (~1 t CO_2-eq/ha/year)	• Technologies like micro irrigation, solar energy, weed management and precision nutrient management • Subsidy on farm machines used for conservation agriculture like Happy Seeder and residue management system

Table 5 contd...

Interventions for enhancing the services	Quantification	Institutional Aspect
Soil and water conservation/ watershed management	• Nitrogen accumulation – Rs. 302.18/ ha • Phosphorous accumulation – Rs. 2.33/ha • Sediment control 10.32 t/ha • Bamboo plantation with staggered contour trench: present value of total indirect benefit of soil conservation over 20 year production period (Rs 15,104 ha^{-1})	• Holistic systems approach • Institutions for collective actions of all the stakeholders • System for water distribution and conflict resolution • Technology-driven management system

Source: Compiled from various presentations at the seminar.

in wind erosion affected area from 75 per cent earlier (1990s) to 73 per cent (2011-13). Sand dune stabilization has enhanced the provision of all the four ecosystem services, e.g. expanding cultivation area of crops (provisioning), use of acacia species as a tree component resulted in provision of timber, fuel, fodder and gum, regulating services in terms of carbon sequestration, nutrient cycling, air quality, reduction in wind erosion, etc. Biodiversity in terms of crops, trees, livestock and other flora increased and tourism in existing sand dunes has increased. Another intervention is shelter bed plantation, which resulted in reduction in wind velocity and better crop productivity. Since these activities need massive investment, there is a need for higher allocation of public funds for this purpose and active participation of state governments.

Agro-forestry systems

Agro-forestry involves a wide range of trees that are protected, regenerated, planted or managed in agricultural landscapes as they interact with crops, livestock, wildlife and humans. Agro-forestry is associated with various services such as habitat for pollinating insects, carbon sequestration, wind and water erosion shield, groundwater recharge, nitrogen fixation and nutrient recycling, biodiversity conservation, etc. Most agro-forestry systems also have a cultural significance and they are fundamental for improving soil health. Multi-functionality of landscapes and perceived value of ecosystem services is a concept that needs more focus. Capturing agroforestry as an evolving concept in multifunctional land use and securing ecosystem services in the context of sustainable development goals (SDGs) are of prime importance. The roles of modified land equivalency ratio for understanding the multifunctional land use perspective deserve more emphasis. Current and future services per unit of land can be multiplied with societal weighting of provisioning services to modify the land equivalency ratio to represent the provisioning, regulating and cultural services of the land-use (van Noordwijk, 2018). Agro-forestry is a win-win strategy for degraded, common lands, which can be developed in partnership with landless farm workers and forest department or village institutions.

Mangroves and coastal systems

As noted earlier, mangroves provide multiple ecosystem services such as groundwater discharge, prevention of soil salinity and nutrient retention (supporting services); flood control, storm protection/wind break, shoreline stabilization and erosion control, micro climatic stabilization and carbon sequestration (*see* Chapter 9). The multiple uses of mangroves, especially the regulating services such as coastal protection, ecological restoration and livelihood security have been analysed using various modeling techniques (Das, 2018). However, there exists a research gap in assessment of economic value which is a challenging task. The effect of climate changes and need for restoration of mangroves is a key area of research in the future. Indian mangroves are of global significance as they comprise 2.7 per cent of global mangroves (Dasgupta and Shaw, 2013). Management of mangroves in India has both legislative and non-legislative approaches. Declarations of coastal systems as protected areas, coastal zoning and various restoration initiatives are on the legislative front, while, community management of mangroves through joint mangrove management (similar to joint forest management) are the non-legislative aspects. Marine and coastal pollution, sedimentation and excessive salinity are some of the major threats faced by these ecosystems, and it is necessary that these factors are included in the management policy initiatives.

Biological amendments

Biological amendments are a part of soil amendments. The common amendments include biostimulants, organic amendments, microbial inocula (as biofertilizers or conditioners), and pelletised formulations such as compost, and their extracts. Major benefits arising out of biological amendments in agriculture are diverse; for instance it helps in energy supply, nutrient cycling, disease supervision and resistance and resilience as part of biological mechanism. In terms of physical mechanism, it provides stability and structure to soil, and improves it bulk density, porosity and hydraulic properties. Chemical mechanisms from the application of biological amendments are related to pH and buffering capacity, cation exchange capacity and chelation. The approaches for valuation of ecosystem services involve all the four services (provisioning, regulating and supporting services) arising out of soil amendments. Biofertilizers such as rhizobium application has enhanced benefits ranging from Rs. 190/ha, and *Azotobacter, Azospirillum*, blue green algae and P-solubelizer have benefits of Rs. 145-200, Rs. 200, Rs. 260-315 and Rs. 600 per hectare, respectively (*see* Chapter 6).

Conservation agriculture

Conservation agriculture (CA) is slowly increasing over the years and it touched 180 million ha globally in 2015. In Asia, CA is spreading rapidly, nearly 408 per cent increase in the last one decade. The twin benefits recognised are increasing farm income and conserving natural resources. As part of conserving agriculture, (CA++) technologies such as micro- irrigation, weed management and precision nutrient management are adopted and the benefits are comparable yield with 85 cm /ha/year less water, half energy use and USD 185/ha/year higher income in north-west India (Jat, 2018). Further, CA based wheat production evidenced better crops with tolerance to extreme climate events than conventional tillage based system in Haryana. In maize, CA played critical role in withstanding climate risk. Ecosystem services from CA include improvement of soil health (SOC 0.5 t/ha/year), reduced weather risk, reduced chemical load (20-25 kg N/ha, less herbicide), per drop more crop (water saving in rice-wheat-mungbean: 40-50 cm/ha/year), and lower GHGs emission (~1 tonne CO_2-eq/ha/year).

Watershed development

Natural resources are scarce and problems like land degradation, low productivity and other exploitations are arising due to their indiscriminate use and poor management, posing a threat to ecosystem services. From the farmers' point of view, watershed development in water scarce areas is critical in increasing crop productivity and farm income. The interventions for enhancing water availability (surface and groundwater), water productivity, income and livelihood have been adopted in the selected villages of the states of Maharashtra, Madhya Pradesh, Karnataka, Rajasthan and Odisha. Most of the interventions for conserving resources are science-based and adopt the measures like water harvesting and storage, soil conservation, suitable cropping systems, and soil test based integrated nutrient management. All these interventions contribute to the provisioning and regulating services. Another example of soil and water conservation is the *shram dan* campaign to integrate the local knowledge with scientific verification for planning the interventions. The interventions showed an increase in the productivity of groundnut by 48 per cent, finger millet by 45 per cent, pigeon pea by 75 per cent and paddy by 35 per cent in the state of Maharashtra. Renovation of existing structure increased storage capacity by 6,000 m^3, and water availability through groundwater recharging structures (7,600 m^3). Another study of Antisar watershed in Gujarat found that the average groundwater recharge was 7.5 per cent of rainfall (*see* Chapter 4).

SAT agricultural systems

A study conducted in Maharashtra and Madhya Pradesh using different methods including use of remote sensing data and crop simulation models revealed that technological interventions (e.g., integrated practices) show different responses depending on bio-physical conditions and management systems (Kumar, 2018). Cereal-based cropping systems are more responsive to improved fertilizers and manure application interventions. Some systems have an advantage in terms of profit but perform worse in terms of overall ecosystem services, which may come at the cost of some dis-service (e.g. water use). Also, the ecosystem services require different governance mechanisms and greater awareness in case some trade-offs is involved in the services like production, profits and water use. Rationalization of subsidies to reduce irrigation costs promotion of water efficient agricultural practices, and use of minimum support price to promote water efficient crops are also essential. There are alternative instruments to alleviate poverty of farmers, which do not have any adverse impact on water use.

Climate change and ecosystem services

Climate change impacts different ecosystem services from agriculture in many ways. Extreme climatic events, such as drought, affect food production, deplete productive assets, increase rural poverty, force out migration, and lead to over-exploitation of natural resources, including land and water. The effect of drought on the provisioning services from agriculture, e.g. rice yield, was discussed. From 1969-2005, there was an average decline in rice yield by 3.5 per cent due to drought. The effect was high (6 per cent) during the initial phase of 1969-1987. Yield declined with severity of drought and a decrease in yield to the order of 13.5 per cent was observed. Technologies such as irrigation and drought tolerant varieties have the adaptation benefits and they can reduce the effects of drought on the provisioning service from agriculture (Birthal, 2018).

Assessment of effects of climate change on agricultural ecosystem services and adaptation strategy across different agro-climatic zones in India, are necessary. A change in temperature (1.5^{o}C increase) and rainfall (15 mm decrease) will decrease the percentage of cropped area under many crops, particularly rice, maize and wheat (see chapter 7). For prioritizing adaptation technologies and strategies across different agro-ecological zones (AEZ), there is a need to identify the location specific adaptive capacity. It was emphasised that there is a need for convergence of various development programmes for mainstreaming climate adaptation.

Ecosystem services provided by livestock are also not devoid of climate change impacts (Sirohi, 2018). Research indicated the impact of heat stress on the production losses in dairy cattle, as there is a negative correlation between temperature humidity index (THI) and milk productivity in dairy cattle. Productivity – climate adaptability trade-off exists in indigenous and temperate breeds of cattle. Effect of climate change on the grazing lands in India showed mixed effects ranging from expected expansion to desertification due to overgrazing. On the other hand, proper maintenance of pastures with three plantations can add to enormous provision services (livestock products and timber) and regulating services in the form of carbon sequestration and reduction in soil erosion. Livestock also contributes towards different ecosystem disservices as it is considered as one of the major sources of methane emission through enteric fermentation by livestock which is 16 per cent of total methane emission (Sirohi, 2018). Technological interventions such as biogas plants can help to convert the disservice to ecosystem service in livestock systems.

Mainstreaming Ecosystem Services in the Development Processes

Ecosystem services and development goals

The Sustainable Development Goals (SDGs) target inclusive development, improved life on earth and climate resilient systems. The specific targets for 2030 are reducing poverty by half, reduction in GHG emission and reversing desertification and resource depletion (UNDP, 2015). All these goals can be achieved if productivity of agricultural systems is increased to ensure adequate income to farmers, structure and processes of ecological systems are improved, and processes to degrade resources are reversed. This implies that agriculture should be seen as a multifunctional system providing various services, which should be enhanced. Wherever there are environmental issues like carbon emission and weakening of ecological foundations of agriculture, technological and policy interventions are necessary. The understanding and valuation of ecosystem services help in suggesting appropriate policy solutions. It is essential for protecting and restoring vulnerable but ecologically important ecosystems through adequate resources and policy support. Also, necessary institutional mechanism should be in place to encourage communities and structures, which are protecting ecosystems and generating ecosystem services.

In the context of agriculture, desertification, land and water degradation, and pesticide residue are directly limiting ecosystems services. These disservices are further compounded by carbon emission and pollution from industry, and crop residue burning. One way to address these concerns is to internalise them by incorporating appropriate cost component so that consumers of goods with negative services must pay for better environment. However, this option may not be consistent with poor consumers who have inadequate purchasing power. Therefore, cost of necessary interventions should be borne by the government and people who have adequate purchasing power. Public investment and policies should take into consideration ecosystem services and any policy distortion causing disservices should be corrected. Notable examples are correcting subsidy on electricity wherever groundwater extraction has reached an alarming rate of exploitation, or subsidizing farm machinery for crop residue management and value creation. Finally, price policy can be used for encouraging cropping systems which generate ecosystem services and bring more area under agro-forestry or perennial crops with capacity to reduce carbon emission and use less water. Such policies coupled with use of appropriate technological interventions will go a long way in promoting agriculture with better ecology and resilience to moderate climate shocks.

Payment for ecosystem services

One of the characteristics of ecosystem services is that these have spatial and temporal dimensions and people or regions that are not generating them can also benefit from them. Notable examples are freshwater from forests clean air, and water harvesting in catchment area of watershed. Benefits of augmentation of natural resources, biodiversity conservation and reduction in carbon emission also benefit future generations. Therefore, it is important that those who generate ecosystem services should be incentivised for their efforts and those who only reap the benefits must pay for the services. Two things are essential to realise this objective. First, there must be a clear assessment of different ecosystem services from the society's perspective, i.e. how much value is attached to a service (*see* Chapter 3). This will enable calculation of charges for the users and payment to generators of services. Unfortunately, there are not many studies on valuation of ecosystem services because of lack of awareness of the topic as well as research capacity. The evidence discussed above clearly established the need for building research capacity in this area and sponsoring studies on priority regions and services. De-desertification, afforestation, carbon sequestration, bioremediation, and land reclamation are immediate priority areas in this context. Since not many economists are working in this area in the country, collaborative programs could be of immense benefit.

The second issue in payment of ecosystem services is that there should be an institutional mechanism for collection of charges from the users and transfer them to those who are generating these services. Some efforts are made to promote carbon trading in developed countries, but real transfer of resources through this mechanism is rather limited. To start with, it would be desirable if the charges are collected by the government or of any public agency, regionally or nationally, and then government pays to the farmers and communities. The payment could be in the forms of subsidy on micro-irrigation, fiscal incentives for afforestation programs, higher prices for crops generating the services or promoting cropping diversity, and special benefits for water harvesting and use in water-scarce regions. An example could be compensating legume crops through higher MSP for nitrogen fixation in soil and promoting soil microbial systems. It can also be considered as a way of indirect incentivization for ecosystem services. Inputs contributing to ecosystem services like biofertilizers, gypsum for land reclamation, and machines for crop residue incorporation in soil can be subsidised to encourage their use.

Afforestation to control desertification, crop residue management and water harvesting have off-site benefits and farming communities should therefore be incentivised to change their practices as social cost of not changing the practices is very high. Instead of burning crop residue, if CA practices are followed, the private cost goes up and the social cost will come down. To compensate increase in the cost for farmers, we need different mechanism for providing incentives, subsidies etc. to them in addition to regulations and legal actions to control residue burning. In this context, markets for carbon and water trading need immediate attention. It is also important to decide the role of different actors (government, urban population and other stakeholders) in payment of services after assessing their willingness to pay for crop residue management. Principle of institutional economics can be applied in ecosystem conservation and restoration of its services. In agriculture, inventory of ecosystem services needs to be developed for assessing the role of technology and institutions to enhance them and also evolve a suitable mechanism to reward the farming community. Further research is needed for suggesting a suitable mode of funding and payment for ecosystem services.

Conclusions

The foregoing discussion has clearly established that there are several ecosystem services from agriculture and related ecosystems like forests, mangroves and wetlands. In some cases, value of the services relating to ecosystem functions far exceed the provisioning services of food, fuel etc. Therefore, it is important that multi-functionality of ecosystems should be recognised and promoted. Since studies are not adequate to establish the importance of ecosystem services, research work in this area will be useful to draw attention of the government and seek appropriate policy interventions to promote these services. Technological interventions can also significantly improve the services and minimise the disservices.

A major research gap is valuation of ecosystem services from the society's perspective. In particular, the valuation of non-use and option (existence) values has greater methodological and field challenges. The methods of stated preferences could be applied to assess the willingness to pay for services, and choice experiments can be applied to elicit these values. But robustness and credibility of the results will largely depend upon how these choice experiments are planned and applied in the field. Some areas like arresting desertification, control of residue burning and land reclamation can be taken for study and assessing the value of benefits to the society.

Once the role of ecosystem services is established, it is appropriate to pay to farmers and rural communities in lieu of ecosystem services provided by them. This needs development of an institutional mechanism, which is responsive and inclusive in terms of participation of all the stakeholders. The structure of the mechanisms may differ depending on the nature of service, but an effective partnership of government, farmers and other stakeholders is necessary for fair distribution of payments. In some cases like carbon sequestration, a trading mechanism can be designed and implemented at the national, regional or global levels. In others, rewards based on certification of farm practices on area basis or price support could be an option to begin with.

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CHAPTER **2**

VALUATION OF ECOSYSTEM SERVICES: A REVIEW OF METHODS AND EVIDENCES

Sulakshana Rao, Ranjith P.C. and Suresh Pal

Introduction

Natural ecosystems provide a wide variety of useful services that enhance human well-being. An ecosystem is a collection of plants, animals, and micro-organisms interacting with each other and with their non-living environment (CBD, 1993). Examples include wetlands, coral reefs, forests, rainforests, deserts, or a cultivated agro-system. Ecosystems are highly productive and valuable systems, which provide a range of services, many of which are of fundamental importance to human well-being, for health, livelihoods, and survival (Costanza *et al.,* 2012, 1997; Millennium Ecosystem Assessment, 2005; TEEB Foundations, 2010). Most ecosystems offer joint products some of which are hidden public goods in nature, leading to neglect of these natural capital assets from national income accounts (Dasgupta, 2014). Chopra (1998) pointed out that ecosystems are conglomerations of goods and services and perform various ecological functions. In 1997, the value of global ecosystem services was estimated to be around US$ 33 trillion per year (in 1995 $US), a figure significantly larger than global gross domestic product (GDP) at the time. Hence, ecosystems are important for obvious reasons and degradation of these services may worsen-off human welfare. This paper reviews the analytical approaches and estimates of ecosystem services provided by various ecosystems.

Ecosystem Services

Ecosystem services are defined as the benefits people derive from ecosystems – the support of sustainable human well-being and therefore ecosystem services are important in sustaining human life on earth (MEA, 2005; Costanza *et al.,* 1997). These are life supporting activities that ecosystem provide us largely in an unrecognized and non-priced way. These have traditionally been disaggregated into goods (products), services (ecosystem functions) and attributes (structure, diversity, etc.). Ecosystem goods and services occur at multiple scales, from climate regulation and carbon sequestration at the global scale to flood protection, water supply, soil formation, nutrient cycling, waste treatment and pollination at the local and regional scales (de Groot *et al.,* 2012).

Millennium Ecosystem Assessment (2005) classified ecosystem services into provisioning, regulating, cultural and supporting services. Provisioning services refer to the provision of goods such as water, food and raw materials. Regulating services are processes that contribute to economic production or save costs, such as flow regulation (including flood reduction, regulation of base flows, groundwater recharge), sediment retention, water purification and carbon sequestration. Cultural services relate to ecosystem attributes and include the spiritual, educational, cultural, recreational, existence and bequest value that is derived from use or appreciation of biodiversity. Supporting services are the biophysical process that underlie the first three, and should not be valued to avoid double-counting. Table 1 shows the world's major ecosystem types and the main services they provide, as described in the Millennium Ecosystem Assessment (2005).

Table 1. Different ecosystems and their services

Ecosystem service	Ecosystems					
	Crop land	Forest	Inland wetlands	Coastal wetlands	Marine	Mountain
Freshwater		*	*	*		*
Food	*	*	*	*	*	*
Timber, fuel, and fiber	*	*				
Biodiversity regulation	*	*	*	*	*	*
Nutrient cycling	*	*	*	*	*	
Air quality and climate	*	*	*	*	*	*
Natural hazard regulation		*	*	*	*	*
Cultural and amenity	*	*	*	*	*	*

Source: Millenium Ecosystem Assessment, 2005.

Ecosystem Services and Agriculture

Agriculture is a dominant source of livelihood globally and it has a robust association with ecosystem and its services. Agriculture is both the producer and consumer of ecosystem services. Agriculture and ecosystem are collectively known as agro-ecosystem and are valued by humans mainly for the provisioning services such as food, forage, fibre, bioenergy, etc. provided by this ecosystem on the one hand and on the other hand, agriculture depends on ecosystem for a range of services it provides. Supporting services include genetic biodiversity for use in breeding crops and livestock, soil formation and structure, soil fertility, nutrient cycling and the provision of water. Regulating services are also used for agriculture like pollination and natural enemies that protect crops etc. Natural ecosystems may also purify water and regulate its flow into agricultural systems, providing sufficient quantities at the appropriate time for plant growth. Traditionally, agro-ecosystems are considered primarily as sources of provisioning services, but more recently their contributions to other types of ecosystem services have been recognized. Agriculture systems if properly managed can provide in return various services such as pollination, pest control, genetic diversity for future agricultural use, soil retention, regulation of soil fertility and nutrient cycling.

Despite their significance, ecosystem services and biodiversity continue to decline at unprecedented rates (TEEB Synthesis, 2010). Forest ecosystems are being converted to other uses; wetlands are being drained; and coral reefs are being destroyed. Freshwater resources are increasingly modified through impoundment, redirection, extraction, land use changes, affecting recharge and flow rates, and pollution. Agricultural soils and pasture lands are degrading due to over-use. Some of these pressures are intentional effects of human activities and others are unintended. Degradation and loss of biodiversity of ecosystems undermine the functioning and resilience and thus threaten their ability to continuously supply the ecosystem services for present and future generations. These threats are expected to become greater in the context of climate change and ever increasing human consumption of resources. Biodiversity and its associated ecosystem services can no longer be treated as inexhaustible and ‘free ‘goods, and their true value to society as well as the costs of their loss and degradation, need to be properly accounted for.

Ecosystem has many dimensions (ecological, socio-cultural and economic) and the effective way of expressing its relative importance to policy makers is through monetary terms. Information on monetary values enables more efficient use of limited funds through identifying where protection and restoration is economically most important and can be provided at a low cost . It can also assist the determination of the extent to which compensation should be paid for the loss of ecosystem services in liability regimes (de Groot *et al*., 2012; Payne and Sand, 2011).

Expressing value of ecosystem services in monetary units also provides guidance in understanding user-preferences and the relative value the current generation places on ecosystem services. These values help make decisions about allocating resources between competing uses, whereby it should be realised that monetary values that are based on market prices only, usually neglect the rights (values) of future generations. Furthermore, assessment of broad range of ecosystem services and their values in monetary units or otherwise is a fundamental step to improve incentives and generate expenditures needed for their conservation and sustainable use, such as systems of payments or rewards for ecological services (Farley and Costanza, 2010; Leimona, 2011). The underlying premise of the economic valuation of biodiversity and ecosystem services is that if proper values are assigned, policymakers will make better informed decisions.

With this background, the objective of this paper is to review the status of ecosystems in India; the ecosystem services they provide and their valuation at global and national level. The rest of the paper is divided into three sections (i) assessment of ecosystems: global scenario; (ii) assessment of ecosystems: national scenario; and, (iii) a case study of coastal wetland for a detailed analysis.

Valuing Ecosystem Services

Ecosystem services valuation (ESV) is the process of assessing the contributions of ecosystem to sustainable human wellbeing, including fair distribution and efficient allocation of the services (Costanza and Folke, 1997; Liu *et al.,* 2010). Valuation of ecosystem services has become one of the fastest growing areas of environmental research. The MEA (2003, 2005) and other studies of economics of ecosystems and biodiversity have recognized the critical role of ecosystem service valuation for sustainable development.

Economic valuation can be defined as the attempt to assign quantitative and monetary values to goods and services provided by environmental resources or systems, whether or not market prices are available to assist us (Lambert, 2003). Atkinson *et al*. (2012) analyzed different studies on valuation of ecosystem and diversity, around the globe. In order to make better decisions regarding the use and management of ecosystem services, their importance to human society must be assessed (de Groot *et al.,* 2006).

Valuation methods

Valuation of ecosystem services is a complex task because the ecosystems are multifunctional, generating myriad goods and services for human welfare. The total economic value (TEV) is defined as the total amount of resources that individuals would be willing to forego for increased amount of ecosystem services (Turner e*t al.,* 2000).

The TEV is divided into different kinds of components (Fig. 1):

A. ***Use values***

i. Direct use values (DUV): The benefits derived from fish, agriculture, fuel wood, recreation, transport, wildlife harvesting, peat/energy, vegetable oils, dyes, fruits.

ii. Indirect use values (IUV): Indirect benefits derived from the ecosystem functions like nutrient retention, flood control, storm protection, groundwater recharge, external ecosystem support, micro-climatic stabilization, shoreline stabilization, etc.

iii. Option value (OV): An individual derives benefits from ensuring that a resource will be available for future use.

B. *Non-use values*

The non-use value (NUV) is derived from the knowledge that a resource (biodiversity, cultural heritage, religious site, and bequest) is maintained. This value is strongly advocated by environmentalists who support the concept of the pure intrinsic value of nature.

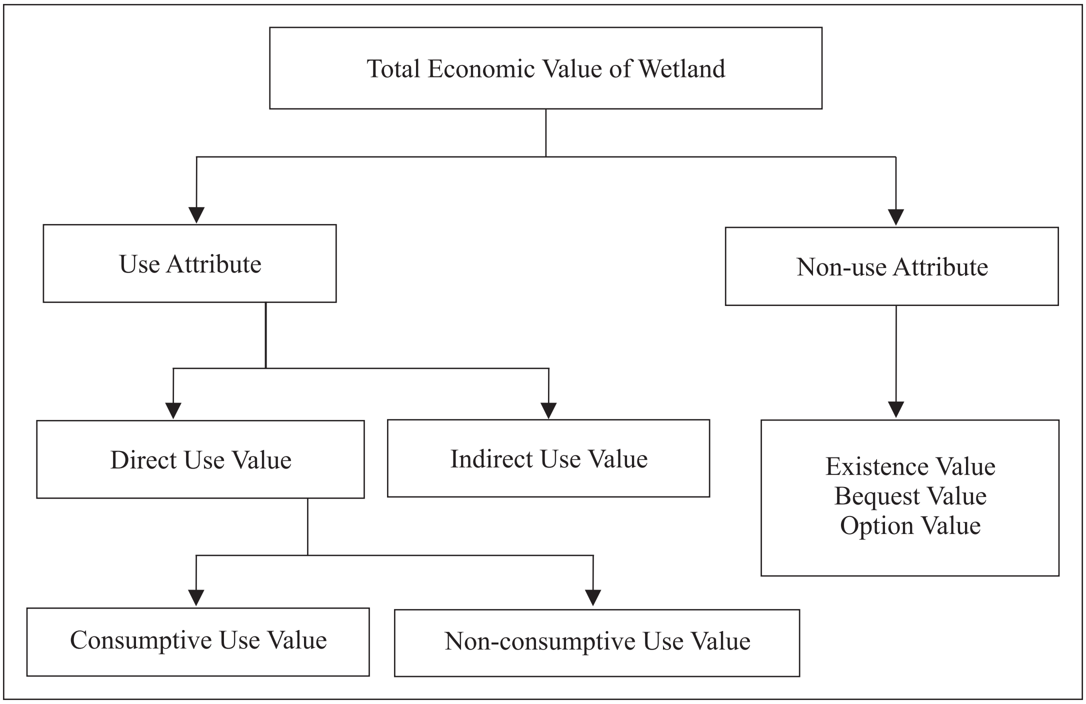


Figure 1. Taxonomy of the economic value of ecosystems (adapted from Ghosh, 2017)

Monetary valuation of ecosystem services: Monetary or financial valuation methods fall into four basic types (de Groot *et al.,* 2006).

i. Direct market valuation: The exchange value that ecosystem services have in trade.

ii. Indirect market valuation: When there are no explicit markets for services, indirect market valuation is used. Examples of indirect market valuation methods are—Avoided Cost method (flood control), Replacement Cost method (groundwater recharge), Hedonic Pricing (clean air or aesthetic views).

iii. Contingent Valuation: A survey questionnaire is used and respondents express their willingness to pay (often used for non use values) for the services.

iv. Benefit-transfer method: Uses results from other, similar area to estimate the value of a given service in the study site when time and resources are scarce.

A summary of monetary valuation methods is presented in Table 2.

Table 2. Monetary valuation methods, features, and examples

Method		Description	Features	Examples
Direct market valuation	**Market price**	The exchange value (based on marginal productivity cost) that ecosystem services have in trade	Market imperfections and policy failures distort market prices.	Mainly applicable to the goods (e.g., fish) but also some cultural (e.g., recreation) and regulating services (e.g., pollination)
	Factor income method	Measures effect of ecosystem services on loss (or productivity gains) in earnings and/or productivity	Care needs to be taken not to double count values	Natural water quality improvements which increase commercial fisheries catch and thereby incomes of fishermen
Indirect market valuation	**Avoided (damage) cost method**	Services that allow society to avoid costs that would have been incurred in the absence of those services	It is assumed that the costs of avoided damage or substitutes match the original benefit.	The value of the flood control service can be derived from the estimated damage if flooding would occur
	Replacement cost & substitution cost	Some services could be replaced with human-made systems	It is assumed that the costs of avoided damage or substitutes match the original benefit.	The value of ground-water recharge can be estimated from the costs of obtaining water from another source (substitute costs).

Table 2 contd...

Method		Description	Features	Examples
	Mitigation or restoration cost	Cost of moderating effects of lost functions (or of their restoration)	It is assumed that the costs of avoided damage or substitutes match the original benefit.	Cost of preventive expenditures in absence of ecosystem service (e.g.,flood barriers) or relocation
	Travel cost method	Use of ecosystem services may require travel and the associated costs can be seen as a reflection of the implied value.	Over-estimates are easily made. The technique is data intensive.	Part of the recreational value of a site is reflected in the amount of time and money that people spend while traveling to the site.
	Hedonic pricing method	Reflection of service demand in the prices people pay for associated marketed goods	The method captures people's willingness to pay for perceived benefits.	Clean air, presence of water, and aesthetic views will increase the price of surrounding real estate.
Surveys	**Contingent valuation method (CVM)**	This method asks people how much they would be willing to pay for specific services through questionnaires or interviews	There are various sources of bias in the interview techniques.	It is often the only way to estimate non-use values.
Benefit transfer	**Benefit transfer**	Uses results from other, similar area to estimate the value of a given service in the study site.	Values are site and context dependent and therefore in principle not transferable.	When time to carry out original research is scarce and/or data is unavailable, benefit transfers can be used.

Source: Adopted from de Groot *et al.* (2006), Barbier *et al.* (1997), Wilson and Carpenter (1999)

Global Assessment of Ecosystems

Valuation studies have been conducted across the globe and different type of valuation methods have been applied to value ecosystem services including production function approach; net factor income approach; total revenue estimation; travel cost method; opportunity cost; replacement cost and contingent valuation method. The suitability of each valuation method is dependent on the ecosystem service being studied and the type of services that are valued (Barbier, 1994; MEA, 2005; Freeman, 2003).

de Groot *et al.* (2012) estimated the global value of ecosystems provided by 10 main biomes (marine and coastal ecosystems, wetlands and freshwater, forests and grasslands) based on local case studies across the world. Some of the studies that have been utilised for the global ecosystem valuation are: wetlands, forests, and water quality.

de Groot *et al*. (2012) and Costanza *et al.* (2012) summarised the monetary value of world biomes and the changes in global flow of ecosystem services value respectively (Tables 3, 4).

Table 3. Summary of monetary values of ecosystem services for different biomes (value in $/ha/year, 2007 price level)

Sl. No.	Ecosystem services	Marine & Coastal ecosystems[a]	Wetlands and fresh water[b]	Forests & grass-lands[c]
1	**Provisioning Services**	**58,222**	**6571**	**4057**
	Food	3154	1831	1743
	Water	0	3433	278
	Raw materials	21,548	783	488
	Genetic resources	33,048	10	14
	Others (medicinal and ornamental reosurces)	472	114	32
2	**Regulating Services**	**197,390**	**35,066**	**3230**
	Climate regulation	1732	553	2243
	Waste treatment	162,210	3208	82
	Erosion prevention	182511	2622	62
	Nutrient cycling	0	1758	96
	Others (include air quality & water flow regulation, pollination and biological control)	16991	14891	727
3	**Habitat Services**	**16,590**	**19,593**	**3,392**
	Nursery services	194	11935	1289
	Genetic diversity	16395	7658	2102
4	**Cultural (recreational and aesthetic) Services**	**109,456**	**8,562**	**2,057**
	Total economic value (1+2+3+4)	**382,557**	**223,794**	**12,736**

Note: [a]Marine & Coastal ecosystems include marine ecosystems, coral reefs and coastal systems.
[b]Wetlands and fresh water ecosystems includes freshwater, inland and coastal wetlands.
[c]Forests and grassland ecosystem includes tropical and temperate forests; woodlands as well as grasslands.

Source: de Groot *et al.* (2012)

Table 4. Changes in aggregate global flow values from 1997 to 2011 (in $/year)

Ecosystems	**Value of ecosystem services** ($/year)		
	1997	**2011**	**Change**
Marine	796	1368	572
Open ocean	348	660	312
Coastal	5592	8944	3352
Others (includes estuaries and coral reefs)	66,119	410,081	343,962
A. Marine & coastal ecosystems	72,855	421,053	348,198
Terrestrial	1109	4901	3792
Forest	4,524	12,319	7,795
Grassland/rangeland	321	4,166	3,845
B. Forests and grasslands	5,954	21,386	15,432
Wetlands	20,404	14,0174	119,770
Tidal/marsh/mangroves	13,786	193,843	180,057
Swamps/floodplains	27,021	25,681	-1340
Lakes/rivers	11,727	12,512	785
C. Wetlands and freshwater	72,938	372,210	299,272
D. Cropland	126	5567	5441
Total economic value (A+B+C+D)	151,873	820,216	668,343

Source: Costanza *et al.* (2012).

The economic value of marine and coastal ecosystems in 2012 was $ 0.38 million per hectare per year. The value of wetlands and freshwater ecosystem services was $ 0.22 million per hectare per year, while forests and grasslands have a total economic value of $ 12 thousand per hectare per year. Among the various categories of services, regulating services provided by marine and coastal system was $ 0.19 million per hectare per year, which accounted for 50 per cent of the total value. Wetlands and freshwater systems are well known for the regulating and supporting services that contribute one-fourth of the total ecosystem value. The global value of ecosystems services has increased by 4.4 times from 1997 to 2011 (Table 4). The growth in value has been the highest in marine ecosystems followed by wetlands and croplands (Costanza *et al.,* 2012).

Assessment of Ecosystems: National Scenario

In this section, the ecosystems have been categorised into (a) wetlands, (b) forests, (c) tank, and; (d) agro-ecosystem or crop lands. This section describes different ecosystems, the range services they provide and their relevance to agriculture and concludes with a review of ecosystem valuation undertaken.

Wetland ecosystems

Wetlands are diverse, highly productive and valuable (economically and ecologically) ecosystems (Brander *et al.,* 2006). The RAMSAR convention on wetlands defines wetlands very broadly as: areas of marsh, fen, peatland 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 six metres. Wetlands are sensitive systems and occupy about 6% of the world's land surface (Turner *et al.,* 2000). They comprise both land ecosystems that are strongly influenced by water, and aquatic ecosystems with special characteristics due to shallowness and proximity to land. Although different classifications of wetlands exist, a useful approach is one provided by the Ramsar Convention on Wetlands. It divides wetlands into three main categories of wetland habitats: (i) marine/coastal wetlands; (ii) inland wetlands; (iii) man-made wetlands. The marine and coastal wetlands include estuaries, inter-tidal marshes, brackish, saline and freshwater lagoons, mangrove swamps, as well as coral reefs and rocky marine shores such as sea cliffs. Inland wetlands refer to such areas as lakes, rivers, streams and creeks, waterfalls, marshes, peat lands and flooded meadows. Lastly, man-made wetlands include canals, aquaculture ponds, water storage areas and even wastewater treatment areas (Ramsar, 2002).

Wetland ecosystem services and agriculture

Wetlands are unique in their ecological nature. Major services provided by wetland include carbon sequestration, flood control, groundwater recharge, nutrient removal, toxics retention and biodiversity maintenance (Bassi *et al.,* 2014; Turner *et al.,* 2000). Wetlands also perform dynamic functions that have economic benefits accrued to different groups of people. In addition, wetlands also provide direct benefits in the form of natural resources such as water, fish, other edible species and also recreational amenities.

Ecosystem services provided by the wetlands such as nutrient recycling and water quality management or waste water purification are of significant relevance in agriculture. Cooper and Moore (2003) revealed the importance of agriculture and wetlands. According to them, wetlands and agriculture are interdependent. Some of the agricultural crops grow in moist and rich soils in wetlands (e.g., paddy) on the one hand and on the other hand, nutrient loads from agricultural lands to wetlands help maintain balance of ecosystem. Hence, agro-ecosystems and wetlands maintain a sustainable balance between crops and natural resources. Wetlands also serve as habitats for various flora and fauna. They also serve as natural buffers for lakes, rivers and streams. Conservation of wetlands parallel with agricultural lands improves the quality of water (wetland ecosystem service) and hence these lands have a direct influence on preservation of aquatic species such as fishes and molluscs. However, there can be negative impacts from agriculture on wetlands. This is mainly due to input intensive cultivation (nitrogenous and phosphatic fertilizers, pesticides etc.) as well as owing to lack of fertility management by reduced flood cycles for cultivation. Hence, agricultural ecosystems and wetland ecosystems are mutualistic and sustainability of wetland ecosystem is conjointly dependent on the sustainability of agriculture.

Globally, wetland ecosystems is spread over 12.8 million km^2 (1999 estimates) with an estimated economic value of about US$ 15 trillion a year (MEA, 2005) and US$ 70 billion per year (Schuyt and Brander, 2010). However, this value is low as it was calculated only from 89 case studies (Schuyt, 2004). The total extent of coastal wetland ecosystems in India is around 43,000 km^2 (Bassi *et al*., 2014). The Millennium Ecosystem Assessment (Smith *et al*., 2007) has identified wetlands as the most threatened of all ecosystem types implying their degradation at an alarming rate. This is because wetland ecosystems are considered as public goods, unrecognized in the policy process and hence are under-valued. These wetlands have undergone enormous changes due to anthropogenic interventions for socio-economic development at the cost of damaging ecosystem services. The root cause of wetland degradation is lack of information on their benefits (Turner *et al.,* 2000). The various stakeholders as well as the policy makers often have insufficient understanding of economic values of wetlands. In order to avoid further damage to the ecosystem, it is quintessential that we understand how these ecosystems contribute to the livelihood and well-being of the people. The studies across wetland ecosystem valuation are summarized in Table 5.

Agro-ecosystems

Agricultural ecosystems or agro-ecosystems are complex ecosystems primarily managed by human beings. These represent the most common form of land management in the world (Power, 2010) and cover around one-third of the global land area (FAOSTAT, 1999). An agro-ecosystem might also be defined as a functional unit, producing agricultural products and services. Kumar and Sandhu (2017) argue a strong linkage between ecosystem services, agriculture and food security.

Agriculture ecosystems provide an array of services such as food, fodder, fuel (provisioning); soil retention, nutrient recycling, pollination, water purification (regulating) ; biodiversity conservation (supporting); and recreational services like ecotourism (cultural services) and these determine bio-physical capacity of the ecosystems (Zhang *et al.,* 2007). Conventionally, agro-ecosystems have been considered mainly as provisioning service providers but they also provide other services like maintaining soil structure, nutrient recycling, flood control, biodiversity conservation, and climate regulation (Power, 2010).

Table 5 : Summary of the studies on wetland ecosystem valuation

Study area	Wetland Functions	Method	Value	Authors
South Asia	Provisioning, regulating, supporting and cultural value	Combination of market and non-market approaches (US$ 2012 price)	Provisioning- $1213/year	Pasupalathi *et al.* (2017)
			Regulating- $4624/ year	
			Supporting- $1605/ year	
			Cultural - $541365/ year	
Bangladesh: Chanda Beel wetland	Non-use values	Contingent Valuation Method	$0.94 million per annum (US$ 2012 price)	Ghosh (2017)
The Middle Cedar River Watershed, Iowa	Flood risk mitigation	Benefit transfer method	$2544 - $3,651/ acre/year (2011 price)	Christie and Stelk (2014)
Australia: Gold coast	Recreational value	Travel cost method	AU$0.36-1.7 billion/year (2010 price)	Raybould *et al.* (2011)
Pakistan: Keenjhar lake	Recreational value	Travel cost method (2009 price)	$42.2 million per annum	Dehlavi and Adil (2011)
India:Gulf of Kachchh region	Coastal protection	Benefit transfer	Rs.2.89 million/ km^2/year (1 US$ =Rs.48)	Dixit *et al.* (2010)
Southern Thailand: Mangrove wetlands	Direct and indirect use values	Market price method	$27264-$35921/ha	Sathirathai and Barbier (2001)
Cape town metropolitan wetlands	Water storage and purification	Replacement cost	$2100- 2325/ha/y	Turpie *et al.* (2001)
Mexico: Coastal wetlands	Fisheries habitat function	Net factor income fisheries-wetland linkage (1980-1990)	Total value: $34 million Value per acre $ 79.7	Barbier and Strand (1998)
Uganda:Nakivubo urban wetland	Total economic value	Market price method and replacement method (1999 prices)	Total value: $2 million US$ 2225-3800/ ha/yr	Emerton *et al.* (1999)

Table 5 contd...

Study area	Wetland Functions	Method	Value	Authors
India: Yamuna wetland Basin	Use values	Contingent Valuation Method	Rs.624 per hectare	Chopra and Kadekodi (1997)
Gotland, Sweden: riverine wetlands	Nitrogen abatement	Contingent Valuation Method, production function, replacement cost	$59/kg of Nitrogen reduction capacity (1990 prices)	Gren *et al.* (1995)
Nigeria:Fresh water wetland	Fishing, crop, fuel wood production	Partial valuation, gross value added, opportunity costs	Total value: $8.8 million Value per acre $ 1475 (1989/90 prices)	Barbier (1994)
Wetlands in Europe	Fishing, crop, fuel wood production Drainage	Partial valuation, gross value added, opportunity costsMitigative or Avertive expenditure	$0.35-$1 million per annum (1990 prices)	Gren *et al.* (1994)
Norfolk Broads, U.K.: freshwater wetlands	Flood control	Contingent Valuation Method	$118 -247 per annum (1991 prices)	Bateman and Hangford (1997)
California wetlands:San Joaquin valley	Fishing, biodiversity conservation, water quality control	Contingent Valuation Method	Total value: $62 million Value per acre $1567 (1987 prices)	Loomis *et al.* (1991)

However, unwanted effects of agriculture or disservices are also a reality. Runoff from agricultural fields pollutes the Indian rivers flowing through Indo-Gangetic plains (Jain *et al.,* 2007). Land use changes associated with agro-ecosystems lead to habitat loss, intensive irrigation leads to decline in water table, over grazing leads to desertification, and intensive use of fertilizers leads to escape of nitrogen and phosphorus in water bodies that may in turn lead to eutrophication. Ecosystem services and dis-services to and from agriculture are reported in Table 6. Zhang *et al.* (2007) argue that the management decisions need to be implemented based on the scales at which these services and disservices are provided. Kremen (2005) highlights the need of better comprehension of ecological services by estimating the ecosystem services flow-in-and-out of agro-ecosystems and their ultimate contribution to total value from agriculture.

Table 6 : Ecosystem services and dis-services to-and-from agriculture

Services to agro-ecosystems	Services from agro-ecosystems
Supporting services	**Provisioning**
• Soil structure and fertility	• Food, fibre, fuel production
• Nutrient cycling	
• Water and soil provisioning	
• Biodiversity	
Agricultural Ecosystems	
Regulating services	**Non-marketed services**
• Soil retention	• Water supply
• Pollination	• Soil conservation
• Control of pests and diseases	• Climate change mitigation
	• Aesthetic landscapes
• Air and water purification	• Wildlife habitat
Ecosystem dis-services	**Ecosystem dis-services**
• Pest damage	• Habitat loss
• Competition for water and pollination from other ecosystems	• Nutrient run-off
	• Pesticide poisoning of non-targeted species

Source: Zhang *et al*. (2007).

Value of agro-ecosystem services

Researchers have analyzed and estimated the various ecosystem services, useful to the human beings, provided by these agro-ecosystems. Harrison *et al.* (2014) studied 11 ecosystem services and showed that ecosystem services are generated from numerous interactions occurring in complex systems. Ajwang Ondeik *et al.* (2016) applied market price method and valued the provisioning services such as rice production (US $ 602.49), fish provision (US$ 1039.50), reeds and thatching grass (US$ 10.29), papyrus (US$ 397.40), cultural services (recreation, ecotourism) of the Kano flood plain of Kenya. Kubiszewski *et al.* (2013) applied benefit transfer approach and valued cropland ecosystem and orchard (in Bhutan), and the total economic value of orchards was $1,548/ha/year while of cropland $1831/ha/year. Bark *et al.* (2016) estimated regulatory services provided by the Murray Darling basin in Australia by using carbon price (carbon sequestration) and alternate cost method. The regulatory services estimated in the study are carbon sequestration (50 Australian $), moderation of sedimentation (17.8 Australian $), and maintenance of bank stability (23.7 Australian $). Non-market goods and services provided by agricultural land or ecosystems in Kern County (California) were estimated by Noel *et al.* (2009) by benefit transfer approach. With a total economic value of $ 966.46 acre/year; the ecosystem provided other services like water regulation ($ 111.57 acre/year), soil formation ($ 6.35 /acre/year), pollination ($ 8.98 /acre/year) and aesthetic and recreational ($ 28.08 /acre/year) annually.

Besides the high economic value, agro-ecosystems are also relevant for other ecosystem services to improve the nature. A well-managed agro-ecosystem can enhance various ecosystem services such as pollination, soil fertility, infiltration, biological pest control and biological diversity. Integrated nutrient management and shift to biological nitrogen fertilizers or legume intensification improves the nitrogen use efficiency by modifying internal nutrient cycling (Power, 2010). Lal (2008) revealed the carbon storing capacity of agro-ecosystems in soil, which reduces the greenhouse gas emissions. Conservation practices and check in erosion improves soil carbon storage in these ecosystems. Thus, carbon sequestration by agro-ecosystem enhances other services beneficial to agriculture by maintaining soil fertility, improving soil organic carbon, improved infiltration, etc. (Smith *et al.,* 2008; Power, 2010). Studies that highlight the net economic value of these enhanced services are limited.

However, agro-ecosystems are characterized by the trade-offs between the supply of agricultural commodities (crop yields and livestock weight gain) and non-marketed ecosystem services (groundcover, soil carbon, nitrogen supply, and water regulation) (Kragt and Robertson 2014). According to them, increasing crop residue retention can jointly increase production value and improve provision of groundcover, soil carbon and nitrogen supply. Conversely, over exploitation of perennial pastures in farming (grazing) results negative trade-offs between production values and non-marketed ecosystem services. In some cases, for example, same ecosystem process (soil erosion by streams) can generate dis-service (siltation of dams) or a service (fertilization of floodplain) (Lele, 2009). A similar study was conducted by Bastian *et al.* (2013) to estimate the trade-off between two ecosystem services, viz. crop food production and soil erosion regulation, using an ecosystem services assessment framework. The study revealed that if seven per cent of the farm land was transformed into grassland or forest, the provisioning service would sink by 0.37 lakh tonnes of rye (resulting in an income loss of €7.4 million per year) on the one hand and on the other hand, soil erosion regulation would be enhanced and soil loss would be reduced by 20 per cent, corresponding to on-site benefit of € 7.1 million. Further, the benefits of the erosion regulation service (€ 656,000) exceed the yield losses (€ 245,000) more than twice. Anaya-Romero *et al.* (2016) analysed how the land-use change affects the provision of ecosystem services. The study underlines the need for a global balance of ecosystem services at different spatio-temporal scales for carbon stock, soil erosion and crop production. This information could provide support for decision making to maintain and expand forest cover, conserve natural habitats, and limit urban sprawl. The necessity of bio-physical models to quantify the final service humans receive from groundwater (e.g., reliability of water supply from a municipal well) was stated by Booth *et al.* (2016). Perevochtchikova and Negrete (2015) suggested that social approaches to the assessment of ecosystem services can complement the predominant ecological and economic approaches, and thereby strengthening the relevancy of ecosystem assessments to policy-making.

Irrigation tanks

Water tanks, human-made ecosystem, are mostly used for irrigation but also provide a wide range of ecosystem services (Ariza *et al.,* 2007). Water tanks are usually small water harvesting structures in villages of India, which are constructed to retain water to overcome water scarcity due to erratic monsoons. The earthen barrages or bunds constructed by the villagers store water from rainfall from the sloppy areas and ensure irrigation for agriculture through the year.

Tanks, multi-use ecosystems (Palanisami, 2001), provide various provisioning services which support agriculture (insurance against erratic rainfall), livestock, fish, duck rearing, raw materials, social forestry, tree crops auction and silt collection etc. (Ariza *et al.,* 2007). Major regulating services provided by the man-made tank ecosystems are soil conservation, flood control, surface and groundwater recharge etc. Besides, the tank also sustains and conserves biodiversity and ecology of the surrounding area (supporting services). Large tanks also have cultural significance as well in the society (because of their recreational services).

Tank ecosystem and agriculture

Tanks have a significant role in agriculture especially in areas characterised by low or erratic monsoon rainfall. These ecosystems significantly contribute to agricultural production by means of irrigation in Tamil Nadu, Andhra Pradesh and Karnataka (Babu and Manasi, 2008). Tanks are mostly managed as common property resources. The significance of tank ecosystem is high in present day agriculture where declining groundwater table is a major problem. In this situation, tanks may be referred to as groundwater recharge structures, besides the biodiversity conservation it supports. Less capital intensive nature and wider geographical coverage of tank irrigation structures signify their usefulness to small and marginal farmers in terms of the affordability (Reyes-Garcia *et al.,* 2011, Palanisami, 2001).

Besides the various ecosystem services provided by the tanks, the area under tank irrigation is on the decline (Balasubramanian, 2006). This may be contributed to factors such as heavy siltation, encroachment of tank foreshore area, damaged sluices and poor management of the tank. In order to improve the conditions of the tank ecosystem and for sustainable management, it is necessary to highlight the significance of tank ecosystems to various stakeholders as well as to policy makers by estimating the total economic value of tanks (Palanisami and Easter, 2000). The value of regulating and supporting services from irrigation tank (Table 7) in India ranges from Rs. 88 per ha to Rs. 275.4 per ha. Most of these values are in the form of use values.

Table 7 : Summary of ecosystem services from irrigation tanks

Study Area	Functions	Method	Value	Authors
Kala Oya River Basin, Srilanka	Carbon storage and soil conservation	Benefit transfer	Total Economic value US$ 23.5 billion (2004 prices)	Gunawardhana (2009)
Mid-Godavari river basin tanks	Tangible and non- tangible benefits from desiltation of tanks	Benefit –cost approach	Net benefit from silt amendment, increased produce and nutrient recycling is Rs 6.6 million	Babu and Manasi (2008)
Sardu watershed conservation	Total economic valuation	Market value and PES	Drinking water: Rs 2.6 crore Irrigation water: Rs 0.21 crore	Paudel (2010)
Peace river watershed, British Columbia	Total economic valuation	Water supply – benefit transfer method Carbon storage- avoided cost value Waste treatment- replacement cost value	Water supply: $2,502,441/yr Carbon storage: $1.56 billion to 8.5 billion/yr Waste treatment: $46,970,791/yr (2012 prices)	Wilson (2014)
Irrigation tanks in Tamil Nadu	Irrigation water	Contingent Valuation method	Irrigation water: Rs. 218.5 per ha per year	Chandrasekharan *et al.* (2009)
Tanks of Tamil Nadu	Multiples uses	Market value approach	Irrigation: Rs. 88 per ha Fishing: Rs. 14.87 per ha Social forestry: Rs. 170.85 per ha TEV: Rs. 275.40 per ha (2001 prices)	K Palanisami and Ruth Meinzen-Dick (2001)
Village tanks of Hambantota district, Sri lanka	Direct, indirect and recreational values	Market price, opportunity cost, contingent valuation	Total economic value (direct use): Rs. 65,840 Carbon storage: Rs. 3.3 million (2005-06 prices)	Dayananda (2014)

Forest ecosystem

Forests are building block of life on earth. The world's forests will have to provide services to fulfil the needs and desires of another three to four billion people by the end of this century. It is home to over three hundred million people worldwide and 1.6 billion depend directly on them for their livelihoods. Forests provide habitat for a vast number of undiscovered plants and animals. The forest provides immense, unconditional and irreplaceable resources without any delay or denial. Probably every organism on this earth has benefitted from forest in one or the other way. They are the factory of oxygen production, without which no human life can exist. Hence, forests are so much more than a collection of trees. It is simultaneously harboring and nourishing over 80 per cent of world's terrestrial biodiversity. Forests also play a critical role in mitigating climate change because they act as a natural carbon sink—soaking up carbon dioxide and other greenhouse gases that severely affect the life on earth.

Forest ecosystems are the landscape areas where the woody trees dominate others species, along with biological integration of the various communities of plants (flora), animals (fauna) and microbes and together they interact with soil, water, air, and other atmospheric substances. In a simple form, it is the reciprocal relationship between the biotic and abiotic components of forest. At the village level, most of the forest ecosystems are more or less confined to hill sides and play important role in bringing rains, protecting biodiversity of the region, acting as a natural barrier to wind for protection of crops, and providing fodder for herds in lean season.

Forests play a significant role in hydrological balance of watershed ecosystems and maintain the high-quality water. And this comes from the way of reducing soil erosion on site, reducing sediment in water bodies (wetlands, ponds and lakes, streams and rivers) and trapping/filtering other water pollutants in the forest litter and under wood. Good forest cover is the most effective land cover for keeping water as sediment-free as possible, moreover it act as natural filter in sieving the sediments. As forest activities involve the no use of fertilizer, pesticide and fossil fuel, or any other industrial effluents, watersheds in the forest are regarded best source of drinking water supply (FAO, 2005).

Forest ecosystem services

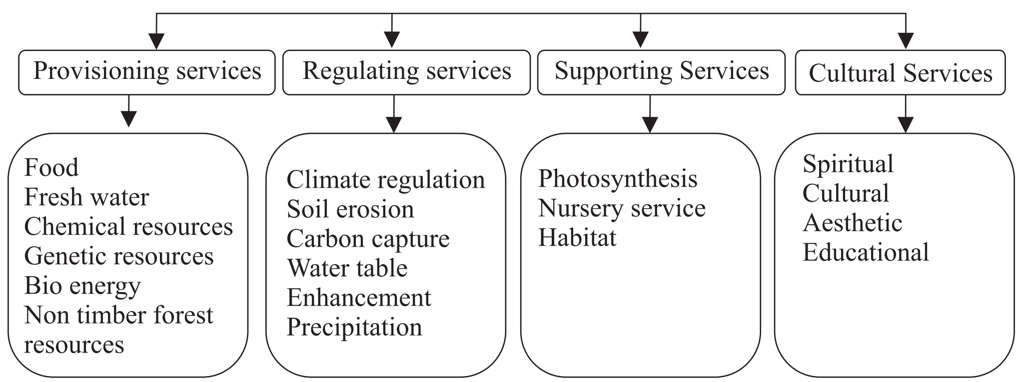
Forest ecosystem services have recently become a key concept in understanding and conceptualizing the way humans interact with the natural environment. They represent what can be broadly understood as the multitude of natural resources and processes that humans benefit from. It is thus by nature an anthropocentric, utilitarian concept, in addition to which we may also consider nature's own right to exist and thrive. The forest ecosystems are the richest in biological diversity only next to marine ecosystem (OECD, 2000). Since biodiversity is an integral part of forest ecosystems, understanding the various services offered to agriculture is need of the hour.

Agricultural and forest ecosystem are both provider as well as receiver of services from each other. Agricultural systems rely on services provided by forest such as pollination, biological pest control, maintenance of soil structure and fertility, nutrient cycling, carbon sequestration and hydrological service. Agro-forestry under agriculture provides wide range of services to forests such as seed conservation, seed development, wild plant species conservation and wide range of planting material, and it also supplements the forest (Dandi Muhmad *et al*., 2014). Plantations such as coffee, tea, and rubber etc. help in reducing the forest degradation and the area under these crops in a way enhances the total forest area. Since agriculture is poorly organised in many parts of the world it started generating disservices such as water pollution, pesticide poisoning, greenhouse gas emissions and leads to loss of forest biodiversity. Expansion of world population paved the way for intensive production systems in agriculture (more product per hectare) and, hence, higher use of inputs (fertilizers, pesticides, stock units, etc.) per unit of area (Tilman *et al*., 2002). Therefore, agriculture with intensive use of inputs is threat to forest ecosystem services. As these developments not only cause irreversible, irreparable damages but also pose incongruous effects that inhibit forest growth and development. Forest products and services are the main derivatives for population living near forest areas as well as actual inhabitants of forest. Forest products are the livelihood options for them, towards meeting their daily needs. Any change in these goods and services may severely disrupt their life. They also act as a conservator in many instances by establishing their own community reserves (eg: sacred forest and sacred groves). If forest serves them they will serve the society, thus the state and the nation. Therefore, the chain of events continue to serve one another thereby maintaining the ecological balance both at society and national level, any disruption to these events is a potential threat to their livelihood. Thus, there is an urgent need to conserve the forest ecosystem services by all stakeholders cutting across their ideology, with one voice to implement suitable landscape management plans; the role of local people is important (Silvano *et al*., 2005). As farmers, pastoralists and horticulturalists, they are the key local stakeholders actively using, managing and changing the surrounding landscape. Therefore, local residents need to be included for the effective management.

Valuation is the key to know the value of the services derived from the forest ecosystem (Summarised in Table 8). The importance of the service would be realized once they stop giving, as most of the forest services are free (non-marketed) to mankind, extensive use without any conservation effort may result in loss of major services. Since the services of these kinds are not offered other than forest, evaluation becomes a significant step to know the value lost on decadal degradation of forest happened so far.

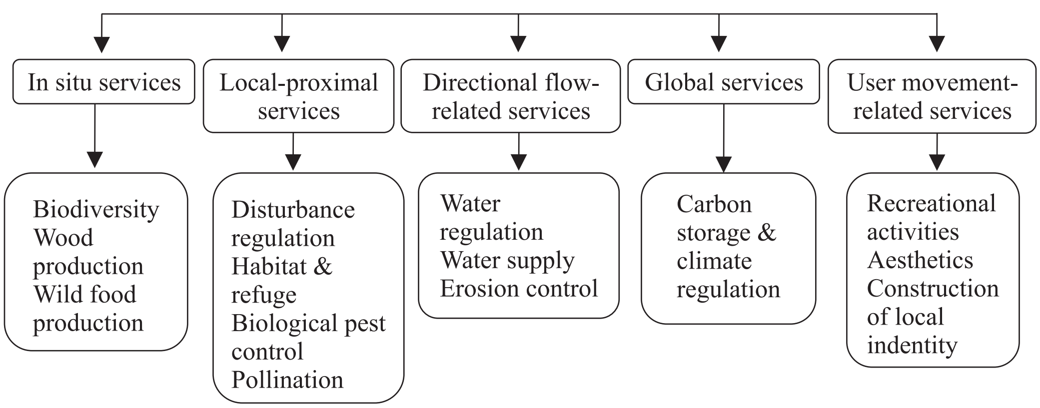
Classification of forest ecosystem

There are various types of forest ecosystems throughout the world and these can be classified as rain forest, mangroves, inland forest (includes agro forest), taiga, lake side forest and mountain forest. Forests provide the numerous services and these services again provide insight to classify the forest ecosystem based on the services it offers to dependent species. The classification of ecosystem services is challenging both conceptually and technically (Fig. 2, 3). Based on spatial distribution these can also be classified as *in situ* services, local-proximal services, directional flow-related services, global services and user movement-related services. The *in-situ* services, the set of services delivered within the forest area and local proximal services, depend on spatial proximity of forest. Directional flow-related services are the service extending from forest to point of use; global services are independent from forest patch location; and user movement related services are the services involving movement of people towards the forest.



Source: MEA, 2005

Figure 2. Forest Ecosystem Services



Source: Decocq *et al.* (2016) and Costanza (2008)

Figure 3. Forest ecosystem services: spatial aspect

Table 8 : Summary of valuation of forest ecosystem services

Study area		Method	Value	Authors
Provisioning services				
Mexico	Food	Market value	Food forest production reached 11,075 ton and income was 1.70 million USD.	Semarnat (2011)
	Fresh water	NA	Water recharge in temperate forests and reduced the risk of sea water intrusion.	Maass *et al*. (2005)
	Wood	Market value	Wood makes an annual contribution of US $1336 million to the Mexican economy and generates 100,000 permanent jobs.	Torres-Rojo (2004)
Western Himalayan region of India	Fuel wood, fodder, timber and resin	Market value	Average monetary value of various provisioning services obtained from the oak forests (Rs 2,164,247/village/year) was notably greater than that obtained from pine forests (Rs 1,589,642/village/year). Study found oak forests were found to be better in terms of provisioning services than rest.	Joshi and Negi (2011)
Regulating services				
Chile	Water quality and quantity improvements	Production function	$15.4/ household (summer); $5.8/ household (rest of year) for 33,000 households; total value of $61.2-$162.4/hectare from native forest.	Nunez *et al*. (2006)
Indonesia		Hedonic Cost function	Savings of $0.40-$1.20/household/year (some cases negative) for 13,700 households with mean incomes of $350/year	Pattanayak (2004)
Northern Italy	Carbon sequestration and Hydro geological protection	Permit method and replacement cost method	The Total Economic Value (TEV) of forest ecosystem is 404 €/ha/yr.	Hayha *et al*. (2015)
Philippines		Contingent valuation	WTP $4.94/household/year for population of 19,517 households with average annual incomes of $2,800	Ahlheim *et al*. (2006)
Madagascar		Production function	NPV $126,700 (total for Madagascar, where 1991 GNP=$207/person)	Kramer *et al*. (1997)
Mexico	Carbon capture	NA	The potential for C sequestration in vegetation and soils of temperate forests is 200 Mg C ha^{-1} and 327 Mg C ha^{-1} , respectively	Monreal *et al*. (2005)
Eastern Nepal	Carbon sequestration	Benefit transfer method	The annual value of the carbon sequestration services was estimated to be NPR 1.65 billion	Pant, *et al*. (2012)

Table 5 contd...

Study area		Method	Value	Authors
Supporting services				
Mexico	Stabilization of soil organic matter	NA	Andosols display a high accumulation of carbon (31 kg m^{-2}), which is explained by the stabilization of soil organic matter with minerals of low structural order and the formation of organometallic compound	Gamboa & Galicia (2012)
Central Mexico	Habitat service	NA	The pine forests accounted for 13.1 And 26.43 Mg ha^{-1} of sink of anthropogenic carbon emission and same was 4.72 Mg ha"1 for mono specific fir forest.	Mendoza-Ponce & Galicia (2010)
Brazil	Carbon uptake	Emergy accounting method	The Net Primary Production (NPP) of provided by the 73 parks of Sao Paulo is about 40 sej/m^2/ year which is vital for crop growth in the surrounding areas.	C.M.V.B. Almeida *et al.* (2018)
Cultural services				
Costa Rica	Ecotourism	Contingent valuation	Aggregate WTP(Willingness to Pay) to protect park by all visitors: $37.51 million	Echeverría *et al*. (1995)
Costa Rica		Travel cost	Total value of all ecotourism visits to Costa Rica by US residents: $68 million	Menkhaus and Lober (1996)
Uganda		Choice experiment	Maximum total revenue from park fees with 20 bird species seen: $18,032 Maximum total revenue from park fees with 80 bird species seen: $40,423	Naidoo and Adamowicz (2005)

Case Study of Kuttanad Coastal Wetlands of Kerala*

Wetlands are diverse and productive ecosystems with ecological and economic values. Kuttanad wetland (Kerala) ecosystem is a complex interaction between the various endemic flora, fauna, birds, fishes, livestock, crops with the human beings. But owing to enormous anthropogenic activities, this region is deteriorating. Hence, in spite of being a source of livelihood their multiple-use potential is seriously undermined due to a narrow management regime focusing only on direct agricultural benefits. Previous studies assessed multiple benefits of ecosystems but did not analyze them from an ecosystem perspective. The multiple-

*The case study is based on Ph.D. thesis by the first author.

use potential of the coastal wetland ecosystems is poorly understood and underrepresented in cost-benefit estimation of the wetland restoration programmes, resulting in inadequate policy and financial support to protect them. This section aims to provide deeper insights into the multiple (direct and indirect) benefits of the Kuttanad wetland ecosystem.

Ecosystem services and economic benefits

Kuttanad wetland system provides an array of services and a total of 22 ecosystem services were identified in the study area (Table 9). Among them nine were provisioning, two were supporting, four were regulating, and seven were cultural or aesthetic services.

Table 9. Ecosystem services identified in the study area

Category of service	Nature of service	Socio-economic indicators
Provisioning	Food and raw materials: Rice, fish, vegetables, ducks, lotus, edible plants, medicinal plants,water for agricultural production potable freshwater	Value of output area irrigated, duration of water supply, quantity and value of water used in agriculture, value of output duration of water use, replacement cost of providing alternative sources
Regulating	Erosion control, nutrient cycling, flood control, water regulation and recharge	Removal of nutrients by wetlands (in tonnes or per cent), water quality in aquatic ecosystems (sediment, turbidity, phosphorous, nutrients etc.)
Supporting	Biodiversity conservation	Number of flora and fauna supported by the ecosystem.
Cultural	Ecotourism	Amount of tourism earnings

Source: Rao, 2018.

The major stakeholders of Kuttanad wetlands are paddy farmers, fishermen, local residents and tourists. All the stakeholders depended directly or indirectly on the wetland for their livelihood. They are affected by the changes in the wetland ecosystem either due to natural and anthropogenic factors. Discussions with local communities revealed that the high ranked service was rice farming followed by fishing, tourism, water for irrigation, and habitats for biodiversity. Another important ecosystem service upon which the stakeholders depend on a day to day basis is water. Water from the canals is used for irrigating rice fields and also for washing and bathing purposes by the residents. The wetlands also provide services like erosion control and also act as a habitat for biodiversity. These services were ranked based on their use by household or ability to sell them in the market for economic returns. The ten important services with their ranking and details on their use by local people are given in Table 10.

Table 10. Ecosystem services, their use and ranking by the stakeholders

Sl. No./ Rank	Ecosystem services and category	Uses	Remarks
1	Rice farming (provisioning)	Food and market value	70 per cent of the population depend on rice farming as a source of income
2	Fishing (provisioning)	Food and market value	More than 60,000 active fishermen in the area.Average income of Rs 1,600 per day during peak seasons
3	Recreational (cultural)	Employment and global recognition	Important tourist destination.Average inflow of tourist is more than two lakh per annum
4	Water (provisioning)	Irrigation and household purposes	Daily dependence by stakeholders for irrigation, washing and bathing purposes
5	Sediment retention (regulating)	Protect and stream banks against erosion action	Act as buffer against run off, also provide drainage and natural irrigation
6	Habitat for biodiversity (supporting)	Global recognition and biodiversity conservation	Diverse species of wild flora and fauna have been identified
7	Nursery for fishes (supporting)	Breeding area for fishes	High diversity of fishes

Source: Rao, 2018.

Total economic value of Kuttanad Wetlands

The total economic value of Kuttanad wetlands from various ecosystem services are summarized in Table 11. The total value estimated at 2017 price level was Rs 51.27 billion per year. The area of wetlands is 162,125 hectares. Hence, per hectare economic value of was Rs 0.316 million per ha per year.

The economic estimate of the direct use values was Rs 8.45 billion per year. The direct use value from wetland ecosystem comprises 16.47 per cent of the total economic value. The indirect use value which includes recreational services and erosion control service were valued approximately Rs 41 billion per year. The recreational services were valued by individual travel cost method and the erosion control service was valued through benefit transfer method. The indirect value comprises 79.96 per cent of the total economic value of the Kuttanad wetlands.

Supporting services like biodiversity conservation which are non-use values were valued by contingent valuation method (CVM). The non-use values, contributing 3.57 per cent of the total economic value, were worth Rs.1.83 billion per year. Thomson (2003) and Kakuru *et al.* (2015) used the contingent valuation method to estimate the non-use values of estuarine biodiversity and Ugandan wetlands, respectively. Thomson (2003) reported the monetary value of non-use value of estuaries in Kerala to be around Rs. 5,469.94 lakh per annum. Kakuru *et al.* (2015) reported the total non-use value of Uganda south western wetlands to be around US$ 298.14 million per annum.

The direct, indirect and non-use value of Kuttanad wetlands was 1.1 per cent of the state GSDP which highlights the economic significance of Kuttanad wetlands in the Kerala economy. With the increasing pressure on land resources owing to growing population, the conservation efforts for management of Kuttanad wetlands require to be strengthened.

Table 11. Total economic value of Kuttanad wetlands (2017 price level)

Sl. No.	Ecosystem services	Total value in Rs billion per year
A.	**Direct values**	
1	Rice farming	3.04
2	Fishing	5.4
3	Domestic Water Supply	0.0062
	Total	**8.45** **(16.47 %)**
B.	**Indirect values**	
4	Recreational services	0.235
5	Sediment retention	40.76
	Total	**40.99** **(79.96 %)**
C.	**Non-use values**	
6	Biodiversity conservation	**1.83** **(3.57 %)**
	Total economic value (Rs. billion per year)	**51.27** **(100%)**
	Area of wetlands (in hectare)	162,125
	Total economic value **(Rs. million per ha per year)**	**0.316**

Source: Based on secondary data (from National Wetland Atlas Kerala, SAC ISRO, 2010) and field survey data, Rao, 2018.

Conclusions

Ecosystems are highly productive systems, which provide a range of valuable services, fundamental to human well-beings. They provide various economically important goods and services and generate intangible yet significant services like climate stabilization, waste water treatment, air filtration, etc. This paper has reviewed ecosystem services, their relevance to agriculture, and economic values for wetlands, forests, agro-ecosystems and irrigation tank. Estimation of direct values of ecosystem is mainly by market price method and indirect values are estimated by replacement cost method, avoided cost method, alternate cost method, benefit transfer method etc. Recreational value provided by ecosystem was estimated mainly using travel cost method and non-use values using contingent valuation method or willingness to pay approach. The estimates of economic value of various ecosystems reviewed in the study illustrate the magnitude of economic significance of ecosystems in addition to their ecological significance. These estimated values would help raise awareness among the policy makers about the economic relevance of the ecosystems and their sustainable management to benefit the society. Furthermore, the valuation of ecosystems would also improve knowledge and awareness of economic importance of the ecosystems among the various stakeholders as well as the society as whole.

The estimates reviewed here indicate that the value of indirect ecosystem services (regulating services) is usually thrice the estimates of direct provisioning services. A large part of the total economic value is indirect use value which includes regulating services like erosion control, waste treatment and recreational services like ecotourism. The direct provisioning services like food, water and raw materials contribute less than the indirect values in the total economic value of the ecosystems. The case study of wetlands also revealed similar results and the indirect use value (erosion control and eco-tourism) were five times the total direct use values. The significance of indirect use services indicates that ecosystems possess value for more than that merely based on the exchange or utility viewpoint.

Even though the direct use values have been estimated in several studies, there is a dearth of studies which elaborate on mutualistic interactions and trade-offs related to agriculture and ecosystems. The lack of adequate and comprehensive inventory of ecosystems on a national level is evident. Ecosystem inventory and inclusion of economic value of ecosystem services are quintessential in policy making. In case of ecosystems like forests and tanks, *in-situ* conservation efforts should be undertaken by the communities living in proximity of the ecosystem and the benefits are distributed over a wider area. The relevance of these services to different stakeholders in the form of economic significance is to be further explored. The institutional mechanism for incentivising practices for conserving ecosystems and enhancing their services for the present and future generations is necessary. The mode of funding and transfer of benefits to the communities protecting the ecosystems is a subject of further research.

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CHAPTER 3

PAYMENT FOR ECOSYSTEM SERVICES: THE CONCEPT AND ITS APPLICATIONS

Priyanka Upreti

Introduction

The Millennium Ecosystem Assessment (MEA-2005), a major study of the effects of human activity on the environment by over 1,300 scientists from 95 countries. It popularized the term ecosystem services and defined them as the benefits that people obtain from the ecosystems. These benefits are categorized mainly into three categories:

1. Direct benefits:
   - Provisioning services: Have value in the market, e.g. water, food, etc.
   - Regulating services: Regulation of land degradation, floods, etc.
2. Indirect benefits:
   - Supporting services: Formation and storage of organic material, processes of photosynthesis, soil creation, nutrient cycling, etc.
3. Non-material benefits:
   - Cultural services: Recreational opportunities, aesthetic pleasure and cultural and spiritual sustenance etc.

Agricultural ecosystems are the largest managed ecosystems in the world. Out of the total land area of about 13 billion hectares, crop and pasture occupy almost 5 billion hectares.

Over the years, ecosystem goods have been consumed without taking considered steps for their conservation MEA has found that over 60 per cent of the ecosystems are being degraded faster than they can recover.

Thanks are due to Suresh Pal for guidance during preparation of this paper.

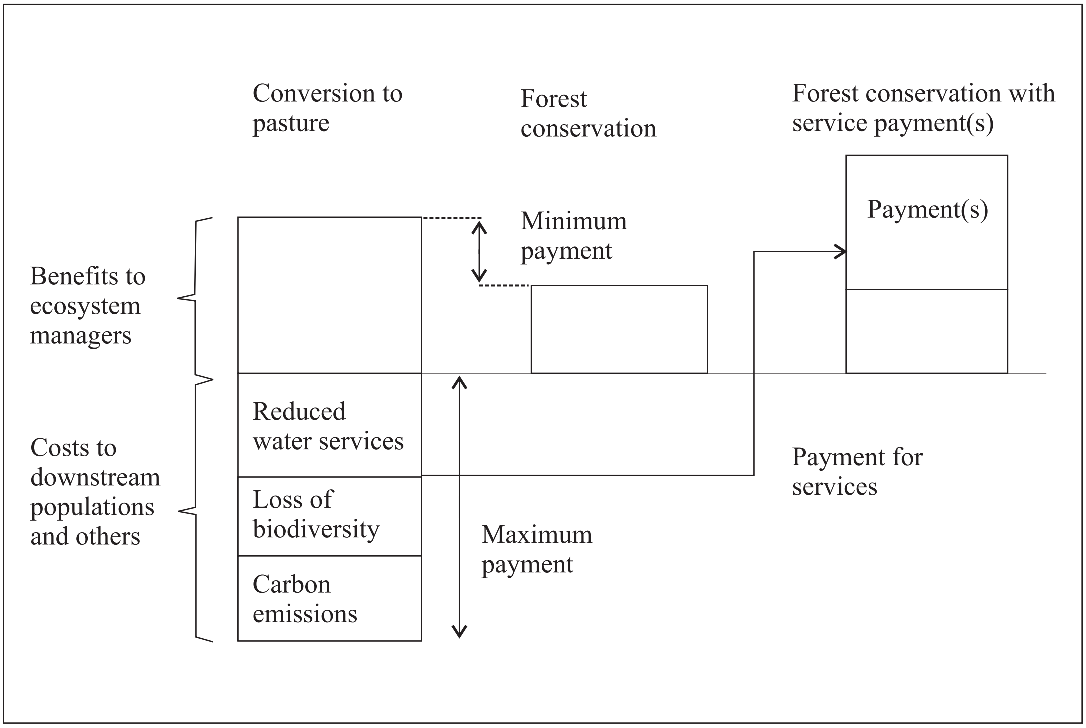
If we look from an economic perspective, degradation occurs because of non-excludability or problem of free riders and non-rivalry problems of ecosystem services, resulting in the externalities. As public goods, ecosystem services have been undervalued till now as there are no such institutions that can internalize the value of these services. Payment for Environmental Services (PES) is discussed as a novel conservation approach and ''probably the most promising innovation in conservation since Rio 1992,'' as it attempts to overcome the problem of externalities (Engel *et al*., 2008).

Environmental services are the subset of ecosystem services. It includes all of the ecosystem services, except provisioning services. Therefore PES includes those ecosystem services which are not marketed yet. Payment for environmental services (PES) is defined as a market based mechanism to translate external, non-market values of the environment into financial incentives so that provisions for such services are ensured. The central principle behind it is that those who provide environmental services should be compensated for doing so and those who receive the services should pay for their provision (Pagiola and Platais, 2007). Wunder (2005) defined PES as "a voluntary transaction where a well-defined environmental service (or a land-use likely to secure that service) is being 'bought' by a (minimum one) service buyer from a (minimum one) service provider, if and only if the service provider secures service provision (conditionality)" (Fig. 1).

Therefore, if market forces reward investments in ecosystem services, a positive feedback loop will start in which there will be increased investments in ecosystem services, leading to increased production of ecosystem goods. This will automatically accelerate sustainable economic growth and ecological restoration.

By converting land to pastures, land owners will realize some benefits. In turn this land conversion will cost to downstream people in terms of reduced water services, loss of biodiversity and carbon emissions. In contrast, land owners are receiving less benefit from using their land for forest conservation but it is providing benefits to the downstream people in terms of water filtration, reduction in biodiversity and carbon storage. Here land owners will be induced to adopt conservation if there will be any provision of payments by the downstream people to them. The payment offered to land owners must exceed the additional benefit they would receive from the alternative land use (or they would not change their behavior) and must be less than the value of the benefit to service users (or users would not be willing to pay for it).

But in practice it is not so simple. One particular kind of land practice provides several environmental services. First these are to be identified and then valuation of those environmental services is to be done. The most important step is to identify those people who are actually receiving the environmental benefits and are willing to pay for that. Then payment is to be done by the willing buyers to the willing sellers.



Source: Adapted from Pagiola and Platais (2007)

Fig 1. The logic of payments for environmental services

Economic Conceptualizations of PES

Two types of conceptualizations of PES (Table 1) are described below:

Coasean conceptualization: According to the Coase theorem, "given low or no transaction costs and clearly deûned and enforceable property rights, no governmental authority is needed to overcome the problem of internalizing external effects". He has restricted the task of government to the initial allocation of property rights. Here the actual service users pay to the service providers.

Pigouvian conceptualization: It is based on the ''Pigouvian philosophy of taxing negative or subsidizing positive externalities''. Here the government is considered as a ''third party acting on behalf of the service buyers'' (Engel *et al*., 2008).

Table 1. A comparison of the Coasean and Pigouvian concepts

	Coasean concept	Pigouvian concept
Also called	User financed PES programs	Government financed PES programs
Efficiency	More efficient (we can observe directly whether the service is being delivered or not and also possibility of re-negotiation is there)	Less efficient
Implementation	Where local monopsony or oligopsony is there*	Where beneficiaries cannot be excluded at all or at reasonable costs.
Payers	Service users	Government
Nature of goods	Focuses on the provision of 'club goods'^	Public goods
Example	The water bottler Vittel in France is paying to farmers for maintaining high water qualities.	Costa Rica's PSA program, Mexico's PSA-H program etc.

*Because if number of buyers increases, free riders problem as well as transaction cost increases.

^Club goods are an intermediate category between public and private goods, that can be consumed by many individuals (the members of the club) without affecting the consumption of others, but whose consumption by non-members can be prevented.

Methods of Valuation of Environmental Services

Revealed preference methods

Market price method: It is mainly used to obtain the value of provisioning services (e.g., food), since the commodities produced by provisioning services are often sold on. It is done with the help of market prices. Sometimes also used in cultural (e.g., recreation) and regulating services (e.g., pollination).

Productivity approach: It is used to value those ecosystem services that contribute to the production of commercially marketed goods. For example, valuation of soil fertility that has improved crop yield is to be done by the increased income of the farmers.

Surrogate market approaches

i. ***Travel cost:*** It is used to value recreational sites on the basis of the amount of time and money people spend while travelling to the site.

ii. ***Hedonic pricing:*** It utilizes information about the implicit demand for an environmental attribute of marketed commodities. e.g. by estimating the demand function of real estate, valuation of environmental attributes, which has surrounded the real estate, like clean air, presence of water and aesthetic views, is to be done.

Cost based methods

i) ***Replacement Cost method*** *:* estimates the costs incurred by replacing ecosystem services with artificial technologies, e.g. valuation of groundwater recharge is done by estimating the cost of obtaining water from another source.

ii) ***Mitigation or Restoration Cost method:*** estimates the cost of mitigating the effects caused by to the loss of ecosystem services or the cost of getting those services restored; e.g., valuation of flood barriers is done by estimating the cost of preventive expenditure.

iii) ***Avoided Cost method****:* estimates costs that would have been incurred in the absence of ecosystem services. For example, valuation of flood control services is done by estimating the damage if flooding will occur.

Stated preference approaches

i) ***Contingent Valuation Method (CV):*** It uses questionnaires to ask people how much they would be willing to pay to increase the provision of an ecosystem service, or alternatively, how much they would be willing to accept for its loss or degradation.

ii) ***Choice Modeling (CM):*** In this method respondents are asked to choose alternative choice sets which have different combination of price and ecosystem attributes.

iii) ***Group Valuation:*** In this method stated preference techniques are combined with elements of deliberative processes from political science. It is a way to tackle shortcomings of traditional monetary valuation methods. Main methods within this approach are *Deliberative Monetary Valuation (DMV)* to express values for environmental change in monetary terms, and *Mediated Modeling* to assess any value that a group of stakeholders could identify and build into a model, and can be used to assess the value of biodiversity from a stakeholder's perspective in developing countries. Further details of all the valuation methods are discussed in Chapter 2.

Options for payment

Payment may be done in the following forms (i) Direct financial payments: First is the monetary compensation to the service providers. Financial support for specific community goals**:** This second option is like building of a clinic or school for compensating the provision of environmental services. (iii) In-kind payments**:** Such as beehive and training of bee-keeping are also followed for improved water management in Bolivia. In the process of payment for ecosystem services, recognition of rights such as increased land rights and increased participation in decision-making processes are critical for success of the payment mechanism (Table 2).

Table 2. Examples of PES from worldwide

Scheme	Services	Buyer	Level	Funding	Selection of sellers	Payment
Pimampiro in Ecuador 2000	Watershed	Municipal government	Local	Water fee, interest on the capital fund, seed capital donation (IAF+FAO) municipality support, CEDERENA support	Nueva America community	US$6-12/ha/year
PROFAFOR in Ecuador 1993	Carbon sequestration	Private company	Regional (selected provinces)	DUTCH electricity generating board	Plantation sites are selected on the basis of Biophysical conditions (slopes, soil, altitude), economic criteria (locally marketability of timber)	US$ 100-200/ha fees, 70-100% value of harvested wood, 100% non-wood and sub-products
Conservation reserve program (CRP) in USA1985	Watershed, biodiversity, soil	Centre, state	National	FSA (farm service agency) via the commodity credit corporation (CCC)	• Producer must have owned or operated the land for at least 12 months prior to CRP • Land must be either crop land or marginal pasture land	Rental payments: • Maintenance incentive payments- 5$/acre/year • Cost share assistance- not more than 50% of participants 'costs • Other incentives -20% of the annual payments for continuous sign-up practices
Vittel in France 1993	Watershed	Private company	Local	Nestlé Waters, through its intermediary 'Agrivair'	Farmers must: • Give up maize cultivation for animal feed • Only one cattle head per hectare • Lower agrochemical use • Improve waste management	• Land debt is abolished and farmers have additional land to farm • Farmers receive a subsidy (on average about 200 Euros /ha/year for five years) • 150,000 euros per farm to cover the cost of all new farm equipment

PES Case Studies Pago por Servicios Ambientales in Costa Rica

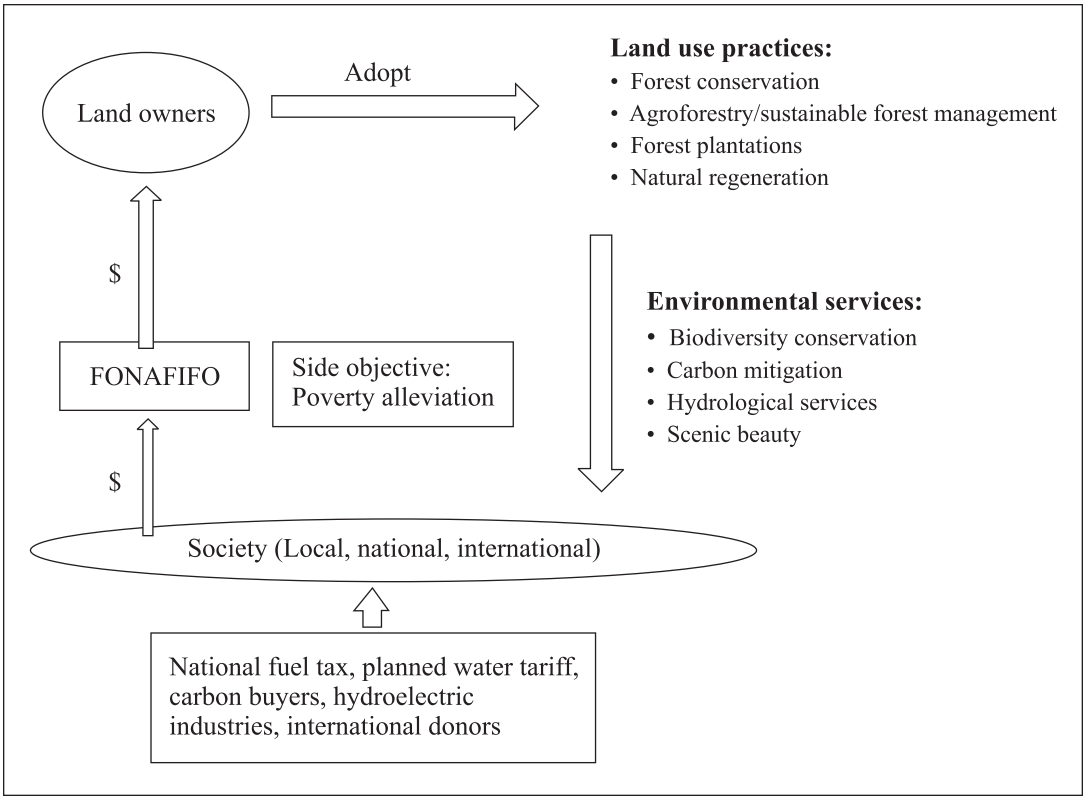
Costa Rica has a long history of payment for afforestation programe. It provided tax credit in 1979 which were replaced by the forest payment certificates during 1986 to 1995. In 1996, the country shifted to PSA (Pago por Servicios Ambientales). Costa Rica pioneered the use of payments for environmental services (PES) in developing countries by establishing a formal, country-wide program of payments, viz. PSA. It has helped the country, once known as having one of the world's highest deforestation rates, to achieve negative net deforestation in the early 2000s. In 1996, Costa Rica developed PSA for hydrologic, aesthetic/ landscape beauty, biodiversity conservation, and carbon sequestration services. The PSA was different from earlier forest management programs in the following two ways: (i) Conceptually: instead of funding only the timber industry, PSA acknowledges all the benefits that a forest land provides and gives them economic value. (ii) Financially: instead of receiving financing from the general budget, PSA obtained funding from tax on fuel, water tariff and voluntary payment from beneficiaries.

The PSA mechanism is given in Fig. 2. . Land owners adopt a particular land practice, which provides different environmental services to the society. The FONAFIFO, a semi-autonomous agency, manages the program. It obtains funds from different sources (Fig.2) and pays to land owners. For different type of contracts different amount of payment is offered based on the opportunity cost of a particular land (Table 3).

Table 3. PSA contracts

Modality	Status	Criteria	Current payments
Forest protection	Dates from forest law 7575 to present	2 to 300 ha enrolled, up to 600 ha within indigenous areas	$64/ha/year for 5 year period; renewable
Reforestation	Dates from forest law 7575 to present	Between 1 to 300 ha enrolled; maximum 50 ha enrolled; minimum 50 ha enrolled	$16/ha over 10 year period
Natural forest regeneration	Dates from 1st mention in 2005 to present	Minimum of 2 ha	$41/ha/year for 5 year period; renewable
Agro-forestry systems	Dates from 2003 to present	350 to 3500 trees per participants; up to 336,000 trees per joint project, cooperative or indigenous reserve; specific requirements per ha	$1.30 per tree; over 3 year period
Forest management	Dates from forest law 7575 until 2002	Criteria determined by conservation area	$343 per ha over 5 year period

Source: Bryan Johns (2012)



Source: Engel, Wunscher, and Wunder (2007)

Fig 2. Mechanism of PSA

Impact of the PSA Program

Area enrolled: At the end of 2005, about 270,000 ha was enrolled in the program. Forest conservation has consistently been the most popular contract, accounting for 91 per cent of the area covered since 1998, and for 95 per cent of the enrolled area at the end of 2005. Total area contracted in the PSA program because of reduced net value of payments and high transaction cost. However, total active contracts under PSA are increasing from 1998 onwards (Pagiola, 2008).

Household budget and poverty

Miranda *et al*. (2003) has done the analysis of Virilla watershed and found that PSA represents approximately 16 per cent of the household budget. The proportion is largest for properties of over 130 ha (34 per cent) and smaller for properties of 30 ha or less (4 per cent), where other economic activities are more prevalent. The proportion of PES of average income for the landowners who declared that PES represents their main activity, second and third activity is 37 per cent, 12 per cent and 18 per cent, respectively (Table 4). They also found that approximately half of the respondents (47 per cent) have used more laborers as a result of joining the PES scheme. The same number of landowners (47 per cent) reported that they have used their existing workers.

The impact of the PSA Program on the poverty was found mixed. Miranda *et al*. (2003) reported that the major portion of program benefits tend to go to larger and relatively better-off farmers. On the contrary, Munoz (2004) found that the PSA Program plays an important role in the livelihood of poor land holders in the Osa Peninsula.

Table 4. Proportion of income from PES by property size

	Income (US$ per year)			**Proportion of PES budget within HB**		
	Payments	Income	Proportion of PES within HB	Main	Second	Third
Less than 10 ha	882	22,000	4%		2%	5%
11 to 30 ha	931	22,000	4%		5%	1%
31 to 80 ha	1,900	19,557	9%		9%	
81 to 130 ha	2,022	15,200	18%	37%	6%	14%
More than 131 ha	11,252	20,663	34%		41%	30%
Total	**4,243**	**19,787**	**16%**	**37%**	**12%**	**18%**

HB: Household budget
Source: Miranda *et al*. (2003)

Impact on forest cover and carbon emission reduction

Arriagada *et al*. (2008) analyzed the effect of PSA on forest cover by propensity score matching (PSM) in the Sarapiqui region of north eastern Costa Rica. PSM is used to estimate the difference in outcomes between the participants and the non-participants of PSA. Here propensity score is the probability of participating in PSA. By using all the methods of PSM, i.e. nearest neighbor, radius matching and kernel matching, they found that the impact of participation in PSA ranged from 0.9 to 1.2 ha indicating very less impact on the forest cover. Here it may also be noted that at the time of introduction of PSA, deforestation was already in declining trend because before PSA there were already some schemes of payment for reforestation and forest management.

Tattenbach *et al*. (2006) found that 644 million m^3/year of water for consumptive uses and 7,224 million m^3/year of water for hydropower production are being protected from the deterioration in quality. They also found that about 65 per cent of PSA conservation contracts were in biodiversity priority areas. The 21,000 ha of plantation under the PSA program sequestered a cumulative total of about one million tonnes of carbon during 1998-2005.

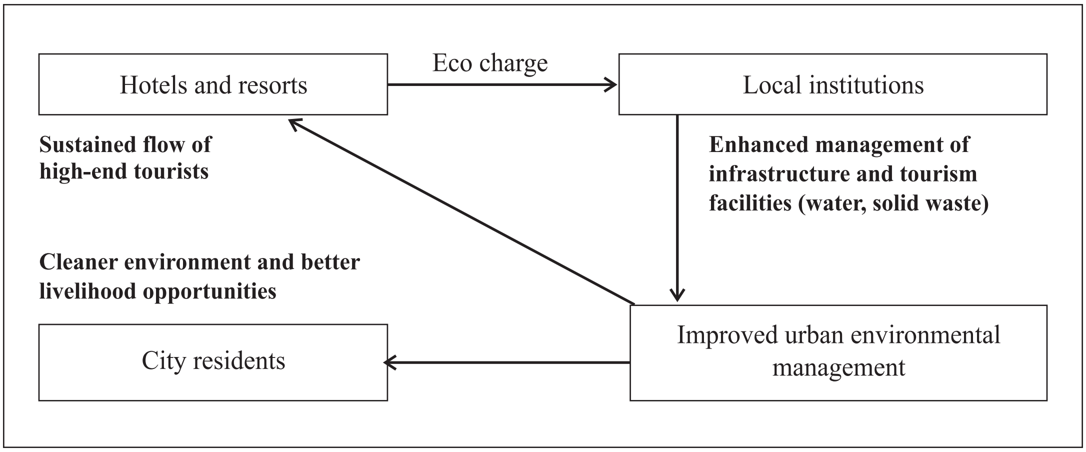
PES in India

Recreation and landscape services

Although PES in India has not formally been implemented at the national level but at the local level in some villages this scheme is being adopted. Examples can be seen in the villages of Himachal Pradesh and Sikkim. Kuhan village in Kangra district of Himachal Pradesh receives high rainfall and yet faces water shortage. In 2003 village pooled resources and with the help of watershed development project constructed a checkdam on Gulana Khad, a nullah (creek). As a result, crop production increased six times with the available irrigation. But in 2005 this reservoir collected silt and its capacity got halved. With the help of Winrock International, villagers identified the problem that silt was coming from grazing land of Ooch village. As a solution, both villages reached a formal agreement (Coasean bargaining): Ooch banned grazing for 8 years and planted saplings of fruits, trees, bamboo etc. and in exchange, Kuhan paid for the saplings and provided irrigation water to them. Because of this silt road in the nullah reduced and the villagers rejoiced again. This is a clear example of PES in India.

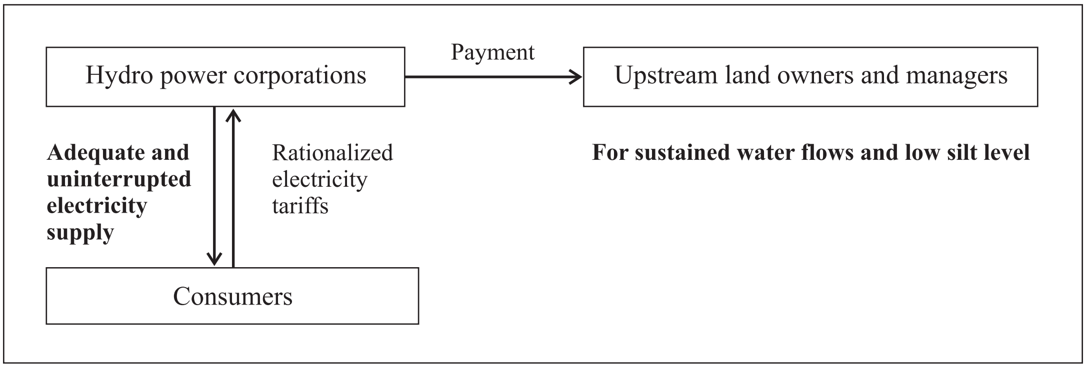
The World Wide Fund for Nature – India, initiated a project in 2008 to examine the potential PES models for selected forest ecosystem services in Gangtok (Sikkim), Shimla (Himachal Pradesh) and Munnar (Kerala) in collaboration with the Institute of Economic Growth and supported by the World Bank (WWF, 2008).

Hotels and resorts can provide payment in the form of eco-charge to the local institutions for the enhanced management of infrastructure and tourism facilities. This will improve urban environment which will benefit hotels and resorts because of high flow of tourists. City residents will also get benefit in the form of cleaner environment and better livelihood opportunities (Fig. 3 & 4).



Source: WWF (2008)

Fig 3. PES Model for Recreation Services in Gangtok, Munnar and Shimla



Source: WWF (2008)

Fig 4. PES model for water supply services in Sikkim, Munnar and Shimla

Hydro power corporations can also provide payment to upstream land owners for sustained water flows and low silt level so that they can provide adequate and uninterrupted electricity supply to the consumers. Similarly in this model, trekking and tour service providers can provide payment to the local communities for maintenance of trekking trails and management of natural areas, benefitting tourism department in terms of increased tourist flow.

Willingness to pay

Some studies were conducted in India for determining willingness to pay (WTP) and willingness to accept (WTA) of the people for the environmental services (Table 5, 6).

Economic value of irrigation water

Venkatachalam and Narayanamoorthy (2012) studied farmers' preferences measured in terms of WTP and WTA compensation for voluntary exchange of irrigation water. They selected a sample of 310 farmers across all the canal systems in the Bhivani basin and using field surveys identified 125 potential buyers and 129 potential sellers, remaining 54 farmers were not willing to participate in water exchange.

Table 5. Change in the WTP values across three rounds

Elicitation round	No. of farmers	Mean value (Rs.)	Median value (Rs.)	Standard deviation
WTP1	125	272.44	250	156.80
WTA1	129	318.44	260	195.31
WTP2	125 (110 farmers revised)	308.12	250	169.53
WTA2	129 (42 farmers revised)	301.97	250	190.51
WTP3	125 (24 farmers revised)	312.64	250	170.14
WTA3	129 (10 farmers revised)	300.03	250	190.25

Source: Venkatachalam and Narayanamoorthy (2012)

Contingent valuation method was used for valuation of irrigation water. In the first round, from the identified buyers and sellers, their initial WTP and WTA values for specific amount of water was asked. In the second round, among all the sellers whose WTA value was the highest was communicated to all the buyers and asked if they want to revise their WTP. Similarly, WTP value of that respondent whose bid was lowest among all the buyers was communicated to sellers and asked if they want to change their WTA value. In the third round, same procedure was repeated and the mean value of WTP and WTA converged to a common value. The results showed that out of all the buyers, 64 per cent of them were willing to pay the equilibrium price of Rs 300 and 63 per cent of sellers are willing to accept this amount as compensation. This means that water trade will take place among 63 per cent of the farmers who were willing to participate in water trade.

Willingness to pay for restoration of natural ecosystem

Ekka and Pandit (2012) analyzed the willingness to pay of people of Gosaba islands of Sundarban Mangroves for its conservation and also analyzed the effect of covariates on WTP. WTP was the dependent variable and explanatory variables were divided into quantitative, binary and categorical variables. Step-wise logistic regression was used to determine, which independent variables were predictor of people's WTP. The cases where the respondents were willing to pay, WTP was given value of one and zero otherwise.

Table 6. Individual's willingness to pay

WTP bid value (Rs)	Accepted (WTP=1)	Rejected (WTP=0)	Total
10	119 (40.07)	27 (16.67)	146
20	81 (27.27)	29 (17.90)	110
30	56 (18.86)	27 (16.67)	83
50	16 (5.39)	19 (11.73)	35
70	6 (2.02)	9 (5.56)	15
100	5 (1.68)	11 (8.02)	16
120	6 (2.02)	7 (3.09)	12
150	4 (1.35)	10 (6.17)	15
200	2 (0.67)	7 (4.32)	9
250	1 (0.34)	6 (3.70)	7
300	1 (0.34)	5 (3.09)	6
500	0 (0.00)	5 (3.09)	5

Source: Ekka and Pandit (2012)

Around 64.71 per cent of the respondents agreed to pay for conservation of mangroves at different bid levels and 35.29 per cent of respondents did not agree to pay at specified bid level. With the help of logistic regression they found that only 3 variables were making significant contribution to the WTP, i.e. the bid value that the respondents were willing to pay, respondent's perception regarding mangrove degradation, and mode of payment. Therefore, for popularization of WTP for ecosystem services, information for education of beneficiaries and payment mechanism, are critical.

Conditions and Challenges for Success of PES

Following conditions are necessary for the successful implementation of PES:

- Flexibility in the model clearly defined and secure property rights over environmental resources.
- A continuous provision of environmental services, and proper assessment of environmental services generation and their appropriate valuation.
- There is always a need to reduce transaction cost so that the schemes are economically viable for both sellers and buyers.
- Multiple sources of revenue can help in reducing uncertainty in the flow of financial resources.

- Lack of transparency and trust between buyers and providers may hinder the success of PES schemes. In common lands when it is necessary to bring all the landowners under new land-use norms, lack of consensus on the part of the landowners may obstruct the progress of the schemes.
- User-financed PES schemes are likely to perform better than government-financed ones.
- Adoption of PES is higher when NGOs and civil society institutions, particularly community-based organizations, are present. Environmental service providers should be provided with adequate technical assistance.

For successful implementation of PES, India faces the following challenges:

- Insecure and ill-defined property rights, and problem with organization of a large number of small landholders and alter their land-use pattern.
- Provision of easy access to credit markets and sufficient technical and extension services to farmers.
- Ensuring the participation of all sections of the people from such a diversified society is a challenge.
- Existing socio-economic, religious and political differences are likely to limit its effectiveness.

If these challenges are met, certainly there is a potential to introduce PES in India. FAO has identified that agriculture can provide a better mix of ecosystem services to meet society's changing needs if better incentives are provided. In order to secure active involvement and support from the Government for large scale projects, more studies covering different ecosystems need to be undertaken on relevant PES models and more information is needed through research in both natural as well as social sciences. The institutions and capacity building for managing PES should also be strengthened.

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CHAPTER 4

WATERSHED MANAGEMENT AND ECOSYSTEM SERVICES

P.K. Mishra, Pradeep Dogra, V.C. Pande and M. Madhu

Introduction

International community has focused, for quite some time, on the importance of ecosystem services (ES) for nature conservation to sustain human well being (West, 2015). This focus further got intensified with the evolution of platforms like Millennium Ecosystem Assessment (MEA) and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) which laid down protocols to formally account for ecosystem benefits/ services and value them to incorporate them into the decision making of relevant stakeholders. The 'Land Degradation Assessment' theme of the IPBES specifically deals with assessment of land degradation and restoration (IPBES 6) (https://www.ipbes.net/event/ipbes-6-plenary). This is in synchronization with the watershed management programmes undertaken in the country to address the issues of natural resource management. Adoption of conservation specific measures may not only help sustain the natural resources but may also help minimize and/ or check the land degradation processes.

Land Degradation

Of India's total geographical area (328.7 M ha), 304.9 M ha comprise the reporting area with 264.5 M ha being used for agriculture, forestry, pasture and other biomass production. The time period wise severity and extent of land degradation in the country has been assessed by different agencies (Table 1) and the estimates vary widely from about 47 M ha to 188 M ha in their assessment due to conceptual and methodological variations.

A recent harmonized national data sets on land degradation in India shows that 120.7 M ha or 36.7% of the total arable and non-arable land area of the country suffers from various forms of land degradation (Maji, 2007; NAAS, 2010). Water erosion is the chief contributor, affecting 83 M ha (68.4%). Further, soil erosion results in loss of soil organic carbon, nutrient imbalance, compaction, decline in soil properties including soil biodiversity, and contamination with heavy metals and pesticides. In a recent study, Sharda and Ojasvi (2016) with updated data have estimated annual soil loss rate in India at about 15.35 t ha^{-1}, resulting in loss of 5.37 to 8.4 M tonnes of nutrients, reduction in crop productivity, occurrence of floods/droughts, reduction in reservoirs capacity (1% to 2% annually), and loss of biodiversity.

Table 1. Extent of land degradation in India, as assessed by different agencies over various time periods

Organizations	Reference	Degraded area (M ha)
National Commission on Agriculture	(NCA,1976)	148.1
Ministry of Agriculture-Soil and Water Conservation Division	(MoA,1978)	175
Department of Environment	(Vohra,1980)	95
National Wasteland Development Board	(NWDB,1985)	123
Society for Promotion of Wastelands Development	(Bhumbla and Khare, 1984)	129.6
National Remote Sensing Agency	(NRSA,1985)	53.3
Ministry of Agriculture	(MoA,1985)	173.6
Ministry of Agriculture	(MoA,1994)	107.4
NBSS&LUP	(NBSS&LUP,1994)	187.7
NBSS&LUP (revised)	(NBSS&LUP,2004)	146.8
National Remote Sensing Centre & Indian Space Research Organization	(NRSC&ISRO,2003)	55.64
National Remote Sensing Centre & Indian Space Research Organization	(NRSC&ISRO,2006)	47.22
National Remote Sensing Centre & Indian Space Research Organization	(NRSC&ISRO,2009)	46.70
National Academy of Agricultural Sciences	(NAAS,2010)	120.7

Watershed Management

Watershed management programmes bring about significant changes in agro-ecosystems, and thereby, improve and sustain the well being of the stakeholders dependent on these ecosystems, primarily the human settlements in and around these agro-ecosystems and different life forms as well as abiotic dependents. Soil conservation interventions support many services viz., formation of alluvial and Aeolian (loess) soils, weathering of alumino silicates and sequestration of atmospheric CO_2, formation and evolution of landscape with distinct soil types in relation to landscape position, biogeochemical recycling, etc., which otherwise would have been lost to accelerated erosion (Lal, 2014). Agricultural practices with conservation measures provide several ecosystem services including modulating water quality and quantity, organic waste disposal, soil formation, biological nitrogen fixation, maintenance of biological diversity, biotic regulation, and contribution to global climatic regulation (Paoletti *et al*., 1992; Pimentel *et al*., 1997; Bjoerklund *et al*., 1999). Soil water available for evaporation and transpiration (green water), similarly, provides ecosystems services viz., increased water availability for crops, increased fluxes towards aquifers, thereby increasing water supply and regulating stream flow, and reduction of erosion and siltation of reservoirs used for hydroelectricity which can be enhanced by up to 20% by SWC measures (Kauffman *et al*., 2014). Downstream effects of soil erosion may be quite serious not only for land users in the upstream but also for hydroelectricity and water companies that are confronted with rapid siltation of their reservoirs (Hunink *et al*., 2013). Thus, conversion to a restorative land use and adoption of conservation-effective measures would sustain/ improve soil and ecosystem C pools, enhance soil quality, and increase net primary productivity (NPP), among numerous ecological benefits. Over and above the beneficial impacts on water quality, a principal ecological benefit of soil conservation and restoration is the increase in the C pool in the soil and the terrestrial biosphere with the attendant negative feedback on climate change. Improvement in soil quality would enhance resilience against climate change by dampening the effects of extreme events, moderating fluctuations in microclimate, reducing diurnal/annual variations in soil temperature and moisture, and mitigating the climate change.

Watershed Management and Ecosystem Services

Watershed management encompasses different types of soil and water conservation measures (SWC), as per land specific degradation problems, are used for natural resource conservation. These can be classified as,

- Agronomic measures: plant/soil cover, conservation farming methods, contour farming
- Vegetative measures: planting barriers (vegetative strips), live fences, windbreaks
- Structural measures : terraces, banks, bunds, cut off drains, barriers
- Others: area closures (relevant to ravines), selective clearing

Various SWC measures and associated ecosystems services are given in Table 2.

Table 2: Soil and water conservation measures and ecosystem services

S.No	Types of services	Soil and water conservation measures					
		Agro-nomic	Vege-tative barriers	Engi-neering	Drain-age line treat-ment	Agro-forestry & plan-tation	Water resource develop-ment
I	**Provisioning services**						
1	Food, fodder, fibre, freshwater	**	*	*		**	**
II	**Regulating services**						
1	**Hydrological**						
a	Water runoff moderation	**	**	**	**	**	
b	Soil water storage	**	**	**		**	
c	Drought mitigation	*	*	**	**	**	**
d	Ground water recharge			**	**	**	**
e	Water quality	*	*	*	*	*	
2	**Micro-climate change**						
a	Resilience to climate change	*	*	*	*	**	***
b	Air quality/gas regulation	*	*			**	
c	Carbon sequestration	**	**			**	
d	Change in soil micro climate	**	**	*		**	
III	**Supporting services**						
1	**Soil**						
a	Soil depth	**	**	**		**	
b	Soil formation	**	**	**		**	
c	Soil biodiversity (habitat)	**	**	**		**	
d	Soil quality	**	**	**		**	
2	**Nutrients cycling**						
a	Soil reserve	**	**	**		**	
b	Plant/crop uptake	**	**	**		**	
c	Soil organic stock	*	*	**		**	
IV	**Cultural services**						
	Recreation & aesthetic value					**	**

Note: Number of asterisk indicate strength of service.

These can be implemented individually or in combination depending upon the problem to be addressed. Different ecosystem services (Table 3) flow from soil and water conservation measures depending upon topography, land use and land cover, climatic conditions, demography etc. Adoption of conservation measures on watershed basis reverses the degradation trend, and thereby, supports production in addition to environmental benefits such as climate change mitigation.

Table 3: Ecosystem services provided by soil and water conservation

Service	Definition	Description
Provisioning services	Provision of food, fodder, fuel wood and fibre	Soils are a medium for plants to grow and it supplies them with nutrients and water, thereby, producing food and providing many other outputs different purposes. Conservation of soil and water sustains these provisioning services
	Provision of raw materials	Soil and water conservation also augments and sustains supply of raw materials, e.g. topsoil, peat, sand, clay minerals, etc. directly, and indirectly from medicinal and ornamental resources
	Provision of water	*In-situ / ex-situ* conservation of water ensures supply of water to meet basic needs of humans and other life forms, and special purposes such as for irrigation.
	Provision of support for human infrastructures and animals.	Soils represent the physical base on which human infrastructures and animals stand. Soil conservation prevents mass erosion that causes loss of infrastructure and life.
Regulating services	Soil retention	Indirect consequences of erosion by water are increased sedimentation of the displaced geo-mass in streams, canals and rivers, particularly in foot hills, which reduces their carrying capacity and increases their width, which in turn leads to degradation of adjoining agricultural lands, meandering of river courses, and smothering of crops and vegetation. Sedimentation also leads to reduction in the storage capacity of many reservoirs. Further, sediments deposited into water bodies pose a serious hazard threat to the aquatic submerged vegetation and the aquatic food chain.
	Flood mitigation	Soils have the capacity to absorb and store water, thereby regulating water flows. Water conservation prevents occurrence of floods.
	Filtering of nutrients and contaminants	Soils can absorb and retain nutrients (N, P) and contaminants and avoid their release in water bodies. Conservation prevents quality of naturally existing water from degrading.

Table 3 contd...

Service	Definition	Description
	Carbon storage and greenhouse gases regulation	Soils have the ability to store carbon and regulate their production of greenhouse gases such as nitrous oxide and methane. Prevention of soil loss boosts this regulating service
	Detoxification and the recycling of wastes	Soils can absorb (physically) or destroy harmful compounds. Soil biota degrade and decompose dead organic matter thereby recycling wastes.
	Regulation of pests and diseases populations	By providing habitat to beneficial species, soils and vegetation of agro-ecosystems can control the proliferation of pests (crops, animals or humans) and harmful disease vectors.
Cultural services	Recreation / ecotourism	Natural and managed landscapes can be used for pleasure and relaxation. Soil and water conservation improves landscapes and micro-climate within a watershed making it conducive for ecotourism.
	Cultural identity / inspiration	Natural and cultivated landscapes establish a strong cultural linkage between humans and their environment.
Supporting services	Soil formation	Soil conservation provides good vegetative cover to the soil which protects the process of soil formation. Soil erosion disrupts this process.
	Nutrient recycling	Soil erosion causes disruption of nutrient recycling. Conversely, conservation prevents this disruption thereby maintaining this supporting service.
	Primary production	Primary production provides the basis of the food web for all higher consumers – herbivores as well as carnivores. Watershed management augments primary production.
	Biodiversity	Biodiversity maintenance is a natural consequence of conservation. Biodiversity helps to keep environment resilient and adaptable to external stress by providing alternative pathways, if a pathway is disrupted.

Attempts have been made for valuation of natural resources (Freeman, 1993) and valuation of natural resource degradation. In India, valuation of natural resources encompasses diverse domains of forest and forest based resource (Chopra and Kadekodi, 1997; Verma, 2000), wetlands (Verma, 2000), soil conservation (Chopra and Kadekodi, 1997; Parikh, 2001) and others such as recreation/ ecotourism (Chopra, 1998; Murty and Menkhaus, 1994) and water supply (Chaturvedi, 1992).

The ecosystem services flowing from watershed, treated with soil and water conservation measures can be measured with different indicators (Table 4).

Table 4: Indicators for determining ES

Ecosystem service	Bio-physical indicator	Valuation
Provisioning services		
Crop production	Annual crop yield	Market price analysis
Pasture production	Annual forage yield	Market price analysis
Freshwater supply	Annual groundwater recharge/ water yield	Productivity method
Regulating services		
Carbon storage	Amount of carbon stored	Market price analysis
Soil retention	Annual sediment yield	Cost based method or productivity loss
Flood regulation	Flood regulation capacity	Cost based method or loss avoided Contingent valuation
Water purification	Annual nutrient (P and N) loading	Cost based method; Contingent valuation
Supporting services		
Nutrient recycling	Annual sediment yield	Cost based method or productivity gains
Primary production	Annual production	Market price analysis

Case Studies

Soil and water are the precious natural resources, which play a major role in providing plenty of ecosystem services in many ways. Effective management of these resources contributes greatly in increasing the value of ecosystems. Some illustrations of ecosystem services of soil and water conservation measures are discussed, as under, following the above framework.

Semi-arid agricultural watershed

Soil and water conservation and water storage structures, under semi-arid conditions, help in groundwater recharge, an important source of irrigation. The study was taken up in a semi-arid tropical watershed Antisar, lying at 73^{0}10' E Longitude and 23^{0} 0' N Latitude and 100 m above mean sea level in district Kheda, in Central Gujarat, which receives an average annual rainfall of 835 mm in about three and a half months (mid June to end of September). Most of the annual rainfall (78%) was received during this period and to conserve this, the soil and water conservation measures were taken up including 23 recharge filtering units and 16 check dams, besides leveling, bunding.

The resultant increase in groundwater recharge was valued in terms of output value of the crops grown with groundwater irrigation. The total actual water extracted during each irrigation event from the watershed was distributed among the farms for irrigating crops in proportion to the product of irrigation time and the pump capacity (hp). Volume of water withdrawal concurrent to an irrigation event was computed based on the water level fluctuations in the wells in conjunction with potential recharge contribution from the surface storage structures to the groundwater aquifer. A production function approach was used to estimate the marginal productivity of water. The inter-season as well as intra-season groundwater use, and the consequent groundwater withdrawals were analyzed based on the marginal value and output elasticity of water at different crop growth stages during the season. The cotton crop realized marginal value product of water, ranging from Rs 1.03/m^3 to Rs 10.43/m^3 at different crop growth stages in cotton. Castor crop had the marginal value product ranging from Rs 2.89/m^3 to Rs 6.81/m^3 (Pande *et al*., 2012).

Lachhaputraghati watershed, Odisha

Lachhaputraghati (LPG) watershed is located at 82°56' to 82°58' E longitude and 19°45'30' to 19°47'30" N latitude with an elevation range of 900 m to 1,258 m above msl. The total area of the watershed is about 601.24 ha with undulating to steeply sloping (up to 50 per cent) topography. Out of the total geographical area of 601.24 ha, maximum area is under degraded forest (61 per cent) followed by the net cultivated area (20.15 per cent), current fallow (11.5 per cent), area under non-agricultural use (6.0 per cent) and area under pasture land (1.4 per cent). The watershed development activities taken in the watersheds included soil and water conservation measures in arable lands, water resource development, productivity enhancement activities, vegetative filter strips, field bunding, hedge planting, stone bunding and trenching, live check dams, brushwood check dams, loose boulders check dams, gabions and stream bank stabilization (Madhu *et al*., 2016).

Enhanced ecosystem services of LPG watershed included provisioning services such as increase in food, fodder, fruits, vegetables and wood biomass. The regulatory services included soil retention (decrease in soil erosion thereby decrease in loss of nutrients and soil carbon by 5 per cent), groundwater recharge (increased rainwater harvesting) and, carbon sequestration (increase by 48.6 per cent). A comparison with pre-watershed scenario revealed considerable increase in ecosystem services value from Rs. 5,398 per ha during pre-project period to Rs. 62,831 per ha during the post-project period from agricultural production systems showing an increase of 11 times. The average value of ecosystem services from watershed was increased to Rs. 32,701 per ha in post project from Rs. 19,358 per ha during pre project which is an increase of 69 per cent during the watershed project period.

Bajni watershed project (Madhya Pradesh)

Bajni watershed (532 ha) lying at 78°27' E longitude and 25°43' N latitude 263-284 m above MSL was treated with various soil and water conservation measures such land leveling and bunding, pond deepening along with improved agronomic measures. Impact of conservation measures was measured at field level. Average runoff decreased from 25.35 per cent to 16.30 percent, i.e. an average decrease of nine percentage points. Similarly average soil loss decreased from 12.08 to 8.27 t/ha/yr (31.5 per cent) due to various soil conservation treatments imposed in the wasteland. Water withdrawal increased from 1.97 ha m to 11.50 ha m (about 5 times) that reflected the impact of water harvesting due to soil conservation structures and other watershed treatments on groundwater availability in open and bore wells. There was increase in the area and yield of different *kharif* and *rabi* crops cultivated in the watershed. Crop productivity changed over the project period in terms of wheat equivalent yield, which increased from 10.21 q/ha to 13.40 q/ha. There was also change in the status of available pool of different nutrients viz. organic carbon, available N, P and K.

Jigna watershed (Madhya Pradesh)

Jigna watershed (620 ha) lying between 25^{0}37'00" to 25^{0} 30'30" N latitude and 78^{0} 20'30" to 78^{0} 23'30" E longitude at the altitude ranging from 240m to 280m above msl was treated with various soil and water conservation measures, such as land leveling and bunding, water resource development along with improved agronomic measures. As a result, an additional storage capacity of the tune 26,105 m^3 was created in the watershed by construction of new as well as by renovation of existing water harvesting structures (WHS). Groundwater depth from surface decreased overtime, indicating a positive trend towards increased availability of groundwater in wells.

Increase in water yield of wells/tube wells was used by farmers for supplemental irrigation to *kharif* and pre-sowing of *rabi* crops. Data collected from a user group of 25 farmers covering 44.17 ha area in the influence zone of one of the WHS indicated increase in water availability for irrigation in wells/tube wells. Total crop productivity from 44.17 ha land in terms of wheat equivalent yield (WEY) increased by almost two folds from 996 q to 1836 q during *rabi* season.

Grass strip at field bund to check sediment loss

Grass strip at the field boundary in agricultural land with slope helps control sediment from going out of the field besides providing grass for animals. Sediment carrying topsoil off the fields reduces the land productivity, besides affecting the dead storage of the reservoir and rivers downstream. The sediment control and nutrient retained in the crop field, in addition to enhanced yield were considered as ecosystem service of grass strip plantation and evaluated at 2016-17 prices. The annual costs included material cost of inputs, labour, cost of raising grass strip. In addition, the opportunity cost of raising strips was added to estimate the total cost of treatment. The annual direct benefit included cotton yield, grass yield, and the indirect benefits included the sediment retained by the grass strips. To impute resource value to sediment retained by grass strips, replacement cost approach was used (Hufschmidt *et al*., 1983; Dixon and Hufschmidt, 1986; Dixon *et al*., 1994). The sediment, if not retained in the field, move to adjacent Mahi river. The cost of dredging the silt from dead storage of river was used to impute a value to the sediment retained. Average dredging cost of Rs 135/ CMT was used. This is the average of dredging cost spent by the Dredging Corporation of India in different dredging projects across the country from 2005 to 2015. The sediment retained due to conservation interventions contained nutrients. Assuming this sediment to be uniformly distributed in the crop field, the retained nutrients in the soil sample were valued at the annual marginal cost of their replacement artificially (Drechsel *et al.*, 2004). The assumption that productivity of soil could be maintained if the lost nutrients and organic matter were replaced artificially justified use of this approach. Grass strips generated annual flow of ecosystem benefits in the range of Rs 910 – 1,187/ ha for strips of different grasses of different width.

Conservation measures with forest tree plantation in reservoir catchment

Soil and moisture conservation measures and forest tree plantation in the catchment of a reservoir avoid loss of live storage capacity caused by high rate of sediment deposition behind the dam, an ecosystem service provided by soil conservation and plantation measure. There are several impacts of soil erosion and sedimentation, which include reservoir siltation leading to loss of hydropower generation capacity, reduction in irrigation water supply affecting agricultural production, and impact on drought or flood cycles. A study was taken up in the SSP catchment area lying in Gujarat to estimate the marginal cost of siltation in the Sardar Sarovar Project (SSP) reservoir. Losses due to sedimentation were estimated in terms of losses in hydropower and irrigation following change in consumer and producer surplus approach.

Based on loss of total storage, the estimated output of hydropower loss varied from 4.2 M kWh in a deficit monsoon scenario to 4.98 M kWh in a surplus monsoon scenario. This worked out to be in the range of Rs 8.1 million to Rs 8.68 million during deficit monsoon and Rs 9.51 million and Rs 10.2 million for surplus monsoon scenario. Similarly, hydropower loss estimate based on loss of dead storage varied from 10.9 M kWh and 12.7 M kWh during deficit and surplus monsoon, respectively. This worked out to be Rs 20.7 million to Rs 22.2 million during deficit monsoon and Rs 24.4 million and Rs 26.2 million for surplus monsoon scenario. The loss of irrigation potential was estimated in the range of Rs 407 million and Rs 434 million based on loss of total storage and Rs 1,045 million and Rs 1,114 million based on loss of dead storage (Pande *et al*., 2014).

Bamboo and grass plantation for soil conservation in degraded ravine land

The bamboos are incredibly versatile and useful vegetation with varying uses. Bamboo, besides various uses in industry and home, has been found to be an effective soil and water conservation bio-engineering measure. It can be grown in different types of conditions, including steep hillsides and along the banks of rivers. The interlocking root system and leaf deposit inhibit soil erosion and protects further deterioration of eroded gullies of ravine lands. Harvesting of bamboo is started after 7 years with 10 old and 3 new culms available per clump in the ravine land (Dhruva Narayana, 1993). Economic analysis of bamboo plantation in the Mahi ravines, Gujarat suggested a cash outflow ranging from Rs. 30,550/ha to Rs .48,000/ha from the seventh year onwards to individual stakeholders in the region, in addition to the benefits accrued to society in terms of value of nutrient (Rs. 2,125 – 5,555/ha) saved through soil conservation and incremental soil carbon build up (Rs. 41,000/ha) (Pande *et al*., 2012).

Agri-horticulture production system on marginal lands of ravine

Ravine lands are marked by their susceptibility to soil erosion along the course of river systems. Introduction of tree component with traditional crops on such marginal lands is beneficial not only in terms of short-term profitability but also in resource conservation. Drumstick (*Moringa oleifera*) cv–PKM1 and grafted aonla (*Emblica officinalis*) cv-NA7 with *Phaseolus radiates* and *Foeniculum vulgare* crops on marginal lands of ravine not only enhanced the income but also built up soil carbon and nutrient over the period of production against control (tobacco monocropping production system). The net present values from *M. oleifera* + *P. radiatus* followed by *F. vulgare* and *E. officinalis* + *P. radiatus* followed by *F. vulgare* were Rs. 25,090 and Rs. 77,350 p/ha , respectively, at 2012–13 local prices over a production cycle of 15 years.

While the additional soil carbon build-up was valued at 11 USD t^{-1} (1 $ = Rs 65), the additional nutrient buildup such as phosphorus and potash were valued at local prices of fertilizer, viz. Diammonium Phosphate (DAP) and Muriate of Potash (MOP). The drumstick+ green gram–fennel agri-horticulture production system resulted in the additional soil carbon and soil nutrient costs of Rs. 15,600 and 1,300/ ha. Aonla + green gram–fennel production system helped build soil carbon and soil nutrient worth Rs. 3,575 and 780/ ha, respectively (Pande *et al*., 2016).

Rainwater harvesting for augmenting water resource, Johranpur, Himachal Pradesh

Rainwater harvesting, through diversion of runoff from agricultural fields to renovated ponds and recycling to grow crops through supplemental irrigations not only increased cropping intensity of the area but also conserved land, water, nutrients and vegetation resources. Top soil of 8.9 ha was conserved and the fields stabilized, through earthen diversion channels and land leveling, from sheet and rill erosion. Nutrient loss worth Rs. 20,677 could be saved and recycled back into fields through irrigation water (Arya and Yadav, 2006).

Soil conservation and rehabilitation of degraded lands, Narayanpur, Haryana

A combination of mechanical and vegetative soil conservation measures were executed for treatment of seasonal torrents and rehabilitation of degraded lands in Narayanpur village, District Panchkula (Haryana). The technology was effective in channelizing the flow of runoff water, which rehabilitated about 100 acres of land for cultivation. The project helped in reducing seasonal migration of landless in search of work in the nearby areas by providing higher on-farm employment opportunities and enhancing the value of land. With more infiltration of runoff water into the soil profile by the conservation measures, base flow increased during dry weather period. One tube well could provide additional irrigation by 150 hours in March and April. Further, the value of agricultural land in the market doubled due to its permanent protection from torrent and increased soil fertility. The project helped in reducing local out migration of people in search of work in the nearby areas by 62 per cent from 47 days per household prior to execution of SWC measures to 18 days per household after SWC measures execution. Similarly, on-farm employment opportunities for landless households have increased from 93 man days per household to 190 man days per household. In addition silt retention worth Rs. 1.08 lakh and Rs. 1.21 lakh worth of addition irrigation from groundwater recharge (Arya *et al*., 2010).

Conclusion

Ecosystem services are greatly influenced by resource management practices of a particular production system. In particular, agricultural production systems are providing multiple economic and ecosystem services to sustain human being and livestock. Natural resources, namely soil and water are the prime resources, which enhance the value of ecosystems. The conservation of these resources through integrated watershed management and other management methods is essential to increase the cumulative and sustainable services from agricultural ecosystem. Soil erosion affects the functioning of soils, decreases biomass production, and increases loss of nutrients, soil carbon etc., apart from directly affecting the hydrological cycle and availability of water for multiple uses. Soil and water conservation measures and watershed activities are highly effective in increasing the value of ecosystem services. The case studies have shown manifold increase in economic benefits, besides reduction in nutrient loss with soils and increase in carbon sequestration. Reduction in sedimentation of water bodies also results in significant cost savings.

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CHAPTER 5

SAND DUNE STABILIZATION IN THE INDIAN THAR DESERT: IMPACT ON THE ECOSYSTEM SERVICES

P.C. Moharana, Praveen Kumar, D.V. Singh and O.P. Yadav

Introduction

Sand dunes, spectacular landforms of the Thar Desert, are spread between the Aravalli hills in the east (in Rajasthan) and the Indus River in the west. The eastern limit of this desert is climatically bound by moisture availability index (also called the aridity index) of – 66.6. The Thar Desert is spread over 38 million ha area or in 12 per cent of country's total geographical area out of which 31.7 million ha is hot arid zone. Maximum area of 19.6 million ha (61.9 per cent) of total geographical area of Thar desert falls within arid western part of Rajasthan, but the hot arid regions also occur in other parts of the country, such as in north-western Gujarat (19.6 per cent), Punjab and Haryana (8.6 per cent), Telangana (6.8 per cent), Karnataka (2.7 per cent), and Maharashtra (0.4 per cent).

The key characteristics of the arid region are: low rainfall (100 to 500 mm yr^{-1}) with highly erratic distribution (30-64 per cent C.V.), potential evapo-transpiration of 1,400-2,000 mm, high temperature during summer (often reaching 50^0C) and low (sometimes below 0^0C) during winter, and high wind speed of 8-12 km h^{-1} during May-July and occasional dust storms. The terrain is predominantly Aeolian (in >80 per cent area) and all the rivers and streams are ephemeral. Droughts are regular phenomena and the region faced about 34 severe droughts between 1875 and 2009 (Attri and Tyagi, 2010). Despite these environmental hindrances and frequent droughts, western Rajasthan has 72.8 per cent area under cultivation which includes 56.3 per cent net sown area, 16.4 per cent, double cropped area and 17.7 per cent net-irrigated area. The region is also thickly populated by humans (28.1 million) and livestock (24.4 million).

Given that the sand dunes cover major part of arid region, work on sand dune stabilization has been given high priority by the ICAR-Central Arid Zone Research Institute (CAZRI). The present article discusses spread of sand dunes, techniques of sand dune stabilization and their impact in the form of ecosystem services in western Rajasthan.

Sand Dunes in Rajasthan: Extent and Types

CAZRI has made an inventory of nine major groups and 21 subgroups of sand dunes in the Thar Desert (Kar, 1993). The linear, parabolic, transverse, star, network and major obstacle dunes belong to the old system while barchans, sand streaks and nebkhas are considered as dunes of new system. Sand dunes are present in almost all the districts of western Rajasthan and they cover 10.09 million ha or 48 per cent of total geographical area of western Rajasthan (Moharana *et al.,* 2016). Major dune fields in western Rajasthan occur in Jaisalmer (2.16 million ha, 10.4 per cent), Bikaner (2.09 million ha, 10 per cent), Barmer (1.57 million ha, 7.6 per cent), Churu (1.55 million ha, 7.4 per cent), Jodhpur (0.52 million ha, 2.5 per cent) and Sri Ganganagar (0.48 million ha, 2.3 per cent).

Need and concept of sand dune stabilization: Sand dunes are surface features created by mass transfer of sandy material by winds through erosion and deposition processes. Loose sand grains on dunes have no cohesion and are easily blown by wind. Sometimes sand tends to deposit on railway tracks and roads, or in canals disrupting the water flow. Deposition of sand on fertile land reduces its productivity and augments the process of desertification. Depending on the direction and diffusive potential of wind, dunes also move. Therefore, the instances of roads, railway tracks, buildings and houses getting buried under the sand in the event of heavy dust storms are not uncommon in arid regions.

As per a recent estimate, 15.2 million ha or 73 per cent of area of western Rajasthan faces land degradation due to wind erosion alone. The problem of wind erosion is very severe in about 5,80 thousand ha area and severe in 25,54 thousand ha area (CAZRI, 2000). Wind erosion in the form of blown sand activity, sand movements and dust storm generation is more intense during summer (April to June) when strong winds sweep across the region. During this period the terrain remains dry, a significant proportion of ephemeral vegetation is dead and there are few crops in agricultural fields. During May-June, the wind speed increases. Strong winds of 15-18 km h^{-1} and occasional higher wind speeds of 60 to 80 km h^{-1} accentuate the dust storm activities. This increases the number of menacing incidences of blown sand deposits over railway tracks, around the settlements and thick undulating sand deposits over roads and croplands (Fig. 1a, 1b). Field measurements have recorded movement of stable dunes at the rate of 3-5 m per year while low and barchan dunes move up to 31 m per year.

The impacts of wind erosion are many in agricultural land: (i) wind blows away nutrient-rich top soil leaving behind coarser substrata, which is poor in nutrients, (ii) causes crop damage by sand blasting or abrasion action on tender stems and leaves, and (iii) buries the short crops through saltation particles. Field-based measurements indicated that during peak summer, about 9 cm of top soil may be removed from bare sandy plains, which may be as high as 37 cm from bare sand dunes. Another measurement during extreme dry conditions from April

Fig. 1a. Sand encroachment over roads

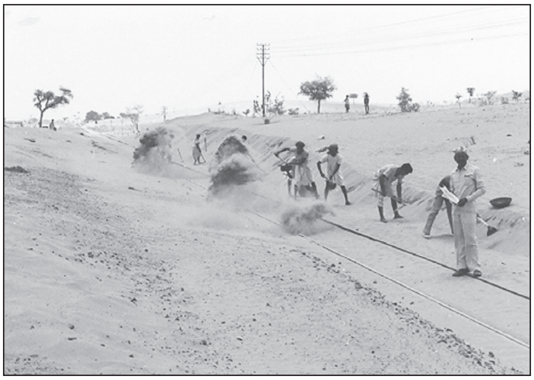

Fig. 1b. Sand deposits over railway tracks

to June indicated soil loss in the range of 31.2-61.5 kg/m^2. Dust blowing in the zone of three meters above the soil surface measured by fixed dust catcher revealed that on a stormy day, soil loss varied from 50 kg/ha to 420 kg/ha (Santra *et al.,* 2016). Considering the severity of such incidences and their impact on the economy and life of desert dwellers, CAZRI developed two popular models, namely sand dune stabilization and shelterbelt plantation for curtailing the adverse impacts of wind erosion.

Techniques of Sand Dune Stabilization

The objective of sand dune fixation is to reduce the free blown sand activities over sand dunes so as to check their onward movements over croplands or infrastructures. The method of sand dune stabilization could be vegetative, mechanical and chemical. The mechanical and chemical methods are neither economical nor feasible for this region as majority of sand dunes are owned by farmers. CAZRI developed vegetative/ biological methods for sand dune stabilization and shelterbelt plantation (Bhimaya and Kaul, 1960; Kaul, 1985). Even though establishing vegetation on dunes is very challenging initially, but benefits of vegetation in long-term could far outweigh the risks of failure in establishment phase. Vegetation cover is regarded as one of the ways of permanent stabilization of sand dunes. It depends upon availability of soil moisture and its utilization by plants. In the past, *Acacia tortilis* used to be the most preferred tree for this purpose as experiments showed that *A. tortilis* tends to develop a deep root system, with extensive spread of lateral roots relatively close to the surface. Saxena (1977) reconstructed the succession pattern of natural vegetation with some interesting observations: initially *Crotalaria*, *Aerva* and *Cyperus* spp. bring about the stabilization of sand to a great extent. This makes the substratum more suitable for success of shrubs and perennial grasses like *Sericostemma pauciflorum, Leptadenia pyrotechnica, Clerodendron phlomoides, Calligonum polygonoides* etc. Subsequent stabilization and undisturbed conditions bring about *Acacia jacquemontii, Lycium barbarum, Balanites aegyptiaca* and *Maytenus emarginatus.* The last three species form the penultimate stage for the climax community of *Prosopis cineraria*. The grassland development in the low-rainfall zone (below 300 mm) is limited to *Panicum turgidum* only, whereas in the high-rainfall zone (above 350 mm), the same stage is surpassed by *Saccharum bengalense*.

Initially the dune stabilization programmes mostly involved plantation of exotic trees and shrubs, but it was soon realized that the locally adapted species can provide some economic returns as well. This would encourage villagers to protect and manage such planted species, provided such plantation does not interfere with crop cultivation. Therefore, several species (trees, shrubs and grass) for different rainfall zones for their use in stabilizing process were advocated on the basis of such qualifications (Table 1).

Table 1. Vegetation species suitable for stabilizing sand dunes

Annual rainfall (mm)	Trees	Shrubs	Grasses
150-300	*Acacia tortilis, Acacia senegal*	*Calligonum polygonoides, Ziziphus nummularia, Citrullus colosynthis*	*Lasiurus sindicus*
300-400	*A. tortilis, A. senegal, Prosopis cineraria, Tecomella undulata, Parkinsonia aculeata, Acacia nubica, Colophospermum mopane, Cordia rothii*	*Ziziphus mauritiana, Z. nummularia, C. polygonoides, C. colocynthis*	*Cenchurus ciliaris, Cenchurus setigerus, L. sindicus, Saccharum munja*
400-550	*A. tortilis, P. cineraria, Dalbargia sisoo, Ailanthus excelsa, Albizzia lebbeck, A. senegal, T. undulata, P. aculeate, C. mopane,*	*Z. mauritiana, Cassia auriculata*	*C. ciliaris, C. setigerus, S. munja and Panicum antidotale*

The technique of sand dune stabilization (Fig. 2) primarily consists of the following interventions :

- Fencing of the area under sand spread or sand reactivation for protection from biotic interference.
- Establishment of micro-wind breaks from crest to base of the dunes in the form of parallel or chessboard pattern.
- Reseeding of grass and creeper seed in between the micro-wind breaks and transplanting of nursery-raised tree seedlings at the spacing of 5 m × 5 m in both vertical or horizontal pattern.

- Continuous and proper management of such dunes for 10-15 years.

For micro-wind breaks, most suitable tree and grass species for the purpose are:

- Brushwood materials: *Leptadenia pyrotechnica* (Khimp), *Ziziphus nummularia* (Pala), *Crotalaria burhia* (Sania) and *Panicum turgidum* (Murath).
- Tree species: *Acacia tortilis*, Prosopis spp., *Acacia senegal, Parkinsonia articulata* and *Tamarix articulate.*
- Grasses : *Lasiurus sindicus* and *Cenchrus ciliaris.*
- Creepers : *Citrullus colocynthis*.

Planting technique: Before planting of vegetation on sand dunes, the usual practice is to erect long parallel barriers (or micro windbreak) of low height, at 5 to 10 m interval across the prevailing wind direction. Where wind direction is variable, cross-barriers are also erected, thus creating a grid pattern. The pattern depends on a number of factors like velocity of wind, steepness of slope and type of sand dune. The sand within the grids/squares is usually stable enough to allow establishment of the transplanted seedlings. In order to ensure a higher survival rate, the planting of seedlings is done after the onset of rainy season (July to September), when the sand is moist. Experiments carried out at Bikaner for determining the planting depths, have shown that planting at 35 to 40 cm depth resulted in higher seedling survival. In case of *Acacia tortilis*, a spacing of 4 × 2 m has been adopted, while in the Indira Gandhi Canal Project Stage II area, the spacing of 4 × 4 m is advocated as most appropriate. Aerial seeding has also been attempted successfully in areas receiving average annual rainfall of 250 mm and also in inaccessible sand dune terrain.

Shelter-belt plantation

Shelter-belt plantations (SB) are longitudinal vegetative barriers of tree, shrub and, or bushes and are effective to minimize the adverse effects of wind related activities. Depending on the magnitude of wind erosion hazard, CAZRI recommended five-row or three-row shelterbelts with staggered planting and pyramidal in shape (Kaul, 1969). They also suggested suitable shrub species for flank rows; *Acacia bivonesa, A. ampliceps, Ziziphus mauritiana* and *Calligonum polygonoides* and for central rows; *Acacia nilotica, A. tortilis, Cassia siamea,* and *Albizia lebbeck*. The Institute erected and maintained shelterbelts in about 500 km length, which included plantation of >100 km length in the state-owned farm at Suratgarh. Roadside plantation of >200 km length on the state highways in Jodhpur, Barmer, Jaisalmer, Churu, Jhunjhunun, Nagaur, Ajmer and Pali districts as well as >100 km long plantation along the railway tracks between Sikar and Loharu, Sikar and Fatehpur and Palana and Deshnokh, were done.

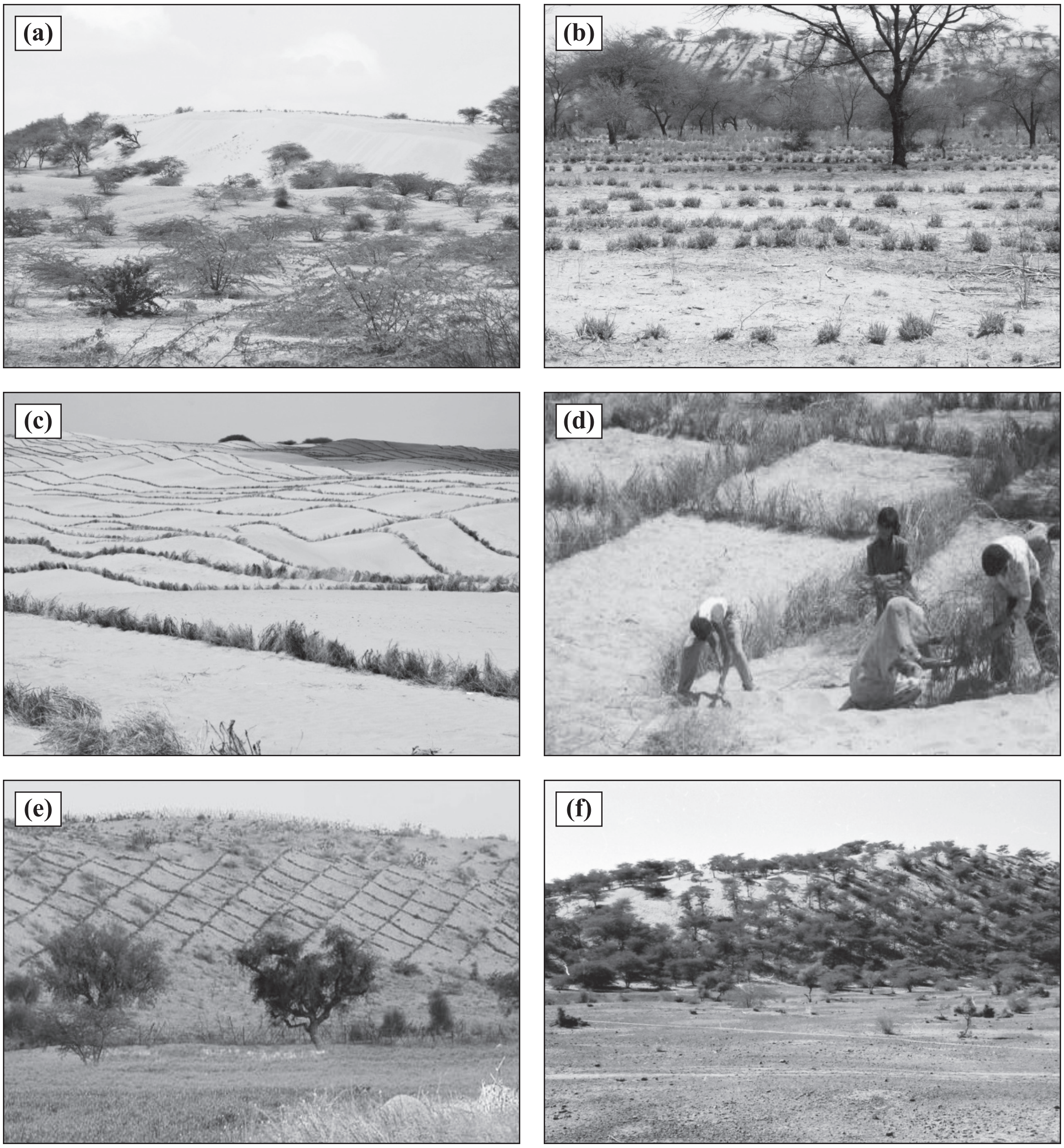

Fig. 2: (a) A barren parabolic dune, (b) grass (*Lasiarus sindicus*) put in horizontal as well as in vertical pattern over a parabolic dune, (c) parallel pattern of native shrubs and grasses,(d) people's participation making a checker board pattern, (e) the checker board model on sand dune, and (f) Tree growth after about a decade of plantationwith no sand accumulation on foot slope.

Impact and Ecosystem Services of Sand Dune Stabilization

The word ecosystem includes all types of living things that exist in a particular area together, interacting constantly with non-living things with complex relationship. The word service denotes a type of activity that is intangible, not manufactured, produced, transported or stocked. The concept of ecosystem services was brought into widespread use by the Millennium Ecosystem Assessment (MA) - a global initiative set up in 1999 to assess how change in ecosystem would affect human well-being (MA, 2005). The MEA defines ecosystem services simply as, "the benefits that people obtain from ecosystems". As per MEA, ecosystem services can be divided into four categories: (a) provisioning, (b) regulating, (c) supporting, and (d) cultural (*see* Chapter 2). Provisioning services include the benefits from increased food production, increased intake of livestock products, production and usage of biomass fuels (wood or timber), genetic resources and other medicinal goods. Regulating services benefits are often invisible and people take them as granted like local climate and air quality, carbon sequestration, slackening of extreme events, reduction of ill effects of industrial effluents, prevention, and maintenance of soil fertility on dunes. Supporting services include nutrient cycling, production and soil formation, which are needed for the production of all other services. Cultural services are mainly non-monetary benefits, such as spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.

Sand dunes in a desert area may mean differently to different people. For example, to an earth scientist, sand dune is a landform having a distinct morphology or an archaeological entity; to a farmer, it is his crop land and grazing land; and to a common man, it is a scenic feature for tourism. So it contributes to agriculture, rangeland, forestry and tourism. Owing to all the above facts, study of sand dunes for analysing its ecosystem services is of importance. Some of these ecosystem services are described here.

Provisioning services

Addition in area for food grain production: Over the years, desert areas in western Rajasthan are witnessing faster changes in terms of land utilization. Extensive dune area in 4 lakh ha has been stabilized, further levelled and converted to croplands. Area under sand dunes has reduced from 58 per cent in 1990s to 48 per cent during 2013, thus a decrease of 2.5 m ha sand dune area has been noticed. During past six decades, increase was noticed in net sown area (51.4 per cent) and double crop area (~ 21 fold), while decrease in culturable waste (~36 per cent), current fallow (~ 18 per cent) and old fallow (~ 48 per cent) (Table 2). Such changes in croplands which are results of bringing many sand dunes under cultivation may represent increased provisioning services by dunes, and is very much apparent in western Rajasthan.

Table 2. Land use /land cover in western Rajasthan

Land use (ha)	1957-58	2005-06	2014-15
Net sown area	73,94,502	1,06,59,661	1,11,96,097
Double crop area	1,45,766	20,74,042	32,18,288
Forest area	1,43,684	4,56,039	4,79,638
Culturable waste	50,35,175	36,79,551	32,06,310
Current fallow	18,88,711	15,32,626	15,48,192
Old fallow	29,65,297	17,07,545	15,29,452

Tree plantation on dunes and its products (timber, fuelwood and fodder): In arid farming system, livestock is an integral component. Therefore, role of shrubs, trees, grasses and legumes is of great importance. Shrubs have unique role in enhancing the production potential of animals. The shrubs like *Ziziphus* species are almost as nutritious as the leguminous fodder crops. *Ziziphus nummularia* has the highest production potential (8.95 kg fuelwood and 4.25 kg leaf/pod fodder) per shrub per year in comparison to *A. senegal* (2.50 kg fuelwood and 1.26 kg leaf/pod fodder) and *Calligonum polygonoides* (7.90 kg fuelwood and 1.40 kg leaf/pod fodder). In trees, *Acacia* species are the most preferred in sand dune stabilization activity. An evaluation of a 10-year-old tree of *Acacia tortilis* for fodder, fuel and timber showed that such a tree can yield green fodder (leaf and pod) on an average 14-16 kg/year, produce average fuel wood of 20-50 kg/year and timber of 1.06 cubic ft per tree per year. The calorific value of the fuel wood will be 4,400 kcal/kg. About 4 lakh ha of sand dune area has been put under tree plantations. These estimates revealed that annually, such trees would produce timber at the rate of 20 t/ha along with fuel wood of 8 t/ha, green fodder of 4 t/ha and gum production of 40 kg/ha.

Regulating services

***Soil loss and crop yield**:* Stabilization of sand dunes has the objective of controlling sand movement. Remote sensing based assessments in western Rajasthan indicate positive results of such measures where in wind erosion/deposition affected area has put under severe category has come in slight to moderate category. Land use wise, 1.23 lakh ha cultivated lands (irrigated and rainfed) in Rajasthan is now free of wind erosion hazards compared to an assessment made for 2003-05 period (SAC, 2016). Dust storms, another major hazard used to occur more frequently, number of days per annum has reduced from 11-17 to 3-5 per year in the Thar desert.

Such a transformation has profound impact on the soil nutrient (Table 3). Santra *et al.* (2017) estimated the loss of soil nutrients and resulting yield loss of major crops of the region in various wind erosion category (Table 4). Their study revealed that soils associated with higher severity category of wind erosion are more depleted of soil nutrients. Assessment of crop production loss using soil test crop response equations (Santra *et al.*, 2016) revealed that in 'very severely' affected areas, the yield gap of major crops as compared to negligible affected areas varied from 57 to 82 per cent, of which about 9-67 per cent was contributed by wind erosion in different crops. Yield reduction due to wind erosion in 'very severe' affected area was 195 kg ha^{-1} for pearl millet crop whereas it was 93 kg ha^{-1} for moth bean and 229 kg ha^{-1} for clusterbean.

Table 3. Soil nutrient loss (kg/ha) and wind severity class

Wind erosion category	Loss of nutrients from soil (kg/ha)		
	N	P_2O_5	K_2O
Very severe	7.58	1.25	14.79
Severe	4.55	0.75	8.87
Moderate	1.11	0.18	2.16
Slight	0.12	0.02	0.23

Table 4. Yield loss (kg/ha/year) of major crops and wind erosion class

Crop	Wind erosion class			
	Very severe	Severe	Moderate	Slight
Pearl millet	195	117	29	3
Moth bean	93	56	14	1
Clusterbean	229	137	33	4

***Tree plantation impact on soil fertility, carbon sequestration and nutrient cycling*:** It is estimated that a single planted tree would contribute 0.3 kg N, 0.04 kg P and 0.20 kg K per year. A tree having crown area of 20 m^2 would save about 15 kg soil from erosion, conserve about 26 per cent of runoff, and can sequester 9 kg of carbon per year. Considering 1 ha of plantation on dunes has a capability to sequester 5 t carbon/ha, 4 lakh ha area that has been put under plantations will sequester 2 million tonnes of carbon. In case of benefits of nutrient cycling which is one of the regulating services, it is estimated that litter fall @ 8-10 t/ha will add a very significant input of nutrients to the soil that include 48,000 t/year N, 6400 t/year P and 32,000 t/year K. Besides, impacts of shade from the tree covers and improvement in air quality are unparallel.

Regulatory services of shelterbelts**:** Reduction in wind speed by 50 per cent at 2 to 10 times distance of shelterbelt height, reduction in pan evaporation by 5-14 per cent, increased soil organic carbon and crop production are some of the regulatory services provided by shelterbelts. Especially in canal area, shelterbelts reduce deposition of sand by 513 m^3 per km in a year. About 800 km long shelterbelt plantations have been achieved. From entire area and canal command with shelterbelts, the additional income only from crops and trees is estimated around Rs 71,342 million in last 15 years at 2017 prices.

Cultural services

Tourism: Thar Desert in Rajasthan represents one of the major cultural ecosystems of the country. Not surprisingly, many of the sand dunes exhibit glimpse of desert's rich and fascinating geomorphic diversity and therefore, are places of natural wonders / scenic spots attracting millions of domestic and international visitors besides host of earth scientists. Barchan dune fields at Sam (Jaisalmer), Chohtan (Barmer), mega-barchan fields in the extreme southern part of Jaisalmer, parabolic sand dunes at Osian, Balesar, Dechu in Jodhpur districts are the known geo-morpho sites for ecosystem services of tourism in western Rajasthan. During 2017-18, about one lakh tourists visited the Sam dunes.

Conclusion

Sand dunes are spectacular surface features created by mass transfer of sand by winds in arid regions through erosion and deposition processes. However, the frequent transfer of top soil makes them unsuitable for agriculture and also creates several economic and health problems. Sand dune stabilization using vegetative methods and shelter-belt plantation is demonstrated by CAZRI on large scale, which is associated with enhanced economic and ecosystem services. Sand dune stabilization enhances economic benefits by increasing area under field crops and production of timber and fuelwood. In addition, it also generates other services like soil fertility, less dust storms and tourism for remaining sand dunes. It is suggested that development agencies of the government should take up sand dune stabilization program on a large scale with committed resources.

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CHAPTER **6**

BIOLOGICAL AMENDMENTS AND THEIR ROLE IN IMPROVING SOIL ECOSYSTEM SERVICES

Bidisha Chakrabarti, Lata Nain and Radha Prasanna

Introduction

Ecosystem services (ES) include the direct and indirect benefits and contributions of ecosystems to human well-being (Stavi *et al*., 2016). Ecosystems sustain human life through the provision of ecosystem services (ES), which include food and fibre production, supply of freshwater, nutrient cycling, soil regeneration, flood control and pollination (Costanza *et al*., 1997; MEA, 2005). ES can be categorised as (i) provisioning services (food, feed, fiber, and freshwater), (ii) regulating services (flood and disease control, climate regulation), (iii) supporting services (soil formation, nutrient and water cycling, production of oxygen, provisioning of habitats), and (iv) cultural services (spiritual, recreational and aesthetic benefits) (Duru *et al*., 2015). The anthropogenic activities are changing the ability of ecosystems to provide ES (MEA, 2005).

Agricultural Production and Ecosystem Services

Intensive agriculture contributes towards food security; it also provides various provisioning, regulating, supporting and cultural ecosystem services (Pathak *et al*., 2017). Ecosystem services provided by agriculture include food production, biodiversity conservation, nutrient cycling, water, soil and air purification. Food production, a crucial ES for the survival of humanity (Sandhu *et al*., 2012), is dependent upon supporting and regulating services like soil fertility and pollination (Zhang *et al.,* 2007). Management of nutrients has a significant influence on diverse soil and plant functions, thereby impacting ecosystem services and agriculture (Figure 1). However, intensive agricultural practices have led to degradation of natural resources causing a decline in soil fertility, increased emission of greenhouse gases (GHG), lowering of groundwater table and enhanced groundwater pollution. Increased use of chemical fertilizers has altered the nutrient cycles (Tully and Ryals, 2017). Most of the surveys or research in this context, are related to chrematistics, or exchange value in a market economy, however, some global studies have quantified the impacts of agricultural production

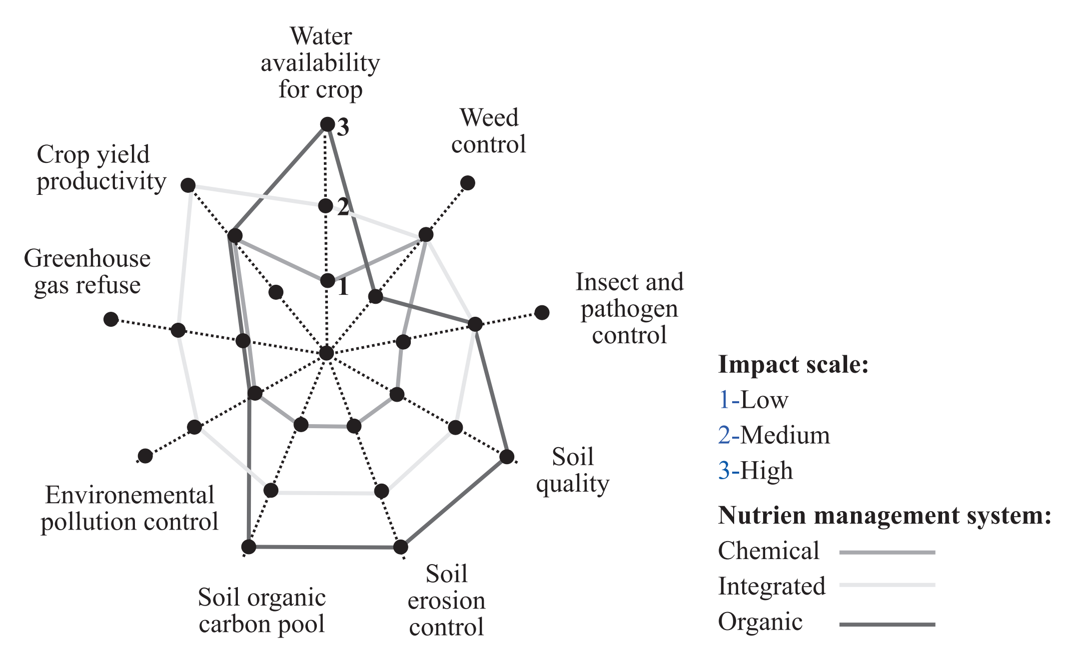

Figure 1. Spider chart of nutrient management impact on soil functions and ecosystem services (*Source:* Stavi *et al.,* 2016**)**

systems on ecosystem services (Dale and Polasky, 2007; Sandhu *et al.,* 2008). The success of conventional agricultural practices is based on the provisioning service provided in terms of food and fibre (Sandhu *et al*., 2012). But expansion of these marketable ecosystem services has degraded other services like climate and water regulation, biodiversity conservation and soil erosion protection (Porter *et al*., 2009).

Heavy fertilizer loads are associated with environmental consequences, which result in diminished ecosystem services (Daoji and Daler, 2004; Galloway *et al*., 2003). However, nutrient cycles in agro-ecosystems can be improved through better farm management, which can also provide additional ecosystem services like regulation of water quality and runoff control, maintenance of soil fertility, soil carbon storage, climate regulation and biodiversity conservation (Power, 2010; Tomich *et al*., 2011). Improvement in nutrient use efficiency and increase in crop productivity can be achieved by using soil or biological amendments, i.e., any physical, chemical or biological material, mostly added to soil to improve the conditions in relation to plant growth.

Biological Amendments

Biological amendments applied in agricultural soils, include bio-stimulants, organic amendments, microbial inocula (as biofertilizers or conditioners), and pelletised formulations and extracts such as compost (Abbott *et al*., 2018). Potential benefits of biological amendments include direct nutrient contributions, plant physiological responses, stimulation of plant growth, protection against plant diseases and improvement in soil health (Abbott *et al*., 2018). Some of the major constraints in agricultural production systems and categories of biological amendments able to address these constraints are listed in Table 1. Although there are potential benefits of biological amendments, their improper or sub-/supra optimal use may also pose certain risks, which include salt and heavy metal accumulation in soils of varied texture, foul odour, increased susceptibility towards certain plant pathogens and greenhouse gas emissions (Cayuela *et al*., 2010).

Different approaches for valuation of ecosystem services

Although the question of value has occupied the human mind for millennia, ascent of neoclassical welfare economists in the twentieth century, defined value to its exchange value in a market economy. This narrowing of meaning allowed economists to use a precise mathematical framework to highlight the contributions of nature to the local and national economy. Nevertheless, current controversies in valuing the cost and benefits of long-lived environmental changes like climate change and biodiversity loss have exposed serious flaws in standard welfare economics. Table 2 illustrates the different methodologies adopted by researchers for quantification of ecosystem services in agriculture.

Biological amendments and soil

Biological amendments influence the plant soil system in several ways. Organic additives used in organic nutrient management regimes increase soil macro aggregates thereby enhancing water availability for crops (Sene and Badiane, 2005; Blanco-Canqui *et al*., 2015). Organic amendments improve soil health and reduce infestation of soil-borne pathogens by sustaining soil microbial activity (Horrigan *et al*., 2002). However, application of immature livestock manure can cause contamination of water sources, affecting environmental quality (Horrigan *et al*., 2002). Besides this, the production of biological amendments in composting facilities and on-farm use of these additives may modulate greenhouse gas emissions, and precautionary and regulatory measures need to be taken (Owen and Silver, 2015).

Biological amendments are able to optimize the services provided by microbial and faunal communities in soil, leading to plant benefits. Ecosystem services provided by them include carbon and nutrient cycling, supply of nutrients and disease suppression (Cytryn *et al*., 2011; O’Donnell *et al*., 2007; Ojeda *et al*., 2010).

Crop growth and productivity

Most of the soil functions and ecosystem services have a direct impact on agricultural productivity (Stavi *et al*., 2016). Agrawal (2005) revealed a positive relationship between

Table 1. Major constraints in agricultural production and categories of biological amendments suitable for revitalization

Constraints	Bio-stimulants		Organic amendments				Microbial inoculants
	Humic substances	Seaweed extracts	Animal manures	Composted Amend-ments/ Compost teas	Vermi-composts	Biochars	
Landscape constraints							
Salinity		x	x	x	x	x	x
Erosion	x	x	x	x	x	x	x
Soil constraints							
Biological							
pH	x		x	x	x	x	
Salinity/Sodicity	x	x	x	x	x		
Physical							
Water holdingcapacity	x		x	x	x	x	
Aggregatestability	x		x	x	x		x
Plant constraints							
Disease	x	x		x	x		x
Low mycorrhizal/ nodulationStatus/ Biological Nitrogen fixation			x	x	x		x
Seasonal constraints							
Drought	x	x		x	x		
Frost	x	x		x	x		
Heat	x			x	x		
Flooding	x			x		x	

Source: Abbott *et al*. (2018)

Table 2. Methodology for estimating ecosystem services from agriculture

Ecosystem service	Formula for estimating economic value (Rs. ha^{-1})	Source
	Price of services (Positive impacts)	
Provisioning services		
Food and raw materials	Produced food and raw materials (t ha^{-1}) x Price of food and raw materials (Rs. t^{-1})	Sandhu *et al.* (2008)
Supporting services		
Soil nutrient enrichment	[Soil nutrient content in cropped area (t ha^{-1}) – Soil nutrient content in non-cropped area (t ha^{-1})] x Price of nutrient (Rs. t^{-1})	Kiran and Kaur (2011)
Organic C enrichment	Amount of carbon accumulated in soil (t ha^{-1}) x Price of equivalent amount of FYM (Rs. t^{-1})	Kumar (2004)
Nutrient mineralization	Nutrients mineralized (kg ha^{-1}) x Price of nutrients (Rs. kg^{-1})	Sandhu *et al.* (2008)
Soil formation	Earthworm mass (kg ha^{-1}) x Price of soil (Rs. kg^{-1})	Pimentel *et al.* (1997)
Nitrogen fixation	Amount of N fixed (kg ha^{-1}) x Price of N fertilizer (Rs. kg^{-1})	Sandhu *et al.* (2008)
P solubilization	Viable count (No. ha^{-1}) x P fertilizer saved (kg ha^{-1}) x Price of P fertilizer (Rs. kg^{-1})	Rao and Patra (2009)
Regulating services		
Carbon sequestration	Amount of carbon sequestered in soil (t ha^{-1}) x Price of carbon (Rs. t^{-1})	Rasul (2009)
Water holding services	Irrigation water saved (mm ha^{-1}) x Price of diesel to pump water (Rs. mm ha^{-1})	Pathak *et al* (2017)
Groundwater recharge	Water recharged in ground (mm ha^{-1}) x Price of diesel to pump water (Rs. mm ha^{-1})	Sandhu *et al.* (2008)

agricultural productivity and environmental quality. Biological amendments, may improve the capacity of crops to tolerate a range of stresses. Erratic rainfall and temperature extremes have now become more frequent due to climate change (IPCC, 2007). Hence, there is a need to reduce the risk of low crop production by stabilising the yields. Among the different biological amendments, legume inoculants, contribute enormously to agricultural productivity when incorporated into farming systems (Abbott *et al.*, 2018). The microbial inoculant industry has a long history, with its success mostly from use of legume nodulation

(Howieson and Dilworth, 2016). According to Sandhu *et al*. (2010a), the use of composts, along with microbial inoculants does not result in any yield reduction in organic agriculture, hence it offers a better sustainable production system.

Application of compost could also result in increased production due to the improvement in humic substances in soil. This can have different consequences at a system level, such as avoiding the use of materials and energy needed for crop production, besides improved yields (Martínez-Blanco *et al*., 2013; Dadhich *et al*., 2012). Regular applications of manure can supply nutrients including N, P K, Ca and Mg in agri-pastoral system and increase productivity (Freschet *et al*., 2008). Since all the nutrients are organically bound in composts, the rate of application is generally very high (5-100 t/ha), but the major advantage is its slow release nature, which sustains plant growth over the life cycle of the crop and beyond.

Soil carbon storage

Carbon storage is an important ecosystem function of soils. A change in soil carbon (C) has an impact on the Earth's climate system through emissions of CO_2 and CH_4 and removal of C from the atmosphere through photosynthesis (Smith *et al*., 2015). Changes in management practices to increase soil organic carbon (SOC) stock, as given in Table 3, is a means of alleviating any adverse effects or mitigating climate change effects (Paustian *et al*., 2016). Soil is an important resource providing medium for plant growth, hosting biodiversity, regulating nutrient cycling, and maintaining fresh water quality (Keesstra *et al*., 2016). Soil organic matter provides multiple benefits like enhancing water holding capacity, providing protection against erosion, water purification and increasing food and fibre yield through improved soil fertility (Pan *et al*., 2013, 2014). Changes in soil organic carbon (SOC) are determined by the balance between C inputs through plant biomass and organic inputs, and C output by heterotrophic catabolism (Paul, 2016). Aboveground or belowground plant litter are the major sources of C to soil. Topsoil receives more amount of aboveground litter while root C and dissolved C transported down the soil profile are the sources of subsoil C (Smith *et al*., 2015). Soil organic matter is composed of plant litter as well as microbial and faunal decomposition products (Paul, 2014). However, land use intensification has led to decline on organic matter content of soil (FAO, 2013). Organic farming has been proposed to increase C levels in soil (Gattinger *et al*., 2012). Some of the management options for increasing SOC stocks include crop diversification (Poeplau and Don, 2015), mineral and organic fertilization (Han *et al*., 2016), retention of crop residues on soil (Turmel *et al*., 2015), and reduced tillage (Luo *et al*., 2010). Tropical soils are highly weathered with low cation exchange capacity (CEC) and require application of organic inputs for water and nutrient retention (Castellanos-Navarrete *et al*., 2015).

Fujisaki *et al*. (2018) compiled data from 214 cases of 48 studies in 13 countries on changes in SOC stocks of the topsoil under different management practices. Mean change in SOC

Table 3. Changes in soil organic carbon under different management practices

Management practices	ΔSOC (Mg C ha^{-1} yr^{-1})	Duration (years)
Crop residue	0.14 ± 0.02	18.5
Exogenous organic matter	0.51 ± 0.18	18.7
Residue + exogenous organic matter	0.43 ± 0.26	15.0
Mineral fertilizer	0.24 ± 0.06	17.2
Mineral fertilizer + Crop residue	0.31 ± 0.09	21.7
Mineral fertilizer + exogenous organic matter	0.37 ± 0.05	22.6
Mineral fertilizer + residue + exogenous organic matter	0.16 ± 0.21	20.5

Source: Fujisaki *et al*. (2018)

(ΔSOC) was 0.41 ± 0.03 Mg C ha^{-1} yr^{-1}, for average experiment duration of 13.6 years. Application of more C inputs resulted in higher SOC stocks. C inputs were found to be the strongest predictor of SOC accumulation rates in this study. Bhattacharyya *et al*. (2007) investigated the effects of long-term manure and fertilizer application on soil under wheat-soybean cropping system in sub-temperate Indian Himalayas. The increase in soil organic C content in the 0 to 45 cm soil layer was more in NPK + FYM treatment compared to NPK and control treatment by 11.0 and 13.9 Mg C ha^{-1}, respectively, at the end of 8-year- study period. The effect of fertilisation on carbon sequestration in soybean-wheat system under rainfed and irrigated conditions revealed that the carbon sequestration potential (CSP) in 0 - 0.45 cm soil ranged from 0.08 Mg C ha^{-1} yr^{-1} in unfertilised plots to 0.95 Mg C ha^{-1} yr^{-1} in NPK +FYM treated plots under rainfed conditions. In irrigated condition, CSP was negative in control plots and was >1 Mg C ha^{-1} yr^{-1} in FYM applied treatment (Bhattacharyya *et al*., 2009). It has been proposed that application of biochar can sequester C, adsorb inorganic and organic contaminants, increase macronutrients and improve water holding capacity of soils (Beesley *et al*., 2010); however, more long term efforts are required to reach any conclusions.

GHG mitigation

Accumulation of SOC in soil is not equivalent to C sequestration because for evaluating the latter, the whole greenhouse gas (GHG) budget of a management practice needs to be considered (Feller and Bernoux, 2008). In the global carbon cycle, any activity which favours decomposition and mineralization of organic material, leading to C emission, should be avoided (Lamb *et al*., 2016). Novais *et al*. (2017) studied the effect of poultry manure and sugarcane straw biochars on GHG emission in a sandy soil. They found that added biochars significantly reduced GHG emission especially CO_2 emission. Martin *et al*. (2015) observed reduction in N_2O emission from soil with biochar application.

Manures from livestock were estimated to contribute 30 to 50% of global N_2O emissions from agriculture (Oenema *et al*., 2005). In UK, manure management and application of manure to land contributed towards 16% of the total agricultural N_2O emissions in 2007 (MacCarthy *et al*., 2010). Methane emissions from manure management were 12 to 41% of total agricultural CH_4 emission (Chadwick *et al.*, 2011). N_2O emission is affected by climate, soil type, application method and manure composition (Sommer *et al*., 2009), while CH_4 emission depends on manure composition, temperature and the time for which it is stored inside animal houses or in outdoor manure stores (Sommer *et al*., 2004). Chadwick *et al*. (2000) compared N_2O emissions from soil following pig and dairy slurry application and found higher emission from dairy slurry (0.97% of total N applied) compared to the pig slurry (0.44% of total N applied). This was attributed to the fact that C content in the slurries were different and the fine solids in the dairy slurry blocked soil pores resulting in more anaerobic conditions in soil, which favoured N_2O emission. Van Groenigen *et al*., (2004) concluded that more water holding capacity and organic matter content in clay soils, as compared to sandy soils, resulted in higher N_2O emissions following manure application. In Netherlands, emission factors for N_2O emission were two times higher (1.21% of applied N) from clay soil than that of sandy soil (0.62% of applied N) owing to application of dairy slurry (van Groenigen *et al*., 2004). Anaerobic digestion decreases volatile solids (VS) in the soil - slurry mixture and reduces risk of N_2O emission as low VS decreases microbial demand for O_2 and consequently heterotrophic denitrification (Petersen *et al*., 1996). Bhandral *et al*. (2009) reported lower N_2O emissions from soils amended with digested slurries than with untreated slurries ; but this result is not consistent (Thomsen *et al*., 2010). Overall, these studies implied that application conditions as well as soil properties may influence N_2O emission (Oenema *et al*., 2005).

Soil nutrient supply

Soil organic matter provides many ecosystem services. Management practices that provide or maintain organic matter in soil can reduce nutrient losses and optimize nutrient uptake by plant (Franzluebbers, 2002). Biological amendments are an important source of nutrients to plants. Wherever low nutrient availability is a constraint affecting plant growth, the application of biological amendments can help overcome the nutrient constraint and improve crop productivity (Abbott *et al*., 2018). Smith and Read (2008) reported that arbuscular mycorrhizal fungi can increase the ability of plants to take up water and nutrients by increasing their effective root surface available for absorption.

Bio-stimulants like humic substances and seaweeds promote root growth (Crouch and van Staden, 1993; Jindo *et al*., 2012), which can enhance plant nutrient acquisition (Rose *et al*., 2014). Composts contain different macro and micronutrients, which influence soil physical and chemical properties like porosity, water holding capacity, pH and CEC (Bulluck *et al*., 2002). Nutrients supplied in organic form provide a slow-release of nutrients as compared to synthetic fertilizers. Low mineralization rates of organic materials supply nutrients to plants consistently to utilize over time (Tully and Ryals, 2017). Organic amendments with C: N ratios exceeding 20:1 immobilize certain nutrients initially making these nutrients immediately less available for plants or gaseous and aqueous loss pathways (Hadas *et al*., 2004).

Biological nitrogen fixation is a natural process, which is important in agriculture (Herridge *et al*., 2008) and has been estimated in various countries, in relation to area and grain yields. Galloway *et al*. (1995) and Smil (1999) estimated annual N_2 fixation for global agricultural systems as 43 Tg and 33 Tg. In the US, soils under soybean cultivation tend to be more fertile with medium to high concentrations of organic matter (Table 4) and available nitrogen (Russelle and Birr, 2004) . In those fields nitrogen derived from biological N fixation, values range between 40 per cent and 80 per cent (van Kessel and Hartley, 2000; Salvagiotti *et al*., 2008). Alves *et al*. (2003) reported increase in nodulation and N_2 fixation of no tilled soybean compared to other crops. Brazilian soybean derived 70–85 per cent of N from fixation, which was equivalent to 70–250 kg N ha^{-1} (Alves *et al*., 2003). Smil (1999) provided a comparison of estimates of nitrogen fixation, based on global data (Table 5).

A majority of agricultural soils contain large reserves of P, but availability of P is very low. Application of phosphate solubilizing microbial inoculants (bacterial/fungal) along with rock phosphates (Gaind and Gaur, 1991) can enhance the P availability in soil and me*et al*l requirements of crop, obviating the need for addition of chemical P fertilizers. A diverse range of microorganisms release potassium from potassium bearing soil minerals (Sheng, 2006). These potassium solubilizing bacteria (KSB) dissolve potassium from insoluble K bearing minerals like micas, illite and orthoclases, by excreting organic acids (Bennett *et al*., 1998). Microbial inoculants capable of K solubilization, can improve its availability due to the production of organic acids.

Table 4. Estimates of amounts of N fixed annually in major soybean producing countries

Country	Area (Mha)	Grain yield (Tg)	Crop N fixed (Tg)
U.S.	30	85	5.74
Brazil	22.9	51.2	4.61
Argentina	14	38.3	3.44
China	9.6	16.8	0.95

Note: Based on FAO data, 2005

Source: Modified from Herridge *et al*. (2008)

Table 5. Comparing estimates of N fixation (kg ha^{-1}) by Smil (1999), using global data from legume growing areas

Legume	Smil (1999) values (kg N ha^{-1} yr^{-1})
Common bean	40
Chickpea	50
Pea	40
Lentil	40
Fababean	100
Other pulses	60
Groundnut	80
Soybean	80

Source: Modified from Herridge *et al*. (2008)

Biofertilizers are another source of nutrients that improve the biological yield of crops and also enhance soil health in a sustainable manner (Subba Rao, 2009, Lata *et al.,* 2002). Biofertilizers such as *Rhizobium*, *Azotobacter, Azospirilium* and blue green algae (BGA) are applied either as seed dressings or soil application, by amendment with carrier or broadcast (in flooded rice fields). They enhance the crop productivity, by proliferating in soil, influencing beneficially soil macro/micro flora/faunal communities and modulating nutrient cycling, thereby improving nutrient availability in soil and its uptake by crop (Tilak, 1993). These biofertilizers provide savings of 20-40 kg N/ha besides improved availability of other macro/micronutrients. The quantification of the anticipated benefits of various biofertilizers is based on data generated through All India Network projects and on farm trials by the Division of Microbiology, Indian Agricultural Research Institute. A summary of the benefits of biofertilizers using benefit cost approach, based on rigorous experimentation and extensive field trials is tabulated in Table 6.

Soil biodiversity

Soils provide a complex and heterogeneous habitat that supports high microbial and faunal diversity (Gans *et al*., 2005). These organisms play a critical role in sustaining the soil ecosystem functioning and providing benefits to human beings. Soil biodiversity contributes to food and fibre production, and is an important regulator of other soil services like greenhouse gas emissions, nutrient cycling and water purification (Bodelier, 2011). Biological amendments are known to stimulate soil microbial growth directly by providing nutrient and energy or indirectly by enhanced plant growth and root C flow (Buyanovsky and Wagner, 1986). Use of biological amendments such as manures or microbial consortia can

Table 6. Benefits of biofertilizers

Name of biofertilizer	Rate (kg/ha)	Crops	Input cost (Rs/ha)	Impact Kg (N/P)	Total benefit (Rs/ha)	Other effects on soil health
Rhizobium	0.5	Legumes	25	20	190-225 540 -880	Enhancement in plant growth and nutrient uptake, nodulation and yields; improved soil fertility
Azotobacter	0.5	Cereals, fodder, oilseeds and vegetables	25	17.5	145-200	Stimulation of plant growth and nutrient uptake, yields and improved soil fertility
Azospirillum	0.5	Fodder and cereals	25	20	200	Enhancement in plant growth and nutrient uptake; improved soil fertility
BGA/ Cyanobacteria	0.75-1.0	Paddy, Wheat, Maize, selected legumes, vegetables and flowers	80	27.5	260-315	Enhancement in plant growth and yields, enrichment of macro/ micronutrients in grains and their availability in soil
P-solubilizer	0.5	All crops	25	25	600	Overall improved plant growth and soil fertility
AM inoculant	0.5	Orchard, nursery raised and all other crops	100	25	420-670	Reduction in seedling / nursery mortality, Improvement in availability and mobilisation of nutrients in soil and plant uptake

Source: Division of Microbiology, Indian Agricultural Research Institute enhance the soil biodiversity in terms of species richness and functional diversity, making soils more resilient to stress and disturbances (Kumar *et al*., 2014; Larney *et al*., 2016). Composts contain active microbial communities (Chander and Joergensen, 2002) which when added to soil can stimulate soil biota and change the microbial community structure (Cytryn *et al*., 2011; Bedi *et al*., 2009).

Soil formation

Soil formation is an important ecosystem service provided by the soil biota (Sandhu *et al*., 2005). According to Pimentel *et al*. (1997), earthworms bring around 10 to 500 tonnes/ha/year of soil to the surface and approximately 1 tonne/ha/year of top soil is formed. Earthworms also help in maintaining soil nutrient levels by mixing the soil, improving aeration and enhancing nutrient availability.

Soil structure and water holding capacity

Addition of organic matter to soil increases microbial abundance and diversity. Some microorganisms secrete polysaccharides, grow as biofilms or form mycelial networks, which help in binding soil particles and improving the structure and functioning of soil (Six and Paustian, 2014; Bharti *et al*., 2017) including enhanced water holding capacity (Caesar-TonThat *et al*., 2007). Besides this, production of mucilage by soil microorganisms enhances micro-aggregate formation (Six *et al*., 2004). Application of compost to soil improves its physical properties by acting as a cementing agent and assisting in formation of stable aggregates (Spaccini *et al*., 2004). This leads to improved aeration and infiltration as well as enhancement of water holding capacity of soil (Babalola *et al*., 2012). Use of biological amendments can improve the structure of both heavy as well as coarse textured soils and influence biological and chemical processes that support growth of plants. Organic amendments improve soil structure by lowering bulk density, improving aggregation, and increasing water holding capacity of soil (Jeffery *et al*., 2011; Zebarth *et al*., 1999). Improvement in soil physical properties reduces risk of soil erosion because better water infiltration, and reduces leaching losses. Babalola *et al*. (2012) concluded that compost amendment caused increase in soil organic carbon and soil microbial activity leading to improvement in soil physical properties.

Resilience to pest and diseases

Organic pest management involves the use of natural enemies for pest control; and has a comparatively low impact on the environment (Birkhofer *et al.*, 2008). Application of manures or biocontrol agents can increase the activity of naturally occurring soil microbial antagonists against fungal pathogens (Bailey and Lazarovits, 2003), making the plants more immune or resistant to attack (Yogev *et al*., 2010). Abundance of bacteria may increase with application of composts and manures which may exude siderophores that bind Fe, making less iron available for pathogenic fungal species (Leong and Neilands, 1981). Higher biodiversity of soils can help in disease suppression through a variety of mechanisms, such as reducing the abundance of soil fungal pathogens and pests, release of allelochemicals, raising soil pH and increasing soil microbial antagonists (Cao *et al*., 2014; Liu *et al*., 2016).

Case Studies on Biological Amendment and ES

Since the early 21st century, different schemes have been proposed to provide incentives to land managers for implementing environment friendly farming practices. Among these schemes, the Farm Bill practiced in USA (Reimer, 2015) is a good example to encourage farmers to ensure food security while sustaining ecosystem services. Some global studies measured impacts of agriculture production on ecosystem services (Dale and Polasky, 2007, Sandhu *et al.,* 2008). Sandhu *et al*. (2010b) assessed three key supporting ecosystem services i.e. biological control of pests, soil formation and mineralisation of nutrients in arable farmland in New Zealand using experimental data. The total economic value of these services was significantly higher in organic fields (US \$232 ha^{-1} yr^{-1}) than conventional US \$146 ha^{-1} yr^{-1}) ones. ES for biological control were significantly higher in organic fields. The economic value of soil formation by earthworms was assessed for arable land in New Zealand (Sandhu *et al*., 2005). The mean value of top soil for organic fields was NZ\$ 6.06 ha^{-1} yr^{-1} and that of non-organic soil NZ\$ 4.56 ha^{-1} yr^{-1}.

Conclusions

At the present juncture, what is needed is a re-envisioning of land-use planning that places human well-being and environment at the centre. A new coalition of ecologists, health and social scientists to conduct research and planners to develop policies should be encouraged to promote human interaction with nature and biodiversity in sustainable manner. Improvements in these areas can lead to better human health, livelihood opportunities and ecosystem sustainability, and human resilience. Also, there is a need for development of improved protocols for monitoring biodiversity, functional measures of ecosystem services, and their valuation for use by the practitioners and scientists.

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CHAPTER 7

ASSESSMENT OF GRASS-ROOT PERCEPTIONS TO CLIMATE IMPACT ON AGRICULTURE ECOSYSTEM AND ADAPTATION PLANNING FOR RESILIENT LIVELIHOOD

Naveen P. Singh, Bhawna Anand, Arshad Khan and Surendra Singh

Introduction

The pervasiveness of climate impacts is posing risks to the ability of the ecosystem services to sustain agriculture production and rural livelihoods (Fischlin *et al*., 2007; Boon *et al*., 2012). Ecosystems provide wide range of goods and services, which are classified into four broad categories: provisioning, such as the production of food, fresh water and fiber; regulating services such as biophysical processes that control climate, floods, diseases, air and water quality, and erosion; supporting, such as nutrient cycles and crop pollination; and cultural, such as spiritual and recreational benefits (MEA, 2005; Irwin *et al*., 2007; Bhatta *et al*., 2015). Variation in temperature and precipitation pattern and recurrence of extreme weather events affects development of crop (Jha and Tripathi, 2011; Auffhammer *et al*., 2012; Rao *et al*., 2014) through changes in these key functions such as pollination, water regulation, soil fertility and proliferation of pests and diseases (Porter, 2014). The Millennium Ecosystem Assessment (2005) recognized that ecosystem degradation adversely affects rural populations which are heavily dependent of ecosystem services for subsistence livelihoods. Adaptation to climate variability and change in the system is imperative to sustain the productivity and profitability for the farmers in developing country like India in short to medium run (Singh *et al*. 2018). Figure 1, depicts the general framework elucidating the link between climate change, ecosystem services and adaptation as a response strategy. Climate change is not only the cause of ecosystem degradation as mentioned above but is also affected by the deterioration of ecosystem services. Ecosystem degradation reduces carbon sequestration in the ecosystems and may turn them from carbon sinks to sources (Fearnside, 2000) exacerbating the vicious spiral (Munang *et al*., 2013). Moreover, ecosystem degradation reduces assimilative capacity of the ecosystem, leading to greater frequency and intensity of natural disaster and breakdown of food chains. All this reduces resilience of natural and

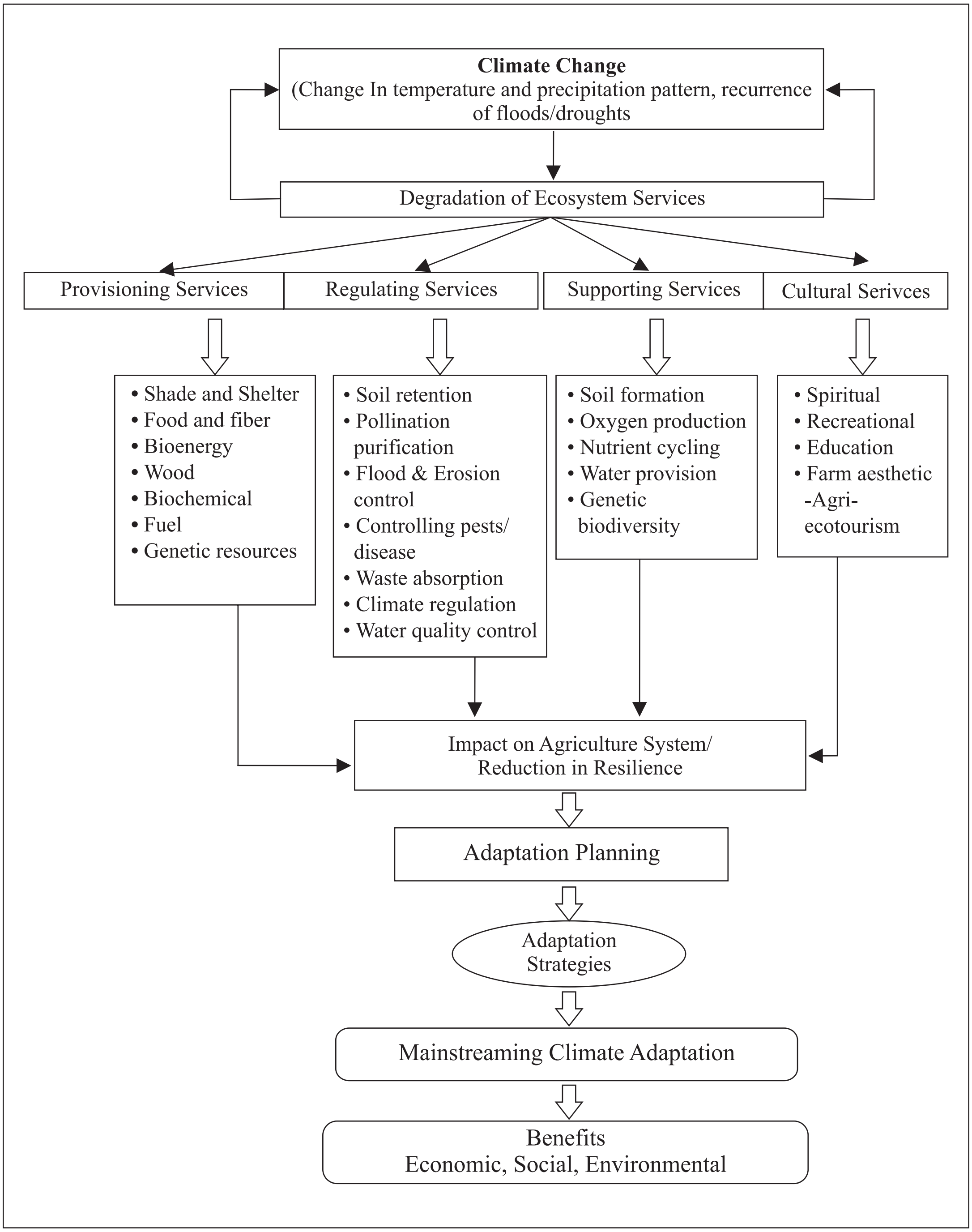

Figure 1. Generic framework depicting the link between climate change, ecosystem services and adaptation

human systems against climatic changes necessitating development of suitable adaptation strategies and policy.

Farm households employ a range of risk coping strategies to limit the losses and vulnerability from climate stimulations (Adger, 2003; Porter *et al*., 2014). These strategies mainly evolve as a result of traditional/ experiential knowledge and show considerable diversity and flexibility based on physiological and socio-economic differences (Singh *et al*., 2015a).

In India, climatic variability adds an additional burden to the small and marginal farm households which exist in a very large proportion of 85% of the total farming community and are already hapless with insufficient financial and technical resources base (Kumar and Parikh, 2001; Jain *et al*., 2014).The heterogeneity in adaptation process and the weaker capacity of the farmers reduce the effectiveness of autonomous coping mechanisms at the grass-root level. This substantiates the need to mainstream or integrate climate responses within the broader framework of long-run sustainable development (Castells-Quintana *et al*., 2018), focusing impacts and constraints to adaptation. Mainstreaming adaptation is an iterative process of integrating considerations of climate change adaptation into policy-making, budgeting, implementation and monitoring processes at different levels of government; national, sectoral and sub national levels (UNDP-UNEP, 2011). The approach aims to create an enabling environment to increase the capacity of an ecosystem to external shocks. Indian rural/ agricultural development and poverty alleviation policy, pay little attention to climate change (Agarwala, 2004) and thus lacks a plan of adaptation planning. Assessment of grass-root vulnerability to climate change and obstacles to adaptation provides useful information to design policies for managing a variety of risks associated with climate change in agriculture (Nhemachena *et al*., 2007, Bryan *et al*., 2009; Singh *et al*., 2015b; Ayanlade *et al*., 2017). While studies assessing the socio-economic impact and barriers to adaptation are growing in the context of Indian agriculture, however, few have endeavored to establishing relation between climate adaptation and development policy. This paper focuses on assessing farmers' perceptions on the impacts of climate variability; risk coping mechanisms and barriers for adopting adaptation strategies in two different regions of India. Further, the study attempts to dovetail grass-root information with the macro-level policy making by suggesting need-based adaptation planning, which integrates various farm level issues, opportunities and the programmatic interventions which could facilitate the suggested options.

Methodology

This work is based on both primary and secondary data. Field survey was conducted to assess farmers' perception of climate variability and adaptation strategies followed. Two states, namely Telangana and Punjab in India, were selected for exploring micro-level adaptation. Multi-stage sampling technique was used for selecting the sample households. In the first stage, two districts, Mahbubnagar in Telangana and Moga in Punjab were purposively selected. In the second stage two blocks from each district and in the third stage two villages from each block were selected. Finally, simple random sampling technique was used for selecting 20 respondents from each of the selected villages. Thus, a total of 160 farmers with different social and demographic characteristics were selected for the study (Table 1). The sample consisted of a mix bag of respondents belonging to each farm size category. The average age and farming experience in the study districts were nearly 47 years and 22 years respectively. More than 40% of the sampled farmers in both the districts had primary education, 30% with secondary level and 20% education up to higher secondary or above. Compositions of the respondents signify an educated and experienced group of farmers, who are able to understand the dynamics of changing climatic conditions and accordingly alter the farming decisions.

Table 1. Farm household attributes in selected districts, India

Variables	**Mahbubnagar, Telangana (n=80)**	**Moga, Punjab (n=80)**
Average family size (persons)	5.20	5.43
Average age (years)	47.07	47.37
Average agricultural workers	2.03	2.27
Average farming experience (in years)	22.63	22.40
Average land holdings size (ha)	3.00	4.20
Education (%)		
Primary education	41.25	46.25
Secondary education	36.25	33.75
Higher secondary and above	22.50	20.00

Informal interviews with the farmers and focused group discussions (FGDs) with 15-20 stakeholders in the selected villages were the major the tools used for extracting micro-level information. During the grass-root enquiry, farmers were asked open-ended questions relating to the changes perceived in the weather parameters and the recurrence of extreme weather events (droughts and floods), changes in crop production system, the socio-economic impacts perceived, risk coping strategies / mechanism and various barriers faced in adaptation to climate change. The information collected was quantified using frequency and percentage analysis.

The study also analyzes susceptibility of different crops to changes in rainfall and temperatures, keeping other factors constant in Punjab and Telangana. The panel consists of district level data on climatic parameters (rainfall and temperature) and crop yields during the period from 1998 -2016 for Punjab (17 districts) and 1997-2016 for Telangana (9 districts). The dependent variable considered is the logarithm of crop yield. Hausmann test is applied for selection of the model, viz., random and fixed effect model.

Following regression model in considered for analysis:

$$ln\ Y_{it} = \alpha_{it} + \beta W_{it} + \varepsilon_{it} \qquad .... (1)$$

Where Y represents crop yield, W is vector of climatic variables (rainfall and temperature) and stochastic error. The subscripts i and t denote district and time.

The marginal effect is estimated by using equation (2)

$$E\left[\frac{dy}{dx}\right] = \beta \times \left[\frac{MX_i}{MY_i}\right] \qquad .... (2)$$

where, $E\left[\frac{\partial y}{\partial x}\right]$ is marginal effect of minimum and maximum temperature and rainfall on the crop productivity, β is coefficient value, MX_i is mean of single climate variables, and MY_i is mean crop yield.

The effects of temperature on crop yields have been projected at three time periods, 2025, 2030 and 2035 using equation (3)

$$\Delta Y = \left[\left(\frac{\partial y}{\partial R}\right)\Delta R + \left(\frac{\partial y}{\partial MAT}\right)\Delta MAT + \left(\frac{\partial y}{\partial MINT}\right)\Delta MINT\right] * 100 \qquad .... (3)$$

Where Y is crop yield, R is rainfall, MAT is the maximum temperature and MINT is the minimum temperatures $\frac{\partial y}{\partial R}$, $\frac{\partial y}{\partial MAT}$ and $\frac{\partial y}{\partial MINT}$ are the coefficients, measured from the regression model (Appendix).

Results and Discussion

Climate impact on crop yields

Higher temperatures and greater variations in rainfall generally have a profound impact on the reproductive cycle of the crops. Changes in crop yield induce changes in production, prices, thereby affecting the farmers' livelihood.

Marginal effect on crop yields in Punjab

There was 0.3 per cent increase in rice yield and a decrease of similar magnitude in wheat and maize due to total change in weather variables. While cotton and chickpea crop has been benefitted, there is yield loss of 1.02 in groundnut due to rise in maximum temperature. *Rabi* crops have been marginally affected due to change in the both rainfall and temperatures during the period. Moreover, rice and cotton yields are expected to grow while all other crops will be negatively affected with the significant changes in temperature. Rape seed and chickpea will be most affected by temperature change.

Marginal effect on crop yields in Telangana

In Telangana, rice showed an increase of 13 per cent and maize (27 per cent) and *jowar* (54 per cent) a decline on account of change in both the climatic variables during the period. *Jowar* showed a decline of 54 per cent and maize of 27 per cent on account of higher precipitation. Rise in maximum temperature has positively affected all the *rabi* crops. Moreover, the projections reveal that all crops expect *jowar* and maize will gain due to change in temperature.

Farmers' perceptions of climate variability and socio-economic impacts

Farmers possess repository of traditional knowledge about crucial linkages between weather parameters, agriculture, and socio-economic repercussions, as they have been practicing agriculture for generations. Understanding farmers' perceptions is imperative for effective and informed adaptation planning (Table 2). From the field survey, it was ascertained that farmers perceived climate variability than long term climate change. Majority of the farmers' felt significant variations in the quantum of rainfall and continuous delay in the arrival of monsoon over the years in both the districts. They believed that rainfall have become more intense over fewer days, leaving rest of the season dry. Earlier the shower used to begin in the first week of July, but it now starts somewhere in August, affecting *kharif* sowing. Moreover, there were growing concerns over off-season rains. Farmers reported increasing stress on groundwater on account of excessive irrigation and increased erraticism in the distribution of rainfall. Increased temperatures and irrigation have resulted in higher level of soil salinity, which is making it difficult to grow/ cultivate traditional crops. Farmers in Moga district of Punjab, unanimously agreed towards a gradual increase in both summer and winter temperatures affecting both *kharif* harvesting and germination of *rabi* crops (high temperatures up to December) and causing high rate of evapo-transpiration. This coupled with water intensive cropping pattern due to an effective government minimum support price (MSP)-linked procurement system in the region and power subsidies, is leading to reckless exploitation of groundwater. In Mahbubnagar district majority of the farmers perceived increasing water stress due to drying up of common property resources like well, tanks. Besides, higher temperatures and significant oscillations in hydrologic variables, as per Jodha *et al*. (2012) can be attributed to poor management of common, increasing population pressure, increased use of chemical fertilizers and a decrease in the use of organic inputs and an overexploitation of groundwater resources. There was also reoccurrence of dry spells/

drought in the region causing yield uncertainty. Moreover, higher incidence of pest and diseases and delay in flowering of the crops was reported in both the districts due to increased variations in atmospheric temperatures.

Climate related risks are expected to impact livelihoods and socio-economic stability of rural households. Farmers expressed lower farm income and profitability due to crop losses associated with increased climatic abnormalities. Financial hardship owing to successive crop failure obligates farm households to sell or mortgage their productive assets for meeting the domestic consumption needs. Failure of agriculture results in loss of employment for farming communities in rural and other areas (Udmale *et al*., 2015). This along with low education level and inadequate skill to serve other areas further adds to their vulnerability.

Table 2. Farmers' perceptions on impact of climate change

Aspects	Responses	Mabubnagar, Telangana	Moga, Punjab
Precipitation			
Amount of rainfall	Quantity of rainfall have changed over the years	83	45
Frequency of rainy day	There is decline in number of rainy days	69	59
Rainfall onset and cessation	Shift in arrival /onset of monsoon affecting sowing	59	73
Distribution of rainfall	Rainfall distribution has become erratic, with increased variation during early and late monsoon season	29	32
Temperature	Increase in average temperature especially in Moga during winters affecting wheat crops	45	81
Droughts/ flood	Increasing frequency of extreme weather events. Frequency of droughts and long dry spells are rising in both the districts.	33	25
Major climate induced problems identified in selected villages	Decline in crop yield and production	79	21
	Declining level of ground water	77	67
	Scarcity in surface water bodies	65	26
	Decline in soil fertility/change in soil salinity	14	6
	Increasing incidence of pest and disease infestation	54	18
	Difficulty in growing traditional crops	34	19
	Changing flowering period of different crops	42	50

Table 2 contd...

Aspects	Responses	Mabubnagar, Telangana	Moga, Punjab
Socio-economic impact as perceived by the farmers	Declining farm income and profitability	57	73
	Rising level of farm unemployment	54	41
	Food shortage	15	5
	Increasing price of essential food items	77	51
	Reduction in domestic consumption	29	13
	Land mortgage	24	5
	Increasing incidence of farm indebtedness	57	37
	Increasing rural migration	46	9
	Reduction in expenditure on festivals/ marriages	69	37
	Reduction in expenditure on child education	17	13
	Rising inter-society water disputes	21	12
	Incidence of farmer's suicide	13	5

Farmers in both the districts expressed similar concern of rising unemployment. They unanimously agreed that declining income and employment opportunities are eventually leading to increased debts/ loans from both institutional and non-institutional sources and subsequent default in repayment leading to farmers' suicides. Moreover, farmers opined income stress are forcing villager especially in Mahbubnagar district to migrate to metropolitan cities. There was also a rise in considerations to escalating prices of necessary commodities, education and family health, and erosion of village / community social support system evident from growing water disputes in the society. Farmers also expressed reduction in expenditures on marriage and festivals celebrations due to increased climatic uncertainty and risks.

Adaptation strategies practiced at the grass-root level

Different practices are exercised by the farmers to address multiple constraints and opportunities directly or indirectly linked with climatic variables (O'Brian *et al*., 2004). The farmers reported that they were substituting to drought/pest tolerant, short duration crop varieties and water-intensive crops and making suitable adjustments in the sowing and harvesting dates (Figure 2). Similar finding were reported by Ogden and Innes (2008) and Deressa *et al*. (2009), and Tao and Zang (2010). Farmers were also diversifying crops (Adger *et al*., 2003) and shifting towards mixed cropping system to reduce exposure to the risk of crop failure.

They were gradually switching towards water efficient technologies like sprinklers and drip irrigation. Banerjee (2014) found that farmers in Maharashtra and Andhra Pradesh, were

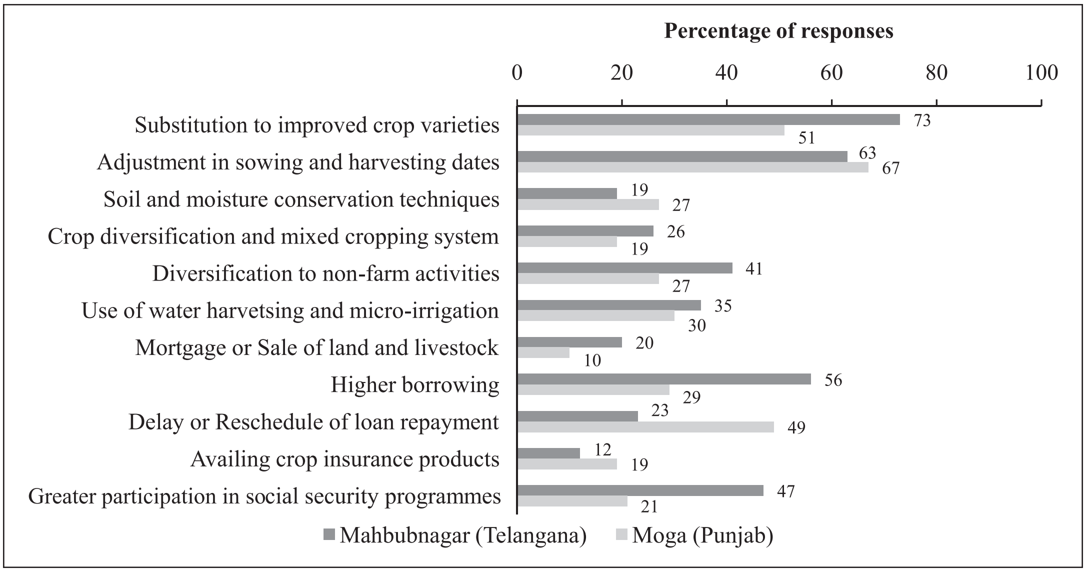

Figure 2. Adaptation measures used by farmers for coping with climate change effect

incorporating irrigation technologies such as farm surface ponds, furrow channels, ditches and checkdams. However, the application of micro-irrigation is mainly restricted to large farmers and remains low across the districts owing to high installation cost and power outages. Only a few farmers expressed availing crop insurance owing to lack of knowledge and incentive especially for small farmers as they have to pay premium. Large proportion of the respondents in Moga district was rescheduling their loan payment, whereas farmers in Mahbubnagar district resorted to higher borrowing due to low profitability. To cushion against the increased uncertainty of rainfall and recurrence of extremes, farmers were diversifying to non-farm or off-farm activities such as dairy, small scale manufacturing, transportation, etc. Besides, there was an increasing participation in social protection and employment schemes of the government and transitory migration.

Constraints to adaptation decision-making/ planning at the farm-level

Farmers' autonomous planning to climate risks are often rendered ineffective due to various barriers. These include socio-economic, institutional, technological, and financial factors that restrict effective implementation of climate adaptation practices (Kelly and Adger, 1999, Bryan *et al*., 2009; Deressa *et al*., 2009). For devising plausible measures to smoothen the process of adaptation, it is crucial to identify the various obstacles at the farm level (Eisenack *et al*., 2014). Focus group discussions (FGDs) revealed several constraints that impede farmers' adaptation to climate variability (Figure 3). There was consensus among the farmers that lack of formal information on shorter-duration crops and drought resilient varieties, lack of accessibility and timely weather information, limited access to agricultural extension

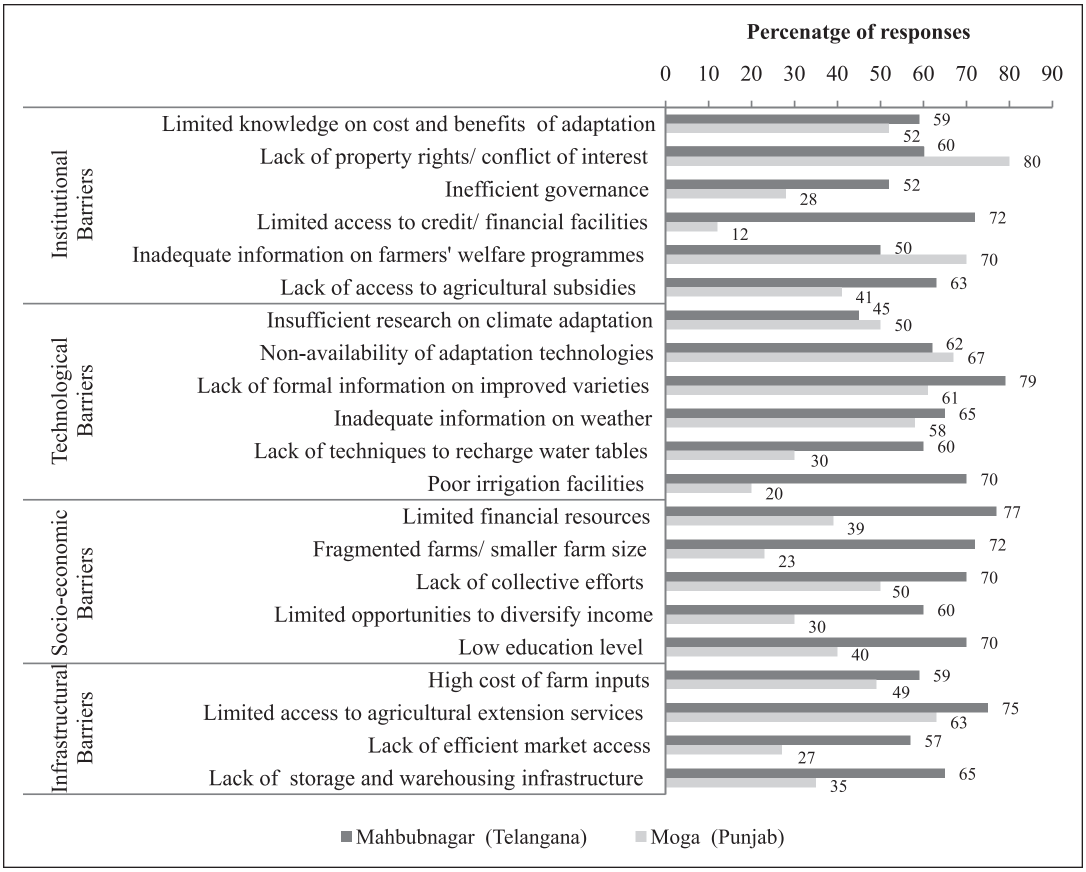

Figure 3. Farmers' response on potential barriers to climate change adaptation

services, and poorly defined property rights as the major deterrents to adaptation across both the regions. Illiteracy, limited knowledge on social costs and benefits of adaptation, high cost of farm inputs and limited access to agricultural markets render adaptation difficult. Farmers voiced that the most urgent need for adaptation to climatic change was to develop and strengthen irrigation facilities.

Poor accessibility to formal credit, saving facilities, and other financial products has been cited as one of the major constraints to adaptation by the farmers especially from Mahbubnagar district. Lack of accountability, lack of mechanisms for continuous evaluation and implementation of policies, leakages, and politics of distribution to satisfy the interest of some vested groups in the system impedes adaptive capacity of rural community. This is evident by the lack of awareness and information on various farmers' centric welfare initiatives of the government among the surveyed farmers. Further, limited resources, lack of awareness on the need for adapting to the changing climate, uncertainty on the success of climate adaptation strategies/technologies, and limited farm size were the other significant constraints as perceived by the farmers especially in Mahbubnagar district. To minimize the climatic and socio-economics risks to climate change, it is pertinent to understand the constraints and interdependence between them. Moreover, creating an environment where such constraints are effectively eliminated should be a key intent of streamlining the country's policy environment (Singh *et al*., 2012).

Building micro-level resilience: need-based policy environment

Impacts of climate change and vulnerability of the farmers are characterized by high degree of diversity across the spatial and temporal scales (Singh *et al*., 2014). The ability of the farm households and rural communities to act and survive against the weather variations depends on their existing capacity, which is influenced by the local environment, institutional setup, and natural resources management. Sen (1985, 1999) argued that people should have substantive freedom to convert their resources into effective functioning as wealth/ income alone determines their ability to adapt. To achieve this task of strengthening farmers' capabilities and making asset of the farm communities more resilient to unpredictable weather perils there is now an emerging consensus among the developing nations to mainstream adaptation into development and poverty alleviation policy (Huq *et al*., 2004; Lemos and Boyd, 2009; Agrawala and Lemos, 2015). However, climate adaptation planning requires location specificity in interventions which cannot be achieved without understanding grass-root imperatives and engagement of local village communities or their representatives. Convergence between micro-level and macro-level is important to address the various layers of constraints faced by the rural household economy at farm, social, technological, and institutional level. Singh *et al.*, 2015b, argues that most of the macro-level policies are designed using aggregated information, and represent a high disconnect from the micro-level needs and constraints/ realities. There is an urgent need to create a repository of micro-level information, and blending it with the programmatic interventions relating to agriculture, food security, and livelihoods implemented across various departments and ministries of the government. This will not only improve the reliability and acceptability of the top initiatives but more importantly capacitate farmers as per the local requirements to cope up with the changing climatic conditions. We attempted to create a need based adaptation approach, an outcome of grass-root level work, linking the climate related issues at the farm level, plausible options with the current rural and agricultural development programmes. These options or opportunities to mainstream adaptation have been broadly segregated into three categories: Development and promotion of climate adaptation knowledge and technologies; natural resource management; and strengthening institutions.

Development and promotion of climate adaptation knowledge and technologies

With a view of simultaneously advancing growth and development of Indian agriculture and the objectives of climate adaptation and mitigation, the Government of India launched several over-arching programmes such as, National Mission for Sustainable Agriculture (one of the eight missions under National Action Plan on Climate Change (NAPCC), National Innovations on Climate Resilient Agriculture (NICRA, an initiative of Indian Council of Agricultural Research) and National Adaptation fund (NABARD as a National Implementing Entity). These programmes have multi-pronged strategy for facilitating climate adaptation at the farm level in the form of infrastructure development, capacity building of local stakeholder and extensive R & D activities for developing suitable crop varieties and technologies so that food and livelihood insecurities can be addressed. Adoption of innovative and efficient technologies (summarised in Table 3) for adaptation at the farm level demands an active extension system which can be achieved through establishment of extension agencies at the lowest level of hierarchy, capacity building, and information dissemination via electronic and print media. Besides the aforesaid mega programmes, interventions such as National Mission on Agriculture and Extension, *Krishi Vigyan Kendra* and *Krishi Call Center* can facilitate farmers' access and also modification of climate adaptation technologies as per suitability. Moreover, weather-based agro-advisories and use of remote sensing and GIS technologies can help farmers in informed agricultural operations and formulation of local contingency plans for mitigating the climate- induced risks.

Natural Resource Management

Climate induced stresses on natural resources results in lower resilience of poor farm households which are heavily dependent on environmental services for their livelihood (Lee *et al*., 2009). Sustaining and protecting natural resources such as water, forest and land requires establishing collective accountability of the locals, regulations by the village/ local authorities and encouraging the role of local government and NGOs in enhancing awareness on the need of adaptation to climate change. Encouraging adoption of *in situ* water harvesting and management technologies, promotion of micro-irrigation (drip and sprinkler) and groundwater recharge techniques, drought proofing and development of infrastructure by venturing into Public Private Partnership (PPP) programmes are useful measures to reduce risks associated with variability in rainfall. It is estimated that India uses 2-4 times more water to produce one unit of major crops than other major agricultural countries like China and Brazil (Hoekstra and Chapagain 2008). To this effect schemes like *Pradhan Mantri Krishi Sinchayee Yojana*, National Water Mission, National Mission on Sustainable Agriculture and MNREGA can help to achieve 'per drop more crop' agenda. Land and nutrient management involving promotion of organic practices and change in agronomic operations form an important segment to climate adaptation in dry areas (Ndjeunga *et al*., 2015). Schemes like Soil Health Card, National Project on Management of Soil Health and Fertility and *Paramparagat Krishi Vikas Yojana* of Ministry of Agriculture and Farmers' Welfare are of great significance in ensuring increased application of integrated nutrient management techniques. (See Table 4). Protection of crops against climate-induced biotic

Table 3. Development and promotion of climate adaptation knowledge and technologies

Issue	Recommendation	How	Schemes
Insufficient technological development in the areas of climate adaptation	• Develop & promote use of crop varieties & animal breeds well suited to climate change • Revise & promote new cropping calendars	• Conduct agricultural research to develop practices & invest in extension to promote the practices • Conduct research to determine new precipitation & temperature patterns and forecasts	✓ National Mission on Sustainable Agriculture ✓ National Innovations on Climate Resilient Agriculture ✓ National Adaptation Fund
Poor extension services and unawareness on importance of climate adaptation and technologies	• Strengthen capacity of agricultural extension services to provide climate-change-smart Sustainable Land and Water Management (SLWM) practices • Conduct research on economics of adaptation • Training farmers and other stakeholders on changing climate conditions and devising appropriate measures / option	• Short-term & long-term training of extension agents • Collaboration with private/ commercial companies • ICTs • Promote the role of NGOs and other providers/agencies to operate in the entire country, ensuring they provide complementary services	✓ National Mission on Sustainable Agriculture ✓ National Innovations on Climate Resilient Agriculture ✓ National Mission on Agricultural Extension and Technology- Sub- Mission on Agricultural Extension ✓ Agriculture Technology Management Agency (ATMA) ✓ Kisan Call Centers ✓ Krishi Vigyan Kendras ✓ National Adaptation Fund
Lack of accessibility and useful information on weather at grass-root level	• Repository of weather –related information and data • Strengthening accurate weather forecasts and early warning system from micro-level data • Active weather based agro-advisories at the farm level	• Installation of weather station at village level • Generation of data at grass-root/ panchayat level • Agro-advisory at Public and Private and NGO level • Institutional support for agro-advisory services.	✓ National Mission on Sustainable Agriculture ✓ National Innovations on Climate Resilient Agriculture ✓ Flood Forecasting ✓ Numerical Modelling of Weather & Climate ✓ Agro-Meteorological Services Programme

Note: Adopted and modified from Singh *et al.* (2017) and Singh *et al.* (2018)

Table 4. Natural Resource Management

Issue	Recommendation	How	Schemes
Change in quantum of rainfall/rainy days/altered onset of monsoon as well as variations in temperature Depletion of surface water bodies and ground water	• Developing irrigation infrastructure • Promotion of micro-irrigation technologies • Ground water recharge techniques, aquifer mapping, water harvesting • Adoption of less water intensive crop varieties	• Better irrigation management; enhancing water use efficiency • Innovative irrigation practices • Shift to improved irrigation methods (sprinkler, mini-sprinkler, trickle) • Reduce soil evaporation losses • Promoting sub surface irrigation (SDI) & restricted deficit irrigation (RDI) • Alternate crops demanding less water • Creation of stakeholders consortium	✓ *Pradhan Mantri Krishi Sinchayee Yojana:* • Accelerated Irrigation & Flood Management Programme • Integrated Watershed Management Programme • On Farm Water Management ✓ National Water Mission ✓ National Mission on Sustainable Agriculture ✓ National Innovations on Climate Resilient Agriculture ✓ Groundwater Management and Regulation Scheme ✓ National River Conservation Plan ✓ National Mission for Clean Ganga ✓ Mahatma Gandhi National Rural Employment Guarantee Scheme (MNREGA) ✓ Long term Irrigation fund and Micro-Irrigation Fund (via NABARD)

Table 4 contd...

Issue	Recommendation	How	Schemes
Increased pest and disease incidence	• Integrated Plan Protection Management	• Judicious use of chemical pesticides for reducing pesticides residues • Biological control and IPM • Surveillance and monitoring	✓ Mission on Plant Protection and Plant Quarantine ✓ *Rashtriya Krishi Vikas Yojana* ✓ National Mission on Oilseeds and Oil Palm ✓ National Food Security Mission
Land degradation	• Land and Nutrient management	• Managing soil erosion, strip/ contour farming, crop rotation • Combating desertification & soil erosion • Organic sources to improve soil fertility, mulching	✓ National Project on Management of Soil Health and Fertility ✓ Soil Health Card
Forest degradation	• Afforestation and regeneration of degraded forest • Strengthening of infrastructure for forest protection • Sustainable and equitable distribution of forest products • Encouraging local participation in decision making	• Afforestation and reforestation • Reduced dependence on wood/ timber products • Rehabilitating degraded lands • Promotion of agroforestry & ecosystem services • Reducing loss of biodiversity	✓ National Afforestation Programme ✓ Intensification of Forest Management Scheme ✓ Green India Mission ✓ *Van Bandhu Kalyan Yojana*

Note: Adopted and modified from Singh *et al.* (2017) and Singh *et al.* (2018)

stresses requires developing pest resilient varieties and models for informed planning at the farm level, promotion and commercialization of bio-pesticides, surveillance and monitoring and continued R & D, effective extension in plant health management. Degradation and loss of forest causes ecological imbalances and have profound impacts on local communities whose livelihood are inextricably linked to the forest ecosystem. Expansion in area under forest and promotion of agro-forestry through schemes like National Afforestation Programme, Intensification of Forest Management Scheme, *Van Bandhu Kalyan Yojana* and other could be a potential adaptation-cum-mitigation measure for climate change.

Strengthening institutions for farmers to adapt

Formulating viable weather-based crop insurance products requires extensive R&D for developing effective models of risk assessment and risk cover mechanism, which not only ensures stability in farm income but also fiscal discipline which often get disturbed due to loan waivers. The *Pradhan Mantri Fasal Bima Yojana* have lower premium rates, broader risk basket covering yield losses, preventive sowing and post-harvest losses, mandates use of remote sensing and other technologies for faster claim settlement and greater participation to protect farmers against non-preventable natural risks (See Table 4). Subsidized interest and easy access to formal credit will help in reducing farmers' indebtedness whilst also promoting adoption of progressive farming practices, high value inputs and advanced technologies. e-National Agricultural Market and other agri-marketing oriented schemes can help farmers to diversify their income sources to high value crops by addressing fragmentation of the markets, price anomalies, multiple functionaries chain and information asymmetry. Moreover, schemes like Mega Food Parks programme envisage improving farmers' income by improved agriculture value chain. Existence of local opportunities to earn income from alternate sources will ensure smooth consumption pattern for the farm households while ensuring further investment in farm productivity and lesser migration. Rural population often lacks adequate skills set and education to serve other off farm sectors and remains unaware to various entitlements and relief measures provided by the government. Mega programmes of the government of India such as MNREGA, National Rural Livelihood Mission, and *Pradhan Mantri Kaushal Vikas Yojana* can help strengthen and empower farmers to diversify their income sources to off-farm or non-farm activities to cushion against production losses.

There is need to strengthen synergy between vertical and horizontal inter-institutional networks to operationalize the intended adaptation for effective integration of climate adaptation planning (Azhoni *et al*., 2017). Desired outcomes of the above programmatic interventions in addressing vulnerability to climate change of farm households are seldom realized, for the want of focus on adaptation and lack of convergence of schemes in implementation. Moreover, creation of enabling environment not only requires an improved institutional mechanism but also behavioral changes in the farming community through dissemination of knowledge and capacity building.

Table 5. Strengthening institutions for farmers to adapt

Issues	Recommendations	How	Schemes
Lack of knowledge and suitability of insurance products	• Risk management through crop insurance with universal coverage.	• Protecting farmers against uncertainties of crop yields • Risk insurance; direct risk transfer • Premium subsidy • Coverage of post-harvest losses • Increasing participation of farmer groups	✓ *Pradhan Mantri Fasal Bima Yojana* ✓ Weather Based crop Insurance Scheme
Lack of credit facilities	• Improved and easy access to credit to cover weather extremes	• Credit and Insurance linkage • Access to formal credit • Access to banking facilities • Collateral services • Financial inclusion	✓ Interest Subvention Scheme for Short Term Crop Loans ✓ Kisan Credit Card scheme ✓ *Pradhan Mantri Jan Dhan Yojana*
High cost of farm inputs	• Improved access to subsidised seeds (stress tolerant varieties), planting material, machinery (conservation agriculture), plant protection chemicals etc.	• Resource use efficiency • Technology adoption • Reduction of yield gaps • Access to improved extension services • Target based application of nutrients based on soil test • Changing crop rotation	✓ National Mission on Agricultural Extension & Technology: • Sub-Mission on Seed and Planting Material • Sub-Mission on Agricultural Mechanization • Sub-Mission on Plant Protection and Plant Quarantine ✓ *Rashtriya Krishi Vikas Yojana* ✓ National Mission on Oilseeds and Oil Palm ✓ National Food Security Mission

Table 5 contd...

Issues	Recommendations	How	Schemes
Lower farm income	• Diversification to high value crops • Improvement in Food Processing capacity and agriculture value addition • Development of roads and electricity • Improved access to markets and greater price discovery and transparency	• Investment in productive assets • Improving agricultural infrastructure • Market support measures • Convergence of govt. programs into umbrella schemes • Setting up of warehouses, cold storage and cold chains • Increased extension services • Irrigation delivery services • Setting up of commodity and region wise clusters for farmers groups (FPOs) for marketing & storage • Participation in commodity futures market • Door delivery of input services & agro advisory • Rural road connectivity • Rural electrification	✓ Integrated Scheme for Agriculture Marketing ✓ E- National Agriculture Market Scheme ✓ Price Stabilization Scheme ✓ Agri-Tech Infrastructure Fund ✓ *Paramparagat Krishi Vikas Yojana* ✓ National Project on Promotion of Organic Farming ✓ Mission for Integrated Development of Horticulture ✓ Mega Food Parks ✓ Cold Chain Value Addition and Preservation Infrastructure ✓ *Pradhan Mantri Gram Sadak Yojana* ✓ *Deen Dayal Upadhyaya Gram Jyoti Yojana*
Rising farm unemployment and migration	• Developing human capacity and opportunities for livelihood diversification (off-farm and non-farm activities)	• Linkage between farm and non-farm activities (Upstream & downstream) • Incentivising rural non-farm activities • Diversification-both vertical and horizontal • Promotion of equipment, training and market facilities • Enhancing gender and youth participation • Skill development • Promotion of livestock, dairy and fisheries sector	✓ Mahatma Gandhi National Rural Employment Guarantee Programme ✓ National Rural Livelihood Mission: Ajeevika ✓ Pradhan Mantri Kaushal Vikas Yojana ✓ Prime Minister's Employment Generation Programme ✓ Dairy Entrepreneurship Development Scheme ✓ National Dairy Plan ✓ Development of Inland Fisheries & Aquaculture

Note: Adopted and modified from Singh *et al.* (2017) and Singh *et al.* (2018)

Conclusions and Implications

Agriculture ecosystem is particularly vulnerable to the climate variations, and adaptation is necessary to safeguard the interest of the poorest farmers for equitable and sustainable development. Wide varieties of short term strategies/ mechanisms are adopted by farmers at the farm level to cushion against the production risks associated with climatic changes. However, limited resources and lower capacity to understand the nexus of agriculture-climate-socio-economic repercussion reduce the effectiveness of such mechanisms. For making agriculture sustainable and resilient to unpredictable weather perils, the onus falls on policymakers and government (at various levels) to develop sustainable adaptation planning and its effective implementation at grass-root level. Assessment of household perception and vulnerability is prerequisite to understand micro-level needs and concerns and streamlining it in the rural developmental framework. Field survey reveals impacts of climate change and several constraints to adaptation faced by the farm households. It is crucial to address these challenges by facilitating informed planning among farmers which requires improving extension services and access to insurance and financial products. Besides role of multiple actors such as NGOs, private/ commercial sector, farmers groups and associations, and cooperatives is important in improve accessibility and promoting the costs and benefits of climate adaptation and technologies for sustaining livelihoods. Policy makers must aim at creating adequate income diversification opportunities and also capacitate rural population through skill and education programmes.

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Appendices

Table A1: Regression Results for *Kharif* and *Rabi* crops: Punjab State, India

Model	Fixed Effect			
***Kharif* crops**	**Rice**	**Maize**	**Cotton**	**Groundnut**
No. of Observation	323	323	323	323
Maximum Temperature	0.0233721 NS (0.473)	-0.0229184 NS (0.474)	-0.0155957 NS (0.680)	0.0173468 NS (0.523)
Minimum Temperature	0.020012 NS (0.725)	-0.0354692 NS (0.526)	0.0639515 NS (0.268)	-0.0602389 NS (0.232)
Rainfall	0.0002842* (0.001)	0.000341* (0.000)	0.0001258 NS (0.134)	0.0001396** (0.055)
Constant	-0.8284119 NS (0.606)	1.838791 NS (0.245)	-0.3634134 NS (0.832)	1.090588 NS (0.420)
***Rabi* crops**	**Wheat**	**Barley**	**Chickpea**	**Rapeseed**
No. of Observation	323	323	323	323
Maximum Temperature	-0.0049032 NS (0.874)	-0.096582* (0.003)	-0.0547909** (0.040)	-0.0790526*** (0.079)
Minimum Temperature	-0.059929** (0.031)	-0.0120075 NS (0.678)	0.0211294 NS (0.379)	0.0050918 NS (0.905)
Rainfall	-0.0003828 (0.087)	0.000149 NS (0.522)	-0.00000416 NS (0.984)	-0.0003991 NS (0.277)
Constant	1.428613** (0.052)	3.27111* (0.000)	1.637414** (0.012)	2.47321** (0.015)

Note: *, **, *** represents 1 percent, 5 per cent & 10 per cent level of significance. NS represents Non-Significance level. Figures within the parentheses are standard errors.

Table A2: Marginal Effect (1998-2016) and Projected change in *Kharif* and *Rabi* crop yields: Punjab, India

Crops	Marginal Effect (1997-2016)			Total	2025	2030	2035
	Rainfall	Maximum Temperature	Minimum Temperature				
***Kharif* crops**							
Rice	0.19	0.09	0.05	0.33	0.16	0.33	0.49
Maize	-0.21	-0.19	0.07	-0.33	-0.17	-0.33	-0.50
Cotton	-0.16	0.37	0.03	0.24	0.12	0.24	0.37
Groundnut	0.29	-1.02	0.09	-0.63	-0.32	-0.63	-0.95
***Rabi* crops**							
Wheat	-0.03	-0.23	-0.06	-0.32	-0.16	-0.32	-0.49
Barley	-0.84	-0.06	0.03	-0.87	-0.43	-0.87	-1.30
Chickpea	-1.60	0.36	0.00	-1.25	-0.62	-1.25	-1.87
Rape seed	-1.98	0.07	-0.23	-2.14	-1.07	-2.14	-3.21

Note: Projected change in crop yield based on temperature rise 0.5, 1, 1.5 ^{0}C in 2025, 2030 & 2035.

Table: A3. Regression Results for *Kharif* and *Rabi* crops: Telangana, India

Model	Fixed Effect	Fixed Effect	Random Effect	Fixed Effect
***Kharif* crops**	**Jowar**	**Maize**	**Green Gram**	**Rice**
No. of Observation	180	180	180	180
Rainfall	-0.04835^{NS} (0.332)	-0.08626^{NS} (0.219)	0.046803^{NS} (0.516)	0.035619^{NS} (0.744)
Maximum Temperature	-0.01646* (0.009)	0.0014^{NS} (0.839)	-0.00245^{NS} (0.760)	-0.00714^{NS} (0.373)
Minimum Temperature	0.002413^{NS} (0.667)	-0.01474** (0.035)	0.009075^{NS} (0.224)	0.008228^{NS} (0.209)
Constant	3.298533* (0.002)	1.969504** (0.051)	-0.13417^{NS} (0.907)	0.505644^{NS} (0.799)
***Rabi* crop**	**Bajra**	**Horse Gram**	**Wheat**	**Black Gram**
No. of Observation	180	180	180	180
Rainfall	-0.0001^{NS} (0.864)	-0.0002 ^{NS} (0.434)	0.0003 ^{NS} (0.349)	0.0004^{NS} (0.128)
Maximum Temperature	0.0722 ^{NS} (0.135)	0.0335 ^{NS} (0.538)	0.1558* (0.019)	0.0512 ^{NS} (0.277)
Minimum Temperature	-0.0193 ^{NS} (0.587)	0.0279 ^{NS} (0.435)	0.0976* (0.008)	-0.0146 (0.704)
Constant	-1.4875 ^{NS} (0.421)	-1.0633 ^{NS} (0.607)	-6.3320* (0.011)	-0.9420 ^{NS} (0.613)

Note: *, **, *** represents 1 percent, 5 per cent & 10 per cent level of significance. NS represents Non Significance level.

Table A4: Marginal Effect (1997-2016) and Projected change in *Kharif* and *Rabi* crop yields: Telangana, India

Crops	Marginal Effect (1997-2016)			Total	2025	2030	2035
	Rainfall	Maximum Temperature	Minimum Temperature				
***Kharif* crops**							
Green Gram	3.74	-0.20	0.46	4.01	2.01	4.01	6.02
Jowar	-54.03	-0.61	0.06	-54.59	-27.30	-54.59	-81.89
Maize	-27.65	0.01	-0.10	-27.73	-13.87	-27.73	-41.60
Rice	13.24	-0.09	0.07	13.22	6.61	13.22	19.83
***Rabi* crops**							
Bajra	-0.12	3.66	-0.63	2.92	1.46	2.92	4.38
Black Gram	0.40	1.54	-0.28	1.66	0.83	1.66	2.49
Horse Gram	-0.64	3.95	2.26	5.58	2.79	5.58	8.36
Wheat	0.30	5.54	2.21	8.05	4.02	8.05	12.07

Note: Projected change in crop yield based on temperature rise 0.5, 1, 1.5 ^{0}C in 2025, 2030 & 2035.

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CHAPTER **8**

EXISTENCE VALUE OF KODAGU DEVARA KADU: SACRED GROVES IN INDIA

M.G. Chandrakanth, M.S. Accavva, Mahadev G. Bhat, M.G. Nagaraja, Guido Van Huylenbroeck

Introduction

Sacred groves are manifested in different parts of the world. They were common among the ancient Germans where people were penalized for debarking. Tree worship was prevalent in ancient Greece and Italy. Sacred groves are found in Europe, North America, Eastern Africa, China and in a few Arabian countries. The park cemeteries of North America, the fetish groves of Nigeria, church forests of Ethiopia, Guthi forests of Nepal, Monastic forests of China, Thailand,the Oostakker sacred grove in Ghent, Belgium, are its few examples (Figures 1 through 5). In India *Devara kadu* commonly found in south India are named as *Devara bana, Pavitra vana* or *Devara kadu* in Karnataka, *Kavu* in Kerala and *Kovil kadu* in Tamil Nadu. In north India, they are known as *Deorais* or *Devrahalisin* in Maharastra, *Sarnas* in Bihar, *Vanis, Orans, Kenkris* or *Shamlaldehs* in Rajastan and *Lawkyntangs* in Megalaya.

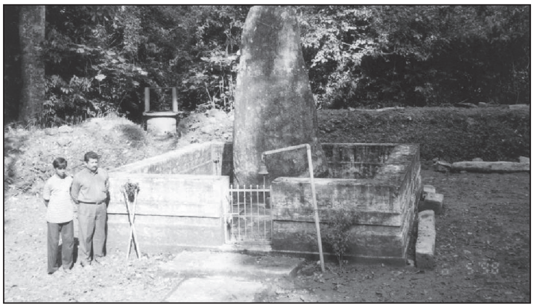

Figure 1: Big Menhir symbolizing Iyyappa (Ishwara) in Kalathode-Bygode in Iyyappa Devara Kadu, Kodagu (Picture by M.G. Nagaraja)

Figure 2: Small Menhir symbolizing Subramanya in Kalathode-Bygode in Iyyappa Devara Kadu, Kodagu (Picture by M.G. Nagaraja)

Senior author is thankful to World Bank for visiting fellowship to Florida International University, Miami for preparing study questionnaire with Professor Mahadev Bhat.

Figure 3: Devotees performing traditional rituals around sacred grove, Kodagu, India

Figure 4: Sacred grove in Oostakker, Ghent, Belgium

Figure 5: Devotees drinking holy water at Oostakker Sacred Grove, Ghent, Belgium

Kodagu is a unique district in India, where every village has at least one sacred grove (Devara kadu). Devara kadu has the sanctum housing the deity, forest surrounding the deity and a small water source to support the sanctum activities. Our investigations give an indication that the tradition of Devara Kadu existed much earlier, during 1000 BC in Kodagu at Kolathode-Bygode enroute Hathur-Kaikeri in Virajpet taluk (Figures 1, 2, 3).

History of tree worship

Tree worship in India dates to the Vedic period. An example is the Fig deity seal" from the ruins of Mohenjodaro, the center of the Indus valley civilization that flourished about 3000 BC. Asko Parpola (1989) presented the iconography and inscriptions of the Fig deity seal at the 10th International Conference of South Asian Archaeologists, Paris. According to him, sacred trees are also observed in non- Hindu religion. In Jainism, which is older than Buddhism, each of the 24 Thirthankaras, was associated with a different species of tree. Vedic texts of 2000 BC describe fig trees as housing the fertility spirits of Ghandharva and *Apsara*. A fig tree (*Ficus religiosa*) alive today in Bodhgaya sheltered Buddha when he gained Nirvana (knowledge of the self) in the sixth century BC. The Buddhist emperor Ashoka also planted this species wherever he spread the new religion (Chandrakanth and Jeff Romm, 1991).

Rights/privileges

The privileges and rights such as extraction of firewood for temple worship, materials for erection of pandals and timber for temple construction vests with the temple committee. The villagers generally do not harvest anything from Devara kadu. They offer social fencing to the Devara Kadu. The forest department has formulated a set of rules to preserve the Devara kadu under section 31 of the Indian forest Act, VII of 1878 as under**:**

Status of Devara Kadu in Kodagu

Devara kadu exists in all villages of Kodagu district and each Devara Kadu is named after a specific deity. Kushalappa (1999) reported that there are about 1,214 Devara kadu in Kodagu district, of which 557 (46 per cent) are of less than one acre, 45 per cent are around 5 to 10 acres and 4 per cent are more than 25 acres in size.

Problem

Devara kadu area has drastically reduced by 62 per cent since 1905. It is in order to analyze the institutional and economic factors for degeneration of Devara kadu. The existence value of the Devara Kadu is estimated to appreciate the preservation value of the village community. Resource economists use the term existence value to refer to non-use values accrued due to non-accessibility of the resource. This answers the key question, "even though the interaction (by visit to Devara kadu) is indirect and off-site (akin to the willingness to pay for preservation of Amazon, even though one may not visit at any time), what is the willingness to pay for the preservation of Devara kadu".

This study focuses on the factors responsible for preservation and valuation of the institution of Devara kadu in Kodagu district with the following objectives: (i) analysis of historical**,** institutional, social and economical factors influencing preservation of Devara kadu, and (ii) estimation of existence value of Devara kadu in Kodagu district.

Sampling and field data

Kodagu district selected for this study on Devara kadu, has 1,214 Devara kadu in 5,000 acres. The district has two forest divisions,viz. Madikeri forest division in the high rainfall zone of evergreen forests, and the Virajpet division in the drier eastern fringe, with moist deciduous forests. From these two ranges four villages each were selected at random. From each village 10 respondents were chosen at random. Primary data relating to Devara kadu were obtained for 15 Devara kadu(s). A study by Kushalappa (1999) on Devara Kadu eliciting data from Temple committee members regarding management of Devara Kadu, information on deities associated, festivals celebrated, rituals followed, different communities involved, encroachments and development activities undertaken in the Devara kadu had data on other 25 Devara kadu(s), which were also used in this study.

In this study, data were collected using pre-tested schedule, information regarding knowledge and opinion on Devara kadu, current contribution made towards Devara kadu to which the planter/ farmer respondent visits and also the Devara kadu which s/he does not visit, were obtained. Further their willingness to pay annually for preserving the Devara kadu in their village as well as for the Devara kadu in another village that they normally do not visit was also obtained. Information relating to socio-economic aspects like social role, education, family composition, land holding and crop economics were also elicited from the respondents. Information regarding the traditional values of the respondents towards their ancestral home - *Iynmane,* the ancestral burial place *Kaimada* and contributions towards the same were also obtained.

Theoretical Framework for Analysis of the Existence Value

Existence value is commonly known as the value an individual has for the existence of a resource from which s/he does not derive any use at present or in future. Krutillia (1967) recognised that existence values were not limited to naturally occurring resource. The concept could also be attributed to manmade resources or items such as rare works of art. Uniqueness was the foundation for existence value. According to Krutilla existence value is the "willingness to pay" for retaining an option to use an area or facility that would be difficult or impossible to replace and for which no close substitutes are available. The demand may exist even though there is no current intention to use the area or facility in question and the option may never be exercised. Such a demand may exist among others who place a value on the mere existence of biological and /or geomorphic variety and its widespread distribution."

Method

In this study the respondent knowledge and opinion about preservation of Devara kadu is elicited. Before asking them their actual willingness to pay for preservation of Devara kadu, their actual contribution for the festivals in the Devara kadu of their village and contribution for festivals in another village was obtained. This is done with the objective of making their actual contribution as basis for eliciting the respondent's true willingness to pay for conservation and preservation of the Devara kadu.

A respondent contributing towards preservation of the Devara kadu in his/her village will have non-consumptive value as s/he is deriving an indirect benefit. However, since existence value is based on the valuation due to non-accessibility to the resource, we elicit the respondent's willingness to pay for preservation of the Devara kadu in another village which s/he does not visit and thus does not derive any direct benefit from the same. Even when the interaction with the Devara kadu is indirect and off-site, this willingness to pay closely represents the existence value.

Respondents were confronted with the Dichotomous choice (DC) Contingent Valuation questions. The questions pertaining to willingness to pay for preservation of Devara kadu in the respondent's village as well as in another village were of DC format. That is the respondent was confronted with an offered amount; then, in the next two follow up questions, was asked to specify his or her bid. Thus, it is argued that the specified bid amount is the respondents' true willingness to pay. This was mainly because the respondent's annual willingness to pay for preservation of Devara kadu was elicited thus trying to obtain his true willingness to pay. Logit model was used to estimate the willingness to pay for preservation of Devara kadu in their own village (WTP1) and that for preservation of Devara Kadu in another village (WTP2).

The dependent variable used is X = willingness to pay (1/0) towards preservation of Devara kadu, with the independent variables such as X_1 = Income, X_2 = Education, X_3 = Monetary contributions towards family festivals, X_4 = Bid amount, and D_1 = Clan depending on the respondent belonging to Kodava clan (1) or non Kodava clan (0).

The logit model based on the logistic probability is specified as:

$$P_i = f(Z_r) = f(\alpha + \sum \beta_i X_i) = 1/1+e^{-Z}$$

Where, $Z_i = \alpha+\beta_i X_i$

After simplifying the above the form for estimation of the logit model is

$$Z=\log (P_i / 1-P_i) = \alpha+\beta_i x_i = L_i$$

Here, P_i = Probability that the respondent has willingness to pay for preservation or for enhancing the Devara kadu in his/her village or in another village; $(1-P_i)$ = Probability that the respondent is not willing to pay for preservation or for enhancing the Devara kadu in his/her village or in another village; β_i = coefficient to be estimated. L_i is called the logit as it follows the logistic regression.

The odds ratio is $P_i/(1-P_i)$ which is the odds ratio in favour of a randomly chosen consumer having willingness to pay. It is the ratio of the number of chances that the respondent is having willingness to pay for preservation or for enhancing the Devara kadu in his/her village or in another village to the chances that he/she is not WTP. An odds ratio of 0.486 indicates that for every one chance that the respondent's WTP, there is 0.5 chance that s/he would not be willing to pay for preservation of the Devara kadu.

Tobit model

Having estimated the odds ratio, which reflects the probability that a respondent is willing to pay to the probability that the respondent is not willing to pay for preservation, it is in order to estimate the actual willingness to pay for preservation the Tobit model is used. The dependent variable in this model used to obtain the existence value is the 'actual amount that each respondent would pay for preservation. The range of this variable is restricted due to the bid amount (as no bids below 0 are allowed) in the Tobit estimation. Tobit model from the Limdep package was used to find the respondents' actual willingness to pay towards preservation of Devara kadu in their village and also in the other village to which they do not visit. The respondents' willingness to pay towards the other village for preservation (WTP2) was considered as the existence value the respondent has towards the Devara kadu. This was considered as the willingness to pay and is purely based on non-use value as the respondent does not derive any kind of benefit from the present or in the future from the Devara kadu, which exists in another village. WTP1 was used as a base to check the accuracy of the willingness to pay and also the estimated existence value.

Festivity and social fencing

The Devara kadu festivals are conducted once a year jointly by all the village communities enjoying a sense of belongingness, in different parts of the year according to the tradition. The rituals such as Tere, Thadambu dance, Ethuporata, Agni keri, Bolakat, Kattu are common in Devara kadu festivals. All the communities in the village participate in the Devara kadu festivity namely Kodavas, Amma Kodavas, Koyyava, Kumbara, Kudiya, Panika, Banna, Heggade, Kaapaala, Kembatti, Irri, Meda, Vakkaliga Gowda, Jamma Gowda, Kuruba, Yerava and Brahmins. However, daily worship in Devara Kadu is not a common practice as in other temples, since Devara Kadu follows the folk tradition and is not a sanskritized temple. Only in a few cases, there are festivals once a month. The institution of Devara Kadu festivity strengthens the social fencing of Devara kadu and thus reduces the transaction cost of protection to the Forest Department.

Economic Factors Influencing Preservation of Devara Kadu

Kodagu is the largest coffee-growing district of India contributing around Rs 1,200 crore towards export of coffee from Karnataka. The increase in domestic and export demand for coffee, cardamom, pepper and recently ginger has increased cultivation of uncultivated land in Kodagu. This is the motivating factor for increase in cultivated area in Kodagu attracting the private forestlands. This in turn influenced encroachment of Devara kadu lands. Area under Devara kadu varies widely. The size of Devara kadu varied from 0.11 acre to 1,315 acre. The Neerulli Bana with 1,315 acre is the largest Devara kadu in Kodagu district. The modal size of Devara kadu varied between five and ten acre.

The Forestry College, UAS, Ponnampet, conducted the Devara kadu festival in 2000, where the temple committees met and shared their experiences regarding preservation of Devara kadu. About 25 per cent of the temple committee heads indicated that their Devara kadu had been encroached. The total area of such Devara kadu worked to 557 acres, of which 116 acres were reported as encroached by the temple committees. Thus encroached area formed 21 per cent of the total Devara kadu area (Table 1).

Table 1: Encroachment of Devara kadu

Details of data and source	**Data from Devara kadu festival**	**Data from the present study**
	n = 40 Devara kadu	**n = 17 Devara kadu**
Number of Devara kadu where Committees are formed	40 (100)	15 (88)
Number of Devara kadu which reported the fact that their area is encroached	18 (45)	4 (23)
Number of Devara kadu which actually reported extent of encroached area	10 (25)	4 (23)
Extent of Devara kadu area encroached (acres)	116 (21)*	70 (26)**
Total area of Devara kadu (acres)	1879	267
Total area of Devara kadu which are encroached (acres)	557	80
Number of Devara kadu in which action is taken on encroachers	6 (33)	3 (75)
Number of Devara kadu surveyed by the Department of survey settlements and land records	27 (68)	2 (11)
Protection activity (fencing, planting) undertaken	5 (12)	2 (11)

Note: Data from Devara kadu festival refers to the data filled by the heads of Devara kadu committees who participated in the Devara kadu festival held during Oct 2000. Figures in parentheses are percentages of the total number of Devara kadu under each study.
* 21 per cent (=116/557) is the reported percentage of Devara kadu area encroached out of the total area of Devara kadu which reported the area encroached.
** 26 per cent (=70/267) is the reported percentage of Devara kadu area encroached out of the total area of Devara kadu which are encroached.

In the present study, from the survey of 17 Devara kadu(s), five Devara kadu temple heads reported that there is encroachment and the total encroached area was to the tune of 70.5 acre forming 26 per cent of total Devara kadu area. Thus, from the both the sources of information, the extent of encroachment of Devara kadu area ranged from 21 to 26 per cent, which are comparable.

Land tenure

About 74 per cent of sample respondents had jamma'(Jamma refers to land offered by the then Kodagu kings in recognition of the services rendered. Thus, the ownership of Jamma is not strictly private as it is a public land donated to those who offered their services. Jamma land can be a wetland assessed at one half of normal (sagu) rate of assessment land tenure, 14 per cent 'sagu' (Sagu refers to the ordinary ryatwari tenure of land held on full assessment at the ordinary rates.) tenure, followed by 12 per cent of the respondents who were landless. Jamma land tenure is one of the most important institutional management systems, which has lead to preservation of the traditions and culture of Kodagu. It is a joint ownership of the land, among all the eligible members of a family with the senior most member of the family exercising the control. In this system of tenure, the land cannot be sold outside the family-fold. In case it has to be sold, then all the joint owners have to sign. This procedure has necessitated the family to work together reflecting the family system of Kodagu. However, in recent times, there has been some dilution of the Jamma land tenure, the details of which are not available. The annual gross income of the respondents varied from Rs 3,000 to Rs 800,000, with an average of Rs 68,491 per respondent, with the modal income being Rs 20,000. The size of coffee plantation ranged from one acre to 100 acre in the sample. The slump in the price of coffee from Rs 1,500 per 50 kg during 1999 to Rs 950 per 50 kg bag during 2000, to Rs 650 per 50 kg bag during 2001 has also contributed to the wide range in gross income (Table 2).

Table 2. Socio-economic characters of the respondents (2000 prices)

Variables	Range (Rs)	Modal value (Rs)
Annual gross income of respondents (Rs)	3000 to 800,000	20,000
Education (years of schooling)	12 to 18	12
Age of the respondent (years)	28 to 85	55
Number of members in the family	3 to 6	4

Accordingly, an estimated 42 per cent of the respondents contributed for the annual Devara kadu festival ranging from Rs 100 to Rs 5,000 per family, modal value being Rs 500. About

45 per cent of the respondents, contributed towards renovation of Devara kadu sanctum ranging from Rs 100 to Rs 15,000, the modal value being Rs 1,000.

Purposes of visit to Devara kadu

About 40 per cent of the respondents performed different rituals and participated in cultural activities in Devara kadu. About 96 per cent of the respondents visited Devara kadu to seek blessings from the deity. A majority of the respondents participated in Devara kadu festivity to meet other members of their family. Out of the 17 Devara kadu(s) in this study, in nine Devara kadu(s), there was the practice of konda where villagers perform the ritual of running on the burning splinters. For this purpose one or two trees is/are cut. In order to facilitate this, about 43 per cent of the respondents helped in the process of cutting the tree/s and in preparation of the ground for burning splinters in the festival. Among the sample respondents, 20 per cent of them were those who settled in Kodagu since the last five years. All these respondents who settled in Kodagu recently indicated that they visited Devara kadu for scenic beauty (Table 3).

Table 3 : Purposes of visit to Devara kadu

Purposes of visit to Devara Kadu	Number of respondents (n = 80)	Per cent
To seek blessings	77	96
To meet other members of family*	67	84
To cut trees for rituals in devara kadu	34	43
As a performer of rituals	32	40
To collect non timber forest products	16	20
To enjoy the scenic beauty	13	16
To participate in the festival	11	14
To obtain mental peace	10	13
To eat fruits	7	9

*Family in Kodagu traditions composes of 20-50-nucleus families under a particular family name spread over two or three villages. The total in a family may number 100 to 300 or even more.

Willingness to Pay for Preservation of Devara Kadu

About 63 per cent of the respondents were willing to pay for preservation of Devara kadu as they believed this would also preserve the forests in Kodagu. Similarly, about 60 per cent of the respondents indicated that they are willing to pay for preservation as their entire village would benefit from preservation (Table 4). About 57 per cent of respondents expressed their willingness to pay for preservation of Devara kadu for performing in the festival. About 42 per cent of the respondents were willing to pay for preservation of Devara kadu so as to sustain the traditions of Kodagu. About, 31 per cent were willing to pay to preserve the Devara kadu for future generation.

Table 4: Reasons for willingness to pay for preservation of Devara kadu

Sl. No.	Reasons	Number	Percent
1.	To preserve the forests in Kodagu	31	63.26
2.	The entire village will benefit from preservation	29	59.18
3.	For performing festival	28	57.14
4.	To continue the traditions of Kodagu culture	21	42.18
5.	To preserve the Devara kadu for future generation	15	30.61
6.	To secure Devara kadu to its original size from encroachment	5	10.2
7.	Plantation and farm are benefited by the Devara kadu due to its location	3	6.12

Factors influencing willingness to pay (WTP) for preservation of Devara kadu

Logistic regression model was used to estimate the factors influencing the respondent's willingness to pay for preservation of Devara kadu in their village. WTP1 refers to willingness to pay towards preservation of Devara kadu in their own village. The independent variables considered in the model are income, education, bid amounts, contribution to family festivals, and whether the respondent belongs to the ethnic clan practicing the Kodava culture or otherwise. Education, contribution to family festivals and bid amount are the major factors influencing the respondents' willingness to pay for preservation of Devara kadu in their village (Table 5). Education was significant at 5 per cent while contribution to family festivals and bid amount was significant at one per cent.

WTP2 is the willingness to pay towards preservation of Devara kadu in another village for which the respondents do not have access. The independent variables considered in the model are income, education, bid amount, contribution to family festivals and whether the respondent belongs to the ethnic clan practicing the Kodava culture or not. The result indicates that education and contribution to family festivals are the two key factors influencing the respondent's willingness to pay. Education is significant at one per cent while contribution towards family festival is significant at ten per cent.

Table 5: Factors influencing willingness to pay (WTP) for preserving Devara kadu (logit model results)

Variable	WTP1	WTP2
Constant	-1.496* (0.811)	-2.309** (0.950)
Income	0.34E-02 (0.0057)	-0.0041 (0.0057)
Education	0.155** (0.073)	.171** (0.076)
Contribution	0.398E-03* (0.232E-03)	0.384E-03* (0.076)
Bid amount	-.497E - 03* (0.265E-03)	0.387E-04 (0.258E-03)
Clan (1)	0.877 (0.782)	0.824 (0.828)
Odds ratio: 1	1.9	1.82
0	0.79	0.8
LR test	13.04***	17.24***
P: 1	0.65	0.64
0	0.44	0.43
N	74	74

*** 1% level of significance; ** 5% level of significance; *10% level of significance
Figures in the parenthesis represent standard error

WTP1 = Willingness to pay towards preserving Devara kadu in their own village (annual contribution); WTP2 = Willingness to pay towards preserving Devara kadu in other villages

Odds ratios for willingness to pay

Odds ratio for WTP1 indicated that the chances for paying towards preservation increased by 1.9 chances when the respondent belongs to the Kodava community. There are 1.9 chances in favour of willingness to pay towards preservation to one chance of not willing to pay. If the respondent does not belong to the ethnic Kodava community, his/her willingness to pay decreases to 0.79 to one chance of not paying.

Odds ratio for WTP2 indicated that the chances for paying towards preservation increased by 1.82 chances when the respondent belongs to the ethnic Kodava community and was 0.8 when s/he did not belong to the community.

Existence Value of Devara Kadu

In this study, willingness to pay towards their own village Devara kadu is the use value as indirect benefits are derived in the form of environmental benefits and increase in farm production. Willingness to pay towards preserving Devara kadu in other village is considered as existence value of the respondent towards his/her Devara kadu since s/he wants the Devara kadu to exist even though s/he does not derive any direct or indirect benefit from the sacred grove.

The results obtained in Table 6 bring out the estimated willingness to pay for preservation of Devara kadu in their village as well as their neighbouring village. As expected the mean willingness to pay towards their own village was much higher at Rs 702 per family (US $ 14). The estimated mean willingness to pay towards preservation of Devara kadu in another village was estimated as Rs 87 per family (US $1.74), which is a flow concept in which the contribution is made annually. In the study, as the willingness to pay towards other Devara kadu is interpreted as existence value, the estimated existence value for preserving the Devara kadu worked to Rs 87 per family (US $1.74).

Table 6: Estimation of willingness to pay for preservation of Devara kadu Kodagu district - 2001 (Tobit model)

Variable	WTP1	WTP2	Mean of X
Constant	204.135 (1256.27)	-383.11 (331.31)	
Income	6.693* 3.91	0.754 (331.31)	66.13
Education	117.081** (59.40)	28.55* (16.06)	10.97
Age	-35.198 (18.26)	-3.127 (4.63)	53.37
Contribution	0.273 (0.10)	0.118E-01 (0.245E-01)	1064
Bid amount	-0.501E-01*** (0.195)	0.913E-01* (0.480E-01)	2096
Clan (1)	467.058 (658.05)	69.55 (175.66)	
Log likelihood function	-416.8638	-344.1938	
Estimated mean willingness to pay	702 (Rs)	87 (Rs)	
(1/0)	235 (Rs)	15 (Rs)	
N	74	74	

*** 1% level of significance, ** 5% level of significance, * 10% level of significance.
WTP1 = Willingness to pay towards preserving Devara kadu in their own village (annual contribution).
WTP2 = Willingness to pay towards preserving Devara kadu in other villages.
Figures in the parenthesis represent standard error.

Implications

The existence value of Kodagu sacred groves per family ($1.74) formed 10 per cent of the total economic value ($15.74), while the use value formed the rest. The use value is dominating over the existence value (non-use value) and hence largely responsible for encroachments and the current status of sacred groves. Hence, there has been a reduction in the area of Devara kadu due to encroachment and conversion of forest area into plantations. In addition, immigration of diverse cultures who have no commitment to preserve the sacred grove as they do not form part of their native culture, weak management, remunerative coffee prices, led to the dilution of the Devara kadu institution and the corresponding existence value. Hence greater concern has to be directed towards preserving the Devara kadu (forests) for our future generations from the point of maintaining biodiversity.

Education and contributions to the family festivals are crucial factors influencing the respondents' willingness to pay towards preservation of Devara kadu. A mechanism has to be developed to involve all communities in the locality for preserving Devara kadu. The willingness to pay by the respondents indicates that the people in Kodagu are ready to contribute for preserving Devara kadu. However it is necessary to ensure that their contributions are properly used by developing a set of guidelines. In this direction, the proposal to form a committee at the village level and a federation of Thakkmukyastha at the district level is worth considering. The committees formed at the village and the district levels are be vested with powers to restore and preserve Devara kadu involving the participation of local people. The Devara kadu land converted to plantations should be reverted to forest land since the land under forest is on the decline especially at the village level. More emphasis has to be laid towards preserving Devara kadu as forests reflecting the local biodiversity for the benefit of future generations. The success stories regarding restoring encroachments be highlighted along with the need for preserving Devara kadu through mass media, have to be highlighted.

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CHAPTER 9

ASSESSMENT OF MANGROVES ECOSYSTEM SERVICES: A CASE STUDY OF ANDAMAN AND NICOBAR ISLANDS

Subhash Chand, Shrawan Singh, Prabhat Kishore, S.J. Balaji and R.C. Srivastava

Introduction

Indian coasts fall within the bounds of the tropics, which measures about 7,516.6 km in nine coastal states and four Union Territories. Of this, over 22.6 per cent of the total length of the coasts of India is of islands (Andaman and Nicobar, Lakshadweep and Diu Islands). The climate along the Indian coast varies from true tropical region in the south to sub-tropical and arid environment in Kachchh in the northwest. Rainfall varies from 300 mm in the Kachchh in western part of Gujarat to a maximum of 3,200 mm in Andaman-Nicobar Islands in the south. On recommendations of the Government of India, 31 mangrove areas in the country have been identified for intensive conservation, and three Biosphere Reserves, Sundarban in West Bengal, the Great Nicobar Island in southern middle islands of Andaman and Nicobar archipelago and the Gulf of Mannar in Tamil Nadu in marine environment were notified, which also support mangroves. The climate change will have direct effect on the productivity of agriculture, livestock and fisheries, the coastal areas are likely to be inundated, disease and malnutrition may increase, and freshwater availability may get reduced. The impact of climate change on the fragile ecosystem is more evident as the islands have witnessed the tragic incidence of earthquake followed by devastating tsunami in 2004. Thus, these major coastal bio-resources-corals and mangroves, are also vulnerable to climate change. For the assessment of ecological services provided by the mangroves, methodologies need to be evolved. Therefore, research effort should be diverted towards developing strategies for adaptation and mitigating the impact of climate change on the agriculture and allied sector for sustainable development in coastal areas. The current, fourth generation work which appears in the IPCC Third Assessment Report reflects further improvements in the substantive and methodological domains. Recognition of spatial in homogeneity in sea level rise associated with global warming is likely to affect the most. Realistic and accurate assessments of sea level rise impacts need to consider the joint effect of secular trends in sea level and storm regimes (Anand, 2006). The mangroves provide direct and indirect benefits and services to the stakeholders. The methods used by various researchers to assess the value of ecological services may not be able to provide broader picture due to non-availability of required data. Keeping in view the above facts, this study was conducted to assess the total economic value, ecological functions and expected impact of climate change in A & N Islands, India.

Study area

The archipelago of Andaman and Nicobar islands is a chain of 572 islands stretched from North to South and located about 1,200 km from mainland having total geographical area of 8,249 sq km. Of the total agricultural area of 50,000 ha, plantation crops occupies 25,912 ha, field crops 11,384 ha, spices 1,592 ha, fruits 3,118 ha, vegetables 5,200 ha and root crops 435 ha (Table 1). Agriculture in the island is carried out under rainfed (Ambast *et al.*, 2011) conditions, which is important for both income and food security. Though islands receive an annual rainfall of more than 3100 mm spread over more than 7 months in a year (Figs 1, 2), there are no freshwater perennial rivers, which can be used as a source of irrigation during dry spell. The maximum and minimum temperature varies from 32 to 22°C and relative humidity is about 80 to 90 per cent.

About 1,200 km from the mainland

36 of 572 islands inhabited; about 3.79 lakh population

8,249 sq km land area; 50,000 ha area under cultivation

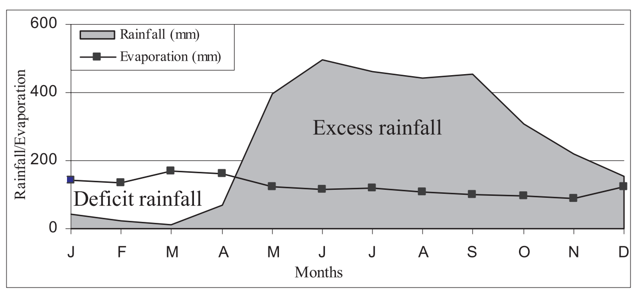


Fig 1. Average annual rainfall about 3,100 mm (May-Nov)

About A & N Islands

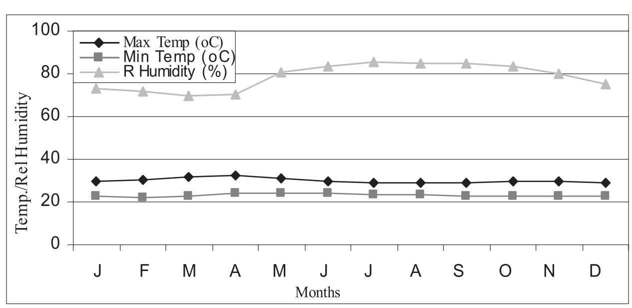


Fig 2. Max, min temperature ranges between 22-32 °C

Table 1. Area and production of major crops

Name of crop	Area ha	Production (MT)
Paddy	81,39.85	24,907.01
Pulses	2,971.09	1,890.66
Oilseeds	110.80	69.80
Black pepper	600.40	58.31
Clove	155.90	4.82
Coconut (million nuts)	21,760.22	84.97
Arecanut	4152.50	5,200.00
Cashewnut	1,077.85	332.13
Banana	1,596.30	14,872.95
Pineapple	224.71	608.42
Sugarcane	141.80	2007.60
Vegetables	5,200.00	41,500.00
Tapioca	274.65	2120.00
Sapota	156.40	2914.60
Sweet potato	161.90	912.02

Source: Dept. of Agriculture, A&N Administration, 2011

The dry spell prohibits growing second crop after paddy and it affects the productivity of the plantation crops. The island encompasses 0.60 million sq. km of the exclusive economic zone (EEZ), which constitutes about 30 per cent of the EEZ of India. The territory has a coastal line of nearly 2,000 km with several protected and semi-protected bays and inlets, which have a vast potential for capture fisheries and agriculture operations. These islands face environmental and socio-economic pressures exacerbated by global climate change and climate variability. They are the most vulnerable areas in the country considering their remarkably flat topography except for some cliffs and geographical isolation. In addition, the limited physical size makes coastal retreat impossible. The islands mangroves have been demonstrated to be at high risk of substantial reductions. In India, mangroves occur on the east, west and on Andaman and Nicobar Islands, but many places they are highly degraded. According to Government of India (1987), India lost nearly 40 per cent of its mangrove area in the last century. A summary of valuation of ecosystem services of mangroves in summarised in Table 2.

Table 2. Valuation of ecosystem services of mangroves

Sl. No.	Study	Place of study	Value
1.	Value of commercial fishery (1990)	Fiji Mangroves	Fiji dollars 1,094 per ha.
2.	Value of fish harvest from mangroves (1991)	Philippines	US $ 438 per ha per year
3.	Value of on-site sustainable fisheries (1992)	Indonesia	US $ 126 per ha per year
4.	Value of tourism in mangroves (1993)	Malaysia	US $ 422 per ha per year
5.	Valuation of mangrove goods (forestry) (1996)	Philippines	US $ 151 per ha per year
6.	Sustainable mangrove forestry (1997)	USA	US $ 756 per ha per year
7.	Valuation of mangrove ecosystems in the world (1997)	World	US $ 1,648 billion
8.	On-site crustacean & mollusc harvest from mangrove (1998)	Vietnam	US $ 126 per ha per year
9.	Off-site mangrove fisheries (1998)	Thailand	US $ 147 per ha per year
10.	Annual market value of fisheries supported by mangroves (2001)	Developing countries	US $ 3400 per ha per year
11.	Total Economic Value of Mangroves (2001)	Thailand	US $ 2.7 million to US $ 3.5 million per sq. km
12.	Carbon storage value of mangroves (2001)	Cambodia	$ 2 per ha per year
13.	Total Use and Non-Use Values (2004)	Gujarat, India	Rs. 2246.93 crores per year
14.	Annual economic median value of mangrove related fish and crab species (2008)	Gulf of California	US $ 37,500 per ha
15.	Value of mangroves through CVM (1999)	Malaysia	US $ 7,512 per ha
16.	Overall value of mangrove fuel wood (1999)	Pakistan	US $ 385,000 per year
17.	Waste disposal function of mangroves (1998)	Mexico	US $ 1193 per ha

Data and Methods

Primary data were obtained by extensive field surveys and open end questionnaire method from the South, North and Middle and Car Nicobar Islands and series of consultations were held with different stakeholders. Fig. 3, represents the ecosystem services framework of mangroves ecosystem. Secondary data from the A&N Administration were obtained with respect to the meteorological parameters, demographic particulars and productivity in agricultural sector. Data collected randomly from 120 stakeholders, 25 experts, 78 tourists and 25 other Government officials. In-person survey and open-ended elicitation methods were used. Potential consumers were asked about maximum amount they would be willing to pay every month or every year for the services/product they take from the mangroves. A hypothetical voluntary organization was chosen as a payment vehicle, which would utilize the monetary investments for conservation and sustainable exploitation of mangroves. The aim was to improve status of mangrove resources surrounding them owing to support to fishery, forestry, eco-tourism and ecosystem services (Fig. 3). The socio-economic data were collected on the aspects, viz. use of mangroves, income of the beneficiaries, family size, education level, utilization pattern of mangroves, and willingness to pay for conservation of mangroves.

Analytical framework for the valuation : There are many techniques available to estimate the economic value of environmental goods and services. Further details and guidance on how

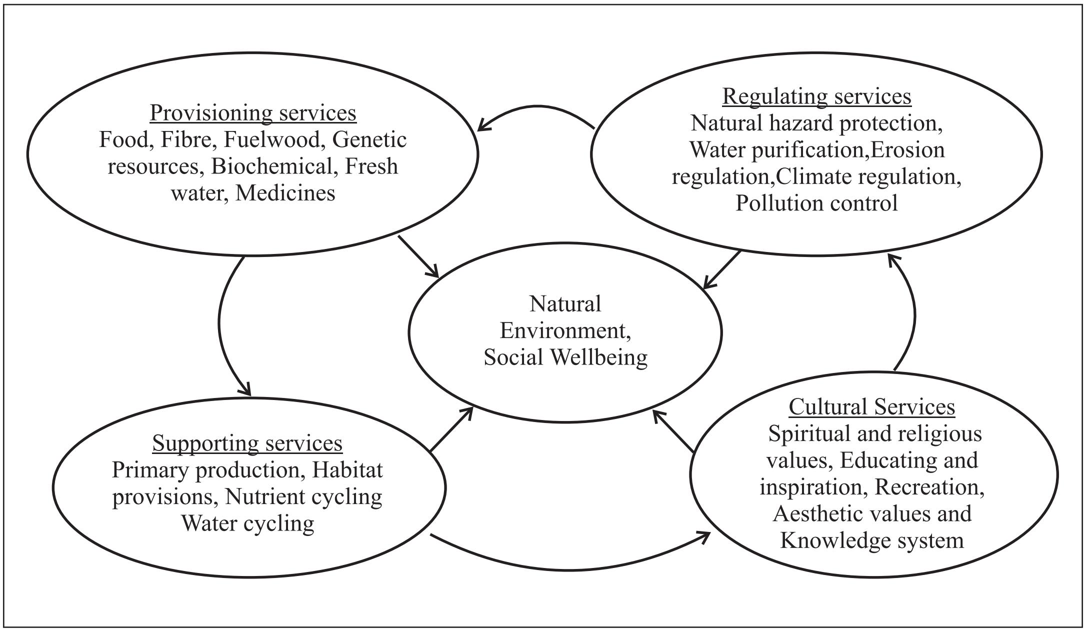


Figure 3. Framework of ecosystem services

and when they should be applied can be found in Hufschmidt *et al*. (1983), Barbier *et al*. (1996), Dixon *et al*. (1997), Bann (1997) and Bennett and Blamey (2001). The collected data were analyzed for logical conclusions. The benefits (direct and indirect) from the mangroves as perceived by different stakeholders, i.e. fisherman, tourism, local community, Government research organization, etc., were given the weights 0= not important, 1= less important, and 3 = very important (James Spurgeon and Jacobs GIBB; 2002). The weights were further categorized based on the potential value for income, employment and other benefits. The total economic value was worked out based on the value of fisheries, fuel wood, transport, medicinal and recreational value. The impact of climate change on mangroves was studied using the stakeholder perception.

Results and Discussion

Status of mangroves system in Asian countries

The world has lost 3.6 million hectares of mangroves over the last 25 years. The studies also indicate that the loss of mangroves showing signs of slowing down in line with the trend in forests (FAO, 2006). From 185,000 ha lost every year since 1980s, the net loss dropped to some 118,500 ha per year in the 1990s and further to 102,000 ha per year (or a loss of 0.66 per cent annually) during the 2000–2005 period. The annual loss in absolute term is still very high. The status of mangroves in Asian countries is depicted in Fig. 5, and it shows that Indonesia occupies maximum areas (50 per cent) followed by Malaysia (10 per cent), Bangladesh, India (8 per cent) and Myanmar (9 per cent). Rests of the countries are occupying only 16 per cent altogether. Among the Indian states, West Bengal occupied maximum (44 per cent) areas followed by Gujarat and A&N Islands.

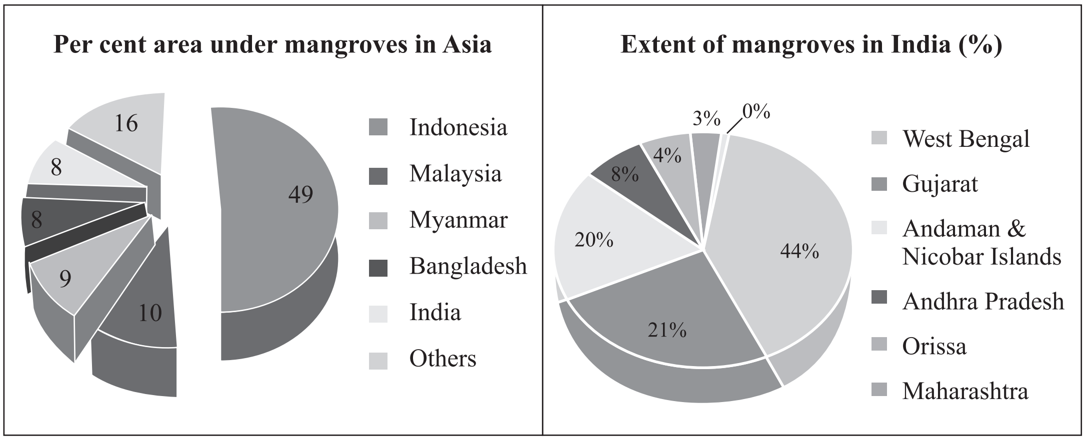


Figure 4. The extent of area coverage of mangroves in Asian countries

Developing countries are likely to be more vulnerable to climate change due to projected magnitude and poor adaptive capacity (IPCC, 2001) following institutional and resource constraints. The contribution of islands to global climate change is negligible though, but they bear the maximum brunt of climate associated disasters. India initiated action through state governments to create network of the Marine Protected Areas (MPAs) under Wildlife (Protection) Act, 1972. Over half of the total mangroves in the country are already managed in over a dozen MPAs (Singh, 2002). In the past, fuel wood and poles were extracted from mangroves on a small scale to meet the local demand including in addition to household use and the fuelling of power station in Port Blair. Major plywood industries and the governments steam vessels/ limited extraction did not cause much damage to the mangroves forests. But in the revenue area destruction of mangroves is capricious. Some area has been reclaimed for agriculture and settlement (A & N Islands Environment and Forest Department, 1997). Mangrove associated fauna play significant role in the functioning of the ecosystem (Dagar *et al*., 1997; Kristensen, 2007; Lee, 2007; Cannicci *et al*., 2008; Kristensen *et al*., 2008; Nagelkerken *et al*., 2008) and thus can be a useful indicator of the state of mangroves, However, silvicultural management often ignores assessing this component of the ecosystem (Ellison, 2007).

The socio-economic importance of natural mangrove goods and services has been documented repeatedly (Walters, 1997; Adger *et al*., 2001; Barbier, 2006; Walters *et al*., 2008), but restored mangroves can also generate income similar to that of natural mangroves. In Andaman & Nicobar Islands, tall dense mangrove forest occurs due to favourable climatic conditions such as short dry season and high tidal fluctuations, heavy rainfall (Naskar and Mandal, 1999). On the other hand, small and sparse mangroves with stunted growth are reported from Latin America (Newberri and Hill, 1981). Impact on highly diverse and productive ecosystems such as mangrove forests will depend upon the rate of sea level rise relative to growth rates and sediments supply, space for and obstacle to horizontal migration, and changes in climate-ocean environment. Existing mangroves can keep pace with a relative sea level rise of 8-9cm/100 years. Most countries have now banned the conversion of mangrove areas for aquaculture purposes and require environmental impact assessments prior to large-scale conversion of these areas for other uses (FAO, 2006). Andaman and Nicobar Islands possessed more than 80 per cent area under forest.

Economic value of mangroves

The trend of forest degradation and deforestation indicated that from 1987 to 2009 about 13 per cent forest cover of these islands had been lost. However, in the case of mangrove, it was about 10 per cent (Table 3). This was nearly one per cent loss per annum which is an alarming signal. This is high time for the policy makers to take appropriate action for restoration of mangroves, before this natural defence vanishes.

Table 3. Total Economic value of A & N Islands mangroves

Year of assessment	Mangroves area (in sq. km)	Change in (%)	Value (Rs. crores)
1987	886	0	1430.99
1993	966	-0.51	2015.07
1995	966	0.00	2015.07
1997	966	0.00	2015.07
2003	658	-16.60	1372.59
2004	658	-16.60	1372.59
2005	635	-23.5	1186.59
2007	615	-20.0	1282.89
2009	637	-3.19	1328.78
2014	595	-1.49	1241.16
2015	592	-0.50	1234.91

Source: Forest Statistics (2015-16), Department of Environment and Forests A & N Islands

This system is not only protecting from the natural disaster but also providing food, fodder, fuel, employment and environment security. It was estimated that total economic value of Andaman mangroves is Rs 1,287 crores/year at 2011-12 prices. Therefore, taking into account the benefits of mangroves, proper policy decisions need to be devised so that mangroves of these Islands can be conserved.

Mangroves support livelihood of the costal people: The income based classification of the respondents, i.e. small (58 per cent), medium (28 per cent) and large (14 per cent) and the values of mangroves products harvested per annum are presented in Figs 5, 6. It was found that on an average, each household benefits by more than Rs. 61,000/- from the mangroves annually. This value was higher in small households (Rs. 70,447) followed by medium and large. Thus, there was significant evidence that small farmers are more dependent on mangrove forests.

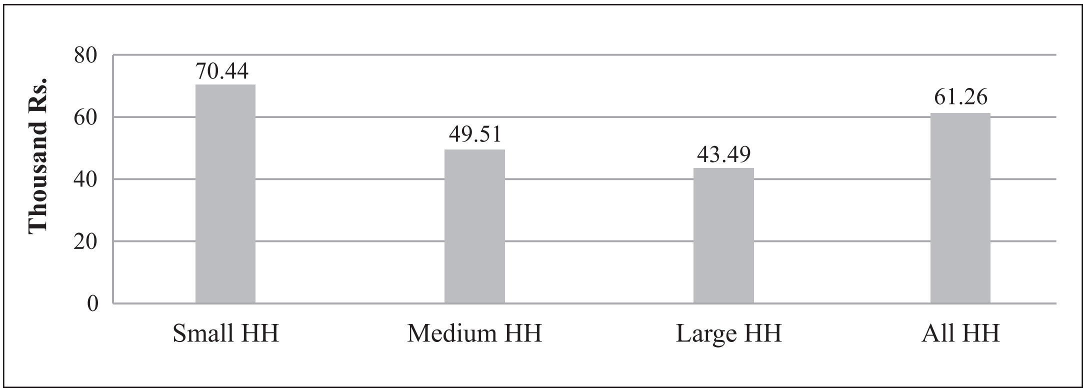
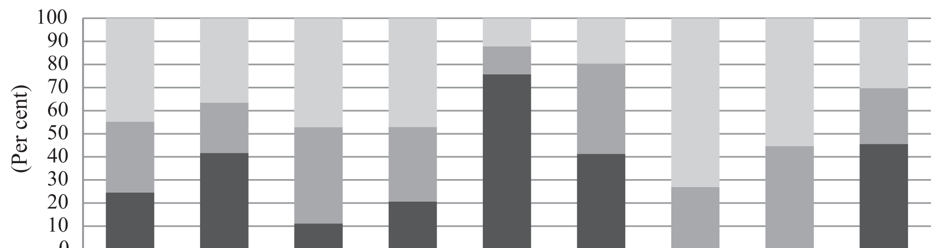


Figure 5. Value of mangrove products collected



	Fish	Shrimp	Crabs	Fuel wood	Timber	Wooden poles	Vegetables	Coir industry	Fraund viewing
Small HH	52400.4	9177.5	3390	2271	400	948	409.1	124	1326.8
Medium HH	35890.5	5465.8	3000	1560.5	400	1890	150.5	100	1055.6
Large HH	28690.5	10500.6	800	1000	2500	2000	0	0	2000

Figure 6. Value of products collected by households, Rs/annum (2012 prices)

Ecological functions of mangroves: To assess the benefits of mangroves in terms of perception by different stakeholders, a scoring technique was used. The scores were assigned for most important (3) and not important (0) and the scores were income, employment, and other benefits. Table 4 indicates that different stakeholders, i.e. fishermen, local people, tourism industry, and Government derive direct and indirect benefits from mangroves. However, ecological functions delivered by the mangroves indirectly were higher than the direct benefits, i.e. income and employment generation. Hence, valuation process should take into account other benefits assessed by using surrogate measures and shadow pricing technique (Table 4).

Table 4: Ecological functions of mangroves perceived by different stakeholders

Functions and Output of mangrove	Stakeholders									Total Score		
	Fishermen			Local People			Tourism					
	I	E	B	I	E	B	I	E	B	I	E	B
1. Direct: Fuel	0	0	1	1	1	1	0	0	0	2	1	3
Fodder	0	0	1	0	0	1	1	1	1	1	1	3
Medicine	1	0	1	0	2	2	0	0	0	1	2	4
Genetic res.	0	0	0	0	2	2	0	0	0	4	5	5
Apiculture	0	0	0	0	1	1	0	0	0	0	1	1
Wild life res	0	0	0	2	0	0	1	1	1	3	1	1
Fish res.	2	2	2	2	0	0	2	0	0	6	2	2
Recreation	0	0	0	1	2	2	0	2	2	3	5	5
Tourism	1	0	2	2	0	0	2	2	2	6	2	5
Education and research		0	0	0	0	0	0	0	0	1	1	1
2. Indirect support to fisheries	2	2	2	2	1	0	0	0	1	4	3	4
Support to habitats & species	0	0	0	0	0	0	0	0	1	0	0	4
Shoreline protection	0	0	0	1	0	0	0	1	1	1	1	1
Sediment & accretion	1	1	1	2	0	0	0	0	2	3	1	4
3. Other function	0	0	0	1	0	0	0	0	1	2	0	2
Non Use Other none use value	2	2	3	3	0	0	0	0	1	5	3	6

I =Income, E= Employment, B= Other Benefits; 3 most important, 0 not important

People's perceptions about climate change effect on mangroves

The information gathered from the 120 stakeholders is presented in Fig. 7. It can be observed that the people were aware of the negative effect of climate change, as they were living in mangroves areas since ages. More than 80 per cent were of the opinion that their houses, infrastructure and agriculture will be affected if mangroves are destroyed. This is mainly due to the fact that if the sea level rises due to high tides or cyclones, these mangroves will act as a natural defense. If these are degraded, livelihood of the people in mangroves area will also be badly affected.

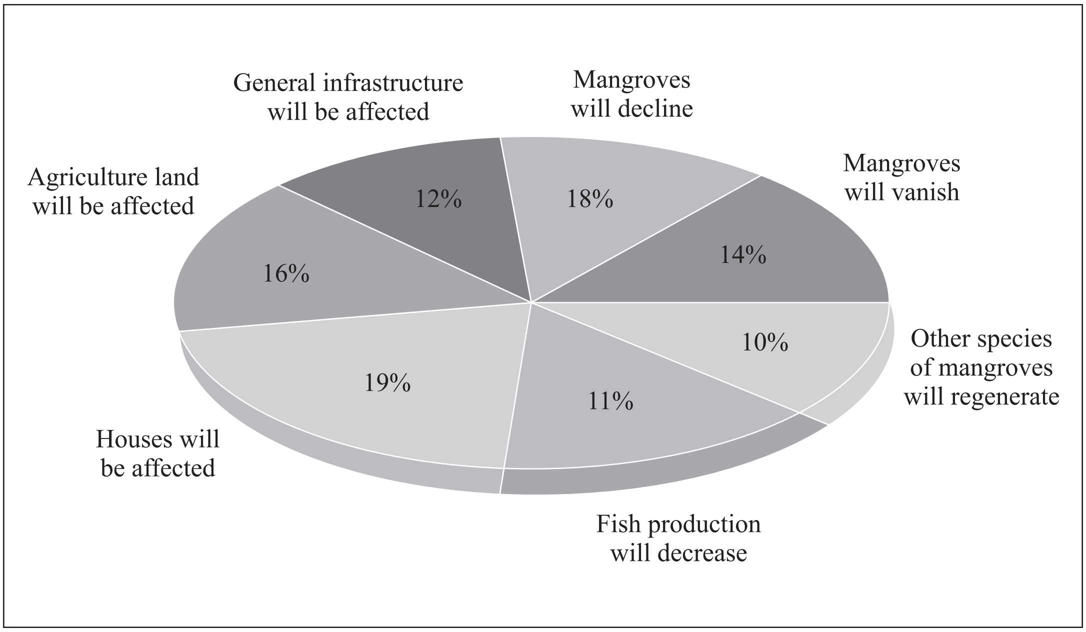


Figure 7: Perceived effect of climate change on mangroves

The ranking of benefits was assessed through a 0 to 10 (0 least -10 most important) scale. The education and research, natural lab, alternate livelihood and enhancing ecotourism were found as important benefits. The results indicate that people are serious about the degradation and loss of mangrove. In spite of their immense role in protecting human resource as well as biodiversity, these unique mangrove habitats of India have been facing tremendous threats due to indiscriminate exploitation of mangrove resources for multiple uses like fodder, fuel wood and timber for building material, alcohol, paper, charcoal and medicine (Upadhyay *et al*., 2002). Apart from those, conversion of forest area into aquaculture and agriculture, construction of port and harbor, extension of human inhabitation, over-grazing, urbanization, industrialization, and chemical pollution are major reasons to decline in mangrove area (Naskar, 2004). A & N Islands lost about 32 per cent mangroves area so far.

Perception about improvement in potential of mangroves

The information was analyzed to understand the extent and scope of improvement in ecological services in future and the same is presented in Fig. 8. It was learned that development of genetic resources and non-use value had the highest potential. The indirect and direct benefits had the mixed response of low to medium potential for improvement.

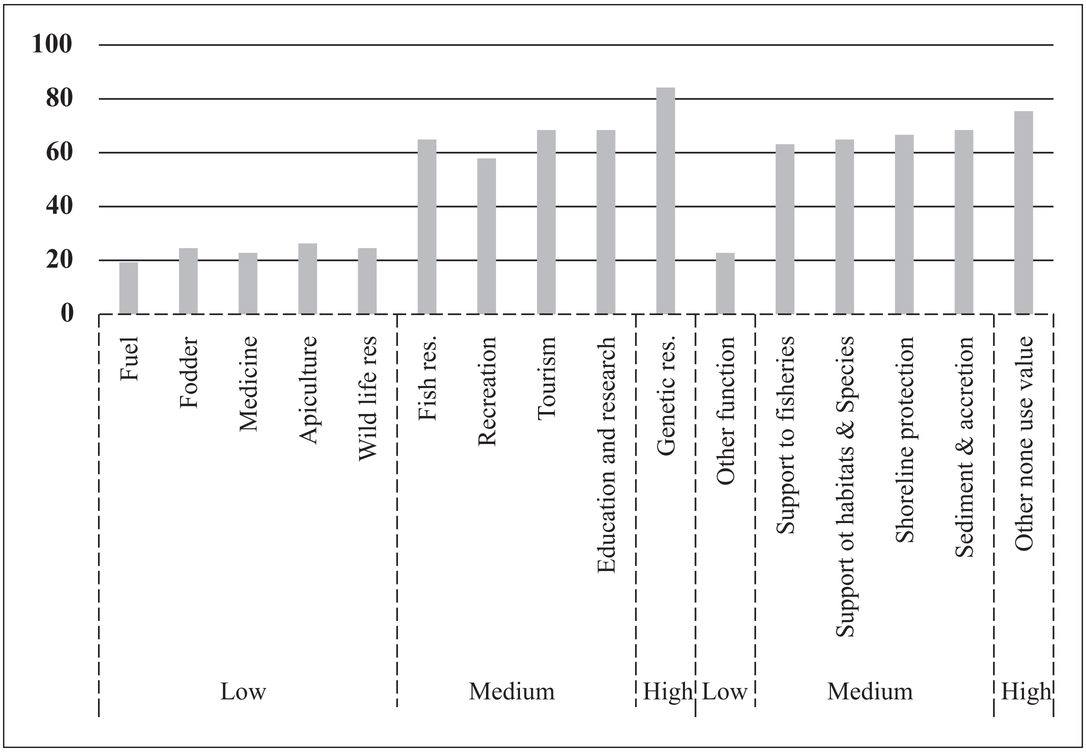


Figure 8: Potential to increase socio-ecological services of mangroves (% responses)

Conclusions and Policy Implications

The role of mangroves in terms of income and employment generation is less than the other indirect benefits. The indirect benefits in true sense cannot be assessed with certainty due to absence of market and pricing mechanism. But qualitative assessment indicates that mangroves give benefits by more than 10 times in comparison to manmade defence system against climate change. The total economic value of Andaman Mangroves was worked out to be more than Rs 1,250 crore with some data constraint in calculation of ecological functions. On an average, each household harvests more than Rs 61,000/ annum worth of goods and services from the mangroves area in A & N Islands. Apart from these multifarious functions in terms of protection of mangroves, the islands also provide livelihood opportunities to the people. Inter-tidal mudflats, saline and less productive coastal lands provide opportunity to raise coastal forests with multiple use in terms of carbon sink; barrier against or cyclone, storm and salty winds, coastal land stability; sustainable agriculture behind shelter belt; and basic needs to the coastal community. The scientific studies and consistent monitoring of ecological changes and sea level rise should be done to provide necessary inputs for management interventions. The mangroves of Andaman and Nicobar Islands have huge potential to protect the coastal people and improve their livelihoods.

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CHAPTER 10

VALUATION OF CARBON SEQUESTRATION: A CASE STUDY OF POPLAR (*Populus deltoides*) BASED AGROFORESTRY SYSTEM IN YAMUNANAGAR DISTRICT OF HARYANA

Mahendra Singh and R.H. Rizvi

Introduction

The climate is changing, human influence on the climate system is clear, therefore, we have the means to limit climate change and build a more prosperous and sustainable future (IPCC, 2014). The clean development mechanism (CDM) of the Kyoto Protocol (1997) imposed carbon emissions limits on its signatories. When manufacturers or producers exceed its emission limit, they must purchase credits from either another entity that is below its limit or from a carbon sequestration project such as reducing emissions through deforestation and degradation, and removals through sinks, conservation, sustainable management of forests and enhancement of forest carbon stocks (REDD+), afforestation / reforestation, grassland, etc. As plant grows, it accumulates biomass, which is incrementally using atmospheric carbon in photosynthesis. Carbon sequestration and storage has made carbon a precious economic commodity. Agriculture and land use, land-use change and forestry (LULUCF) are among the most frequently included sectors in majority of countries' mitigation contributions, about 88 per cent of countries (116 out of 131) mention forestry as a sector for adaptation (FAO, 2016a). In fact, the assignment of value to the carbon is one of the innovative mechanisms for solutions of the global climate change. Markets for carbon allow for the purchase of carbon 'credits' by carbon emitters who need to offset their emissions based on concerned country's government set 'cap'.

In spite of importance of forests for providing various ecosystem services, the area under forest is decelerating. The scale of global forest loss is staggering, with as many as 130 million hectares of forest disappearing in first decade of this century (Alforte *et al.*, 2014). There was a net forest loss of seven million hectares per year in tropical countries in 2000–2010 and a net gain in agricultural land of six million hectares per year. The greatest net loss of forests and net gain in agricultural land over the period was in the low-income group of countries, where rural populations are growing. Large-scale commercial agriculture accounts for about 40 per cent of deforestation in the tropics and subtropics, local subsistence agriculture for 33 per cent, infrastructure for 10 per cent, urban expansion for 10 per cent and mining for 7 per cent (FAO, 2016b).

Agroforestry systems have been identified as panacea for trade-off between food and environmental security especially in tropical countries where forest is converted into agricultural uses. In fact, this system has continued since time immemorial in India and area under agroforestry is estimated at 16.59 million hectares of ten agro-climatic zones out of 15 agro-climatic zones in the country (ICAR-CAFRI, 2016-17). Several ago-climatic specific models have been developed for adoption by farmers in respective zones. Given the nature of multi-functionality of agroforestry, it also has roles to play to achieve the targets of SDG1: ending poverty; SDG2: ending hunger; SDG6: protecting water-related ecosystems; SDG7: providing access to sustainable energy to all; SDG13: combating climate change; and SDG15: protecting terrestrial ecosystems.

The Trans-Gangetic Plain zone encompasses areas included in the states of Punjab, Haryana, Plain region of Rajasthan as well as the Union Territories of Chandigarh and Delhi. The sub-zones cut across state boundaries. The climate is arid, semi-arid and sub-humid in different districts. Many seminal studies have been conducted for estimation of carbon storage (Rizvi *et al.*, 2011; Gaur and Gupta, 2012; Singh and Gill, 2014; Chauhan *et al.*, 2015; Zapfack, *et al.*, 2016), but there is dearth of study on valuation of carbon stock by poplar trees. Therefore, this study was conducted to bridge the knowledge gap regarding payment for ecosystem services through carbon sequestration by Poplar farmers in the study area. The specific objective of the present study was to estimate the quantity and value of carbon sequestered by poplar based agroforestry system in Yamunanagar district of Haryana.

Materials and Methods

Study area

The study was conducted in the Yamunanagar district of Haryana, which is bounded by the state of Himachal Pradesh in the North 30° 17' latitude, by the state of Uttar Pradesh in the east and south east, by the districts of Karnal and Kurukshetra in the south and north; and by Ambala district in the east (Fig. 1). Sugarcane, wheat and rice are the major crops in the area and because of good potency and fertility, the farmers are also growing poplar and eucalyptus trees. The area under agroforestry system is estimated as 18.76 per cent of geographical area in district (Rizvi *et al.*, 2011). Poplar is the dominant species among tree species grown at farmers' field and occupied about 13.97 per cent of geographical area or about 75 per cent of the total area under agroforestry in the district.

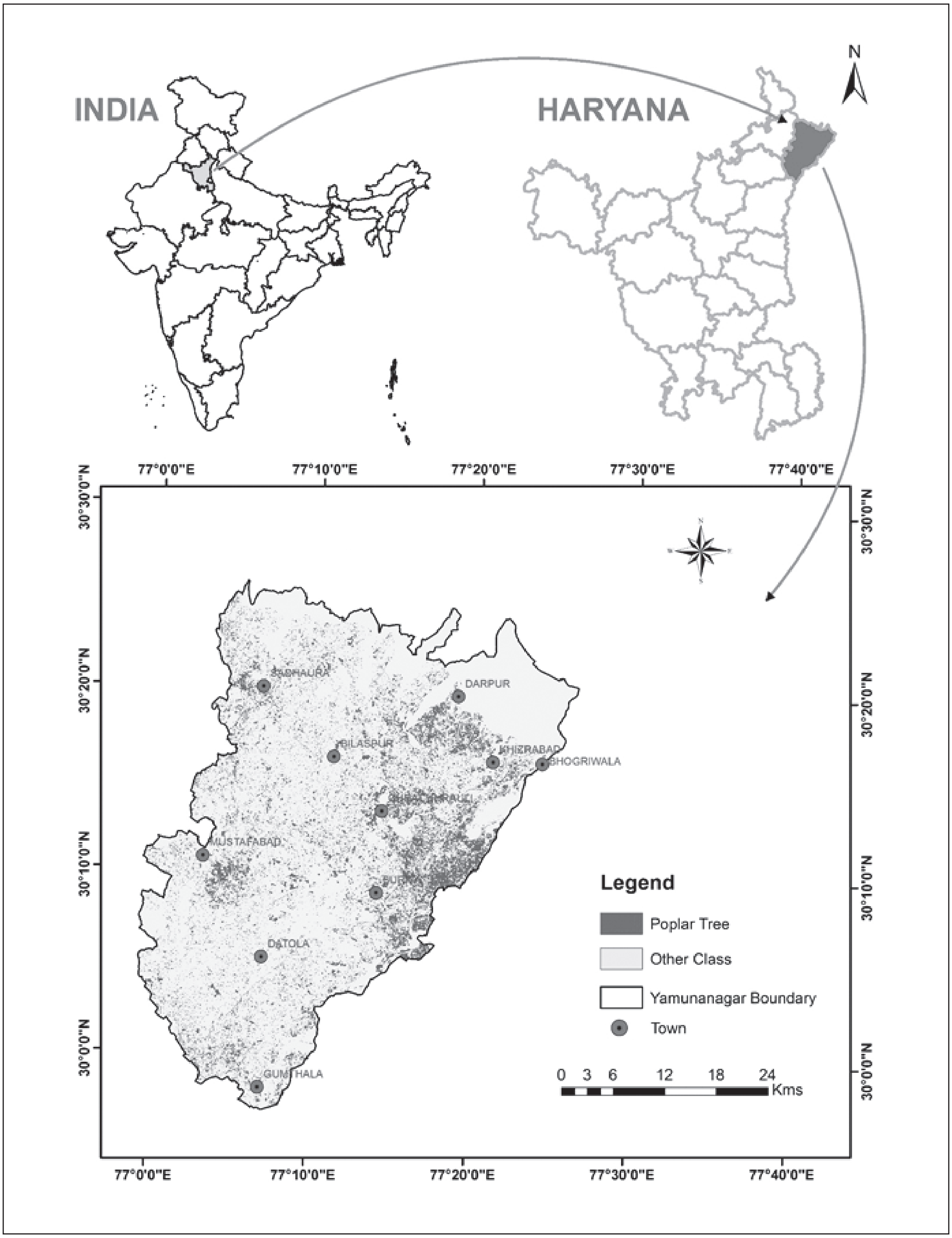

Figure 1. Map of study area

Data collection

The field survey was conducted in six development blocks of Haryana in the year 2008-09 and 2017-18. The primary data on height and diameter at breast height (DBH) for various age of poplar trees were collected from selected farmers' field in study area. Geographic information system (GIS) and remote sensing technique used for estimation of area under poplar based agroforestry system. Data on different physiographical parameters were collected from Statistical Abstract of Haryana published by Department of Economics and Statistical Analysis, Government of Haryana, and price of carbon sequestrated was taken from Ecosystem Market price as US$5.1/t$CO_2$ e for the year 2016-17.

Data analysis

The biomass of poplar trees was estimated using allometric equation (Rizvi *et al.*, 2011):

$$W=25.21-6.5D+0.7D^2-0.006D^3,$$

where D is the diameter at breast height (dbh;cm); W is the dry stem wood biomass (kg) .

The total dry biomass was computed from dry stem wood biomass by assuming it to be 51 per cent of the total biomass. The carbon storage in total biomass computed as: C=0.455*B; where C is the carbon storage; and B is the dry biomass. The total carbon assimilation by biomass of poplar trees as CO_2 was computed as: C*3.67; where C is the total carbon storage. It is assumed that first and second year of tree has very small amount of biomass, hence only three to seven years of data on all parameters of poplar trees were estimated.

Results and Discussion

The average height, diameter at breast height (dbh) and timber volume of poplar trees in boundary plantation (BP) and agri-silviculture system (AS) in Yamunanagar, Haryana are presented in Table 1. The average values of the all parameters were higher in agri-silviculture than boundary plantation system, which might be due to higher nutrients and water availability in the former than the later. The per ha timber production of poplar trees estimated as 459 q and 1,133 q for seven years of rotation of poplar trees from boundary and agri-silviculture system respectively.

Table 1. Average growth and yield of poplar tree in boundary plantation and agri-silviculture system in Yamunanagar, Haryana

Growth/yield parameters	Age (years)				
	3	4	5	6	7
	Boundary plantation (BP)				
Height (m)	12.57	15.33	18.28	21.71	22.83
Diameter at breast height (cm)	13.67	15.91	19.04	20.11	21.43
Timber weight (kg/tree)	101.33	131.92	177.48	216.43	229.53
Timber weight (q/ha)	202.66	263.84	354.96	432.86	459.06
Timber volume (m^2/tree)	0.06	0.10	0.16	0.21	0.23
Timber volume (m^2/ha/200 tree)	12.40	19.80	31.80	41.00	45.80
	Agri-silviculture system (AS)				
Height (m)	15.34	17.82	18.45	19.81	21.96
Diameter at breast height (cm)	15.77	17.48	18.19	19.86	21.38
Timber weight (kg/tree)	130.22	159.07	168.99	195.34	226.55
Timber weight (q/ha)	651.10	795.35	844.95	976.70	1132.75
Timber volume (m^2/tree)	0.10	0.14	0.16	0.19	0.24
Timber volume (m^2/ha/500 tree)	52.00	71.50	78.00	96.50	118.50

Source: Authors' estimate based on data from field survey.

The estimated quantity and value of carbon stock by age of poplar per hectare in Yamunanagar are depicted in Table 2. As assimilation of carbon stock depends on biomass of trees, the quantity of carbon was relatively higher in agri-silviculture than that in boundary plantation system. The total value of sequestered carbon was estimated as US$ 1,778 and US$ 4,673 for poplar trees for seven years of rotation in boundary and agri-silviculture system, respectively. If we consider the time value of money on carbon value with discount rate of 12 percent, then the estimated value reduces to US$ 1,009 and 2,651 in boundary and agri-silviculture system, respectively. However, the value of net income from rice-wheat rotation, which is US$ 3,501 per ha for seven years, is higher as compared to, the value of carbon from poplar for the same period (US$ 2,651) in the study area. It implies that the payment of ecosystem services in terms of carbon sequestration by poplar plantation having about 75 per cent net income of rice-wheat system, which need much water and exhausts precious natural resources.

Table 2. Estimated quantity and value of carbon stock by age of poplar per hectare in Yamunanagar, Haryana

Age (years)	Total carbon stock (t/ ha)	Total CO_2 sequestered (tCO_2 e)	Total value of CO_2 sequestered/ ha @US$5.1/ tCO_2 e	Total value of CO_2 sequestered (1 US$=¹ 65)
Boundary plantation (200 trees/ha)				
3	9.56	35.09	178.93	11631
4	13.65	50.10	255.49	16607
5	20.42	74.94	382.20	24843
6	24.33	89.29	455.38	29600
7	27.03	99.20	505.92	32885
Total tree cycle	94.99	348.61	1777.93	115565
Agri-silviculture system (500 trees/ha)				
3	33.04	121.26	618.41	40197
4	42.14	154.65	788.73	51268
5	51.55	189.19	964.86	62716
6	56.96	209.04	1066.12	69298
7	65.96	242.07	1234.57	80247
Total tree cycle	249.65	916.22	4672.70	303725

Source: Authors' estimate based on data from field survey.

The report of the High level Commission on carbon prices (World Bank, 2017) concluded that the explicit carbon price level consistent with achieving the Paris temperature target would be at least US$40-80/$tCO_2$ e by 2020 and US$50-100/$tCO_2$ e by 2030, provided a supportive policy environment is in place. However, it is well documented that the past trend of price of carbon showed much volatility and difference in source and country of production of certified emission reductions (CERs). The latest data (year 2016-17) on average price from all sources of per CERs for India was US$ 0.6/t CO_2 e.

The sensitivity analysis was conducted on the basis of the minimum price offered for India and the lowest price suggested by the Commission was US$40-80/$tCO_2$ e by 2020 to meet the Paris temperature target. It shows that the farmer can obtain US$ 549.73/ha by poplar based agri-silviculture, if the price reduces from present price of US$ 5.1/ t CO_2 e to US$0.6/t$CO_2$ e. It is also possible that the farmer obtains US$ 36,648.62 if international community is willing to accept US$40/t$CO_2$ e as suggested by Commission (Table 3).

Table 3. Sensitivity analysis based on changes in price of carbon sequestrated from Poplar in Yamunanagar, Haryana

Age (years)	Total carbon stock (t ha ^{1})	Total CO_2 sequestered (tCO_2 e)	Total value of CO_2 sequestered/ha			
			@US$40/ t$CO_2$ e	(1 US$= ^{1} 65 (^{1}/ha)	@US$0.6/ t$CO_2$ e	(1 US$= ^{1} 65)
Boundary plantation (200 trees/ha)						
3	9.56	35.09	1,403.41	91,222	21.05	1,368
4	13.65	50.10	2,003.82	130,248	30.06	1,954
5	20.42	74.94	2,997.66	194,848	44.96	2,923
6	24.33	89.29	3,571.64	232,157	53.57	3,482
7	27.03	99.20	3,968.00	257,920	59.52	3,869
Total tree cycle	94.99	348.61	13,944.53	906,395	209.17	13,596
Agri-silviculture system (500 trees/ha)						
3	33.04	121.26	4,850.27	315,268	72.75	4,729
4	42.14	154.65	6,186.15	402,100	92.79	6,031
5	51.55	189.19	7,567.54	491,890	113.51	7,378
6	56.96	209.04	8,361.73	543,512	125.43	8,153
7	65.96	242.07	9,682.93	629,390	145.24	9,441
Total tree cycle	249.65	916.22	36,648.62	2,382,160	549.73	35,732

Source: Authors' estimate based on data from field survey

On the basis of estimated area under agroforestry and share of poplar in agroforestry in district of Yamunanagar, the total carbon stock and their value was computed. It shows that the total value of US$ 4,284,969 was substantial for carbon sequester by poplar based agroforestry system in the district. If we consider entire area under agroforestry and estimate at state and national level, this value will increase manifold (Table 4).

Table 4. Total estimated quantity and value of carbon stock and sequestration by poplar in Yamunanagar, Haryana

Age of poplar trees (year)	Share in area by age of poplar trees (%)	Estimated area by age of poplar trees (ha)	Timber weight (q)	Total carbon stock (t/ ha)	Total carbon stock (t)	Total value of CO_2 sequestered		
						(tCO_2 e)	@US$5.1/ tCO_2 e	(1 US$=₹ 65)
3	5	1,205	651.10	33.04	21,512.34	78,950.30	402,646.54	26,172,025.27
4	10	2,411	795.35	42.14	33,516.05	123,003.90	627,319.89	40,775,792.79
5	20	4,822	844.95	51.55	43,557.17	159,854.82	815,259.60	52,991,873.85
6	30	7,233	976.70	56.96	55,632.83	204,172.49	1,041,279.72	67,683,181.58
7	35	8,438	1,132.75	65.96	74,716.19	274,208.42	1,398,462.93	90,900,090.33
Total	100	24,109	4,401	250	228,935	840,190	4,284,969	278,522,964

Source: Authors' estimate based on data from field survey

Conclusion

The study analysed the importance of poplar based agroforestry system in terms of carbon sequestration in Haryana. A comparison of net income from rice-wheat rotation for seven years and the value of carbon sequestration from poplar for the same period revealed that the latter amounts to about 75 per cent of the net income from the rice-wheat system, which uses scarce water. If the farmers receive remunerative price for the timber and reward for their contribution in mitigation of climate change through suitable policy mechanism, the adoption of agroforestry will increase considerably. To achieve the committed targets under Paris agreement (2015), agroforestry is a sustainable solution along with the enhancement of farmers' income.

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LIST OF CONTRIBUTORS

Suresh Pal, Director, ICAR- National Institute of Agricultural Economics and Policy Research, New Delhi

P.K. Mishra, Former Director, ICAR-Indian Institute of Soil and Water Conservation, Dehradun, Uttrakhand

O.P. Yadav, Director, ICAR-Central Arid Zone Research Institute, Jodhpur

M.G. Chandrakanth, Director, Institute for Social and Economic Change, Bengaluru

R.C. Srivastava, Vice Chancellor, Central Agricultural University, Pusa, Samastipur, Bihar

Guido Van Huylenbroeck, Professor,University of Ghent, Belgium

Lata Nain, Principal Scientist, Division of Microbiology, ICAR-Indian Agricultural Research Institute, New Delhi

Praveen Kumar, Head of Division, ICAR-Central Arid Zone Research Institute, Jodhpur

Mahadev G. Bhat, Professor, Environmental Studies, Florida International University, Miami

R.H. Rizvi, Regional Representative, World Agro-forestry Centre, Nairobi, Kenya

Subhash Chand, Principal Scientist, ICAR- National Institute of Agricultural Economics and Policy Research

Radha Prasanna, Principal Scientist, Division of Microbiology, ICAR-Indian Agricultural Research Institute, New Delhi

Naveen P. Singh, Principal Scientist, ICAR- National Institute of Agricultural Economics and Policy Research, New Delhi

Pradeep Dogra, Principal Scientist, ICAR-Indian Institute of Soil and Water Conservation, Dehradun, Uttrakhand

V.C. Pande, Principal Scientist, ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Vasad.

P.C. Moharana, Principal Scientist, ICAR-Central Arid Zone Research Institute, Jodhpur

M. Madhu, Principal Scientist, ICAR-Indian Institute of Soil and Water Conservation, Odisha

D.V. Singh, Senior Scientist, ICAR-Central Arid Zone Research Institute, Jodhpur

Bidisha Chakrabarti, Senior Scientist, Centre for Environment Science and Climate Resilient Agriculture ICAR-Indian Agricultural Research Institute, New Delhi

Shrawan Singh, Senior Scientist, ICAR-Indian Agricultural Research Institute, New Delhi

Mahendra Singh, Senior Scientist, ICAR-Central Agroforestry Research Institute, Jhansi, Uttar Pradesh

M.G. Nagaraja, working with The Mythic Society, Bangalore

Prem Chand, Scientist, ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi

S.J. Balaji, Scientist, ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi

Prabhat Kishore, Scientist, ICAR- National Institute of Agricultural Economics and Policy Research, New Delhi

Sulakshana Rao, Research Associate, ICAR- National Institute of Agricultural Economics and Policy Research, New Delhi

Bhawna Anand, Research Associate, ICAR- National Institute of Agricultural Economics and Policy Research, New Delhi

Surendra Singh, Research Associate, ICAR- National Institute of Agricultural Economics and Policy Research, New Delhi

Priyanka Upreti, PhD scholar, Division of Agricultural Economics, ICAR-Indian Agricultural Research Institute, New Delhi

Ranjith P.C., Young Professional-II, ICAR- National Institute of Agricultural Economics and Policy Research, New Delhi

M.S. Accavva, M.Sc. Student, Department of Agricultural Economics, University of Agricultural Sciences, GKVK, Bangalore

Arshad Khan, Research Associate, ICAR- National Institute of Agricultural Economics and Policy Research, New Delhi

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भा.कृ.अ.प.–राष्ट्रीय कृषि आर्थिकी एवम् नीति अनुसंधान संस्थान
ICAR – NATIONAL INSTITUTE OF AGRICULTURAL ECONOMICS AND POLICY RESEARCH
(Indian Council of Agricultural Research)
Dev Prakash Shastri Marg, Pusa, New Delhi-110 012, INDIA
Phone : 91-11-25847628, 25848731, Fax : 91-11-25842684 E-mail : director.niap@icar.gov.in
http: // www.ncap.res.in