Assessment of watershed management ecosystem services in India: a meta-analysis

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Besides increasing agricultural productivity, well-developed watersheds have immense potential to minimize land degradation, mitigating the adverse impact of climate change and generating several other ecosystem services (ES). Quantifying these services is quintessential in operationalizing the concept of management and decision-making relating to watershed management. The present study estimates the value of regulating (soil conservation and carbon sequestration) and supporting ES (groundwater recharge) generated by watersheds in India, and examines the factors that influence the flow of ES from watersheds. The study followed a meta-analysis approach using information from 221 watersheds in 5 major agro-climatic zones of the country. We found that the watershed generates ES to the tune of Rs 34,113 per ha, with water recharging alone accounting for 60% of it. It shows that people's participation in the planning, implementation and management of watersheds significantly enhances ES. Macro-watersheds (≥ 1000 ha) are more effective in generating ES, underscoring the need for investment in watersheds management in the semi-arid tropical regions, where problems of degradation of natural resources are more pronounced. This study suggests policies for land restoration and payment for ES to increase their flow.

Keywords: Carbon sequestration, ecosystem services, groundwater management, meta-analysis, participatory watershed, soil conservation.

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 programmes have evolved from focusing on a structure-driven compartmental approach to soil conservation and rainwater harvesting to an integrated land management approach for the constant flow of ecosystem services (ES) – benefits that humans get from natural and healthy ecosystems – while neutralizing land degradation and water scarcity[2–5]. Besides strengthening food and livelihood security, watershed management can increase the resilience of agricultural systems to climate change, achieve the targets of land degradation neutrality and generate multiple ES (provisioning, supporting, regulating and cultural) for the society[6].

Watershed services had no identifiable monetary terms and were therefore overlooked in the trading system. Valuation of ES builds the economic basis for investing in natural resource programmes and efficient use of limited funds, specifically in the ecologies where the problems of degradation of natural resources are more pronounced. Quantifying of ES 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 this article), 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. is scattered and inconsistent[9–11]. With this background, the present study estimates the monetary value of regulating and supporting services provided by watersheds. These ES vary across watersheds due to factors such as physiography, soil type, rainfall, size of the watershed, institutions/implementing agencies, people's participation, etc. The insight into factors that influence ES generated by watersheds is crucial for the efficient, cost-effective and sustainable management of these watersheds. Therefore, the present study identifies the key factors influencing these watershed services.

Data and methods

Data collection and database structure

This study is a meta-analysis of the scientific literature evaluating watersheds in India. The keywords used in different combinations in exploring the scientific studies were 'watershed', 'watershed impact', 'watershed development', 'watershed management' + 'ecosystem services', 'environmental services', 'ecological services', 'soil loss', 'soil retention', 'carbon sequestration', 'aquifer recharge' and 'water augmentation' + 'India'. Scopus, the popular abstract and citation database, was used to perform this task. 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

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Table 1. Data requirement and valuation methodologies for watershed ecosystem services (WES)

WES	Data	Valuation methods
Soil retention (tonne ha^{-1})	Soil loss, nutrient content of soil, market price of nutrients	Avoided cost method[38,39]
Carbon sequestration (kg ha^{-1})	Carbon stock in soil, carbon price[15]	Avoided cost method[16]
Water augmentation (m)	Groundwater level, irrigation water price	Market price method[37,40]

criteria and were used to estimate the unit coefficients of WES. Of the total studies, 148 were concerned with the estimation of groundwater augmentation, 28 with soil loss and 25 with 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 the analysis[12].

Monetization of WES

Once the unit coefficients of three different WES (soil retention, water augmentation and carbon retention) were calculated, the monetary values associated with them were computed using the avoided cost principle or the market price method. Table 1 summarizes data requirements and valuation methodologies for different services, while the detailed methodology is described below.

Soil retention

Soil retention is one of the most important ES generated by 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 expense needed to restore or avoid damage caused to the ecosystem, assuming that the value of retaining ES is higher than the replacement cost[13]. Presently, the avoided cost is the economical price of fertilizers required to supply the equivalent quantity of nutrients that otherwise would have been lost, i.e. without watershed management. The per hectare quantity of nutrients saved was multiplied by the economical price (market price and subsidies) of chemical fertilizers, as shown in eq. (1) below. The data on prices of fertilizers in terms of nutrients were taken from the Department of Fertilizers, Ministry of Chemicals and Fertilizers, Government of India (GoI).

$$\mathrm{MV_{SR}} = Q_{\mathrm{N}}P_{\mathrm{N}} + Q_{\mathrm{P}}P_{\mathrm{P}} + Q_{\mathrm{K}}P_{\mathrm{K}}, \qquad (1)$$

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 the economical price for N, P and K respectively.

Carbon sequestration

Soil degradation strongly impacts the emission of carbon dioxide (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 can sequester carbon, thereby offsetting greenhouse gas emissions[14]. Similar to the soil retention service, the monetary value of the carbon sequestration ($\mathrm{MV_{CS}}$) was estimated by multiplying the avoided cost per tonne of CO_2 by the per hectare carbon sequestration potential of watershed management (tonne/ha). The damage avoided cost of CO_2 was taken from the published literature[15,16]. In most of the studies, carbon sequestration has been reported in the form of soil organic carbon (SOC) and hence it was converted into CO_2 equivalent using the conversion coefficient of the Intergovernmental Panel on Climate Change (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 price of irrigation water is not available on a volumetric basis, it was estimated indirectly using the plot-level data collected under the cost of cultivation (CoC) scheme of GoI[18]. This scheme provides data on the per-hectare cost of irrigation and pumping hours (h/ha). To arrive at the irrigation water price (Rs/m^3), the per hectare cost of irrigation was divided by the per hectare volume of water required, which was estimated by multiplying the discharge rate (m^3/h) by pumping hours. The data on discharge rates were collected from the Central Groundwater Development Board (GoI)[19].

Determinants of WES

The focus and implementation approach of the watersheds have been evolving over time the experience and learning. The flow of ES varies across watersheds depending on several factors, viz. geographical location, type of soil, rainfall, land cover or vegetation, size of the watershed, the extent of people's participation, implementing agencies, the focus area of the watershed, etc.[8,20]. Ordinary least square (OLS) model was used to identify the determinants of WES. The dependent variable in the regression was the quantity of ecosystem services generated from watershed while explanatory variables are listed below. The mathematical expression of the model is given in eq. (2).

$$\mathrm{WES} = b_0 + Xb + \varepsilon, \tag{2}$$

where WES is the value of watershed ecosystem services, b_0 the intercept, X the matrix of explanatory variables, b the vector of slope coefficients and ε is the error term. Separate models were formulated for soil retention and water augmentation services. Due to the lack of studies there for carbon sequestration, a separate model could not be run.

The list of explanatory variables and the a priori hypothesis is given below.

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

Rainfall: Run-off and soil loss are positively correlated with rainfall amount and intensity[22]. High precipitation will allow more water to infiltrate the subsoil. 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 micro-watersheds[2].

Implementing agency: The implementing agencies often influence the implementation of watersheds due to their different institutional arrangements, different levels of technology and social intervention skills[23]. We hypothesized that the watersheds implemented by Government institutions have better institutional arrangements and technology skills, and hence generate high ES than the private and non-Governmental organizations.

Soil type: We assumed that watersheds with alluvial soil generate relatively more WES than those with 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 vital 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 the variables were present and zero if not. The data were analysed using the statistical software STATA[14].

Results and discussion

Estimation of ecosystem services

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

The volume of ES computed was converted into economic terms using the methodology mentioned above. The findings show that a watershed annually generates an economic value equivalent to 34,113/ha. Water augmentation with a value of Rs 19,796 was the foremost ES. Ensuring the availability of 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 depend upon groundwater for their requirements[26,27]. Groundwater recharge is an important ecosystem function of the watersheds for sustaining agriculture productivity in drought years, and enhancing food and livelihood security[28]. It is key to the welfare of human by solving the water scarcity problem in the present and future, and delaying the need for costly alternatives such as water purification and deep boreholes technology[29]. Therefore, scaling-up watershed management programmes will not only help solve water scarcity, but also minimize the risks associated with agriculture.

WES estimated for five major agro-climate zones of India, where watershed development programmes have mainly been implemented, showed that the impact of the watershed on groundwater recharge was highest in the Gujarat plains (Table 4). This is due to the plain and less undulating physiography 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. Carbon sequestration was significantly high in the 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 these zones. The area under forests is relatively high in these zones.

Given the complex challenges of natural resource management, the appropriate scale of implementation of watersheds is important. While some studies have concluded that the micro-watershed ($\leq$1000 ha) approach enables amicable

Table 2. Ecosystem services from watershed development

Particulars	Mean	Minimum	Maximum	*t* stat	Value (Rs/ha)
Soil retention (tonne ha^{-1})	11.54	1.00	55.30	4.97	6923
Carbon sequestration (kg ha^{-1})	337	33	722	3.10	7394
Water augmentation (m)	1.94	0.10	10.00	15.38	19,796

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

Soil retention (tonne 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. WES by agro-climatic zones in India

Agro-climatic zone	States covered	Groundwater recharge (GWR; m)	Soil retention (tonne ha^{-1})	Carbon sequestration (kg ha^{-1})
Western Himalayan and Shiwalik Foothills (Geographical area (GA): 42.60 m ha)	Jammu and Kashmir, Uttarakhand, Himachal Pradesh, Haryana and Punjab	1.66 (22)	12.8 (9)	246.43 (5)
Gujarat plains (GA: 5.04 m ha)	Gujarat	3.60 (3)	10.2 (1)	183.50 (1)
Southern semi-arid tropics (GA: 59.69 m ha)	Andhra Pradesh, Karnataka, Telangana and Tamil Nadu	2.40 (53)	4.70 (7)	114.17 (8)
Central and Western plateau and hills (GA: 96.19 m ha)	Madhya Pradesh, Rajasthan, Maharashtra and Goa	1.70 (58)	10.9 (7)	580.28 (9)
Eastern plateau and hills (GA: 46.48 m ha)	Chhattisgarh, Jharkhand, Bihar and Odisha	1.13 (12)	22.3 (4)	378.09 (2)

Figures in parenthesis show the number of watersheds.

integration of land, water and infrastructure development, and promotes ecological and institutional sustainability[30], concerns of upstream–downstream interactions have equally been highlighted in the literature[31]. Studies have shown that hydrologic problems that arise in micro-watersheds can be best addressed by operating at a macro-watershed (>1000 ha) scale. ES were analysed by the scale of watersheds showed that macro-watersheds were more effective in generating groundwater, soil retention and carbon sequestration services (Table 5). The differences were high in the 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 the Common Guidelines for Watershed Development Projects, 2008 (ref. 32).

Analysis of ES by soil type revealed that soil retention was highest in watersheds with sandy loam soils (23.76 tonne/ha) followed by red soils (16.85 tonne/ha), and lowest in black cotton soils as these are rich in clay and resist erosion because of the strong bonding forces between soil 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 watersheds with sandy loam and red soils due to the high infiltration rate compared to black cotton soil. Carbon retention was highest in alluvial soil-type watersheds and lowest in black soil watersheds.

The level of people's participation in the planning, implementation, maintenance and monitoring phases of watershed programmes also affects the management of watersheds, and hence the level of ES generated. We estimated ES services by the level of people's participation. In most of the studies, the level of participation was categorized as high (people's participation in planning, implementation and maintenance as more than 80% of the watershed activities), medium (level of participation ranged from 50% to 80%), and low (level of participation in <50% activities). The results showed that people's participation enhanced ES to a great extent. For example, soil retention was higher by 55% and groundwater recharge was higher by 3.67 times in watersheds where the level of participation was high 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 essential in achieving sustainability of watershed programmes and receiving higher ES.

Table 5. WES by scale of watershed and soil type

Particulars	GWR (m)	Soil retention (tonne 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 soil	2.31	16.85	37.18	357
Sandy loam soil	2.21	23.76	49.21	292
Black cotton soil	1.73	7.71	36.62	134

Table 6. WES by the level of people's participation

	People's participation		
Ecosystem service	High	Medium	Low
Soil retention (tonne ha^{-1})	13.81 (3.74)	10.71 (3.83)	8.93 (3.82)
Carbon sequestration (kg ha^{-1})	335 (2.96)	211 (1.27)	367 (7.74)
GWR (m)	2.79 (10.63)	1.88 (9.98)	0.76 (4.76)

Figures in parentheses are the *t*-values.

Table 7. Key determinants of WES: regression coefficients

Variables	Variable name	GWR (m)	Soil retention (%)
Agro-climatic zone (reference: Eastern plateau and hills)	Intercept	–0.34	13.50
	Western Himalayan and Shiwalik Foothills zone	1.47*	23.44
	Gujarat plains and Hill zone	1.35	12.32
	Southern zone	1.11	9.86
	Central and western plateau and 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)	Government	0.78	5.08
Soil type (reference: black cotton)	Alluvial soil	0.47	21.57
	Red soil	0.30	4.50
	Sandy loam soil	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

*Indicates level of significance at 5%.

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

The payment for ecosystem services (PES) is being encouraged in environmental governance[33] under the assumption that this might increase the economic efficiency of managing ES[34,35]. South Africa and Mexico have started PES for services provided by watersheds, and USA, Costa Rica and Nicaragua for biodiversity conservation[36] and providing incentives for positive environmental externalities[37]. However, there is no PES mechanism in India due to the lack of studies on the valuation of ES.

Conclusion

Assessments connect ecosystem and human welfare to achieve restoration. An increasing number of studies have been conducted on various ES assessments, but little has been done on watershed management. The present study estimated and evaluated the supporting and regulating ES from watersheds and found that a well-managed watershed can generate ES (excluding provisioning) to the tune of Rs 34,113/ha. Groundwater recharge was the foremost important function of the watershed accounting for nearly 60%

of total regulating and supporting services generated. Participatory management was more effective in watersheds and addressed the socio-economic considerations, hence enhancing the ES. However, operating at the micro-watershed scale does not necessarily help augment the total value of ES, as hydrological problems and issues of upstream–downstream interactions are better addressed in macro-watersheds. Therefore, implementing a large-sized watershed (macro-level) with active people's participation is required to acquire the potential benefits of watershed programmes in terms of socio-economic, ecological balance and equity aspects. Macro-watersheds can be implemented by managing clusters of micro-watersheds simultaneously instead of managing them in a scattered manner. This will require building the watershed governance capacity. To encourage people's engagement and watershed success, trust must be built by incorporating the needs of local communities into watershed management objections. This can be done by ensuring equal distribution of tangible and intangible benefits for the communities associated with the watersheds.

This study will help sensitize the stakeholders and policy-makers about the ES provided by watersheds, and the need to protect and enhance these services. It also highlights that efforts are needed to strengthen the database at various levels so that other WES such as flood mitigation, nutrients, water recycling, regulation of greenhouse gases (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 WES. It will also facilitate mainstreaming ES in the development process.

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1. Wang, G., Mang, S., Cai, H., Liu, S., Zhang, Z., Wang, L. and Innes, J. L., Integrated watershed management: evolution, development and emerging trends. *J. For. Res*., 2016, **27**, 967–994.
2. Joshi, P. K., Jha, A. K., Wani, S. P., Sreedevi, T. K. and Shaheen, F. A., Impact of watershed program and conditions for success: a meta-analysis approach. In Global theme on agroecosystems (Report no. 46), International Crops Research Institute for the Semi-Arid Tropics (ICRISAI), Hyderabad, and National Centre for Agricultural Economics and Policy Research, New Delhi, 2008.
3. Wani, S. P., Anantha, K. H., Sreedevi, T, K., Sudi, R., Singh, S. N. and D'Souza, M., Assessing the environmental benefits of watershed development: evidence from the Indian semi-arid tropics. *J. Sustain. Watershed Sci. Manage*., 2011, **1**(1), 10–20.
4. IPBES, Preliminary guide regarding diverse conceptualization of multiple values of nature and its benefits, including biodiversity and ecosystem functions and services. Intergovernmental Platform on Biodiversity and Ecosystem Services, Bonn, Germany, 2015.
5. Tezer, A. *et al.*, Ecosystem services-based multi-criteria assessment for ecologically sensitive watershed management. *Environ. Dev. Sustain*., 2018, **22**, 2431–2450.
6. NAAS, Mitigating land degradation due to water erosion. Policy Paper 88, National Academy of Agricultural Sciences, New Delhi, 2017.
7. De Groot, Alkemade, R. S., Braat, L. H. and Willemen, L., Challenges in integrating the concept of ecosystem services and values in landscape planning, management, and decision making. *Ecol. Complex*, 2010, **7**(3), 260–272.
8. Joshi, P. K., Jha, A. K., Wani, S. P., Joshi, L. and Shiyani, R. L., Meta-analysis to assess the impact of watershed program and people's participation. In Comprehensive assessment of Watershed Management in Agriculture (Research Report No. 8), ICRISA and Asian Development Bank, Hyderabad, 2005.
9. Ram Babu and Dhyani, B. L., Impact assessment of watershed technology in India (Chapter 15). In *Impact of Agriculture: Post-Green Revolution Evidence from India*, ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi, India, 2005, pp. 175–186.
10. Palsaniya, D. R., Singh, R., Tewari, R. K., Yadav, R. S. and Dhyani, S. K., Integrated watershed management for natural resource conservation and livelihood security in semi-arid tropics of India. *Indian J. Agric. Sci*., 2012, **82**(3), 241–247.
11. Mondal, B. *et al.*, Augmentation of water resources potential and cropping intensification through watershed programs. *Water Environ. Res*., 2018, **90**(2), 101–109.
12. Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G. and Grp, P., Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement (reprinted from *Annals of Internal Medicine*). *Phys. Ther*., 2009, **89**(9), 873–880.
13. Jonsson, J. O. and Daviosdottir, B., Classification and valuation of soil ecosystem services. *Agric. Syst*., 2016, **145**, 24–38.
14. Hanson, C., Yonavjak, L., Clark, C., Minnemeyer, S., Leach, A. and Boisrobert, L., Southern Forests for the Future, World Resources Institute, Washington, DC, 2010.
15. Ricke, K., Drouet, L., Caldeira, K. and Tavoni, M., Country-level social cost of carbon. *Nature Climate Chang*., 2018, **8**, 895–900.
16. Ecosystem accounts for India – report of the NCAVES project. Ministry of Statistics and Programme Implementation, Government of India, 2021, p. 76.
17. Mekuria, W., Veldkamp, E., Tilahun, M. and Olschewski, R., Economic valuation of land restoration: the case of exclosures established on communal grazing lands in Tigray, Ethiopia. *Land Degrad. Dev*., 2011, **22**, 334–344.
18. MoA&FW, Plot level summary data under the cost of cultivation scheme. Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India, 2018.
19. CGWB, National compilation on dynamic groundwater resources of India. Central Groundwater Development Board, Ministry of Jal Shakti, GoI, 2019.
20. Ziadat, F. M. and Taimeh, A. Y., Effect of rainfall intensity, slope, land use and antecedent soil moisture on soil erosion in an arid environment. *Land Degrad. Dev*., 2013, **24**, 582–590.
21. Nolan, B. T., Healy, R. W., Taber, P. E., Perkins, K., Hit, K. J. and Wolock, D. M., Factors influencing groundwater recharge in the eastern United States. *J. Hydrol*., 2007, **332**(1–2), 187–205.
22. Zhang, X., Hu, M. G., Yang, H., Zhang, Z. and Zhang, K., Effects of topographic factors on runoff and soil loss in Southwest China. *Catena*, 2018, **160**, 394–402.
23. Floress, K., Akamani, K., Halvorsen, K. E., Kozich, A. T. and Davenport, M., The role of social science in successfully implementing watershed management strategies. *Contemp. Water Res. Educ*., 2015, **154**, 85–105.
24. Selvarani, G., Maheswaran, G. and Elangovan, K., Identification of artificial recharge sites for Noyyal River Basin using GIS and remote sensing. *J. Indian Soc. Remote Sensing*, 2017, **45**, 67–77.
25. Wani, S. P., Sreedevi, T. K., Vamsidhar, T. S., Reddy, T. V. S., Venkateshvarlu, B. and Prasad, C. S., Community watersheds for improved livelihoods through consortium approach in drought-prone rainfed areas. *J. Hydrol. Res. Dev*., 2008, **23**, 55–77.
26. Dynamic Groundwater Resources of India, Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation, GoI, 2014.
27. Das, B., Pal, S. C., Malik, S. and Chakrabortty, R., Modeling groundwater potential zones of Puruliya district, West Bengal, India using remote sensing and GIS techniques. *Geol. Ecol. Landsc*., 2018, **3**(3), 223–237.

28. Nagaraja, N., Pradhania, U., Chengappab, P. G., Basavaraja, G. and Kanwar, R., Cost effectiveness of rainwater harvesting for groundwater recharge in micro-watersheds of Kolar District of India: the case study of Thotli micro-watershed. *Agric. Econ. Res. Rev.*, 2011, **24**, 217–223.
29. Burnett, K. and Wada, C. A., Optimal groundwater management when recharge is declining: a method for valuing the recharge benefits of watershed conservation. *Environ. Econ. Policy Stud.*, 2014, **16**, 263–278.
30. Farrington, Turton, J. C. and James, A. J. (eds), *Participatory Watershed Development Challenges for the Twenty–First Century*, Oxford University Press, New Delhi and New York, 1999.
31. Reddy, V. R., Saharawat, Y. S. and George, B., Watershed management in South Asia: a synoptic review. *J. Hydrol.*, 2017, **551**, 4–13.
32. GoI, Common guidelines for watershed development projects – 2008, National Rainfed Area Authority, Planning Commission, Government of India, 2011.
33. Salzman, J., Bennett, G., Carroll, N., Goldstein, A. and Jenkins, M., The global status and trends of payments for ecosystem services. *Nature Sustain.*, 2018, **1**, 136–144.
34. Pirard, R., Market-based instruments for biodiversity and ecosystem services: a lexicon. *Environ. Sci. Policy*, 2012, **19–20**, 59–68.
35. Wunder, S., Revisiting the concept of payments for environmental services. *Ecol. Econ.*, 2015, **117**, 234–243.
36. Kinzig, A. P., Perrings, C., Chapin, F. S., Polasky, S., Smith, V. K., Tilman, D. and Turner, B. L., Paying for ecosystem services–promise and peril. *Science*, 2011, **334**, 603–604.
37. Nayak, A. K. *et al.*, Assessment of ecosystem services of rice farms in eastern India. *Ecol. Process.*, 2019, **8**, 35.
38. Gulati, A. and Rai, S. C., Cost estimation of soil erosion and nutrient loss from a watershed of the Chotanagpur Plateau, India. *Curr. Sci.*, 2014, **107**(4), 670–674.
39. Sharda, V. N., Mandal, D. and Dogra, P., Assessment of cost of soil erosion and energy-saving value of soil conservation measures in India. *Indian J. Soil Conserv.*, 2019, **47**(1), 1–6.
40. Wilson, M. A. and Carpenter, S. R., Economic valuation of freshwater services in the United States: 1971–1997. *Ecol. Appl.*, 1999, **9**(3), 772–783.

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