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Ecosystem Services vis-à-vis Watershed Management

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Foreword

Millennium Ecosystem Assessment revealed that more than 60% of world's ecosystems are being used in ways that cannot be sustained, and their degradation will be much faster under the future climate change scenario. An accelerating use of natural resources under intensive agriculture is continuing to affect key ecosystem services (ES), threatening ecosystem sustainability and food security, adoption of soil and water conservation technologies through participatory integrated watershed management is a viable approach to combat land degradation *vis-a-vis* sustain ecosystem services.

It is noteworthy that Indian Institute of Soil and Water Conservation (ICAR-IISWC) has come out with a manual entitled "*Ecosystem Services vis-à-vis Watershed Management*" for formulation of a structured approach and methodology that was lacking to compute values of different ecosystem services benefited through adoption of soil and water conservation measures and watershed management. The manual will provide a rich and important reference source for advanced students, researchers and policy-makers in sustainable land management, ecology, environmental studies, ecological economics and sustainable development.

I congratulate the authors for their diligent efforts in bringing out this comprehensive manual which is very timely and pertinent. I hope that this publication will contribute to conservation and restoration of ecosystems around the world in general and India in particular.

(S.K. Chaudhari)

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PREFACE

Soils are an important component of ecosystems which represents the space formed at the intersection of the lithosphere, biosphere, atmosphere and hydrosphere. It regulates the majority of ecosystem processes in a watershed. The Indian Institute of Soil and Water Conservation (ICAR-IISWC), formerly known as Central Soil and Water Conservation Research and Training Institute (CSWCRTI), initiated such ecosystem based watershed management projects from 1974-75 onwards for demonstrating efficacy and efficiency of soil and water conservation technologies to combat degradation problem of ecosystem services through adoption of participatory integrated watershed development approach. However, very limited work has been done on valuation techniques for computation of various Ecosystem Services (ES) on watershed basis. Therefore, the Institute planned to prepare a methodology and conceptual based publication in the form of manual entitled "**Ecosystem Services vis-à-vis Watershed Management**". Through this manual, we present the methodologies and concepts for pricing of prominent ecosystem services parameters influenced in watershed management and address the problem specific to selection of appropriate measurable indicators for each ecosystem service. All these are presented in five chapters.

Chapter 1 is an overall introduction of the publication mainly describing the background and significance of measuring ecosystem services with the framework of watershed management. Chapter 2 elaborates Ecosystem Services (ES) from Integrated Watershed Management and Soil and Water Conservation Interventions. It mainly highlights the fact that if any soil and water conservation intervention is implemented in the field following watershed approach, what are the several benefits in terms of four ES described earlier. Chapter 3 presents the measurement devices and data processing methods of biophysical indicators for quantification and valuation. A detailed account of quantification and valuation techniques for 12 indicators of provisioning services, 8 of regulating services, 3 of cultural services and one of supporting services is presented in this chapter. Chapter 4 presents a representative example of ecosystem services estimation and valuation of some ecosystem services with the matrix of the ecosystem indicator filled up with the data of the chosen watershed.The authors wish to place on record their sincere thanks to all contributors who participated in two workshops organized exclusively for the purpose of documentation of methodology for quantifying ES. The authors express their gratitude to all Heads and scientists of Divisions / Research Centres of the Institute who have directly or indirectly contributed to ensure timely completion of the document. We have duly acknowledged the sources of the equations and formulae that have been reproduced from other sources and publications.

Vinod Chandra Pande
Pradeep Dogra
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Contents

1 Introduction

The ecosystem is composed of four mega sub ecosystems, namely solar, water, earth and atmosphere. They are closely interrelated through multiple complex relationships among themselves and with living organisms, and majority of Earth's lithosphere living organisms derive number of goods and services from its ecosystem for their existence. They are called ecosystem services (ES). Ecosystem services are natural processes and functions essential for human well-being and livelihood (Mueller *et al.*, 2016; Sannigrahi *et al.*, 2021; Wondie, 2018; Li *et al.*, 2020). Ecosystem services are defined generally as services provided by the natural environment that benefit people in all societies. ES produce outputs or effects that have a direct and indirect impact on human well-being, culture, and the global economic system (Feng *et al.*, 2018; Ma *et al.*, 2020). Humans benefit from ecosystems, and the destruction of these natural resources, directly and indirectly, affects their well-being (Millennium Assessment, 2005). Human health and well-being are dependent on these services, which range from the provision of sufficient food and water to disease regulation. If ES are no longer sufficient to meet social needs, significant direct human health effects can occur (Dressler *et al.*, 2017). Changes in ES have an indirect impact on livelihoods, jobs, local migration, and even political and social conflict (WHO, 2018; Rodríguez-Robayo *et al.*, 2020). Overall, the ecosystem provides a number of goods and services termed as ecosystem services (ES) to satisfy multiple needs of multi-stakeholders (humans as well as other organisms).The concept of ES includes transmission, arrangement, creation, support, or the act of keeping goods and services that humans consider to be essential (Chee, 2004; Daryanto *et al.*, 2019). ES involve goods like seafood, animal food, trees, biomass fuels, natural fibres, medicines, industrial products; services like maintaining biodiversity; and life supporting actions such as waste absorption, sanitization, restoration, renewal, and abstract, artistic, and cultural profits (Aerts and Honnay, 2011; Hicks *et al.*, 2014). They include socio-cultural programs as well as supporting services required to keep the other services running (Otto *et al.*, 2017). Provisioning of natural products/resources and raw materials such as food, fodder, fibre, water, genetic material, medicines, raw material etc. are Provisioning Services. ES also include processes for maintenance of essential ecological processes and life support systems for living organisms – transformation and/or movement of soil, water, nutrients, wastes, atmospheric gases, climate etc. – called Regulating Services. Ecological structures and functions that are essential for delivery of other ES such as hydrological cycle, net primary production, nutrient cycling and biodiversity are called Supporting Services, and ES that enhance emotional, psychological, and cognitive well-being are Cultural Services (Table 1.1).Ecosystem services in relation to human wellbeing are presented in Figure 1.1.

How is Ecosystem Services Concept/Approach Helpful?

The ES concept focuses on preserving the ecosystem as a whole rather than on managing specific natural resources and uses, and therefore, it enhances understanding of environmental problems and promotes sustainable solutions within local decision making (Posner *et al.*, 2016). This evolutionary approach promotes a new mindset that favours a better understanding of interactions between functioning of parts of ecosystems and components of human well-being, thereby of natural environment's contribution to human prosperousness (Fisher *et al.*, 2009; MA, 2005; Carpenter *et al.*, 2006; Sachs and Reid, 2006; Daily and Matson, 2008; Bolzonella *et al.*, 2019; Prentice *et al.*, 2019). As a result, it provides a policy shift from previous resource-and-species-centered visions of environmental preservation, towards a new environmental policy vision based on preservation of ecological functions and ES (Cordier *et al.*, 2014). The Ecosystem Services (ES) concept has become an important tool to support the integration of environmental needs in public policy (Daily *et al.*, 2009; Guerry *et al.*, 2015; van Oudenhoven *et al.*, 2018). Relevant information, maps, classifications and scenarios are used in order to enhance the process of decision-making to include environmental stakes in their choices (Polasky *et al.*, 2015; Schirpke *et al.*, 2017; Falk *et al.*, 2018).

Table 1.1: Ecosystem functions and services

Provisioning services	Regulating services	Supportive services	Cultural services
Water supply	Gas regulation	Nutrient cycling	Recreation
Food	Climate regulation	Net primary production	Aesthetic
Ornamental resources	Disturbance regulation	Pollination and seed dispersal	Science and education
Genetic resources	Biological regulation	Habitat	Spiritual and historic
Medicinal resources	Water regulation	Hydrological cycle	
Raw materials	Soil retention		
	Waste regulation		
	Nutrient regulation		

Source: Farber *et al.* (2006)

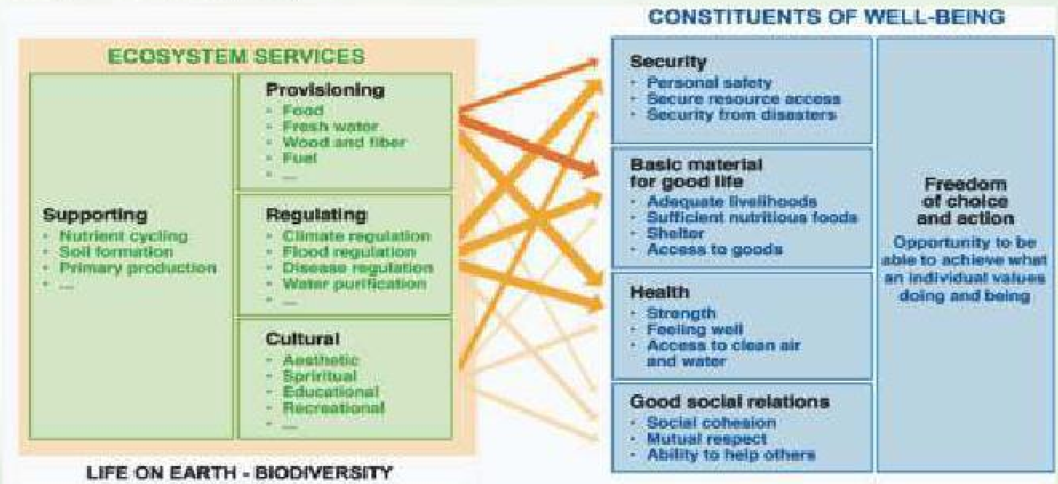

Figure 1.1: Ecosystem services and human wellbeing

Ecosystem Services vis-à-vis Integrated Watershed Management and Soil and Water Conservation Interventions

Adoption of conservation-effective measures on eroded landscape reverses degradation trends and increases ecosystem services (ES). Conversion to a restorative land use and adoption of conservation-effective measures sustain/improve soil and ecosystem C pools, enhance soil quality, and increase net primary productivity (NPP), among numerous ecological benefits. Soil conservation supports many ES 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 ES 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.*, 1995; Bjoerklund *et al.*, 1999; Kauffman *et al.*, 2014). Over and above the beneficial impacts on water quality, a principal ecological benefit of soil conservation and restoration is the increase in C pool in the soil and terrestrial biosphere. Improvement in soil quality enhances 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.Different types of conservation measures, as per land specific degradation problems, are used for natural resource conservation. These can be implemented individually or in combination depending upon the problem to be addressed. Various SWC measures and associated ES are given in Table 2.1.

Tallis and Kareiva (2006) reviewed the MA scenario analyses approach (models) and they considered river basin an ideal unit for assessment of ES where four independent models (IMPACT, IMAGE, WaterGap, and Eco-path with Ecosim) may be integrated and impact on majority of ES may be estimated. They further emphasized on assessment of ES at smaller scale based on diverse live demonstrations of improved human well-being as a result of improved ecosystem management. Watershed is a smallest hydro-geological ecosystem unit of the basin where investment may be made to promote enhanced ES, provided they are designed, planned and properly implemented after appropriate boundary work. Watershed ecosystem has potential for sourcing all four categories of ES i.e. provisioning, regulating, cultural and supporting services (de Groot *et al*. 2002, MA 2005, Lalika *et al*. 2014, Locatelli and Vignola, 2009). Integrated watershed management (IWM) programs envisage restoring the degraded land in rainfed regions to increase their capacity to capture and store rainwater, reduce soil erosion, and improve soil nutrient and carbon content. The improved production base helps enhance agricultural production and other benefits for the majority of India's rural poor, who live in these regions and are dependent on natural resources for their livelihoods and sustenance. At the same time, these interventions affect the flow of the ES, thereby, affecting the human well-being. Integrated watershed development capitalizes synergistic effects of different sectors and interventions that may lead to win-win situation rather than trade-off (Howe *et al*. 2014). The win-win situation results in sustained supply of ES for the stakeholders. Watershed approach facilitates budgeting of majority of indicators related to provisioning, regulating, supportive and cultural benefits of ES (McDonald and Schemie, 2014; Lalika *et al*., 2014; Guerry *et al*., 2015; Geneletti, 2015; Geneletti *et al*., 2016; Esmail and Geneletti, 2017).

Table 2.1: Soil and water conservation measures and ecosystem services

S. No.	Types of Services	Soil and Water Conservation Measures					
		Agronomic	Vege-tative Barriers	Engineering	Drainage Line Treatment	Agro-forestry & Plantation	Water Resource Develop-ment
I	**Provisioning Services**						
1	Food, Fodder, Fibre, Fresh water	**	*	*		**	**
II	**Regulatory 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 & Esthetic Value					**	**

The ES in the context of soil and water conservation interventions / integrated watershed management can, broadly, be based on:

Provision of physically measurable outputs specifically for human needs:	Provisioning Services
Regulation / retention / mitigation / filtration / accumulation / detoxification of natural resources and services:	Regulating Services
Services/ functions by nature necessary to maintain other three services or supporting all other services:	Supporting Services
Non materialistic benefits (recreational, educational, inspirational, institutional, aesthetic, capacity building activities):	Cultural Services

A number of probable ecosystem services flowing from watershed management interventions have been identified (Tables 2.2 & 2.3, Figure 2.1). Different ecosystem services flow from soil and water conservation measures implemented following integrated watershed management approach depending upon topography, land use / 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 2.2: Ecosystem services from Integrated Watershed Management / Soil and Water Conservation Interventions

Type of eco system service	Probable ecosystem services flow from watershed management interventions
Provisioning Services	i) Production/productivity (Agriculture, Livestock, Horticulture, Forestry/ Agro-forestry, Fisheries for food, fodder, fuel wood, fiber) ii) Medicinal and non-timber forest produce iii) Fresh Water (drinking, domestic use) stored iv) Livelihood/ income generation/ entrepreneurship v) Employment generation
Regulating Services	i) Reduction in soil loss / sedimentation/ nutrient loss ii) Reduction in runoff iii) Groundwater recharge iv) In-situ water conservation v) Water purification / quality maintenance vi) Flood / drought mitigation vii) Carbon sequestration viii) Air quality ix) Soil health - Soil biota, physical properties x) Biodiversity augmentation
Cultural Services	i) Aesthetic/ recreational service ii) Awareness creation/ capacity building/ educational service (excluding academic) iii) Inspirational service iv) Linkage/ convergence creation v) Institutionalization
Supporting Services	i) Soil regeneration/ mineralization including Nutrient recycling

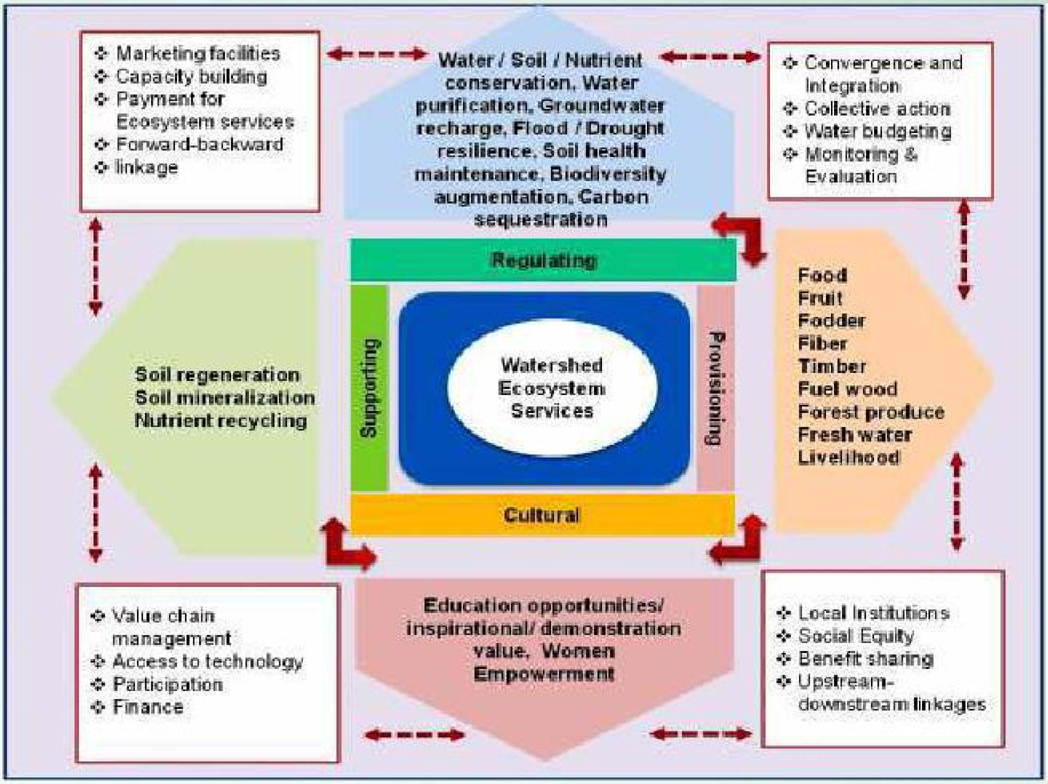

Figure 2.1: Watershed based ecosystem services

Table 2.3: Description of ecosystem services *vis-à-vis* soil and water conservation on watershed basis

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 ins treams, canals and rivers, particularly in foot hill areas, which reduces their carrying capacity and increases their width, which in turn leads to degradation of adjoining agricultural lands, meandering of r iver courses, and smothering of crops and vegetation. Sedi mentation also leads to reduction in the storage capacity of many reservoirs. Further, sediments deposited into the water bodies pose a serious hazard/ threat to the submerged aquatic 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.
	Carbon storage and greenhouse gases regulation	Soils have the ability to store carbon and regulate the production of greenhouse gases such as nitrous oxide and methane. P revention of soil loss boosts this regulating service.
	Detoxification and recycling of wastes	Soils can absorb (physically) or destroy harmful compounds. Soil biota degrades and decomposes dead organic matter, thereby recycling wastes.
	Regulation of pests and diseases	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 man aged 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 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 prov ides 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.

2.1 Linkage between Ecosystem Services and Economic Valuation

Majority of scientific efforts have focused on efficiently harvesting large number of tangible products from the ecosystems to satisfy high priority needs of human beings. The subject of efficiently harvesting products and services from ecosystems gained importance in late 1970's, and in the present age (Costanza *et al.* 1997, Gomez-Bagfethum *et al.* 2010) have been named as Ecosystem Services (ES). The assessment of ES, as illustrated by Costanza *et al*. (1997), Pittini (2011), and Mangi (2016), includes assessing improvements in quality and quantity and their impact on human well-being. Braat and Groot (2012) have presented a review on ecological and economic roots of the subject, indicators for its commoditization, and methods of monetization, alongwith capturing and managing the values. As per TEEB's (2010) study, monetary valuation of the natural environment has increasingly been linked to the concept of ecosystem services, and The Economics of Ecosystems and Biodiversity (TEEB) framework is "intended to guide policy-makers in designing their own processes for appraising and considering nature's benefits" (TEEB, 2010; p.7).Values are considered when dealing with the concept in practice. Estimating monetary value of ecosystem services (ES) has received significant interest from policymakers and scholars in recent decades. Notwithstanding Kronenberg (2015), valuation of ES can help accentuate their effects on human well-being (Salles, 2011) and achieve their integration in public decision-making (Constanza *et al*., 1997; Su and Peng, 2018). Such evaluation quantitatively measures benefits that people obtain from ecosystems and can be used to estimate economic losses due to ecosystem degradation caused by overexploitation (Keith *et al*., 2017), for example estimating the cost of damage to ecosystem services can be effective in preventing further damage to wetland ecosystems (Badamfirooz *et al*., 2021). Economic valuation aims to meet the monetary public expectations to achieve environmental conversation goals (Defra, 2007; Wangai *et al*., 2016). As a result, economic valuation approaches' primary goal is to provide sufficient evidence for cost-benefit analysis (Muthee *et al*., 2017).

The valuation of ES is an approach to support decision making that involves the environment (trade-offs between production and environmental conservation). It measures the advantages presented by ecosystems and the effect of ecosystem adjustments on the comfort of everyone. Thus, monetary values must be taken into account when creating economic decisions. The supporters of ecosystem service estimation believe that estimations can: (i) enhance our perception of difficulties and possible arrangements, (ii) be applied precisely to make choices, (iii) show profit allocation and thus help cost-sharing administrative actions, and (iv) encourage making creative organizational and market devices that support viable ecosystem administration (Arowolo *et al*., 2018). Therefore, the aim to use valuation of ES for informing decision-makers and stressing their importance for human well-being is the most common rationale to conduct valuation studies and referred to as its main objective (Salles, 2011; Chan *et al*., 2012; Laurans *et al*., 2014; Raymond *et al*., 2014). These estimates may then inspire policymakers to consider the ES valuation information when balancing competing land-use and making environmentally sustainable decisions (Kieslich and Salles, 2021).Many research works deal with the difficulty of valuating ES (e.g. Costanza *et al*., 1997; de Groot *et al*., 2002) and the complexity to apprehend interactions between ecological functionalities and the production of ES used by humans (Daily *et al*., 2009; Polasky *et al*., 2011). Since the causal connections between environmental change and human health are often indirect, displaced in space and time, and based on a variety of modifying forces, they are difficult to understand (Otto *et al*., 2017; Bogardi *et al*., 2020). There have been great improvements in ES valuation methods; however, lack of ecosystem dynamics understanding, human needs, and valuation process technical issues leads to uncertainty which has some effects on the valuation methods in general, and on the stated preference methods in particular (Pandeya *et al*., 2016). When using specified preferences methods, market imperfections and policy failures will distort the expected monetary value of ES. High-quality transaction data, large data sets, and sophisticated statistical analysis are needed by scientists. As a result, approaches based on specified preferences are both expensive and time-consuming (Carson, 2012). Market valuation methods primarily rely on production or cost data, which are generally easier to determine the demand for ES. However, when it comes to valuing ES, these methods have serious limitations. These are primarily due to the lack of or distorted markets for ES. As a result, estimated ES values will be skewed and will not provide reliable data on which to base policy decisions (Muthee *et al*., 2017).The ES approach, however, helps in understanding that ES contribute to economic well-being in two ways: first, by making contributions to income and well-being generation, and second, by preventing human-made damages through their evaluations. Ultimately, the evaluation of ES using monetary valuation methods can help: 1) determine whether a policy intervention (which alters the ecosystem condition) provides net benefits to society, and 2) assess liability for the damage to the environment (Azadi *et al*., 2021). While ES are important for everyone's comfort, their help to economic growth is difficult to be measured in monetary terms. As they are not exchanged in trading markets, they are usually considered less important or unimportant in policy-making; but, economic analysis may indicate that ES really have marketing importance, replacing the unsuitable use of ecosystems with more cost-effective ones in a limited amount of time (GIZ, 2012; Ma *et al*., 2020).

2.2 Ecosystem Services and Watershed Management Projects – Assessment and Valuation

Following the goal of Millennium Assessment (MA), 2005 i.e. considering ecology as global science and its increasing integration with social sciences, any informed decision regarding energy, development and land use options will require more than just academic research (Tallis and Kareiva 2006). This indicates that there is a need of projects that effectively connect the sciences of ecosystem services to land conservation for poverty alleviation with inter-generation and intra-generation sustainability and equity. While the agro-ecosystems provide for some of these services, these agro-ecosystems themselves use some of these services for their sustenance. However, the natural resource management / soil and water conservation interventions undertaken on watershed basis to combat land degradation process and enhance production positively affects the two way flow of these ecosystem services.The Indian Institute of Soil and Water Conservation (ICAR-IISWC) in India as the erstwhile Central Soil and Water Conservation Research and Training Institute (CSWCRTI) initiated such ecosystem based watershed management projects from 1974-75 onwards for demonstrating efficacy and efficiency of soil and water conservation technologies to combat degradation problem of ecosystem services through adoption of participatory integrated watershed development approach (Dhyani and Samra, 2004). Massive efforts are being made by the Government of India to replicate the concept by formulating enabling policy guidelines for watershed development projects in the country in support of rural transformation and inclusive growth through participation of primary stakeholders (NRAA 2008 & 2011).

Assessment of ES from integrated watershed management / soil and water conservation can be undertaken as under:

1) Physical process based models, of natural resource interventions, from hydrology (agricultural/ forest/grassland) and soil processes may be used to develop structural relationships between IWM intervention and ES in the respective agro-ecological region.
2) Using the relationship, ES resulting from the particular intervention(s) may be assessed and compared with the base line scenario. The net benefit due to NRCM may be estimated as enhanced ES over the baseline ES.

In absence of sufficient data, however, it will be prudent to begin with proxy method of data generation, indicator assessment and valuation. With availability of sound estimates, the ecosystem services' values may be refined. Several studies suggest that the ecosystem types, ES, valuation methods, and economic development level may have a significant influence on the estimated values (Costanza *et al*., 2014; He *et al*., 2014; Sutton and Costanza, 2002; Teoh *et al*., 2019). The estimated values in the existing literatures often show large variations and inconsistent patterns. Large variations in the ES values in China are observed. Among eight valuation methods used, the market price methods, together with the avoided cost method and Contingent Valuation Method/Choice Experiment Method, produced higher values than the other five methods - Equivalent factor method, Shadow price method, Replacement cost method, and Travel cost method. The estimated values are sensitive to valuation methods (Kang *et al*., 2021).The use of several types of valuation techniques has been shown to be beneficial to account for different value dimensions (Jacobs *et al*., 2018). For ES valuation, the use of different methods not only gives opportunities for integrating different user groups and value types (Jacobs *et al*., 2018), but also for exploiting complementarities between top-down and bottom-up contexts. If researchers focus on improving the relevance of their results to policy makers and practitioners, these complementarities should be used such as to enhance the trans-disciplinary scope of science policy interface (Kieslich and Salles, 2021).The net benefit from integrated watershed management / soil and water conservation may be valued using different valuation techniques. Further, the different services identified are not mutually exclusive. The ecosystem services may have different utilities in different agro-ecological zones and, therefore, valuation approach may differ as anthropocentric approach of valuation relies on utility/ priority of the ecosystem service flow to the beneficiaries. Further, value of ecosystem services depends upon the context of valuation, whether the ecosystem services are proposed to be valued as raw (point of origin) or end use. In the latter, the cost of transport (delivery) and processing of ecosystem services needs to be adjusted in valuation of the concerned ecosystem service. The values arrived at with alternative valuation techniques may be examined in the context of the particular agro-ecological region and a single ES value or range of values may be suggested.

3 Indicators for Ecosystem Services

The assessment of ES, as illustrated by Costanza *et al*. (1997), Pittini (2011), and Mangi (2016), includes assessing improvements in quality and quantity and their impact on human well-being. Indicators are variables, statistics or measures that help to quantify changes in a given phenomenon, changes in state of something valued or change of quality. An indicator is a quantitative measure which represents a complex system or phenomenon (the indicandum, i.e. the subject to be indicated). It is a proxy measurement – one easily measured, which is closely related to a target phenomenon that is more difficult to measure. It quantifies a relevant property of the indicandum; the relationship between the indicator and the indicandum is of key importance. For an indicator to be 'useful' this relationship needs to be 'close enough', a property which is difficult to formalize in a general way, but which includes aspects of association, monotonity, and low error rates (Czucz and Arany, 2016). A further layer of complexity emerges from the fact that as systems are nested, indicator-indicandum relationships can also have nested hierarchies. Accordingly, an indicandum such as diversity, which can be assessed through an ecological indicator such as species richness, can in turn be itself an indicator for the ecological quality of the studied area (Turnhout *et al*., 2007).The application of indicators is, in fact, the most straightforward solution for providing policy relevant information on the inherently complex flow of ES from nature to society. The concept of ES is in itself a transdisciplinary boundary object on the margins of natural and social sciences, and policy (Hauck *et al*., 2016). It is ES indicators that operationalize this scientific object, making it appropriate for conveying simplified messages for policy makers in the form of assessments (Czucz and Arany, 2016). A major challenge specifically relevant to this operationalization process is linking indicators to the ES cascade model (Potschin and Haines-Young, 2016). If the cascade framework is considered as a functional systems model describing the flow of services from nature to society, then the different levels of the cascade can be seen as entry points for information through indicators (Fig.3.1). There is already a conspicuous tendency in literature for using cascade levels as a template for indicators (e.g. van Oudenhoven *et al*., 2012; Villamagna *et al*., 2013; Burkhard *et al*., 2014; Maes *et al*., 2014, 2016; Spangenberg *et al*., 2014; Mononen *et al*., 2016). Assessments of ecosystem services require both (a) biophysical measures related to ecosystems; these reflect underlying changes in biophysical structure and function driven by alternative management decisions or environmental change (e.g., climate change) and (b) social or economic measures of preference or value; these reflect the impact of ecosystem services on human welfare. The link between the biophysical measure and a measure of what that biophysical entity means to (or how it affects) people is not clear. This is particularly important when valuation in monetary or non-monetary terms is not feasible or acceptable, but some measure of what is valued by people is needed for decision making (Olander *et al*., 2018).According to the measurement theory by Stevens (1946), indicators need to be measured in specific units against a specific scale (e.g. nominal, ordinal, interval, or ratio scale) and linked to a well-specified measurement protocol. Protocols and standardization are thus inherent parts of the indicator development process, which can establish repeatability and ensure data quality. Watershed scale has been adopted in this document for assessment and valuation of ES. Tallis and Kareiva (2006) emphasized on assessment of ES at smaller scale based on diverse live demonstrations of improved human well-being as a result of improved ecosystem management. Watershed is a smallest hydro-geological ecosystem unit of the basin where investment may be made to promote enhanced ES, provided they are designed, planned and properly implemented after appropriate boundary work. Watershed ecosystem has potential for sourcing all four categories of ES i.e. provisioning, regulating, cultural and supporting services (de Groot *et al.* 2002, MA 2005, Lalika *et al.* 2014, Locatelli and Vignola, 2009).Watershed approach facilitates budgeting of majority of indicators related to all four categories of ES benefits (McDonald and Schemie, 2014; Lalika *et al.*, 2014; Guerry *et al.*, 2015; Geneletti, 2015; Geneletti *et al.*, 2016; Esmail and Geneletti, 2017). Further, a systematic approach has been adopted for ES assessment. Let impact on ES due to integrated watershed management / soil and water conservation interventions be denoted as ES_{WM}, then,

$$ES_{WM} = IWM_{ES1} - IWM_{ES0}$$

Where,

ES_{WM} = Ecosystem Service due to IWM

IWM_{ES0} = ES prior to IWM intervention (base line scenario)

IWM_{ES1} = ES due to IWM intervention(s)

The above protocol has been operationalized in the form of a matrix for each ES that is supported by integrated watershed management.

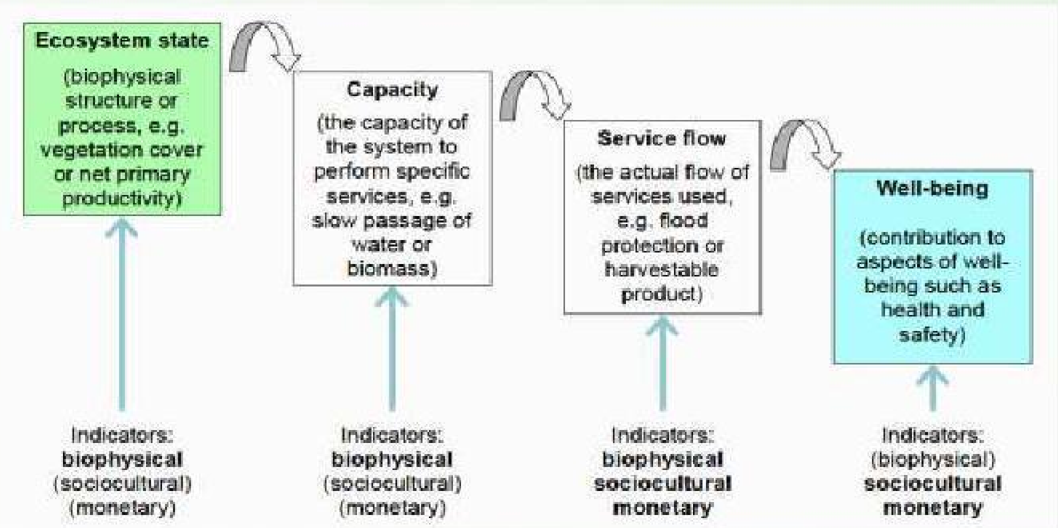

Fig.3.1 The ES cascade model as an indicator template (amended from Potschin and Haines-Young, 2011 by Czucz and Arany, 2016).

Simple, measurable, achievable, relevant and time-sensitive (SMART) indicators were identified / devised for quantification and valuation of the various provisioning, regulating, cultural and supporting ecosystem services identified as affected by integrated watershed management and soil and water conservation interventions,.

3.1 Provisioning Services

3.1.1 Crop Production

Sectors	Agriculture
Product	**Crop production**
Ecosystem service	Provision of food, fodder, fuel wood and fibre
Ecosystem function affected by WSM / SWC	Water augmentation, soil movement regulation, soil formation
Focus of indicator	Production from land
Indicator relevance	Soils are the medium for plants to grow and it supplies them with nutrients and water, thereby, producing food and providing many other outputs for different purposes. Conservation of soil and water sustains these provisioning services.
Indicator	Crop productivity
Unit of measurement	Mg ha^{-1}
Spatial scale	Field, catchment, watershed
Data needs	Crop wise area, production yield, market price or minimum support price (MSP) or farm harvest price; local prices of by-products
Data sources, collection methods	Observed / field survey
Calculation of the indicator	Difference in crop productivity due to watershed management/ soil and water conservation interventions before and after the intervention or with and without intervention as the case may be.
Methodology	i) In case of annual crop production, yield of crops with respective area under the crop production grown under different land uses before and after the watershed intervention may be collected and converted into major crop equivalence terms for comparison. ii) The production (yield x area) of all the crops grown in the watershed may be summed and divided by the total area (area summed over all the crops grown in the watershed) to compute the crop productivity at watershed scale. $$CY = \frac{\sum_{i=1}^{n}(Y_i A_i)}{\sum_{i=1}^{n} A_i}$$ *CY*= Crop yield in the watershed (Mg ha^{-1}), Y_i= Yield of ith crop in the watershed (Mg ha^{-1}), A_i= Area under i th crop in the watershed (ha),*n*= number of crops grown iii) If fodder is grown as crop, the crop productivity may be estimated as food crop. iv) In case of introduction of fodder grass on bunds, grass harvest and area under the grass may be estimated. v) Rainfed and irrigated cropping systems may be considered.
Valuation	The production in major crop equivalent terms is multiplied with market price of the concerned crop to give an economic value. Minimum support price (MSP) of crop output should be used for valuation. For region specific crop for which MSP is not available, farm harvest price may be used. The by -product may also be converted into grain equivalent terms using farm harvest prices of crop output and local prices of by-products, i.e. total productivity must be taken into account while comparing before and after or with and without NRM interventions. Finally, economic value to be expressed on watershed scale multiplying area of crop land.

3.1.2. Agro-forestry / Forestry Produce

Sectors	**Agriculture, Horticulture and Forestry**
Product	**Agro-forestry / Forestry produce**
Ecosystem service	Provision of food, timber, fodder, fuel wood and fibre
Ecosystem function affected by WSM / SWC	Water augmentation, soil movement regulation, soil formation
Focus of indicator	Production from land
Indicator relevance	Soils are the medium for plants to grow and it supplies them with nutrients and water, thereby, producing food and providing many other outputs for different purposes. Conservation of soil and water sustains these provisioning services.
Indicator	Forest productivity
Unit of measurement	Mg ha^{-1}
Spatial scale	Field, catchment, watershed
Data needs	Tree / grass species wise are a, number of trees, height and diameter at breast height (dbh), grass yield, market price of grass and fuel wood, timber stumpage price
Data sources, collection methods	Observed / field survey
Calculation of the indicator	Difference in the annual increme ntal gain of tree due to watershed management / soil and water conservation interventions before and after the intervention or with and without intervention as the case may be
Methodology	i) If data on tree diameter is available, allometric equations may be used to estimate the biomass and productivity (Appendix-I). ii) The fire wood / timber yield, with area under the forest tree, raised in the watershed may be estimated as total biomass (yield x area) of all forest trees from different land uses, summed over al l land uses and divided by the total area under land uses to estimate the forest productivity in the watershed. iii) If allometric equations for estimating biomass are not available, the following equation may be used for estimating biomass: $AGB = VOB \times WD \times BEF$ *AGB* = above ground biomass density (Mg ha^{-1}), *VOB*= volume over bark of free bole (first main trunk), *WD*= volume -weighted average wood density (Mg of oven-dry biomass per m^3 green volume), *BEF* = biomass expansion factor (ratio of above-ground oven-dry biomass of trees to oven-dry biomass of inventoried volume) The methods for volume, wood density and BEF are given in Appendix I. Below ground biomass (fine and coars e roots) of trees may be calculated using regression equation given by Cairns *et al.* (1997). $BGBD = \exp\{1.059+0.884 \ln(AGBD)+0.284\}$ Where, AGBD = Below ground biomass density BGBD = Above ground biomass density Below ground biomass of trees, crops and grasses can be calculated by multiplying aboveground biomass of each tree / crop / grass with its respective root: shoot ratio, Below ground biomass = above ground biomass X root: shoot ratio

	vi) The productivity at watershed scale may be estimated by summing the vegetation biomass over different land uses and dividing by total land under these land uses.
Valuation	The valuation may be done by multiplying timber productivity with stumpage price of timber; fuel wood productivity by local fuel wood price and grass productivity by local fodder prices.

3.1.3. Non Timber Forest Produce

Sectors	Forestry
Product	**Non timber forest produce (NTFP)**
Ecosystem service	Provision of food, fodder, fuel wood and fibre
Ecosystem function affected by WSM / SWC	Water augmentation, soil movement regulation, soil formation
Focus of indicator	Production from land
Indicator relevance	Soils are the medium for plants to grow and it supplies them with nutrients and water, thereby, producing food and providing many other outputs for different purposes. Conservation of soil and water sustains these provisioning services.
Indicator	NTFP productivity
Unit of measurement	Mg ha^{-1}
Spatial scale	Field, catchment, watershed
Data needs	Number of NTFPs, yield of different NTFPs, area under different NTFPs, price of different NTFPs
Data sources, collection methods	Observed / field survey
Calculation of the indicator	Difference in NTFPs harvest due to watershed management/ soil and water conservation interventions before and after the intervention or with and without intervention as the case may be.
Methodology	i) The different NTFPs harvested (Mg), with area under particular land use (ha), in the watershed may be estimated. Total production of different NTFPs (in major produce equivalent terms) may be summed and divided by the total area under different land uses to estimate the NTFPS productivity in the watershed. $$\text{NTFP} = \frac{\sum_{i=1}^{n}(Q_i A_i)}{\sum_{i=1}^{n} A_i}$$ *NTFP*= NTFP harvested in the watershed (Mg ha^{-1}), Q_i= Quantity of i^{th}NTFP harvested (Mg ha^{-1}), A_i= Area under i^{th} NTFP in the watershed (ha),n= Number of non-timber forest products harvested ii) Quantity may be converted into major produce equivalent terms using MSP of NTFPs announced by Government of India. For those NTFPs for which prices are not announced, local prices may be used.
Valuation	The NTFP yield is multiplied with market price (MSP)of the produce to give an economic value.

3.1.4. Medicinal Plant Production

Sectors	Agriculture, Horticulture and Forestry
Product	Medicinal plant production
Ecosystem service	Provision of food, fodder, fuel wood and fibre
Ecosystem function affected by WSM / SWC	Water augmentation, soil movement regulation, soil formation
Focus of indicator	Production from land
Indicator relevance	Soils are the medium for plants to grow and it supplies them with nutrients and water, thereby, pr oducing food and providing many other outputs for different purposes. Conservation of soil and water sustains these provisioning services.
Indicator	Productivity of medicinal species
Unit of measurement	Mg ha^{-1}
Spatial scale	Field, catchment, watershed
Data needs	Number of medicinal plants harvested, yield of different medicinal plants, area under different medicinal plants, price of different medicinal plants
Data sources, collection methods	Observed / field survey
Calculation of the indicator	Difference in me dicinal plants' yield due to watershed management / soil and water conservation interventions before and after the intervention or with and without intervention as the case may be.
Methodology	i) The different medicinal species harvested (Mg), wi th area under the medicinal species (ha) under different land uses, in the watershed may be assessed as total production of different medicinal species (in major produce equivalent terms) summed over different land uses and divided by the total area to estimate the productivity in the watershed. $MedP = \frac{\sum_{i=1}^{n}(Q_i A_i)}{\sum_{i=1}^{n} A_i}$ *MedP*= Medicinal species harvested in the watershed (Mg ha^{-1}), Q_i= Quantity of i^{th} medicinal species harvested (Mg ha^{-1}), A_i= Area under i^{th} medicinal species in the watershed (ha), *n*= Number of different medicinal species harvested ii) Quantity may be converted into major produce equivalent terms using local prices of medicinal species.
Valuation	The yield is multiplied with market price of the produce to give an economic value.

3.1.5. Horticultural Production

Sectors	Horticulture
Product	**Horticultural production**
Ecosystem service	Provision of food, fodder, fuel wood and fibre
Ecosystem function affected by WSM / SWC	Water augmentation, soil movement regulation, soil formation
Focus of indicator	Production from land
Indicator relevance	Soils are the medium for plants to grow and it supplies them with nutrients and water, thereby, producing food and providing many other outputs for different purposes. Conservation of soil and water sustains these provisioning services.
Indicator	Horticulture productivity
Unit of measurement	Mg ha^{-1}
Spatial scale	Field, catchment, watershed
Data needs	Number of different fruit trees, yield of different fruit trees, area under different fruit trees, price of different fruits
Data sources, collection methods	Observed / field survey
Calculation of the indicator	Difference in horticultural productivity (fruit,vegetables) due to watershed management / soil and water conservati on interventions before and after the intervention or with and without intervention as the case may be.
Methodology	i) The fruit yield data of the horticultural plants may be used for stability period (stable fruit yield) to estimate the benefit. ii) The fruit yield, with area under the concerned fruit of all the fruit species grown in the watershed may be estimated. Total fruit production (yield x area), of all fruits grown in the watershed, in major fruit equivalent terms may be summed and divided by the total area under fruit production. $HP = \frac{\sum_{i=1}^{n} (Q_i A_i)}{\sum_{i=1}^{n} A_i}$ *HP*= Horticultural productivity in the watershed (Mg ha^{-1}), Q_i= Quantity of i^{th} fruit species harvested (Mg ha^{-1}), A_i= Area under i^{th} fruit species in the watershed (ha), *n*= Number of fruit species harvested iii) Quantity may be converted into major fruit produce equivalent terms using market prices.
Valuation	The yield is multiplied with market price of the concerned fruit to give an economic value.

3.1.6. Milk and Dung Production

Sector	**Livestock**
Product	**Milk and dung production**
Ecosystem service	Provision of food, fodder, fuel wood and fibre
Ecosystem function affected by WSM / SWC	Water augmentation, soil movement regulation, soil formation
Focus of indicator	Production from land
Indicator relevance	Soils are the medium for plants to grow and it supplies them with nutrients and water, thereby, producing food, fodder and providing many other outputs for different purposes. Conservation of soil and water sustains these provisioning services.
Indicator	Livestock productivity
Unit of measurement	Milk: l ha^{-1}; Dung: Mg ha^{-1}
Spatial scale	Farm household, catchment, watershed
Data needs	a) Milk production (l $animal^{-1}$ $year^{-1}$ or lactation $period^{-1}$ during pre-and post-project or with and without intervention b) No. of cattle during pre- and post-project or with and without intervention c) Dung produced (Mg $animal^{-1}$ $year^{-1}$) during pre - and post-project or with and without intervention d) Area of watershed e) Market price of milk f) Prices of nutrients in animal dung
Data sources, collection methods	Observed / field survey
Calculation of the indicator	Difference in milk and dung productivity due to watershed management interventions before and after the intervention or with and without intervention as the case may be.
Methodology	The milk and dung production of all animals, in the watershed, may be assessed as total production divided by the area of watershed. $$MY = \frac{\sum (Y*N)}{A}$$ *MY*= Milk yield in the watershed (l ha^{-1}), *Y*= Milk production of a cattle in the watershed (l per cattle), *N*= Number of cattle in the watershed, *A* =area of the watershed (ha) $$DP = \frac{\sum (P*N)}{A}$$ *DP*= Dung productivity in the watershed (M g ha^{-1}), *P*= Dung production(Mg per cattle), *N*= Number of cattle in the watershed, *A*= area of the watershed (ha)
Valuation	The yield is multiplied with market price of the milk in the watershed to give an economic value. In c ase of dung, the dung productivity is multiplied with the value of nutrients in animal dung using replacement cost method.

3.1.7. Egg and Meat Production

Sector	Livestock
Product	**Egg / Meat production**
Ecosystem service	Provision of food, fodder, fuel wood and fibre
Ecosystem function affected by WSM / SWC	Water augmentation, soil movement regulation, soil formation
Focus of indicator	Production from land
Indicator relevance	Soils are the medium for plants to grow and it supplies them with nutrients and water, thereby, producing food, fodder and providing many other outputs for different purposes. Conservation of soil and water sustains these provisioning services.
Indicator	Egg / Meat productivity
Unit of measurement	Egg: Number household^{-1} Meat: Mg ha^{-1}
Spatial scale	Farm household, catchment, watershed
Data needs	i) No. of eggs produced hen $^{-1}$ year^{-1} or laying-cycle^{-1} during pre-and post-project or with and without intervention ii) No. of poultry birds household $^{-1}$ and in watershed during pre-and post-project or with and without intervention iii) Total number of households in watershed during pre- and post-project or with and without intervention period iv) Area of watershed v) Meat yield animal $^{-1}$ (goat, sheep, pig etc.) reared during pre-and post-project or with and without intervention vi) No. of animals (goat, sheep, pig etc.) reared during pre- and post-project or with and without intervention vii) Market price of egg or poultry / goat / pig meat
Data sources, collection methods	Observed / field survey
Calculation of the indicator	Difference in egg/ meat productivity due to watershed management interventions before and after the intervention or with and without intervention as the case may be.
Methodology	The egg / meat production (poultry and/or goat or pig) in the watershed may be estimated as total production in the watershed divided by number of households or the area of the watershed. $$PY = \frac{\sum (P*N)}{A}$$ *PY*= Poultry / meat yield in the watershed (number of eggshousehold^{-1}- meat ha^{-1}), *Y*= Egg / meat production per poultry/ goat/pig reared in the or Mgof watershed, *N*= Number of poultry / goat / pig reared in the watershed, *A*=No. of households in the watershed (for eggs) or Area of the watershed (for meat)
Valuation	The yield is multiplied with market price of the egg or poultry/ goat/ pig meat to give an economic value.

3.1.8. Livestock Supported by Pasture Land

Sector	Livestock production
Product	Livestock supported by pasture land
Ecosystem service	Provision of food, fodder, fuel wood and fibre
Ecosystem function affected by WSM / SWC	Water augmentation, soil movement regulation, soil formation
Focus of indicator	Production from land
Indicator relevance	Soils are the medium for plants to grow and it supplies them with nutrients and water, thereby , producing food, fodder and providing many other outputs for different purposes. Conservation of soil and water sustains these provisioning services.
Indicator	Stocking rate in pasture land
Unit of measurement	Number GLU ha^{-1} (Grazing livestock unit)
Spatial scale	Catchment, watershed
Data needs	a) No. of cattle or animals depending on pasture land for grazing during pre- and post-project or with and without intervention b) Area of pasture land present during pre-and post-project or with and without intervention c) Average sale price of animal
Data sources, collection methods	Observed / field survey
Calculation of the indicator	Difference in GLUs supported due to watershed management interventions (animals using grazing / pasture land) before and after the inter ventionor with and without intervention as the case may be (this would reflect pasture land improvement as a result of watershed management).
Methodology	Total GLUs supported by the pasture land may be divided by the pasture land area of watershed to estimate the number of grazing livestock unit per hectare supported by pasture land in the watershed.
Valuation	The number of GLU may be multiplied with average sale price of the animal to give an economic value.

3.1.9. Fish Production

Sector	Fisheries
Product	Fish production
Ecosystem service	Provision of food, fodder, fuel wood and fibre
Ecosystem function affected by WSM / SWC	Water augmentation, soil movement regulation, soil formation
Focus of indicator	Production from land
Indicator relevance	Soils are the medium for plants and water is medium for fish to grow and soil and water supply them with nutrients and water, thereby, producing food and providing many other outputs for different purpos es. Conservation of soil and water sustains these provisioning services.
Indicator	Fish productivity
Unit of measurement	Mg ha^{-1}
Spatial scale	Farm household, catchment, watershed

Data needs	a) Fish produced (Mg pond $^{-1}$) in watershed during pre- and post-project or with and without intervention b) No. of fish ponds present in watershed during pre- and post-project or with and without intervention c) Area of watershed d) Average sale price of fish
Data sources, collection methods	Observed / field survey
Calculation of the indicator	Difference in fish productivit y due to wat ershed management interventions before and after the intervention or with and without intervention as the case may be.
Methodology	Fish production from all the ponds raising fish in the watershed may be assessed and summed over all the ponds. The total fish production may be divided by the watershed area. $$FY = \frac{\sum_{i=1}^{n} (P*N)}{A}$$ *FY*= Fish yield in the watershed (Mg ha^{-1}), *Y*= Fish production from a pond in the watershed (t), *N*= Number of ponds in the watershed (ha), *A*= Area of the watershed
Valuation	The fish yield may be mult iplied with average sale price of fish to give an economic value.

3.1.10. Provision of Irrigation Water

Ecosystem service	Provision of irrigation water
Ecosystem function affected by IWM / SWC	Water resource augmentation
Focus of indicator	Fresh water availability for agriculture / domestic use – surface water storage in water harvesting structures in the watershed
Indicator relevance	The hydrological cycle renews the earth's supply of water by distilling and distributing it (Gordon *et al*., 2005) into groundwater, surface water and soil moisture profile. The harvested water which is stored on surface ensures the irrigation needs of agricultural production or domestic use of families.
Indicator	Annual surface water availability
Unit of measurement	m^3 ha^{-1} $year^{-1}$
Spatial scale	Catchment, micro watershed, macro watershed, basin, sub basin
Data needs	Surface water stored in watershed in different water harvesting structures, watershed area, cost of municipal water supply
Data sources, collection methods	Observed / field survey
Calculation of the indicator	Difference in volume of fresh surface water stored due to watershed management technologies before and after the inter ventionsor with and without intervention as the case may be.

Methodology	May be measured by the amount of rain water stored in the individual structures of catchment / watershed / basin or may be measured through modelling based on secondary local and regional weather data (Wang *et al.*, 2010; Townsend *et al.*, 2012; Fu *et al.*, 2014; Fan and Shibata, 2014; Fanaian *et al.*, 2015). The volume of stored water may be divided by watershed area.
Valuation	▪ The economic value of water may be assessed using market price method (Wilson and Carpenter, 1999). The volume of water may be multiplied with supply cost of piped water by municipality using replacement cost method. ▪ Contingent valuation method (Zhongmin et al., 2003; Hensher et al., 2005; Birol et al., 2006) has also been used by scholars.

3.1.11. Provision of Livelihood / Income Generation / Entrepreneurship

Ecosystem service	Provision of livelihood / income generation / entrepreneurship
Ecosystem function affected by IWM / SWC	Livelihood opportunities
Focus of indicator	Watershed management schemes targeting income generating and livelihood supplementing / entrepreneurship activities.
Indicator relevance	Integrated Watershed Management Programmes envisage improving livelihood of watershed beneficiaries through income generation by skill and entrepreneurship development. This enhances the financial resources at their disposal, which improves their standard of living.
Indicator	Income generated
Unit of measurement	Rs ha^{-1} $year^{-1}$
Spatial scale	Household, catchment, watershed
Data needs	Number of beneficiaries, income generating activities undertaken, income generated per household, watershed area
Data sources, collection methods	Observed / field survey
Calculation of the indicator	Difference in supplementary income generated due to Integrated Watershed Management Programme (IWMP) before and after execution of IWMP or with and without IWMP as the case may be.
Methodology	Income generation by different households from different income generating activities (other than crop and livestock) may be assessed by personal surveys in the watershed. $$L_a = \frac{\sum_{j=1}^{n}\sum_{k=1}^{m} I_{jk}}{A}$$ I_a= Income (Rs per ha), I_{jk}= Income of j^{th} household from k^{th} income generating activity (Rs), A= Watershed area (ha), n= Number of households involved in different income generating activities, m = Number of different income-generating activities under taken in the watershed
Valuation	The income generated through entrepreneurship development may be corrected for inflation for the two points of time (before and after the intervention) as enhanced income not in pace with enhanced consumer prices does not improve living standard. The income estimated for post IWMP period may be divided by the change in Consumer Price Index (CPI) between the two time periods and compared with pre IWMP income generated.

3.1.12. Provision for Employment Generation

Ecosystem service	Provision for employment generation
Ecosystem function affected by IWM / SWC	Livelihood opportunities
Focus of indicator	Employment generated through watershed management interventions
Indicator relevance	The watershed management interventions generate employment during execution of works as well as improved cropping intensities from resource conservation and augmentation. This creates opportunities for people to be engaged within watershed and minimizes out migration / distress particularly for land less people.
Indicator	Employment generated
Unit of measurement	Man days ha^{-1} $year^{-1}$
Spatial scale	Household, catchment
Data needs	Number of b eneficiaries,soil and water conservation structures constructed, number of days engaged in structure construction or cultivation activities benefitted in a year , area under benefitted different crops, watershed area, standard wage rate such as MGNREGA
Data sources, collection methods	Observed / field survey
Calculation of the indicator	Difference in employment generated due to watershed management interventions before and after execution of IWMP or with and without IWMP as the case may be.
Methodology	Employment generation of different households under different activities may be assessed by personal surveys in the watershed. Generally, watershed programmes create temporary (one-time) and permanent (continuous) employment opportunity from the execution of soil and water conservation structures and through change in cropping pattern within in watershed, respectively. $$E_{Hh} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} E_{ij}}{A}$$ E_{Hh}= Employment (temporary) generated per household (man days per ha),E_{ij}= Employment generation of i th household in j th soil and water conservation structure / activi ty (man days), A= Area of watershed (ha),n= Number of households employed in construction of soil and water conservation structures/ activity, m= Number of different types of soil and water conservation structures executed / activities undertaken in watershed requiring manual labours. $$E_{Hhp} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} \{(A_{aij}*L_{aij})-(A_{bij}*L_{bij})\}}{A}$$ E_{Hhp} Permanent employment opportunities created per household per ha per year; n= number of farmers cultivating crops; j= numbers different types of crops grown in watershed; Aaij = area before watershed interventions under jthcrop grown by i th farmer; Laij= labour employed by i th farmer for cultivation of jth crop; Abij and Lbij are same as Aaij and Laij , respectively after watershed interventions.
Valuation	The employment generated may be multiplied with standard wage rate such as MGNREGA (as major work in watershed constitutes earthwork) prevailing in the region.

3.2 Regulating Services

3.2.1. Reduction in Soil Loss / Nutrient Loss (Soil Retention)

Ecosystem service	Reduction in soil loss / nutrient loss (soil retention)
Ecosystem function affected by IWM / SWC	Water resource regulation, Soil movement regulation
Focus of indicator	Prevention of soil loss
Indicator relevance	Direct consequences of erosion by water are increased sedimentation of the displaced soil material in streams, canals and rivers, which reduce their carrying capacity and increase their width, which in turn leads to degradation of adjoinin g agricultural lands, meandering of river courses, and smothering of crops and vegetation. Soil loss also leads to reduction in the storage capacity of many reservoirs. Further, soil loss also carries away nutrients in top soil layers affecting the productivity.
Indicator	Annual soil loss
Unit of measurement	Mg $ha^{-1} yr^{-1}$
Spatial scale	Field, catchment / sub-catchment, basin
Data needs	Soil loss from different land uses, catchment area, nutrient content of soil, market prices of nutrients (cost of fertil izers), mark et price of Emission Reduction Certificate (carbon credit), dredging cost (of silted dam)
Data sources, collection methods	Observed / field survey, secondary sources, extrapolation of available data for similar soil, slope, land use and climate
Calculation of the indicator	Soil loss at the catchment outlet may be measured. Difference in volume of soil loss, beyond soil tolerance limit of the region (Mandal *et al*., 2006; 2010; Mandal and Sharda, 2011),between after catchment treatment and before treatment or control condition may be worked out. In case theoretical model is used for estimation, the estimate may be multiplied with sediment delivery ratio.
Methodology	Soil loss within a watershed is usually measured at the catchment outlet. The universal soil loss equation (USLE) proposed by Wis chmeier and Smith (1978) is the most widely used model in predicting the loss of soil. It is described by the following equation: $$SL = R \times K \times LS \times C \times P$$ *SL*= estimated average soil loss (Mg $ha^{-1} year^{-1}$), *R*= erosivity of rainfall (Mj mm $ha^{-1} h^{-1} year^{-1}$), *K*= soil erodibility factor (Mg ha h $ha^{-1} Mj^{-1} mm^{-1}$), *LS*= topographic factor integrating slope length and steepness (LS) dimension less, *C*= cover -management factor, dimension less, *P*= support practice factor, dimensionless $$R = \frac{\sum_{i=1}^{n} EI^{i}3.0}{N}$$ *R*= Average annual sum of individual storm erosion index value, EI^{i}_{30} = storm erosion index value of i^{th} event= $E_c \times I_{30}$, E_c = total kinetic energy of rain (mj h^{-1}), I_{30} = Maximum intensity of rain in 30 minutes (mm h^{-1}), *N*= Total number of events recorded in the watershed $$SL_{av} = \frac{\sum_{i=1}^{n} SL_i = A_i}{\sum_{i=1}^{n} A_i}$$ SL_{av} = Avera ge soil loss in the watershed (Mg $ha^{-1} year^{-1}$), SL_i = average soil loss in the i^{th} land use in the watershed (Mg $ha^{-1} year^{-1}$), A_i = Area under i^{th} land use in the watershed (ha) Using appropriate analysis method, soil carbon, nitrogen, phosphorus and potash stocks may be determined in laboratory.
Valuation	▪ Market price of nitrogen, phosphorus and potash may be used to value the nutrient inretained soil (Mekuria *et al*., 2011) following replacement cost approach. Soil carbon may be valued at market price of Emission Reduction Certificate (carbon credit) or replacement cost of FYM.

3.2.2. Reduction in Runoff

Ecosystem service	Reduction in run off
Ecosystem function affected by IWM / SWC	Water resource regulation
Focus of indicator	Prevention of runoff going down stream
Indicator relevance	Soils have the capacity to store water, there by regulating water flows. Soil and water conservation measures control run off and, thus, enhance water storage capacity within the watershed.
Indicator	Runoff reduced
Unit of measurement	mm ha^{-1} $year^{-1}$
Spatial scale	Catchment
Data needs	Run off from catchment, area of catchment, cost of municipal water supply
Data sources, collection methods	Observed / field survey, secondary sources through modelled rainfall and run off
Calculation of the indicator	Difference in volume of runoff reduced after catchment treatment over before treatment or control condition as the case may be
Methodology	May be measured by the amount of rain water, flowing on the landscape, retained at the catchment exit or may be measured through modelling based on secondary local and regional weather data (Wang *et al*., 2010; Townsend *et al*., 2012; Fu *et al*., 2014; Fan and Shibata, 2014; Fanaian *et al*., 2015) SCS-CN method is usually followed for runoff estimation, $R_O = \left\{ \sum^{n} \frac{(P-0.3S_T)^2}{(P+0.7S_T)} \right\} \div A$ $S_T = \frac{25400}{CN} - 254$ R_O= estimated runoff (mm ha^{-1} $year^{-1}$), *P*= Rainfall (mm), S_T = Maximum potential storage of the watershed after i^{th} runoff begins (mm), *CN*= Weighted curve number depending upon hydrologic soil group, antecedent soil moisture conditions, land use and land cover, depth of seasonal high water table, *n*= number of runoff causing rainfall events occurring in a particular year within the watershed; *A*= area of the watershed (ha).
Valuation	▪ Valuation may be done using replacement cost of supplying water for storage in the watershed *viz*., supply cost of piped water by local municipality. Production function can also be used to estimate the marginal value of the irrigation. ▪ The reduced runoff, if already accounted for in surface and / or groundwater augmentation, will not be again valued to avoid double counting. How ever, if it impacts aesthetic value it may be valued by non-market approach such as contingent valuation.

3.2.3. Groundwater Recharge

Ecosystem service	Groundwater recharge
Ecosystem function affected by IWM / SWC	Water resource regulation
Focus of indicator	Water percolated and stored in underground strata
Indicator relevance	The hydrological cycle renews the earth's supply of water by distilling and distributing it (Gordon *et al*., 2005) in to groundwater, surface water and soil moisture profile. The harvested water which percolates into ground replenishes the groundwater.
Indicator	Annual groundwater recharge
Unit of measurement	m ha^{-1}
Spatial scale	Catchment, basin
Data needs	Average groundwater table fluctuation, specific yield of aquifer ground water extraction, return flow from surface, area of watershed, marginal cost of groundwater / cost of municipal water supply to watershed
Data sources, collection methods	Observed / field survey, Water table data from Central Groundwater Board, Well logs or specific yield of aquifer
Calculation of the indicator	Difference in volume of groundwater water recharged due to watershed management interventions before and after the intervention or with and without intervention as the case may be.
Methodology	May be assessed by estimating the amount of water that is recharged into the ground (Allen *et al*., 1998). Total water recharged may be divided by the area of the watershed to estimate annual ground water recharge per hectare in the watershed. a) Groundwater balance method: Change in storage over a period of time (Potential groundwater recharge)= inflow to the system – out flow from the system Or b) Groundwater table fluctuation method: $R = (S_y \times \Delta h + P - R_i)$ Where, R= Groundwater recharge (m^3 ha^{-1}),S_y= Specific yield of aquifer (dimensionless), Δh= Change in depth of water table during pre-and post-monsoon (m), P= Groundwater extraction / draft for irrigation, domestic use, etc. (m), R_i= Return flow from irrigation field , other surface water bodies, etc. (m), A= area of the watershed (ha)
Valuation	▪ The total groundwater recharge volume may be multiplied by marginal value of groundwater , which can be estimated in terms of marginal value of supplemental irrigation using the production function approach . It may also be valued using alternative cost such as supply cost of municipal water. ▪ The economic value of water may also be assessed based on the utility of groundwater in the watershed. Values may be assigned such as market price method (Wilson and Carpenter, 1999)and contingent valuation method (Zhongmin *et al*., 2003; Hensher *et al*., 2005; Birol *et al*., 2006).

3.2.4. Flood Mitigation

Ecosystem service	Flood mitigation
Ecosystem function affected by IWM / SWC	Water resource regulation
Focus of indicator	Reduction of water flow / flood in streams affecting adjoining land
Indicator relevance	Watershed management interventions control run off and increase the opportunity time for runoff to infiltrate into the soil, thereby reducing flood levels in streams flowing across watershed and consequently protecting adjoining downstream areas.
Indicator	Flood damage evaded
Unit of measurement	Rs ha^{-1} $year^{-1}$
Spatial scale	Catchment
Data needs	Flood volume, past flood frequency, area (submerged agricultural land) /stream flow data affected by flood, population affected by flood, watershed area
Data sources, collection methods	Observed / field survey, secondary sources, modelled flood frequency based on rainfall and run off
Calculation of the indicator	Difference in frequency of flood after catchmenttreatment over before treatment or control condition as the case may be
Methodology	▪ The amount of excess rainfall (flood volume) on the landscape may be assessed (through SCS-CN) and multiplied with the catchment area or using a hydrograph (flow vs time). ▪ Frequency of flood forecast may be done using precipitation and stream flow data in rainfall-runoff models and stream flow routing models. ▪ The flood loss estimation may be obtained through flood parameters such as flow velocity, depth, and duration at a given location and establishing the relationship between flood parameters and flood damage through stage–damage function, based on historical flood damage information, questionnaire survey data on damage etc.
Valuation	▪ Subject to the condition of flood occurrence to higher frequency within watershed, the amount of investment made to protect the area from flooding and the cost of damage avoided in the flood prone area may be assessed. This can be extrapolated to the watershed area. ▪ In a watershed, the cost of agricultural field damage avoided along the stream under flood condition may be assessed.

3.2.5. Carbon Sequestration

Ecosystem service	Carbon sequestration
Ecosystem function affected by IWM / SWC	Climate regulation
Focus of indicator	Quantity of carbon retained / absorbed by soil and vegetation
Indicator relevance	Soils and vegetation have the ability to store carbon, and soil and water conservation measures strengthen soil and vegetation condition and, thus, boost this regulating service.
Indicator	Amount of carbon stored in soil and vegetation
Unit of measurement	Mg ha^{-1} $year^{-1}$ – soil (below ground) Mg ha^{-1} – forest / tree / vegetation (above ground)
Spatial scale	Catchment, sub-catchment
Data needs	Carbon stock in soil, vegetation biomass, watershed area, Certified Emission Reduction (CER) price
Data sources, collection methods	Observed / measured in field, secondary sources
Calculation of the indicator	Difference in carbon stock after catchment treatment over before treatment or control condition
Methodology	i) Using appropriate sampling method and laboratory analysis, soil survey may be conducted to determine soil carbon content. ii) In vegetation, the stock includes five carbon pools: above -ground biomass, below-ground biomass, litter, dead wood, and soils (IPCC, 2006). Above-ground biomass consists of the living biomass material above the soil. Below-ground biomass consists of all of the live roots below the soil surface. Litter consists of all of the non-living biomass with a diameter less than 10 cm (or other diameter set by a country) above the mineral or organic soil surface layers. Dead wood consists of all non-living wood not contained in the litter, including woody debris, dead roots up to 2 mm in diameter, and stumps greater than or equal to 10 cm in diameter. Soil organic carbon consists of decomposed organic matter in mineral and organic soil layers. Above and belowground carbon stock in vegetation is determined by multipling the vegetation biomass quantitywith IPCC default valueof0.5 (IPCC, 1996). $$C_{av} = \frac{\sum_{j=1}^{n} C_i A_i}{A}$$ *Cav* = Average carbon sequestered in the watershed (Mg ha^{-1}), *Ci* = average carbon sequestered in the i^{th} land use in the watershed (Mg ha^{-1}), *Ai* = Area under i^{th} land use in the watershed (ha), *A* = Area of the watershed (ha) Tree harvested for fuel wood in the watershed may be excluded for this estimation.
Valuation	Carbon may be converted into CO_2 using standard factor (3.67) and may be multiplied with the price of certified emission reduction (carbon credit) (Mekuria *et al.*, 2011).

3.2.6. Soil Health Maintenance

Ecosystem service	Soil health maintenance
Ecosystem function affected by IWM / SWC	Water resource regulation (*in-situ* moisture), nutrient regulation
Focus of indicator	Soil health (physical, chemical, biological properties)
Indicator relevance	Resource conservation, land management changes and vegetation improvement due to watershed management interventions affect soil in watershed. The management interventio ns lead to nutrient (N, P, K, carbon) changes/ soil fertility build up,and change in soil physical structure and infiltration rate affects soil quality. Soil organic matter directly impacts water infiltration rates, soil aggregate stability and soil structure.Soil organic matter is also a significant source of nutrients.
Indicator	Soil nutrients content
Unit of measurement	Mg ha^{-1}
Spatial scale	Catchment, sub-catchment
Data needs	Soil nutrient (N, P) content insoil under different land uses, area under different land uses, watershed area, market price of nitrogen and phosphorus
Data sources, collection methods	Field survey, data records
Calculation of the indicator	Difference in nutrient (N, P) content after watershed management intervention over before watershed intervention or control condition
Methodology	Assess the total soil nutrient (N, P) content under each land use before and after the watershed interventions. $$Nc_{av} = \frac{\sum_{j=1}^{n} Nc_i \times A_i}{A}$$ Nc_{av} = Average nutrient (N, P) content in the watershed (Mg ha^{-1}), Nc_i= nutrient (N, P) content in i^{th} land use in the watershed (Mgha^{-1}), A_i = Area under i^{th} land use in the watershed (ha), A = Area of the watershed
Valuation	The nitrogen and phosphorus content (p roxy for soil health) may be valued in terms of the replacement cost of N and P at market prices.

3.2.7. Biodiversity Augmentation

Ecosystem service	Biodiversity augmentation
Ecosystem function affected by IWM / SWC	Water resource augmentation, nutrient regulation
Focus of indicator	Sustenance of plant biodiversity through watershed management; plant diversity storage service of watershed intervention
Indicator relevance	Resource augmentation and vegetation cover improvement due to watershed management interventions support plant biodiversity in the watershed. This biodiversity, in turn, helps improve soil health, soil biota, controls soil and environmental pollution.
Indicator	Number of plant species (proxy for species richness)
Unit of measurement	Number ha^{-1}
Spatial scale	Catchment, sub-catchment
Data needs	Number of naturally growing species, area under different plant species, watershed area, value of acquisition and maintenance of species in living conditions in botanical garden
Data sources, collection methods	Field survey, data records
Calculation of the indicator	Difference in natural plant species coming up after watershed management intervention over that existing before watershed intervention or control condition as the case may be.
Methodology	Total number of different naturally occurring species may be assessed through field surveys. The number of species per hectare in the watershed may be estimated by dividing the number of species with watershed area.
Valuation	The number of naturally occurring plants per unit area may be valued at the cost of acquiring and maintaining species in living conditions in a botanical garden.

3.2.8. Drought Mitigation

Ecosystem service	Drought mitigation
Ecosystem function	Water augmentation
Focus of indicator	Enhanced water potential in the watershed
Indicator relevance	Soils have the capacity to store water in profile. The soil moisture retention supports agricultural production during periods of drought and minimizes the moisture stress. Watershed management programme helps to augment groundwater which supports agricultural production during drought.
Indicator	1) Value of enhanced net returns – rainfed agriculture 2) Value of groundwater used for supplementary irrigation–irrigated agriculture
Unit of measurement	Rs ha^{-1}
Spatial scale	Household, sub-catchment, catchment
Data needs	a) Rainfed crops with area, input-output of crops during drought period in the watershed, market prices of input and output b) Irrigated crops with area, input-output of crops during drought period in the watershed, area of watershed, market prices of input and output
Data sources, collection methods	Primary survey, observed / measured
Calculation of the indicator	Difference in input saved or output harvested during drought period with watershed management intervention over that without intervention

Methodology and valuation	i) Net returns from rainfed agriculture mainly because of saving in seed and fertilizer inputs or yield during drought as a result of watershed management (IWMP) / soil and water conservation (SWC) interventions may be assessed and compared without IWMP / SWC intervention. This can then be divided by total rainfed area to estimate the per hectare value of enhanced net returns during drought. ii) Under irrigated agriculture, total volume of groundwater extracted for supplementary irrigation during drought period can be multiplied with marginal value product of groundwater in the watershed. This can then be divided by the watershed area to estimate the per hectare value of groundwater used during drought.

3.3 Cultural Services

3.3.1. Aesthetic / Recreational Services

Ecosystem service	Aesthetic / Recreational services
Ecosystem function affected by IWM / SWC	Landscape aesthetics
Focus of indicator	Aesthetic / recreational value of landscape
Indicator relevance	Natural and managed landscapes such as barren / degraded land put under vegetation and water bodies in watershed provide pleasure / relaxation and mental peace to local residents. Watershed management interventions improve such landscapes features in the region.
Indicator	Area of landscape with revealed value
Unit of measurement	Rs ha^{-1}
Spatial scale	Catchment, sub-catchment, water body
Data needs	Target population, questionnaire for contingent survey of watershed beneficiaries
Data sources, collection methods	Observed / measured, survey method
Calculation of the indicator	People's willingness to pay for landscape development and management is assessed for an individual and multiplied with number of beneficiaries.
Methodology and valuation	Stated preference (contingent valuation) surveys are conducted after identifying the target population and selection of representative sample. Individual's willingness to pay for landscape aesthetic value is asked contingent upon a hypothetical market created and explained to beneficiaries. The values expressed by individual are verified with the socio- economic characteristics of the individual and the average value expressed by individual is multiplied with total number of individuals. The total value is divided by the watershed area to estimate per unit value in the watershed.

3.3.2. Awareness Creation / Educational Service

Ecosystem service	Awareness creation / educational service
Ecosystem function affected by IWM / SWC	Land opportunities
Focus of indicator	Natural resource management wisdom gained by local people for sustainable agricultural production from natural services and products
Indicator relevance	Watershed management approach with people's participation creates awareness, and strengthens knowledge about natural resource management and utilization. This knowledge helps to develop linkages between people's livelihood and local environment leading to sustainable management of these resources and, thus, overall livelihood improvement.
Indicator	Natural resource management knowledge acquired with revealed value
Unit of measurement	Rs year^{-1}
Spatial scale	Catchment, sub-catchment
Data needs	Number of people involved in the participatory watershed management and acquiring knowledge about watershed management, average expenditure on capacity building
Data sources, collection methods	Observed / measured, survey method
Calculation of the indicator	Beneficiaries of watershed who obtained knowledge about various soil and water conservation interventions and watershed management may be identified, through survey.
Methodology and valuation	▪ Primary survey may be conducted to assess the number of local people who acquired natural resource management knowledge before and after the watershed programme. Number of people acquiring the knowledge may be multiplied with average cost of capacity building. ▪ In case of model or famous watersheds likes Suk homajri and Fakot, travel cost method can be used to esti mate the demonstration/education value of the watershed.

3.3.3. Institutionalization

Ecosystem service	Institutionalization
Ecosystem function affected by IWM / SWC	Land opportunities, livelihood opportunities
Focus of indicator	Creation and / or sustenance of institutions that strengthen social fabric and / or generate supplementary income for livelihood support
Indicator relevance	Watershed management approach with people's participation strengthens either existing village institutions or helps create institutions for building and managing public assets supporting people's livelihood in the watershed. These institutions in the longrun strengthensocial bond among people, support income generating opportunities and support their livelihood.
Indicator	Number of institutions created / sustained with resource generated
Unit of measurement	Rs ha^{-1} year^{-1}
Spatial scale	Catchment, sub-catchment, water body
Data needs	Number of institutions created during watershed execution; value of resource / income generated

Data sources, collection methods	Observed / measured, survey method
Calculation of the indicator	Difference in number of institutions with average value of resources or income before and after the watershed programme or control condition may be assessed
Methodology and valuation	Primary surveys may be conducted to assess the change in number of local institutions before and after the watershed programme. The value of resource created and / or income generated by the institutions may be collected from their records. The cumulative value summed over different institutions and years may be divided by the number of years and watershed area to estimate the value per hectare per year.

3.4 Supporting Services

3.4.1. Soil Regeneration and Mineralization / Soil Formation

Ecosystem service	Soil regeneration and mineralization / soil formation
Ecosystem function affected by IWM / SWC	Soil regeneration, nutrient mineralization
Focus of indicator	Conservation of productive top soil layer which supports soil biota that is helpful for mineralization of nutrients through decomposition of organic matter, and for improving soil quality
Indicator relevance	Earthworms are the most important component of the soil biota (van Breemen and Buurman, 2002; Butt, 2008) which provides soil formation and mineralization functions. Earthworms also help in maintenance of soil structure and fertility (Edwards, 2004). Their activities bring sub -surface soil to the top (between 10 and 500 Mg ha-1 year-I), providing nutrients in the plant root zone and aiding the formation of approximately 1 Mgha-1 year-1 of top soil (Pimentel et al., 1995). Soil and water conservation provides conducive environment for support and growth of earthworms, which helps to support the process of soil formation. Soil micro -organisms and invertebrates help in breaking down organic matter in soil (Brady and Weil, 2004; Bashan and de -Bashan, 2010). This releases organically bound nutrients such as nitrogen for use by plants (Edwards and Arancon, 2004).
Indicator	Top soil regenerated and mineralized
Unit of measurement	Mg ha-1 year-1
Spatial scale	Field, catchment, sub-catchment
Data needs	Soil earthworm count
Data sources, collection methods	Secondary source (literature), Soil survey (earthworm population count per unit volume of soil by taking four to five soil samples from 10m3area from each field, counting earthworms in the soil samples and working out mean earthworm population densities, and from it mean biomass of earthworms)
Calculation of the indicator	Difference in soil formation and mineralization (based on soil loss tolerance limit values, Mandal et al., 2006; 2010; Mandal and Sharda, 2011)multiplied with value of top soil before and after the watershed programme or control as the case may be.

Methodology	Soil sample for earthworm count per unit area may be projected for earthworm biomass per hectare. Contribution of earthworms in soil formation may be calculated based on the assumptions that the mean biomass of an earthworm is 0.2g (Fraser, 1996) and one Mg of earthworms forms 1000 kg of soil ha-1year-1 (Pimentel et al., 1995). This may be projected to assess quantum of soil formation over a given period of time due to earthworm in the conserved soil. Mineralization rate of organic matter by soil micro-organisms and invertebrates (Brady and We il, 2004) may be done by assessing organic matter (OM) from weight of soil (obtained from bulk density at 10cm depth) and soil nitrogen from soil testing. Ratio of OM to nitrogen may be taken 20:1 (Brady, 1990) and total mineralized nitrogen may be estimated. $$N_{min} = n \times_b \times_v \times_k \times 10 \text{ kg}$$ N_{min} = amount of N mineralized , n= total amount of N (%) in soil, b= bulk density of soil (g cm-3 or Mg m-3), v= volume of soil (cm3), k= percentage of mineralization (%)
Valuation	▪ The quantum of soil formed (Mg ha-1 year-1) may be multiplied with the value of top soil following market price method (Sandhu et al., 2008). ▪ The amount of nitrogen mineralized may be multiplied with market price of nitrogen (Rs kg-1) (Sandhu et al., 2008). ▪ Benefit transfer method may be used with values from tropical region. ▪ Another way of estimation of the value of soil formation is using the marginal value of soil depth ba sed on the data of output from the different soil depth or based on simulation studies.

4 Ecosystem Services Estimation and Valuation, Antisar Watershed

4.1 Watershed Details

4.1.1 Name: **Antisar Watershed** Villages covered: **7 Nos.**
4.1.2 Location - Latitude: **23°0' N** Longitude: **73° 10'E**
4.1.3 State: **Gujarat** District: **Kheda**
Block/Tehsil: **Kapadwanj**
4.1.4 Area (ha): **812 ha**
Average Annual Rainfall (mm): **834 mm**
Elevation range (m amsl): **30**
4.1.5 Average slope (%): **1% to 10% for agriculture land**
4.1.6 Implementation Period: **1997 to 2002 (5 years)**
4.1.7 Sponsored by: **Integrated Wastelands Development Programme, Ministry of Rural Development. Govt. of India, New Delhi**
4.1.8 Total Budget: **Rs.15.83 lakh**

4.2 Demographic Details

4.2.1 Total Population (number): **2104** SC/ST (%): **20%**
Total number of families: **500**
Number of farm families: **442** Number of landless families: **58**

4.2.2 General Socio-Economic Status:
34 families (19.8%) own more than >2.8 ha land
94 families (54.6%) own more than 0.9 to 2.8 ha land
44 families (25.6%) own more than < 0.9 ha land
Maximum population depends on agriculture & livestock.

4.2.3 General Agricultural Status: **812 ha**
(Total cultivable area **698.58 ha;** Rainfed area **586.05 ha;** Irrigated area **112.53 ha;** Forest land, other land **113.42 ha**)

4.3 Soil Properties, Major Problems, Scope and Interventions Undertaken

Table 4.1: Major soil properties under different Land Capability Classes (LCC)

Particulars	II	III	V	VI
Soil depth	0-30	0-30	0-30	0-30
Textural and hydraulic properties				
Gravel (%)	Nil	Nil	Nil	Nil
Sand (%)	67.37 (36.34-87.17)	62.73 (23.33-75.64)	51.48 (24.32-78.23)	46.13 (14.96-64.10)
Silt (%)	8.46 (2.53-19.17)	10.37 (2.64-40.81)	11.59 (7.74-15.52)	16.80 (4.14-48.86)
Clay(%)	24.17 (10.26-43.38)	26.90 (18.16-42.01)	36.93 (6.30-60.52)	37.06 (27.39-56.26)
Texture	Sandy loam sandy clay loam	Sandy loam sandy clay loam	Clay	Sandy clay loam
Bulk density	1.43	1.41	1.34	1.33
Water holding capacity (%)	36-49	37-49	47-52	42-48
Field capacity (%)	24.0	25.0	30.0	31.0
Permanent wilting point(%)	15.0	16.0	20.0	20.0
Saturated hydraulic conductivity (cm/day)	10.32	7.92	4.08	4.56
Chemical Properties				
pH	6.4-9.0 Neutral-Alkaline	6.7-9.3 Neutral-Alkaline	7.2-8.7 Neutral-Alkaline	6.6-8.5 Neutral-alkaline
EC (dsm^{-1})	<1.0	<1.0	<1.0	<1.0
Organic carbon (%)	0.30 (0.18–0.50)	0.30 (0.13-0.42)	0.34 (0.15-0.44)	0.41 (0.23-0.53)
N (Kg/ha)	517 (318-862)	517 (224-724)	586 (259-758)	707 (396-913)
P_2O_5 (kg/ha)	36.1 (3.0–176.8)	34.8 (3.2-149.2)	66.5 (28.3-93.4)	49.2 (13.0-123.8)
K_2O (Kg/ha)	228.6 (116.8-630.8)	235.9 (115.5-613.9)	471.2 (246.7-652.6)	365.2 (145.9-670.7)
Infiltration rate (cm/h)	3.54	1.98	0.21	1.38

Table 4.2: Soil fertility status and nutrient content in Antisar watershed

S. No.	Particulars	Values
1.	Depth (cm)	0-30
2.	Organic carbon (%)	0.31 (0.13 –0.53)
3.	Total N (Kg/ha)	520 (224-913)
4.	P_2O_5 (Kg/ha)	39.61(2.99-176.80)
5.	K_2O (Kg/ha)	261.15 (114.4-984.7)
6.	pH	7.8 (6.4 -9.3)
7.	EC (dsm^{-1})	0.21 (0.08-0.56)
8.	Nutrient Indices (Pre-project) · Organic carbon (as a measure of N) · Phosphorous · Potassium	 1.03 1.75 2.07

Figures in parentheses denote range
Total 'N' is calculated from organic carbon values

Table 4.3: Physiographic characteristics, major problems and scope of different Land Capability Classes

Particulars	II	III	V	VI
Area (ha)	542.05	156.53	18.12	58.22
Percent of total Area (ha)	66.75	19.28	2.23	7.17
Soil depth	> 90 cm	> 90 cm	> 90 cm	> 90 cm
Slope (%)	<1-3	1-5	0-1	3-10
Drainage	Fairly well drained	Well to moderately well drained	Poorly drained. subject to seasonal submergence	Well to excessively drained due to high slope
Major land use	Agriculture	Agriculture	Partly trees plantation and partly barren	Community grazing land
	Maize, Cotton, Fennel, Cumin, Castor, Pearlmillet, Blackgram, Greengram, Sesame	Maize, Castor, Sorghum, Paddy, Pearlmillet, Blackgram, Greengram, Sesame, Pigeonpea		
Major problems	1.Uneven slope 2.Cultivation with precaution 3.Limited ground water availability	1. Undulating terrain 2.Limited ground water availability	1. Submergence during significant part of the year 2. shrink and swell properties of soil	1. Rill to gully erosion 2. Low moisture regime 3. Uncontrolled grazing 4. Breached earthen dams resulting huge loss of water going outside the area.

Scope:	1. These lands are presently under agriculture. 2. Intensity of cropping can be increased in these areas by enhancing irrigation facilities. 3.Crop yields can be sustained by adopting moisture conservation practices. 4. Levelingof and smoothening of mild slopes, contour cultivation etc. 5. Safe disposal of rainwater.	1. Bunding leveling of mild slopes. 2.Adoption of soil moisture conservation practices for cultivation 3. Construction of structures for safe disposal of rain water. 4. Increasing water regime on uplands. 5. Management of drainage in low lands. 6. Selection of suitable crops for fine textured soils with high moisture regime. 7.Nala bunding	1. Water logging resistance tree species and grasses can be grown.	Good silvi-pasture development and water harvesting through checkdams.

Table 4.4: Interventions and expenditures

S. No.	Activities/works	Number/ Quantity	Amount Spent (Rs.)
1	Survey and Planning	-	4734
2	Entry point & community Organization (no.)	4	100,030
3	Training / visits (nos.)	4 / 6	1,04,535
4	Field levelling (ha)	142	3,97,938
5	Repair of major earthen dam (nos.)	1	1,44,168
6	Checkdams and bunds (nos.)	16	6,04,727
7	Renovation of existing ponds (nos.)	4	1,97,003
8	Well recharge (nos.)	23	6,59,169
9	Gauging bund / others	1	7697
10	Vegetative barriers	1.75	2270
11	Afforestation and pasture development (ha)	37	2,82,984
12	Crop demonstration (ha)	136	1,34,766
13	Horticulture development (no. of plants)	3784	51,049
14	Administrative overhead		4,36,902
Total project expenditure			31,27,972

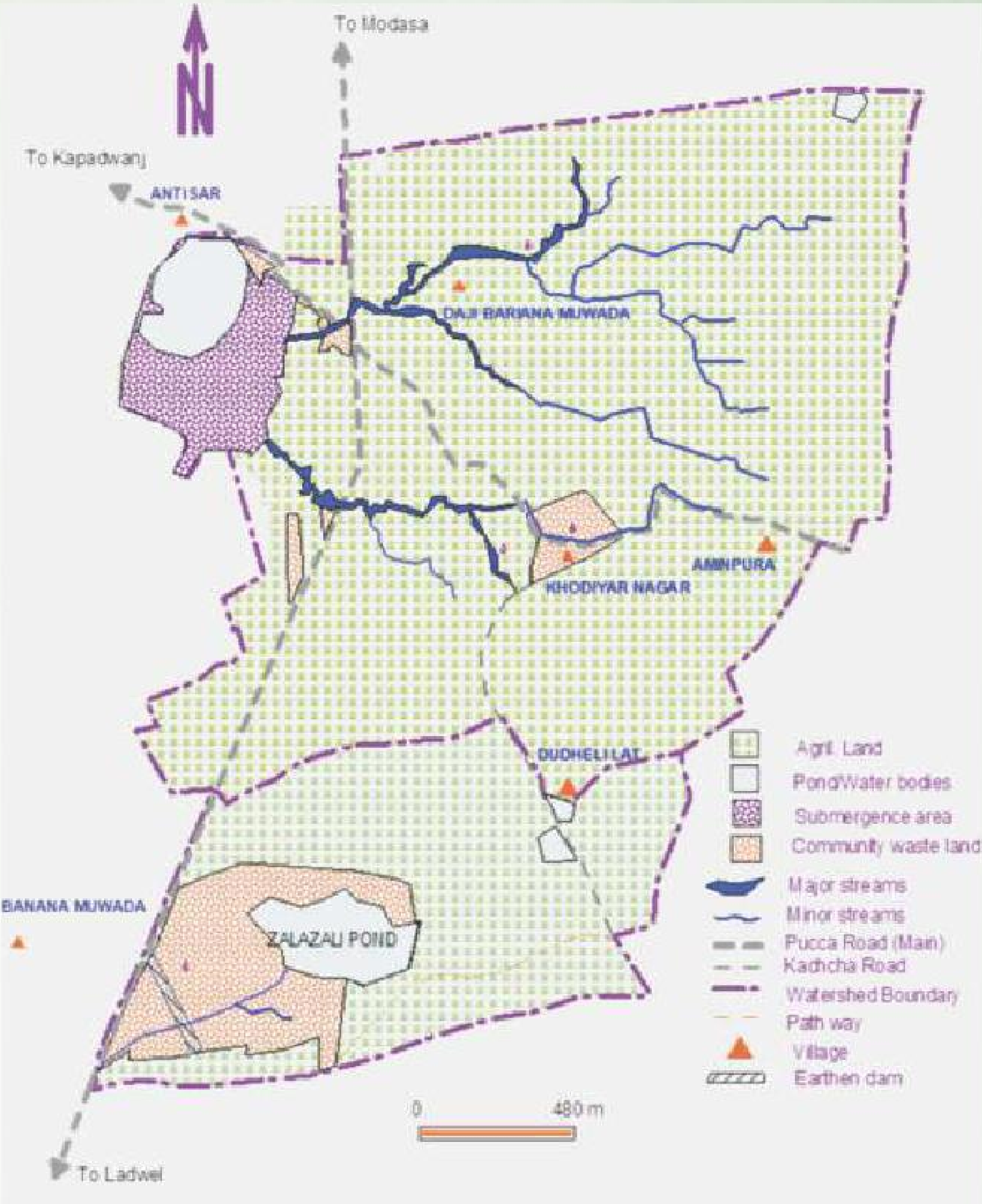

Fig. Land use map of Antisar Watershed

Figure 4.1: Land use map of Antisar watershed

4.4 Ecosystem Services Estimation and Valuation

4.4.1 Crop Production

(a)Physical account of production before and after watershed interventions

(I) Crop main products

Agricultural products	Before		After	
	Productivity (kg/ha)	Pearl millet equivalent productivity (PEP) (kg/ha)	Productivity (kg/ha)	Pearl millet equivalent productivity (PEP) (kg/ha)
Maize	972	847	1827	1593
Cotton	742	1960	1931	5099
Pearl millet	2139	2139	1230	1230
Castor	1917	6193	2299	7428
Pigeonpea	486	1414	332	966
Fennel	667	1778	1920	5120
Paddy	21	23	2820	2531
Pearl millet+pigeonpea*	910	910	1964	1964
Maize+pigeonpea**	576	502	2837	2473
Cumin	435	1160	640	1707
Capsicum	325	167	426	217
Isabgol	902	2775	1098	3371
Sunflower	525	1451	885	2443
Black gram	320	822	919	2362
Green gram	610	1751	2182	6262
Maize+cotton*	4977	4330	5051	4394
Cotton+green gram***	2659	7019	3618	9551
Sesame	600	1920	1923	6154
Tobacco	700	1071	1076	1646
Lady's finger	960	490	1011	516
Drumstick	8718	6626	11333	8613
Castor	2295	7413	7428	23993
Fennel	1920	5107	5120	13619
Total area (ha)	**566**		**565**	

*Pearl millet equivalent; **Maize equivalent; *** Cotton equivalent

(ii) Crop By-products

Agricultural by products		Before		After	
		Productivity (kg/ha)	Pearl millet equivalent Productivity (kg/ha)	Productivity (kg/ha)	Pearl millet equivalent Productivity (kg/ha)
Maize	Cob	292	254	416	478
	Stalk	1944	1695	2777	3185
Cotton	Stalk	2820	7447	24752	9373
	Husk	816	2156	14817	5608
Pearl millet	Cob	706	706	406	406
	Husk	642	642	369	369
	Stalk	4278	4278	2460	2460
Castor	Stalk	4793	5484	9768	8537
Pigeon pea	Stalk	1215	3536	7031	2416
Fennel	Straw	867	2312	17749	6656
Paddy	Straw	4320	3845	3379	3796
	Husk	564	502	130	146
Pearl millet+pigeonpea*	Cob	300	300	648	648
	Husk	273	273	589	589
	Stalk	1820	1820	3928	3928
Maize+pigeonpea**	Cob	173	151	648	742
	Stalk	69	61	263	298
Cumin	Stalk	522	1392	5461	2048
Isabgol	Stalk	1082	3331	10904	3542
Sunflower	Stalk	1575	4352	13418	4856
Black gram	Stalk	352	1011	6597	2297
Green gram	Stalk	671	2395	19471	5455
Cotton+green gram***	Stalk	602	1589	17635	6681
	Husk	1507	3978	20386	7723
Lady's finger	Stalk	2979	1519	628	1231
Castor	Stalk	5748	8156	11601	8176
Fennel	Stalk	2304	6128	16341	6144

*Pearl millet equivalent; **Maize equivalent; *** Cotton equivalent

(b) Change in crop, by-product and residue physical stock, and value of productivity and production due to integrated watershed management interventions

Agricultural products	Before				After				Change as a result of IWM		
	Area (ha)	Average Producti-vity* (kg/ha)	Value of Productivity* (Rs/ha)	Value of Produc-tion* (Rs)	Area (ha)	Average Producti-vity* (kg/ha)	Value of Productivity* (Rs/ha)	Value of Produc-tion* (Rs)	Average Productivity* (kg/ha)	Value of Productivity* (Rs/ha)	Value of Produc-tion* (Rs)
Crop main	566	2318	45202	25592200	565	3834	74766	42206280	1516	29565	16614079
Crop by products - cob	284	353	2467	699895	327	568	3979	1302681	216	1511	602786
Crop residue											
- Husk	211	1410	4230	892128	184	2887	8661	1597133	1477	4432	705004
- Stalk	439	3141	15705	6894040	378	4504	22521	8503715	1363	6816	1609675
Total	1500			34078263	1454			53609809			19531545
										Rs/ha**	13434

*In pearl millet equivalent terms; **Based on total area of 1454 ha after watershed interventions

4.4.2 Livestock Production

(a) Physical account of milk production before and after watershed interventions

Particulars		Before			After		
Livestock	Breed	Numbers	Annual Productivity (L / animal)	Annual Production (L)	Numbers	Annual Productivity (L / animal)	Annual Production (L)
Buffalo	Murrah	334	2400	801600	341	2712	924792
Cow	Desi	30	1080	32400	32	1440	46080
Goat	Desi	0	0	0	27	540	14580

(b) Change in physical stock and value of milk production due to integrated watershed management interventions

Particulars		Before			After			Change as a result of IWM		
i) Milk Production	Breed	Annual Production (L)	Value of Annual Production* (Rs)	Value of Annual Producti-vity** (Rs / ha)	Annual Production (L)	Value of Annual Production* (Rs)	Value of Annual Producti-vity** (Rs / ha)	Annual Producti on (L)	Value of Annual Production* (Rs)	Value of Annual Producti-vity** (Rs / ha)
Buffalo	Murrah	801600	8392752	10336	924792	9682572	11924	123192	1289820	1588
Cow	Desi	32400	275400	339	46080	391680	482	13680	116280	143
Goat	Desi	0	0	0	14580	291600	359	14580	291600	359
Total		834000	8668152	10675	985452	10365852	12766	151452	1697700	2090

*Based on post watershed project respective milk prices; **Based on total area of 812 ha of the watershed.

4.4.3 Soil Nutrients

(a) Physical account of soil nutrients before and after watershed interventions

Land uses	Area (ha)	Phosphorus		Potassium		Carbon	
		Stock of available P_2O_5 (kg/ha)	Stock of available P (kg/ha)	Stock of available K_2O (kg/ha)	Stock of available K (kg/ha)	Stock of carbon* (Mg/ha)	CO_2 equivalent (Mg/ha)
Before							
a) Agriculture Land (Crops)	586.04	38.8	17.0	262.0	216.4	13.14	48.2
b) Community land (Protective Vegetative Cover, Grassland / Pasture, Permanent Fallow)	68.12	45.5	19.9	240.0	198.2	13.21	48.5
c) Community land under streams and water bodies	25.64	57.5	25.1	358.8	296.4	13.67	50.2
Total	679.8						
After							
a) Agriculture Land (Crops)	613.12	39.8	17.4	234.0	193.3	15.51	56.9
b) Community land (Protective Vegetative Cover, Grassland / Pasture, Permanent Fallow)	68.12	24.5	10.7	200.1	165.3	16.47	60.4
c) Community land under streams and water bodies	25.64	78.1	34.1	885.6	731.5	24.53	90.0
Total	706.88						

* Considering 50% organic carbon content in soil organic matter

P_2O_5 and K_2O converted to P and K using conversion factor 0.437 and 0.826, respectively

Carbon stock converted to CO_2 using conversion factor 3.67

(b) Change in physical stock and value of soil nutrients due to integrated watershed management interventions

Land uses	Before				After				Change as a result of IWM		
	Area (ha)	Soil nutrient stock per unit area (kg/ha)	Value of soil nutrient stock per unit area (Rs/ha)	Value of soil nutrient (Rs)	Area (ha)	Soil nutrient stock per unit area (kg/ha)	Value of soil nutrient stock per unit area (Rs/ha)	Value of soil nutrient (Rs)	Soil nutrient stock per unit area (kg/ha)	Value of soil nutrient stock per unit area (Rs/ha)	Value of soil nutrient (Rs)
Available P											
a) Agriculture Land	586.04	17	179	104901	613.12	17.4	183	112201	0	4	7300
b) Community land	68.12	19.9	209	14237	68.12	10.7	113	7698	-9	-96	-6540
c) Community land under water bodies	25.64	25.1	264	6769	25.64	34.1	359	9205	9	95	2436
Available K											
a) Agriculture Land	586.04	216.4	5842	3423646	613.12	193.3	5219	3199873	-23	-623	-223772
b) Community land	68.12	198.2	5351	364510	68.12	165.3	4463	304020	-33	-888	-60491
c) Community land under water bodies	25.64	296.4	8002	205171	25.64	731.5	19748	506339	435	11746	301167
CO_2 equivalent											
a) Agriculture Land	586.04	48.2*	39355	23063604	613.12	56.9*	46459	28484942	9*	7104	5421338
b) Community land	68.12	48.5*	39600	2697552	68.12	60.4*	49317	3359474	12*	9717	661922
c) Community land under water bodies	25.64	50.2*	40988	1050932	25.64	90.0*	73485	1884155	40*	32497	833223
										Grand Total (Rs)	**6936584**
										Rs/ha**	**9813**

* Mg/ha; ** Based on total area of 706.88 ha after watershed interventions

4.4.4 Soil Health

(a) Physical account of soil organic matter (SOM) before and after watershed interventions

Land uses	Area (ha)	Soil organic matter (Mg/ha)	Stock of carbon* (Mg/ha)	Nitrogen available to plants as SOM is broken** (Mg/ha)
Before				
a) Agriculture Land (Crops)	586.04	26.28	13.14	1.314
b) Community land (Protective Vegetative Cover, Grassland / Pasture, Permanent Fallow)	68.12	26.43	13.21	1.321
c) Community land under streams and water bodies	25.64	27.36	13.67	1.367
Total	679.8			
After				
a) Agriculture Land (Crops)	613.12	31.04	15.51	1.551
b) Community land (Protective Vegetative Cover, Grassland / Pasture, Permanent Fallow)	68.12	32.93	16.47	1.647
c) Community land under streams and water bodies	25.64	49.08	24.53	2.453
Total	706.88			

* Considering 50% organic carbon content in soil organic matter
** Considering 0.1 tonne nitrogen per tonne of organic carbon

(b) Change in soil organic matter and value of soil nutrients due to integrated watershed management interventions

Land uses	Before				After				Change as a result of IWM		
	Area (ha)	Nitrogen available to plants as SOM is broken (Mg/ha)	Value of nitrogen available to plants per unit area (Rs/ha)	Value of nitrogen available to plants (Rs)	Area (ha)	Nitrogen available to plants as SOM is broken (Mg/ha)	Value of nitrogen available to plants per unit area (Rs/ha)	Value of nitrogen available to plants (Rs)	Nitrogen available to plants as SOM is broken (Mg/ha)	Value of nitrogen available to plants per unit area (Rs/ha)	Value of nitrogen available to plants (Rs)
a) Agriculture Land (Crops)	586.04	1.314	18282	10713983	613.12	1.551	21579	13230516	0.237	3297	2516533
b) Community land (Protective Vegetative Cover, Grassland / Pasture, Permanent Fallow)	68.12	1.321	18379	1251977	68.12	1.647	22915	1560970	0.326	4536	308992
c) Community land under streams and water bodies	25.64	1.367	19019	487647	25.64	2.453	34129	875068	1.086	15110	387420
									Grand Total (Rs)		3212946
										Rs/ha*	4545

* Based on total area of 706.88 ha after watershed interventions

4.4.5 Groundwater

(a) Groundwater storage in the watershed (cum)

S. No.	Details	Unit	Before	After	Change (After-Before)
1	Area of watershed	ha	812	812	0.0
2	Average water level fluctuation	m	3.6	10.7	7.1
3	Specific yield		0.00339	0.00339	0.0
4	Storage volume (1*2*3)*10000				
	i. Total	cum	99096	294537	195441
	ii. Per unit (4i/1)	cum/ha	122	363	241
5	Valuation@				
	i. Total	Rs	327018	971971	644953
	ii. Per unit (5i/1)	Rs/ha	403	1197	794

@Rs.3.31 per cum, which is average marginal productivity of water in different crops' production using the production function approach.

Note: In case specific yield of watershed is not available, the reference value may be taken from the Report of the Groundwater Resources Estimation Committee (GEC-2015). Ministry of Water Resources, River Development and Ganga Rejuvenation, New Delhi, 2017

4.4.6 Employment

(a) Change in employment due to integrated watershed management interventions

Employment source	Before			After			Change as a result of IWM		
	Employ-ment (mandays)	Value of employ-ment* (Rs)	Value of employ-ment per unit area** (Rs/ha)	Employ-ment (mandays)	Value of employ-ment* (Rs)	Value of employ-ment per unit area** (Rs/ha)	Employ-ment (mandays)	Value of employ-ment* (Rs)	Value of employ-ment per unit area** (Rs/ha)
a) Crop production	70565	12017220	14800	113150	19269445	23731	42585	7252226	8931
b) Livestock production	48138	8197901	10096	53438	9100491	11208	5300	902590	1112
c) Casual employment during execution of conservation works				51461	8763808	10793	51461	8763808	10793
Total	118703	20215121		218049	37133745		99346	16918624	
Rs/ha**			24895			45731			20836

* Based on MGNREGA wage rate = Rs 170.3/manday ** Based on total area of 812 ha of the watershed

4.4.7 Summary

Impact of Integrated Watershed Management Interventions on Ecosystem Services in Antisar Watershed, Gujarat

S. No.	Ecosystem service	Details	Value of ES (Rs)	Value of ES per unit area (Rs/ha)
1.	Crop production	Main product, by products and crop residues (husk and stalk)	1,95,31,545	13,434
2.	Milk production	Livestock comprising of buffalo, cow and goat	16,97,700	2,090
3.	Soil nutrients	Available P, Available K and CO_2 equivalent carbon	69,36,584	9,813
4.	Soil health	Nitrogen available to plants from broken soil organic matter	32,12,946	4,545
5.	Groundwater	Recharge	6,44,953	794
6.	Employment	Regular (crop, livestock production) and casual (conservation works) employments	1,69,18,624	20,836

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Appendix I

Estimation of Above and Below Ground Tree Biomass

A. Aboveground Tree Biomass

A1. Volume estimation

The trees falling in the plot (10 x 10 m^2) will be enumerated. The diameter at breast height (dbh) will be measured with the help of tree calliper and height with Ravi's multimeter. Local volume equation developed (Table A-1) for specific tree species and region will be used for calculating the volume of the forest trees of the sample plot.

A2. Biomass estimation

The volume obtained from above will be used for estimating tree biomass by using expansion factors and specific gravity as per the following:

Aboveground biomass density (Mg ha^{-1}) = VOB × WD × BEF

Where,

VOB = Volume over bark

WD = Wood density

BEF = Biomass expansion factor

A3. Biomass expansion factor (BEF)

Biomass expansion factoris the ratio of total aboveground oven-dry biomass density of trees with a minimum dbh of 10 cm or more to the oven-dry biomass density of the inventoried volume.

The biomass expansion can be calculated using the following equation (Brown *et al*., 1999):

For hard woods, ,

Table A-1: Volume equations, Wood specific gravity, biomass expansion factor and root: shoot ration of some important agroforestry MPTs

S. No.	Tree species	Volume equation	Wood specific gravity	Biomass Expan-sion Factor (BEF)	Root: Shoot ratio
1.	*Abies pindrow*	$V=0.061+0.244D+7.92D^2$			
2.	*Abiess mithiana*	$V=0.163269-2.232068\ D +11.770869\ D^2+1.06041D^3$			
3.	*Acacia auriculiformis*	$V/D^2= 0100961+4.03861D-56.387D^2+362.638D^3-668D^4$	0.637 (0.47-0.52)		
4.	*Acacia catechu*	$V = 0.048535 - 0.183567\sqrt{D} + 3.78725\ D^2$ $V=0.16609-2.78851D+17.22127D^2$ (Northern Plain)	0.875 (0.48-0.58)	2.52	0.25
5.	*Acacia chundra*	$V= -0.048108+5.873169D^2$	0.980		
6.	*Acacia mangium*	$V = 0.00006(D^2H)^{0.934}$	0.500		
7.	*Acacia nilotica*	$V = 0.0281 + 0.6872 \times ND^2H$ $V = 0.000071*D^{2.735778}$	0.670	2.52	0.25
8.	*Acacia* sp.	$\sqrt{V}= -0.00142+2.61911D-0.54703\sqrt{D}$	0.670		
9.	*Acrocarpus fraxinifolious*	$V/D^2= -0.0941/D^2-0.00097$	0.680		
10.	*Adina cordifoilia*	$V=0.296-2.829D+12.207D^2$	0.590 (0.34-0.38)		

11.	*Aegle marmelos*	$V/D2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454\ D$	0.754	1.40	0.27
12.	*Aesculus indica*	$\sqrt{V} = 0.220191 + 3.923711\ D - 1.117475\ \sqrt{D}$	0.428	1.40	0.27
13.	*Ailanthus excelsa*	$V = 0.193297-2.267002\ D + 10.679492D^2$	0.356	1.63	0.27
14.	*Albizzia amara*	$V=0.058237+4.597986D*D*D$			
15.	*Albizzia procera*	$\sqrt{V}= -0.07109 + 2.99732\ D - 0.26953\ \sqrt{D}$	0.534	2.90	0.27
16.	*Albizzia lebbek*	$\sqrt{V}= - 0.07109 + 2.99732\ D - 0.26953\ \sqrt{D}$	0.7	2.90	0.27
17.	*Albizzia stipulata*	$\sqrt{V}= - 0.07109 + 2.99732\ D - 0.26953\ \sqrt{D}$	0.434	2.90	0.27
18.	*Albizzia odoratissima*	$V=0.270-2.953D+12.336D^2$	0.760 (0.47-0.57)		
19.	*Albizzia* sp.	$\sqrt{V}=-0.07109+2.99732D-0.26953\sqrt{D}$	0.760		
20.	*Alnus nepalensis/A. nitida*	$V = 0.193297-2.267002\ D + 10.679492D^2$ $V=0.0741-1.3603D=10.9229D^2$	0.434	1.40	0.27
21.	*Anogeissus latifolia*	$V=-0.06868+1.56245D-2.9161D^2$ $V=0.055883+5.603009D^3$	0.780 (0.56-0.64)		
22.	*Artocarpus hirsutus*	$V=0.076-1.319D+11.370D^2$	0.520		
23.	*Artocarpus lakoocha*	$V=0.012951+0.000027D^2H$	0.640		
24.	*Azadirachta indica*	$V/D^2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454\ D$	0.693 (0.52-0.58)	1.74	0.28
25.	*Bauhinia variegata*	$V/D^2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454\ D$	0.67	1.40	0.27
26.	*Bauhinia racemosa*		0.52 - 0.58		
27.	*Bauhinia* sp.	$V=-0.04262+6.09491D^2$ $\sqrt{V}=-0.07109+2.99732D-0.26953\sqrt{D}$	0.700		
28.	*Bombax ceiba*	$V/D^2H=0.002994/\ D2H+0.457283-0.00054\ D^2$ OR $V/D^2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454\ D$	0.329 - 0.330	1.40	0.27
29.	*Boswellia serrata*	$\sqrt{V}=-0.18655+3.021335D$	0.34-0.38		
30.	*Bridelia retusa*	$V/D^2H=-0.003872/\ D2H+.383012$	0.500 (0.48-0.56)		
31.	*Buchanania lanzan*		(0.45-0.56)		
32.	*Butea monosperma*	$V/D^2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454\ D$ $V=-0.032$	0.560 0.465	2.39	0.37
33.	*Calophyllum spp.*		0.530		
34.	*Canthium dicoccum* (Gaertn.) Teijsm.& Birin	$V=0.058237+4.597986D^3$			
35.	*Careya arborea*	$V=0.003-0.848D+7.342D^2$	0.800		
36.	*Carissa spinarum*		(0.52-0.57)		
37.	*Cassia fistula*	$V=0.0066+0.287\ D^2H$	0.710 (0.51-0.56)		

38.	*Callophyllum elatum*	V=0.02492+0.43282D²H			
39.	*Cedrus deodara*	V/D² = 0.2421/D² 2.68191 / D + 14.77955 V=0.07367-1.28303D+10.03982D²	0.468	1.40	0.27
40.	*Chloroxylon swietenia*		(0.47-0.54)		
41.	*Cinnamom ummalabatrum*	V=0.089-1.242D+9.732D²	0.430		
42.	*Dalbergia latifolia*	V=0.018945-2.46215D+10.54462 D²	0.800		
43.	*Dalbergia sissoo*	V=0.00331+6.36D² V = - 0.013703 + 3.943499 D² V = -0.0023 + 0.0000364 D²H	0.692	1.86	0.20
44.	*Dendrocalamus strictus*		(0.45-0.49)		
45.	*Dillenia pentagyna*	V=0.070-1.295D+9.429D²	0.530		
46.	*Diospyros* sp.	V=0.024814-0.578532D+6.11017D²	0.680 (0.53-0.58)		
47.	*Dipterocarpu indicus*	V=0.0303+0.4444D²H			
48.	*Dysoxyllum malabaricum*	V=0.0795+0.457D²H			
49.	*Elaeodendron glaucum*		(0.51–0.57)		
50.	*Emblica officinalis*	V=-0.406+3.540D-3.231 D² V = 0.13734 - 2.49039 D + 15.59566 D² 11.06205 D³	0.800 (0.53-0.58)	1.49	0.18
51.	*Erythrina indica*	V=0.07803+1.70258D-9.1618D²+33.91455D³	0.320		
52.	*Eucalyptus camaldulensis*	V = -0.00226 + 0.0000333 D²H			
53.	*Eucalyptus hybrid*	V = 0.000076*D^2.761477^ V = 0.000014*D^2.141947^H^1.168588^			
54.	*Eucalyptus territicornis*	V=0.02894-0.89284D+8.72416 D²	0.640		
55.	*Ficus bengalensis*	SQRT V=0.03629+3.95389D-0.84421SQRT D	0.590		
56.	*Ficus* sp.	SQRT V=0.03629+3.95389D-0.84421 SQRT D	0.390		
57.	*Flacourtia indica*	V=0.081467-1.063661D+6.452918D²	(0.55–0.59)		
58.	*Gardenia latifolia*		(0.48-0.53)		
59.	*Gardenia turgida*		(0-51-0.55)		
60.	*Garuga pinnata*	V=0.034-0.901D+6.898D²	0.511		
61.	*Gmelina arborea*	V=0.25058-3.55124D+16.41720D²-8.32129D³	0.560		
62.	*Grevillea robusta*	V/D² = 0.007602/D² - 0.033037/D + 1.868567 + 4.483454 D	0.472-0.478	1.40	0.27
63.	*Grewia hirsuta*		(0.48-0.53)		
64.	*Grewia serrulata*		(0.51–0.55)		

65.	*Grewia optiva/G. oppositifolia*	$V/D^2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454\,D$	0.642	2.01	0.27
66.	*Grewia tiliaefolia*	$V=-0.01611+4.90810\,D^2$	0.651		
67.	*Hardwickia binata*	$V=-0.02219+0.12491D+1.91214D^2$	(0.58-0.65)		
68.	*Holarrhena antidysenterica*		(0.52–0.55)		
69.	*Holoptelea integrifolia*		(0.52–0.58)		
70.	*Hymenodiction excelsum*		(0.48–0.54)		
71.	*Indigofera cassioides*		(0.48-0.52)		
72.	*Juglans regia*	$\sqrt{V} = 0.207299 + 3.254007\,D$	0.465	1.40	0.27
73.	*Kydia calycina*	$\sqrt{V}=-0.02297+2.68423D$			
74.	*Lagerstroemia lanceolata*	$V=0.23839-2.48071D+10.14106D^2$	0.579		
75.	*Lagerstroemia parviflora*	$V=0.11740-1.58941D+9.76464D^2$	0.620 (0.52-0.57)		
76.	*Lannea coromandelica*	$V=-0.027403+3.069449D^2$	0.540 (0.35-0.41)		
77.	*Lantana camara*		(0.42–0.46)		
78.	*Macaranga peltata*	$V=0.13333-2.18825D+13.12678\,D^2$	0.290		
79.	*Madhuca longifolia*		0.47–0.54		
80.	*Mallotus philippensis*	$V=0.14749-2.87503D+19.61977\,D^2-19.11630D^3$	0.640		
81.	*Mangifera indica*	$V/D^2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454\,D$	0.581-0.680	1.40	0.17
82.	*Melia azadirchta*	$V = -0.03510 + 5.32981\,D^2$	0.491	1.74	0.27
83.	*Michelia champaca*	SQRTV=0.37142+5.64184D-2.27448SQRT D	0.590		
84.	*Miliusa tomentosa*		(0.52–0.56)		
85.	*Mitragyna parvifolia*	$V=0.099768-1.744274D+10.086934D^2$	(0.51– 0.59)		
86.	*Morus alba*	$V=0.167174-1.735312\times D+12.039017\times D^2$	0.603	1.40	0.27
87.	*Myristica* sp.	$V=0.79131-10.40359D+45.56029D^2-37.81912D^3$	0.530		
88.	*Mitragyna parviflora*	$V=0.048795-1.241364D+9.496613D^2$	0.560		
89.	*Nyctanthes arbortristis*		(0.48–0.53)		
90.	*Olea dioica*	$V=-0.03001+5.755523D^2$			
91.	*Olea glandulifera*	$V = 0.193297-2.267002\,D + 10.679492D^2$	0.427	1.40	0.27
92.	*Ougeinia oogenesis*		(0.51–0.54)		

93.	*Palaquim ellipticum*	$V=0.02245+0.047522D^2H$			
94.	*Pinus roxburghii*	$V/D^2 = 0.167095/D^2 - 2.085944/D + 9.929936$ $\sqrt{V}=0.05131+3.9859D-1.0245\sqrt{D}$	0.491	1.91	0.21
95.	*Pinus wallichiana*	$V = 0.193297-2.267002 D + 10.679492D^2$	0.427	1.91	0.27
96.	*Pongamia pinnata*	$V/D^2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454 D$	0.609-0.640	1.40	0.27
97.	*Populus deltoides/P.ciliata/ P. alba*	$V = 0.193297-2.267002 D + 10.679492D^2$	0.4	1.58	0.19
98.	*Prunus armeniaca*	$V = 0.193297-2.267002 D + 10.679492D^2$		1.40	0.27
99.	*Propospis juliflora*		0.63		
100.	*Pterocarpus marsupium*	$V=0.070-1.295D+9.429D^2$	0.670 (0.58-0.67)		
101.	*Quercus floribunda*	$V=0.0988-1.5547D+10.1631D^2$			
102.	*Quercus leucotrichophora*	$\sqrt{V} = 0.240157 + 3.820069 D - 1.394520 \sqrt{D}$	0.826	1.91	0.39
103.	*Quercus semicarpifolia*	$V=0.098800-1.55471D+10.16317D^2$			
104.	*Rhododendron arboreum*	$\sqrt{V}=0.306492+4.315360-1.749908\sqrt{D}$			
105.	*Robinia pseudoacacia*	$V = 0.193297-2.267002 D + 10.679492D^2$	0.629	1.40	0.27
106.	*Salix alba*	$V = 0.193297-2.267002 D + 10.679492D^2$	0.459	1.40	0.27
107.	*Sapindus mukorossii*	$V/D^2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454 D$	0.77	1.40	0.27
108.	*Schleichera oleosa*		(0.51–0.54)		
109.	*Schimia walichii*	$V=0.27609-3.68443D+15.86687D^2$			
110.	*Schrebera swietenioides*		(0.51–0.58)		
111.	*Semecarpus anacardium*		(0.41–0.46)		
112.	*Shorea robusta*	$V=0.118+0.257\times D^2\times H$ $\sqrt{V}=0.16306+4.8991D-1.57402\sqrt{D}$ $V=0.16019-2.81861D+16.19328D^2$ (North East ranges)	0.745 (0.61-0.67)	1.59	0.30
113.	*Soymida febrifuga*		(0.53–0.58)		
114.	*Stereospermum sp.*	SQRT V=0.49746+5.98454D-2.84986 SQRT D	0.600		
115.	*Syzygium cumini*	$V=0.0238+0.41681D^2H$ $\sqrt{V} = -0.05923 +2.33654 D$	0.760 0.647	2.22	 0.27
116.	*Syzygium* sp.	$V=0.08481-1.81774D+12.63047D^2-6.69555D^3$	0.760		
117.	*Tecomela undulata*	$V = 0.000088 D^{2.381398}$ $V = 0.000066 D^{2.100121}H^{0.553696}$			

118.	*Tectona grandis*	$V=-0.27773+3.10419D-6.12739 D2+15.16993D^3$ $V = 0.08847 - 1.46936 D + 11.98979 D^2 + 1.970560 D^3$ $V=0.19112-3.25372D+17.9194D2-1.66117D^2$ (North East	0.604 0.57	1.74	0.20
119.	*Terminalia arjuna*	$V = 0.50603 - 6.64203D + 25.23882 D^2 - 9.19797 D^3$	0.622	1.56	0.25
120.	*Terminalia bellerica*	SQRTV $V=-0.23519+2.672250D$ $\sqrt{V} = - 0.14325 + 3.07937 D$	0.628	1.56	0.25
121.	*Terminalia chebula*	$V = -0.05004 - 0.03440 D + 6.35715 D^2$	0.880 0.642	2.37	0.25
122.	*Terminalia crenulata*	$V=0.06517-0.21738D+3.96894D^2+4.63954D^3$	0.760		
123.	*Terminalia myriocarpa*	$V=-0.096981+0.001065D^2$			
124.	*Terminalia paniculata*	$V=0.13100-1.87132D+9.47861D^2$	0.720		
125.	*Terminalia tomentosa*	$V = 0.50603 - 6.64203D + 25.23882 D^2 - 9.19797 D^3$	0.73 (0.61-0.67)	1.56	0.25
126.	*Tetrameles nudiflora*	$V=-0.50980+2.4116D+1.12639$SQRT D	0.300		
127.	*Trema orientalis*		0.310		
128.	*Toona ciliata*	$V/D^2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454 D$	0.424	1.40	0.27
129.	*Ulmus laevigata/U. wallichiana.*	$V = 0.193297-2.267002 D + 10.679492D^2$	0.435	1.40	0.27
130.	*Vateria indica*	$V=-0.39452+2.7392D+6.03205D^2$	0.480		
131.	*Vitex* sp.	$V=-0.16386+2.23116D-7.00969D^2+22.13099D^3$	0.300		
132.	*Woodfordia fruticosa*		(0.49–0.55)		
133.	*Wrightia tinctoria*	SQRT $V=0.23229+4.41646D-1.55899$SQRT D	0.800		
134.	*Xylia xylocarpa*	SQRT $V=0.01631+2.20921D$	0.810		
135.	*Zizyphus glaberrima*		(0.48–0.55)		
136.	*Ziziphus mauritiana*Lam	$V=0.058237+4.597986D*D*D$			
137.	*Zizyphus nummularia*		(0.52–0.56)		
138.	*Zizyphus oenoplea*		(0.47–0.53)		
139.	Common Equation	$V=0.058237+4.597986D^3$			

V=volume (m^3), D= DBH (m), H= height (m), SQRT=square root, G=GBH (m), Figures in parentheses are specific gravity for juvenile trees

Source: FSI (1996); Devagiri *et al.*, 2013; IPCC; Rajput *et al.* (1985) ;IPCC (1996); Kumar (1998); Rana and Singh (1990); Chatuvedi and Khanna (1994); Chaturvedi *et al.* (2012)*; Gurumurthi *et al.* (1986); IPCC (2003); Kaul and Sharma (1983); IPCC (2003); Rana *et al.* (2002); Singh *et al.* (1987); Rana *et al.* (2002); Rawat and Tandon (1993); Hall and Uhlig (1991); Gurumurthi *et al.* (1986); Kaul and Sharma (1983); Behera and Misra (2006); Rai *et al.* (2000); IPCC (2003); Singh (1994); Chowdhury and Ghosh (1958); Rai *et al.* (2002); IPCC (2006); IPCC 2003.

A5. Standing Trees Biomass

Standing tree biomass can also be measured by using direct measurement method or allometric biomass regression equation. The commonly used approach to estimate the biomass of standing trees is the use of the allometric regression equation or biomass equation with the help of measured DBH and height from field inventory data. If such equations are not available, then it is better to develop site-specific allometric equations by collecting data from individual trees. Biomass can also be estimated directly by using the biomass equations directly. The biomass equations for different tree species are as below:

Table A-2: Biomass equations for standing (Allometric biomass regression equation)

S. No.	Species	Bole	Branch	Foliage	Twigs	Total Above ground total	Below ground	Reference
1.	*Populus deltoides*	$0.058D^{2.485}$	$0.037D^{2.478}$	$0.003D^{2.714}$	$0.038D^{1.741}$	$0.109D^{2.470}$		
2.	*Grewia optiva*	$0.348D^{1.704}$	$0.109D^{1.523}$	$0.067D^{1.435}$		$0.692D^{1.667}$	$0.103D^{0.612}$ (tap root) $0.078D^{1.786}$ (lateral roots)	Verma *et al.* (2014)
3.	*Dendrocalamus strictus*	$0.0537D^{2.4260}$ (culm)	$0.00031D^{4.4420}$	$0.1902D^{0.4587}$		$0.1002D^{2.266}$		Kaushal *et al.* (2015)
4.	*Pinus roxburghii*	- 6.418+2.598D	- 9.8333+2.978D (First order branch) -9.338+2.630D (other branches)	- 6.111+1.872D		- 6.398+2.655	- 7.220+2.448D (Stump root) - 9.161+2.593D (Lateral root) - 9.102+2.069D (Fine roots) - 7.015+2.469D (Total roots)	Chaturvedi and Singh (1987)

5.	*Dalbergia sissoo*	22.0780+2.8541D	4.7404+0.6164D	1.7329+0.22583D	1.9716+0.2583D		- 3.4393+0.4626D (Stump root) 2.8214+0.3849D (Lateral root) 1.3691+0.1649D (Fine roots)	
6.	*Lantana camara*	1.6415+3.6484D		1.4610+1.1457D			1.4610+2.8511D	
7.	*Murraya koenigii*	1.0385+4.5665D		1.1142+1.8202D			1.1081+3.0192D	
8.	*Quercus leucotrichophora* Y=a-blogG (1600-2490m amsl,Thalkedhar, Uttarakhand, Kumaun Himalaya)	0.574+1.064logG	0.573+0.882logG	0.376+0.687logG	0.544+0.729logG	0.851+0.807logG		
9.	*Quercus leucotrichophora* lnY=a+blnG 1950 m amsl,Nainital, Uttarakhand, Central himalaya	-0.523+1.367lnG	-0.718+1.302lnG	-0.976+0.954lnG	0.065+0.895lnG	0.685+1.524lnG	0.982+0.904lnG (Stump root) -0.3120.809lnG (Lateral root) - 1.326+0.504lnG (Fine root) 0.112+0.924lnG (Total below ground)	Rawat and Singh (1988)
10.	*Quercus floribunda*	0.748+1.106logG	0.810+0.685logG	0.798+0.519logG	0.620+0.702logG	1.067+0.827logG		
11.	*Quercus floribunda, 2194 m amsl*	-1.109+1.518lnG	-0.987+1.377lnG	-1.229+1.384lnG	-1.128+1.268lnG	0.028+1.429lnG	- 0.246+1.106lnG (Stump root) - 1.590+1.004lnG (Lateral root) - 1.048+0.246lnG (Fine root) 0.702+0.804lnG (Total below ground)	Rawat and Singh (1988)

12.	*Rhododendron arboreum*	0.928+0.696logG	0.541+0.752logG	0.655+0.398logG	0.381+0.760logG	1.240+0.681logG		
13.	*Rhododendron arboreum*	1.120=ln0.704lnG	1.113+0.609lnG	1.194+0.170lnG	1.155+0.373lnG	1.176+0.855lnG	- 0.119+0.867lnG (Stump root) - 1.752+0.984lnG (Lateral root) - 1.009+0.407lnG (Fine root) 0.942+0.506lnG (Total below ground)	Rawat and Singh (1988)
14.	*Lyonia ovalifolia*	0.810+0.559logG	1.161+0.022G	0.261+0.563logG	0.865+0.031logG	1.072+0.232logG		
15.	Interspecies of Himalayan moist temperate forest	1.882+0.002logD	1.825+0.002logD	1.081+0.006logG	1.282+0.006logG	2.178=0.8790logG	0.098+0.948lnG (Stump root) - 2.346+0.997lnG (Lateral root) - 2.874ln0.529lnG (Fine root)	Rawat and Singh (1988)
16.	*Bambusa balcooa*					Y= -3225.8 + 1730.4 D Y = Biomass (kg) clump^{-1}, D-clump diameter at breast height		
17.	*Hevea brasiliensis*					$0.0026G^{2.78}$		
18.								
19.	Common equations for juvenile trees*					$Ln(Y) = 3.344 + 0.443 \ln D^2$ $Ln(Y) = 2.666 + 0.432 \ln \rho D^2$ $Ln(Y) = 3.204 + 0.315 \ln D^2H$ $Ln(Y) = 3.428 + 0.310 \ln \rho D^2H$		

*juvenile stage: individuals having ≥30 cm height and <10 cm stem circumference 10 cm above the ground surface.

A. Belowground Biomass

B1. Trees

The method for estimating the root biomass is not given in any standardized form. The estimation of root biomass is a complex, tedious and expensive task in itself. However root biomass ranges from 10-40% of the above ground biomass, hence for considering this pool the most common approach is to use the values addressed by various scientists / researchers in the existing published literature or default values on root: shoot ratio for different forest wise. Below ground biomass of trees can be calculated by multiplying above ground biomass of trees with a factor of root: shoot ratio of particular crop/grass.

$$\text{Below ground biomass} = \text{above ground biomass} \times \text{root: shoot ratio}$$

The root shoot ratio of some of the important trees of the country is given in Table A-1. In absence of root shoot ratio, belowground biomass (fine and coarse roots) can also be estimated using regression equation given by Cairns *et al*. (1997).

$$\text{BGBD} = \exp \{1.059 + 0{:}884 \times \text{Ln (AGBD)} +0.284.$$

Where,
BGBD= Below ground biomass density
ABGD: Above ground biomass density†

B2. Crops/grasses

Belowground biomass of crops and grasses can be calculated by multiplying aboveground biomass of crops/grasses with a factor of root: shoot ratio of particular crop/grass.

$$\text{Below ground biomass} = \text{above ground biomass} \times \text{Root: shoot ratio}$$

B3. Carbon Stock

Vegetation carbon stock

Above and below ground carbon stock in vegetation is determined by vegetation biomass multiply with default value 0.5 (IPCC, 1996).

$$\text{Carbon stock} = \text{Biomass} \times 0.5 \text{ (IPCC default value)}$$

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