Assessment of Watershed Management Ecosystem Services in India: a meta-analysis

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Abstract

Well-developed watersheds, besides increasing agricultural productivity, have immense potential in minimizing land degradation, mitigating the adverse impact of climate change and generating several such other ecosystem services. Quantifying these services is quintessential in operationalizing the concept for management and decision-making relating to watershed management. This study estimates the value of regulating (soil conservation and carbon sequestration) and supporting ecosystem services (groundwater recharge) generated by watersheds in India and examines the factors that influence the flow of ecosystem services from watersheds. The study followed a meta-analysis approach using information from 221 watersheds in five major agro-climatic zones of India. We found that watershed generates ecosystem services to the tune of Rs. 34113 per ha, with water recharging alone accounted for 60 percent of it. The study showed that people's participation in the planning, implementation and management of watersheds significantly enhances the ecosystem services. Macro-watersheds (≥ 1000 ha) are more effective in generating ES, underscoring the need for investment in watersheds management in Semi-Arid Tropical regions where problems of degradation of natural resources are more pronounced. The study suggests policies for land restoration and payment for ecosystem services to increase their flow.

Keywords: Carbon sequestration, Groundwater management, Soil conservation, Participatory watershed, Payment for ecosystem services

Introduction

A watershed is a geographical area drained by a watercourse, and is one of the most suitable socio-economic-political units for land management planning and implementation[1]. Over time, the watershed programs have evolved from focusing on a structural-driven compartmental approach to soil conservation and rainwater harvesting to an integrated land management approach for the constant flow of ecosystem services-benefits that humans get from natural and healthy ecosystems-while neutralizing land degradation and water scarcity[2-5]. Watershed management, besides strengthening food and livelihood security, can increase the resilience of agricultural systems to climate change, achieve the targets of land degradation neutrality, and generate multiple ecosystem services (provisioning, supporting, regulating and cultural) for the society[6].

The services provided by watershed had no readily identifiable monetary terms and were therefore overlooked in the trading system. Valuation of ecosystem services (ES) builds the economic basis for investing in natural resource programs and efficient use of limited funds, more specifically in the ecologies where the problems of degradation of natural resources are more pronounced. Quantification of ecosystem services and translating them into a monetary value is the fundamental step in setting up the payment or compensation system for their conservation and sustainable use[7].

Despite the increasing demand for and importance of watershed ecosystem services (WES) (ecosystem services and watershed ecosystem services are interchangeably used throughout the manuscript), their valuation is limited to provisioning services only[2&8]. The existing literature on the impact of watershed management on regulating and supporting ES in terms of improved soil and water conservation, biodiversity, water storage, soil retention, aquifer recharge, carbon sequestration, etc. are scattered and inconsistent [9-11]. With this background, the study estimates the monitory value of regulating and supporting services provided by the watersheds. These ecosystem services vary across watersheds due to multiple factors such as physiography, soil type, rainfall, size of the watershed, institutions/implementing agencies, people participation, etc. The insight into factors that influence ecosystem services generated by watersheds is crucial for the efficient, cost-effective, and sustainable management of watersheds. Therefore, the study also identifies the key factors influencing these watershed services.

Data and method

Data collection and database structure

This study is a meta-analysis of scientific literature on the evaluation of watersheds in India. The keywords used in different combinations in exploring the scientific studies were “watershed”, or “watershed impact” or “watershed development” or “watershed management” + “ecosystem services” or “environmental services” or “ecological services”, “soil loss”, “soil retention”, “carbon sequestration”, “aquifer recharge”, “water augmentation” + “India”. Scopus, the world’s most considerable abstraction and citation database, was used to perform this task. Besides, other external sources such as Google Scholar, Science Direct, Wiley, RePEc, AgEcon Search, etc. were also explored. Overall 445 studies were extracted of which 221 could satisfy the criteria and were used to estimate the unit coefficients of WES. Out of total studies, 148 were related to the estimation of groundwater augmentation, 28 were on estimation of soil losses and 25 were on carbon sequestration. An additional filter “people’s participation” or “participatory” was applied to extract data for identifying factors affecting WES. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach for including studies in analysis[12].

Monetization of WES

Once the unit coefficients of three different watershed ecosystem services (soil retention, water augmentation, and carbon retention) are calculated, the monetary values associated with these services were computed using the avoided cost principle or the market price method. A summary of data requirements and valuation methodologies for different services are presented in Table 1, while the detailed methodology is described in the following Sections.

Soil retention

Soil retention is one of the most important ecosystem services generated by the watersheds. Eroded soils carry nutrients, organic carbon, minerals and other important compounds. Development and management of watersheds help check soil erosion and thereby minimize the loss of nutrients from the soil. Valuation of soil retention services was done using the avoided cost method. The avoided cost is the potential expenses that are needed to restore or avoid the damage caused to the ecosystem with the assumption that the value of retaining ES is higher than the replacement cost[13]. In our case, the avoided cost is the economical prices of fertilizers required to supply the equivalent quantity of nutrients that otherwise would have been lost, i.e. without the management of the watershed. The per hectare quantity of nutrients saved was multiplied by the economical prices (market prices and subsidies) of chemical fertilizers as shown in Expressions (1) given below. The data on prices of fertilizers in terms of nutrients were taken from the Department of Fertilizers, Ministry of Chemicals & Fertilizers, Government of India.

$$MV_{SR} = Q_N P_N + Q_P P_P + Q_K P_K \qquad (1)$$

Where MV_{SR} is the monetary value (Rs./ha) of nutrients saved due to retained soil that otherwise would have been lost; Q_N, Q_P and Q_K are unit coefficients of saved N, P, and K respectively; and P_N, P_P and P_K are economical prices for N, P & K, respectively.

Carbon sequestration

Soil degradation has a strong impact on the emission of CO_2 in the atmosphere and society bears huge costs in terms of replacing its economic damages. Watersheds with vegetation cover and intact soil resources are capable of sequestering carbon, thereby offsetting greenhouse gas emissions[14]. Similar to the soil retention service, the monetary value of the carbon sequestration (MV_{CS}) was estimated by multiplying the avoided cost per ton of CO_2 by the per ha carbon sequestration potential of watershed management (t/ha). The damage avoided cost of CO_2 was taken from the published literature[15&16]. In most of the studies, the carbon sequestration was reported in the form of soil organic carbon (SOC) and hence was converted into CO_2 equivalent using the conversion coefficient of IPCC[17].

Water augmentation

The valuation of water augmentation was done by applying the market price of irrigation to the volume of water recharged through watershed management. Since the market prices of irrigation water are not available on a volumetric basis, these were estimated indirectly using the plot level data collected under the Cost of Cultivation (CoC) scheme of the Government of India[18]. The CoC scheme provides the data on the per ha cost of irrigation and pumping hours (hr/ha). To arrive at irrigation water prices (Rs/m^3), the per ha cost of irrigation was divided by the per ha volume of water required which was estimated by multiplying the discharge rate (m^3/hour) by pumping hours. and the product . The data on discharge rates were collected from the Central Groundwater Development Board[19].

Determinants of WES

The execution approach and focus of the watershed have evolved with experience and learning. The flow of ecosystem services varies across watersheds depending on various factors *viz.*

geographical location, type of soil, rainfall, land cover or vegetation, size of the watershed, extent of people participation, the implementing agencies, focus area of the watershed, etc.[8&20]. Ordinary Least Square (OLS) model was used to identify the determinants of WES and the quantity of ecosystem services generated was regressed of a set of seven explanatory variables. The mathematical expression of the model is given in Equation (2).

$$WES = \mathrm{b0} + \mathrm{X\,b} + \varepsilon \qquad (2)$$

Where WES is the value of watershed ecosystem services, b_0 is the intercept, X is the matrix of explanatory variables, b is the vector of slope coefficients, and ε is the error term. Separate models were formulated for soil retention and water augmentation services. Since no sufficient studies were there for carbon sequestration, separate model could not be run.

The list of the explanatory variable along with a-priory hypothesis is given below.

Agro-climatic conditions of the watershed: Agro-climatic conditions of watershed is one of the important factor in generating ecosystem services as topography, soil types, vegetation cover, etc varies considerably. The occurrence of runoff is relatively higher in barren lands, regions with high rainfall intensity and steep slopes, higher clay content soil, and the small size catchment. Contrary to this, the forestland and grassland have strong soil retention and water infiltration ability[21]. Therefore, it was assumed that there exists a positive relationship between runoff and soil loss. Considering this, we formulated the hypothesis that WES varies with the location of watersheds.

Rainfall: Runoff and soil loss are positively correlated with rainfall amount and intensity[22]. High precipitation will allow more water to infiltrate the sub-soil. Similar is the relationship between precipitation and aquifer recharge.

Scale of the watershed: The size of the watershed plays a vital role in generating multiple benefits. Macro watersheds are considered to be more economically efficient than the micro watersheds[2].

Implementing agency: The implemented agencies often influence the implementation of watersheds due to their different institutional arrangements, different levels of technology, and social interventions skills[23]. We hypothesized that the watershed implemented by the Government institutions has better institutional arrangements and technology skills and hence generates high ecosystem services than the private and non-governmental organizations.

Soil types: We assumed that watersheds with alluvial soil generate relatively more WES than the black cotton soils. The water infiltration rate is high in alluvial soil and low in black cotton soil[24].

Participatory management: Active and collective participation of different stakeholders in watershed activities is a vital component for the wider sustainable success of the watershed project[25]. Therefore, it was postulated that the watershed with participatory management generates higher services.

All the explanatory variables (except rainfall) were dichotomous dummy variables and coded as equal to one if variables are present and zero if they are not. The data were analysed using the statistical software STATA 14.

Results and Discussion

Estimation of ecosystem services

Tagging the monetary value of the ecosystem services become possible only if there is a proper accounting of the volume of ecosystem services. The per hectare volume of ecosystem services, estimated based on the meta-analysis of 221 watersheds, showed that watersheds management helps control soil erosion by 11.54 t $ha^{-1}y^{-1}$ ranging from one ton per ha to 55 tons/ha. It helps recharge groundwater by 1.94 meters varying from 0.10 meter to 10 meters, and sequestrating carbon by 0.34 t ha^{-1} ranging from 33kg to 722 kg (Table 2). In two-thirds of watersheds, the soil loss reduction was ≥5t ha^{-1} and in 35% of the watersheds, it was ≥10t ha^{-1}. The soil retention was as high as 20 t ha^{-1} in 17 % of the watershed (Table 3). Similarly, in about three-fourths of watersheds, the groundwater recharge was above one meter, and in 30% of watersheds, the water recharge was more than 2 meters.

The volume of ecosystem services computed in the previous section was converted into economic terms using the methodology specified above. The findings showed that watershed annually generates an economic value equivalent to 34113/ha. Water augmentation with the value of Rs. 19,796 was the foremost ES. Ensuring the availability of a safe and reliable water supply is a critical issue in Semi-arid tropical countries and more so in India. Estimates show that about 80–90% of rural and 50% of the urban population and half of the total irrigated area depends upon groundwater for their water requirement[26&27]. Groundwater recharge is also an important ecosystem function of the watershed for sustaining agriculture productivity in drought years and enhancing food and livelihood security[28]. It increases welfare of human-beings by solving the water scarcity problem in both the present and future and delaying the need for costly alternatives such as water purification and deep boreholes technology[29]. Therefore, scaling-up of watershed management programmes will not only help in solving water scarcity but also in minimizing the risks associated with agriculture.

The WES estimated for five major agro-climate zones of the country, where watershed development programmes have mainly been implemented, showed that the impact of watershed on groundwater recharge is highest in the Gujarat Plains (Table 4). This is due to the plain and less undulating physiographic along with alluvial and sandy loam soils in the zone. The soil retention function was maximum in the Eastern plateau and hills —the zone most prone to land degradation due to its topographic and land cover characteristics. The carbon sequestration was significantly high in watersheds in the Central and Western Plateau and Hills, and in the Eastern Plateau and Hills. This may be due to relatively higher vegetation cover in the zones. The area under the forest is relatively higher in these zones.

Given the complex challenges of natural resource management, the appropriate scale of implementation of watersheds is important. While there are studies that concluded that micro-watershed (<=1000 ha) approach enables amicable integration of land, water, and infrastructure development and promotes ecological and institutional sustainability[30], concerns of upstream-downstream interactions are equally been highlighted in the literature[31]. Studies have shown that hydrologic problems that arise in micro-watershed can be best addressed by operating at a macro-watershed (>1000 ha) scale. Ecosystem services were analyzed by the scale of watersheds showed that macro-watersheds are more effective in generating groundwater, soil retention and carbon sequestration services (Table 5). The differences were very high in case of groundwater and carbon retention. In future generation integrated watershed management, there is a need to scale up and implement macro-watersheds by managing clusters of micro-watersheds simultaneously instead of managing micro watersheds in a scattered manner, as this approach has already been included in Common Guidelines for Watershed Development Projects, 2008.

Analysis of ecosystem services by soil type revealed that soil retention was highest in watersheds with sandy loam soils (23.76 t/ha) followed by red soils (16.85 t/ha) and lowest in black cotton soils as these are rich in clay and resist erosion well because of the strong bonding forces between particles and the humus. However, in relative terms, it was highest in alluvial soils (53%). The same was true in the case of groundwater recharge as it was relatively higher in the watershed with sandy lams and red soils due to high infiltration rate compared to black cotton soils. Carbon retention was highest in alluvial-soil type-watersheds and lowest in black soils.

The level of participation of people in the planning, implementation, maintenance, and monitoring phases of watershed programs also affects the management of watersheds and hence the level of ecosystem services generated. We estimated ecosystem services by level of people's participation. In most of the studies, the level of participation was categories as high (people participate in planning, implementation and maintenance is more than 80% of the watershed activities), medium (level of participation ranges from 50-80%), and low (level of participation in <50% activities). The results of the impact of people's participation showed that people's participation enhances ecosystem services to a great extent. For example, the soil retention was higher by 55 per cent and the groundwater recharge was higher by 3.67 times where the level of participation was high as compared to the watershed where the level of participation was low (Table 6). Hence, one can conclude that the active participation of all stakeholders is an essential element in achieving sustainability of watershed programs and receiving higher ES.

The robustness of the results was tested empirically using econometric analysis. Two separate models were run to identify the factors affecting ecosystem services wherein the services generated from groundwater recharge function and soil retention function were regressed on a set of explanatory variables listed in the methodology section. The results confirmed that the location of the watershed, the scale of the watershed, and the people's participation significantly affect the level of ecosystem generated (Table 7).

The payment for Ecosystem Services (PES) is being encouraged in environmental governance[32] under the assumption that this procedure might increase the economic efficiency of managing ES[33&34]. South Africa and Mexico have started PES for services provided by watersheds, and the USA, Costa Rica, and Nicaragua for biodiversity conservation[35] and providing incentives for positive environmental externalities[36]. However, there is no PES mechanism adopted in India because of a lack of studies on the valuation of ES.

Conclusion

Assessments connect ecosystem and human welfare to achieve restoration. There have been an increasing number of studies conducted on various ecosystem service assessments, but little has been done on watershed management. This study estimated and evaluated the supporting and regulating ecosystem services from watersheds and find that a well-managed watershed generated ecosystem services (excluding provisioning) to the tune of Rs. 34,113 per hectare. Groundwater recharge is the foremost important function of watershed accounting for close to 60 per cent of total regulating and supporting services generated. Participatory management of watersheds is more effective in watersheds and addressing socio-economic considerations and hence enhancing the ecosystem services. However, operating at the micro-watershed scale does not necessarily help in augmenting the total value of ecosystem services as hydrological problems and issues of upstream-downstream interactions are better addressed in macro-watersheds. Therefore, implementing a large size watershed (macro-level) with active people's participation is required to acquire the potential benefits of watershed programs in terms of socio-economic, ecological balance, and equity aspects. The macro-watershed can be implemented by managing clusters of micro-watersheds simultaneously instead of managing micro watersheds in a scattered manner. This will require building the watershed governance capacity. To improve people's participation and success of watersheds, there is a need for trust building through incorporating the need of local communities in the objective of watershed management. This can be done by ensuring equal distribution of tangible and intangible benefits for the community associated with the watershed.

The study will sensitize the stakeholders and policymakers about ES provided by watersheds and the need for protecting and enhancing these services. The study also highlights that efforts are needed to strengthen the database at various levels so that other WES such as flood mitigation, nutrients, water recycling, greenhouse gases regulation (regulating services), recreation, inspiration, institutional capacity building, education enhancement (cultural services), etc. can be included in future studies for valuation in monetary terms of these important WESs. It will facilitate mainstreaming ecosystem services in the development process.

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Table 1. Data requirement and valuation methodologies for Watershed Ecosystem Services

WES	WES unit	Data	Valuation methods
Soil retention	t ha^{-1}	Soil loss, nutrient content of the soil, the market price of nutrients	Avoided cost method[37&38]
Carbon sequestration	kg ha^{-1}	Carbon stock in soil, carbon price (Rick et al. 2018)	Avoided cost method[16]
Water augmentation	Meter (m)	GW level, irrigation water price	Market price method[36 &39]

Note: 't', 'ha', and GW stand for tons, hectare, and groundwater, respectively.

Table 2. Ecosystem services from watershed development

Particulars	Mean	Min.	Max.	t stat	Values (Rs/ha)
Soil retention (t $ha^{-1)}$	11.54	1.00	55.30	4.97	6,923
Carbon sequestration (kg $ha^{-1)}$	337	33	722	3.10	7394
Water augmentation (Meter)	1.94	0.10	10.00	15.38	19,796

Table 3. Distribution (%) of the watershed by different ranges of soil retention, carbon sequestration and groundwater recharge

Soil retention (t ha^{-1})	< 5	5-10	10 -20	> 20
Watershed (%)	34	31	18	17
Carbon sequestration (kg ha^{-1})	<200	200-400	400-600	>600
Watershed (%)	56	32	08	04
Water augmentation (m)	<0.5	0.5-1	1-2	>2

Watershed (%)	07	17	46	30

Table 4. Watershed ecosystem services by agro-climatic zones in India

Agro-climatic zone	States covered	GWR (m)	Soil retention (t ha^{-1})	Carbon sequestration (kg ha^{-1})
Western Himalayan and Shiwalik Foothills (GA: 42.60 m ha)	Jammu Kashmir, Uttarakhand, Himachal Pradesh, Haryana and Punjab	1.66 (22)	12.8 (09)	246.43 (05)
Gujarat Plains (GA:5.04 m ha)	Gujarat	3.60 (03)	10.2 (01)	183.50 (01)
Southern Semi-arid Tropics (GA: 59.69 m ha)	Andhra Pradesh, Karnataka, Telangana and Tamil Nadu	2.40 (53)	4.70 (07)	114.17 (08)
Central and Western Plateau and Hills (GA: 96.19 m ha)	Madhya Pradesh, Rajasthan, Maharashtra and Goa	1.70 (58)	10.9 (07)	580.28 (09)
Eastern plateau and hills (GA: 46.48 m ha)	Chhattisgarh, Jharkhand, Bihar, Jharkhand and Odisha	1.13 (12)	22.3 (04)	378.09 (02)

Note: GA is the geographical area in million ha: Figures presented in parenthesis are the number of watersheds; GWR is groundwater recharge

Table 5. Watershed ecosystem services by scale of watershed and soil type

Particulars	GWR(m)	Soil retention (t ha^{-1})	Soil retention (%)	Carbon retention (kg ha^{-1})
Scale of watershed				
Micro (<=1000 ha)	1.39	11.62	59.77	244

Macro (>1000 ha)	2.46	11.43	67.50	584
Soil type				
Alluvial soil	1.83	7.85	52.61	505
Red soils	2.31	16.85	37.18	357
Sandy loam soils	2.21	23.76	49.21	292
Black cotton soil	1.73	7.71	36.62	134

Table 6. Watershed Ecosystem Services by the level of people's participation

Ecosystem services	Unit	People's participation		
		High	Medium	Low
Soil retention	t ha^{-1}	13.81 (3.74)	10.71 (3.83)	8.93 (3.82)
Carbon sequestration	kg ha^{-}	335 (2.96)	211 (1.27)	367 (7.74)
Groundwater recharge	meters	2.79 (10.63)	1.88 (9.98)	0.76 (4.76)

Note: Figures in parentheses are the t-values

Table 7. Key determinants of watershed ecosystem services: Regression coefficients

Variables	Variable name	GWR	Soil retention
	Intercept	-0.34	13.50
Agro-climatic zone (Reference: Eastern plateau and hills)	Western Himalayan and Shiwalik foothills zone	1.47*	23.44
	Gujarat plain & hill zone	1.35	12.32
	Southern zone	1.11	9.86
	Central and Western plateau- hill zone	0.98	9.44
Rainfall	Continuous variable	0.00002	-11.54
Size of watershed (Reference: Micro watersheds)	Macro (>1000 ha)	0.69*	13.65*
Implementing agency (Reference: Non-governmental organization)	Governments	0.78	5.08
Soil types (Reference: Black cotton)	Alluvial soil	0.47	21.57
	Red soils	0.30	4.50
	Sandy loam soils	0.26	1.27

People's participation (Reference: Low participation)	High	1.12*	34.04*
	Medium	0.08	6.94
R^2		0.45	0.60
Number of observations		69	56

Note: * Indicate levels of significance at 5%.