NOTATION TRENDPLUS PUBLISHING
WHERE IDEAS MEET IMPACT

Volume-1, Issue 1, August 2026, Page No- 88-106

Journal of Sustainable Futures and Interdisciplinary Solutions (JSFIS)

Integrated Watershed Management for Sustainable Water Resource Conservation: A Comprehensive Assessment of Hydrological, Environmental, and Socioeconomic Outcomes

Kuldeep Singh

Tata Institute of Social Sciences (TISS), Mumbai.

Article Received: 29-03-2026

Revised Version: 29-06-2026

Accepted: 08-07-2026

*Corresponding Author

Kuldeep Singh

E-Mail Id: singhkuldeep224@gmail.com

Abstract: Comparative quantitative study across five representative watershed regions to evaluate the effectiveness of integrated watershed management (IWM) for sustainable water resource conservation. The research employed a field-based experimental design integrating hydrological assessments, remote sensing analysis, socioeconomic surveys, and statistical modeling across 25 micro-watersheds and 350 households. Ten IWM interventions were implemented and monitored, including rainwater harvesting, check dams, farm ponds, contour bunding, afforestation, and community-based watershed management. Key parameters such as groundwater recharge, surface runoff, soil moisture, agricultural productivity, and a composite sustainability index (scored 0–100) were measured before and after intervention. Statistical analyses included paired t-tests, ANOVA, Pearson correlation, and multiple linear regression at $p<0.05$. Community-based watershed management achieved the highest sustainability index of 93, followed by check dams at 89. Across all watersheds, groundwater recharge increased significantly from 118 mm yr^{-1} to 186 mm yr^{-1} (57.6% improvement), while surface runoff decreased from 452 mm to 296 mm (34.5% reduction). Soil moisture rose by 58.1%, water use efficiency improved by 46.5%, vegetation cover increased by 52.9%, and agricultural productivity grew by 41.2%. Annual farm income rose from \$1,560 ha^{-1} to\$2,340 ha^{-1} (50% gain). Pearson correlation analysis revealed strong positive relationships among variables, with groundwater recharge correlating with agricultural productivity at $r=0.91$ and with the sustainability index at $r=0.93$. Major constraints included insufficient funding (mean 4.58/5) and poor community participation (4.33/5). Projections from 2025 to 2035 indicate that the sustainability index could rise from 72 to 94 under continued integrated management.

Keywords: Integrated Watershed Management, Water Resource Conservation, Hydrological Assessment, Environmental Sustainability, Socioeconomic Outcomes.

Introduction

Water crisis is one of the highly serious issues in the world, exacerbated by changing climate, rising population, and higher intensity land use (Wani, 2021). Freshwater resources are undergoing a series of changes at multiple spatial and temporal scales, both in terms of quality and quantity, and for both supply and uses purposes, including domestic, agriculture and industry (Davis, 2007). This fragile state of sustainable water management is common in many parts of the developing world, in particular in regions that possess a variety of agro-climatic zones, characterized by a combination of unpredictable rainfall patterns, insufficient topography and land cover and weak institutional capacity, which is making it increasingly difficult to cope with sustainable water management (Aliaga, 2002). In this context, watershed management is developing as an essential approach to tackle the multifaceted issues of water conservation, land restoration and enhancement of rural livelihood (Tesfaye et al., 2018).

Integrated watershed management (IWM) is participatory, multi-sectoral approaches that coordinate the use of land resource, water resource and vegetation resource in a hydrological unit towards sustainable development outcomes (Meshesha & Khare 2019). IWM is based on the concept of deep interaction between upstream and downstream activities and necessity of structural (check dams, farm ponds), vegetative (afforestation, agroforestry) and institutional (community based governance) interventions, which need to be implemented jointly/synergically (Wani et al., 2003). Studies conducted in the past have found that IWM can result in less surface flow (9-24%) (Sharda et al, 2005) and improve groundwater recharge, along with better agricultural production in the semi-arid regions. However, most of the literature focuses on individual interventions or individual dimensions of outcomes, and there is much that remains unanswered to date about the impact of multiple interventions that are co-ordinated and that influence all dimensions of the hydrological, environmental and socioeconomic aspects simultaneously. (Qi & Altinakar, 2011).

The significance of this research is that it was comprehensive multi dimensional with ten interventions for IWM, in five representative regions in watersheds and in a plethora of agro climatic situation. The underlying hypothesis in motivating this study is that the coordinated practices that are implemented in IWM regime will lead to an increase in GWRP, reduction in surface runoff and betterment of agriculture and the sustainability of the watershed is significant. The ultimate objectives were to evaluate the effectiveness of these interventions in the field using a strict experimental design across all interventions to include hydrological monitoring, remote sensing analysis and socioeconomic surveys along with statistical modelling. Prior to and following intervention, there were measurements of water recharge, soil moisture, water use efficiency, vegetation cover, sediment loss, and a composite sustainability index (0-100) in 25 micro-watersheds, and within 350 households. The uniqueness of this work is the integration of holistic quantitative field measurements as well as modelling projections based on a realistic setting. The contribution of this work lies in bringing these methods together, and the novel knowledge and evidence generated for policy makers and practitioners to reach a balance between ecological integrity and the development potential of people living in water-stressed areas.

This paper continues like this in the remainder. Section 2 reviews the literature on IWM and gaps in knowledge are established. The materials and methods are described in Section 3 comprising of description of study area, design of the experiment and statistics employed. The results are shown in both hydrological, environmental and socioeconomic aspects as constraint analysis and future projection in Section 4. The results are discussed in terms of implications and compared with previous research, in Section 5, and policy recommendations are offered in Section 6.

Literature Review

Over the years, versatile, multi-objective, participatory watershed management approaches have been developing, and diverging from the traditional water resources management bottom up, top down, sectoral approaches (Tesfaye et al., 2018). Watershed projects adopted mainly provided structural measures (check dams and contour bunding) for controlling erosion and the prevention of the run-off, and social aspects and ecological feedback were seldom incorporated (Aliaga, 2002). In humans, it was the increased understanding of the interconnections between the various hydrological processes, communities' and institutions' livelihoods, and time, which resulted in the shift towards an integrated watershed management (IWM) paradigm (Davis, 2007).

There are numerous large-scale empiric, or 'what works' studies on the hydrological consequences of IWM interventions. In Tamilnadu, India, it was seen that participatory watershed programmes in which a combination of rain water harvesting structures associated with vegetative land management was applied reduces surface water runoff by 9–24%, while increasing the groundwater recharge by 20–35% (Sharda et al., 2005). A similar case study in the Somodo watershed in Ethiopia showed that the integrated interventions led to better baseflow water regimes and smaller peak water runoffs, which in turn, led to increased water availability during dry seasons (Tesfaye et al., 2018). The results illustrate the ability of coordinated action to alter the watershed flow characteristics, although most of these apply generally only to the agro-climatic areas, where conditions can vary.

The effects of waste on the environment have also been heavily discussed in the IWM literature. Significant improvements have been observed in the vegetative barrier in terms of vegetation cover, which led to reduced sediment loss in many afforestation and vegetative barrier projects, including the afforestation project implemented in the Pastan Hidupiatan River Catchment in Aceh, Indonesia, where water infiltration increased in the soil under vegetative barrier, thereby reducing sediment loses (Yudono, 2021). The impact of water quality improvements after the implementation of IWM have also been reported in various scenarios, including, the check dams and percolation tanks that increased the amount of sedimentation trapped and provided for better nutrient reduction, which resulted in increased water quality index (Wani et al., 2003). However, this multi-ecosystem approach, which quantifies several environmental factors at once (vegetation cover, sediment loss, water quality and biodiversity) is not very widespread, and as such, calls for a holistic study such as the present.

Participatory assessments, household surveys – and socioeconomic aspects of IWM – have been discussed. A series of studies on community involvement in water resource development plans in the Mayurakshi watershed showed that increased community involvement in such plans resulted in better adoption rates of conservation technologies, and improvements in agricultural productivity (Qi & Altinakar, 2011). In addition, economic feasibility analysis of IWM interventions also revealed an improvement in the farm income and cropping intensity in particular, primarily through the use of technological interventions such as drip irrigation (Meshesha & Khare, 2019). The relationship between socioeconomic outcomes and hydrological parameters, however, has been rarely investigated using a well-defined framework of correlation or regression analysis and the level of linkage and interconnection is thus not well known.

Various constraints for effective IWM can be found in various geographical contexts. The financial constraints and weak and divided institutional setup can also be a large problem in remote areas such as Yudono (Yudono, 2021). Community participation is known to be a critical component of sustainability success, but conflicting interests, unaware populations and limited incentives are key barriers to participation (Sharda et al., 2005). However, structural and vegetative strategies are inadequate in the face of climate variability, which is an additional challenge, and more adaptogenic management strategies are needed (Davis, 2007). Such limitations are documented on their own in most instances, but rarely are they prioritized or assessed as a whole from a perspective of watershed Sustainability to see how much impact each has.The relative impact and rank of these constraints has not been done before at the watershed level, which is the purpose of this research.

The present study is novel because for the first time it foregrounds 10 various IWM methods (pre- and post-) in five contrasting watersheds and analyses a wide variety of hydrological, environmental and socio-economic metrics. In addition, through the analysis of the interdependencies between the main features – groundwater recharge, vegetative cover, and agricultural productivity and sustainability index – new concepts are introduced about the synergistic mechanisms that can be applied through an integrated management technique. This project though, has synthesized this degree of ground-truth field measurement into water resources research with a predictive projection modelling and a systematic constraint ranking in a single experiment design, and so, in so doing, made a remarkable contribution to the body of evidence towards conservation of water resources for sustainability.

Materials and Methods

Study Design and Sampling Strategy

The field study results showed that a comparative quantitative and experimental research design were successfully applied in this research to evaluate water source conservation and integrated watershed management (IWM) practice. The research framework combined with hydrological assessments, watershed characterization with GIS, remote sensing analysis, direct field measurements, socioeconomic surveys and multivariate statistical modeling. The central concept of the design was to compare the soils performance of watersheds with and without conservation practices in the various agro-climatic zones to enable an understanding of watershed change that would occur due to coordinated management practices, not natural variation.

The study area comprised five watershed regions with different topographic, climatic and land-use conditions, typical of water-stressed areas – upper, middle, lower, semi-arid and forest watersheds. 25 micro-watershed units were selected to get 5 micro-watershed units in each region by stratified random sampling. A total of 14 households were drawn from each of the micro-watersheds that were proportional to the settlement density and 140 such households were surveyed. This stratification resulted in proper representation of all elevation zones, rainfall regimes and land-use types, providing high external validity of findings.

Integrated Watershed Management Interventions

Ten different interventions with integrated welfare of the watershed were implemented in all the study sites and their impact systematically studied. These interventions were distinguished into structural and vegetative and community based measures. These structural interventions included rainwater harvesting systems both rooftop and surface water catchment intervention structures, check dams, low height masonry/gabion structure at ephemeral stream to trap the runoff and enhance groundwater recharge rates, farm ponds, earthen constructed pond to store the runoff for supplementary irrigation, contour bunding, earthen built structure at contour lines to reduce the slope length and making ground to improve infiltration to groundwater and terracing, stepwise landscape design in steep landscape/earthen built structures at the contour lines to reduce the runoff of soil and to preserve the soil moisture, and percolation tanks, excavated earthen tanks to enhance groundwater recharge through inundation for a longer period. The vegetative measures undertaken comprised amendment of riparian zones by afforestation and dense lines of perennial grasses or shrubs planted along contours, to entrap sediment and slow sediment flow. The agronomic intervention included the implementation of drip irrigation (micro-irrigation systems for the better utilization of water resources by delivering water directly to the plant rhizosphere) while the institutional intervention comprised the creation of a community based watershed management (user groups, where there is participative involvement in the decision-making process regarding water allocation, maintenance schedules, and conflict resolution at the watershed level).

Baseline was conducted first, followed by one phase of each intervention as part of development by collaborating with school community.Planning and implementing interventions involved local stakeholders, and each was carried out in one implementation after basics. Implementation processes have adopted the common technical rules and procedures elaborated by the national watershed development programmes and the interventions on water in the two construction/operational evaluation phases have been carried out over the course of the process for quality assurance.

Data Collection Procedures

Primary data was gathered by various complementary approaches. Structured questionnaires to collect socioeconomic data were used for administering household surveys and capturing data in the domains of household water availability, agricultural production, farm income, cropping pattern and perceptions of the effectiveness of interventions. Field observations were conducted to verify the actions taken and land use changes. Global Positioning System (GPS) mapping was used to georeference all structures of intervention, monitoring points and all sampling locations. The instrument used to monitor stream flow was TBMs (tibba micro-watershed) which in turn were fitted with stage-discharge relationship at the outlet of each TBM and measurements were taken at weekly intervals throughout the monsoon season and fortnightly during the dry season. A network of 125 observation wells (five per micro-watershed) equipped with electronic water level recorders were used to measure groundwater levels monthly. Pre- and post-intervention soil moisture was measured in three random locations within each micro-watershed at 0 – 30 cm depth, composited and analyzed using the gravimetric method. Standard laboratory water quality analytical procedures were used to measure parameters like pH, turbidity, total dissolved solids, and biological oxygen demand for water samples taken quarterly at both upstream and downstream monitoring sites in each watershed (American Water Works Association et al., 1989).

The secondary data consisted of: Meteorological data (rainfall, temperature and evapotranspiration data from the closest weather stations pre- and post-intervention), remote sensing images (Landsat 8 OLI, at 30 m resolution and Sentinel2 MSI at 10 m resolution acquired during pre- and post-intervention periods), Digital Elevation Models (SRTM at 30 m resolution), and watershed development reports prepared by state and national agencies, government water resource databases and peer-reviewed scientific literature.

Parameters Measured and Analytical Methods

The parameters measured in this study, along with their units, are summarized in Table 1.

Table 1. Parameters measured in the study.

Parameter	Unit
Groundwater Recharge	mm year^{-1}
Surface Runoff	mm
Soil Moisture	%
Water Use Efficiency	kg m^{-3}
Sediment Loss	t ha^{-1} year^{-1}

Parameter	Unit
Vegetation Cover	%
Agricultural Productivity	t ha^{-1}
Household Water Availability	L day^{-1}
Sustainability Index	Score (0–100)

Groundwater recharge estimated using water table fluctuation method: , specific yield in the method determined from pumping tests, groundwater level in the monitoring period, period of time for which the groundwater level was monitored. Surface runoff was calculated at the watershed outlets by using calibrated structures of flumes and stage-discharge rating curves by considering the discharge over the storms and seasons. The moisture content of the soil was determined by gravimetric method and quoted as per cent of dry soil weight. The water use efficiency defined as crop yield (kg ha^{-1}) divided by total water application (m^3 ha^{-1}) was computed for the most common croptypes. The Universal Soil Loss Equation (USLE) was used to estimate the sediment loss at the gauging stations, and sediment samples of runoff were utilized for this purpose to validate the estimates. Derived vegetation cover data from Normalised Difference Vegetation Index (NDVI) using satellite data were calibrated using field data. Productivity was measured in terms of average production of the main crop (usually maize, rice or millet) for sample household farmers who are engaged in agriculture. The quantity of water consumed for various domestic purposes during the week for each household in weekly recall surveys was added together to determine the amount of water available to households for domestic use. The sustainability index was a composite score (range from 0 to 100) calculated by integrating the hydrological, environmental and socioeconomic indicators by applying a weighted additive model, giving equal weights to three domains: hydrological performance; groundwater recharge; surface runoff reduction; soil moisture; environmental health; vegetation cover; sediment loss reduction; water quality index; soil biodiversity score; socioeconomic well-being; agricultural productivity; household water availability; farm income; cropping intensity.

Experimental Procedure

In the study, there were seven stages. The first was to demarcate the watershed and GIS & remote sensing data was provided to help identify the micro-watersheds boundaries through hydrologic analysis tools in ArcGIS from the SRTM DEM. The second stage included the baseline hydrological and environmental assessment, that resulted in measuring all the hydrometric parameters that have been reported in Table 1 for 12 months before the implementation of the interventions. In the third stage, the ten interventions (described in Section 3.2) were rolled out, requiring approximately 6 months. The fourth step was to sample hydrological and agricultural variables at a certain time interval along the season during the 24 months period after the completion of the intervention, as described in the Section 3.3. The 5th step was a socio-economic impact assessment which involved retaking the household surveys with the 350 households to capture changes post-intervention. For the 6th stage comparison between pre- and post-intervention conditions was performed statistically, utilizing the analytical framework described in section 3.6. The final step, future projections of watershed management scenarios, was accomplished by linear projections of the observed data which yielded future projections of trajectory of the sustainability index and groundwater recharge between 2025 and 2035.

Statistical Analysis

Data was analysed using SPSS Version: 26.0 and R Software: 4.1.0. All the parameters were measured under pre and post intervention and changes in the mean, standard deviation and range was calculated for each of them. To compare pre and post mean differences for each watershed type for each parameter, paired t-tests were used with the null hypothesis of a difference between the means of zero. One way

ANOVA was used to test the homogeneity of the 10 different interventions groups - when the groups were found to be heterogeneous, the differences between the interventions groups were determined using Tukey's honest significant difference (HSD) test. The bivariate relationships between continuous variables were explored by measuring the Pearson correlation with a value between indicating weak correlation, moderate and strong correlation with value between respectively. To reduce the number of dimensions in the parameter set, Principal component analysis (PCA) was used, and to identify latent factors which affect the watershed's sustainability. All the measured parameters were used as independent variables and the sustainability index as the dependent variable. Multiple linear regressions were carried out and put through stepwise regression to identify those that are significant. The equation of the regression model was: is the Sustainability Index, is the intercept, are regression coefficients, are predictor variables and is the error term. The threshold for statistical significance was used with all tests. Normality test (Shapiro-Wilk test) and test of homogeneity of variance (Levene's test) were performed before analysing data using parametric methods, and before results from tests failed to satisfy these assumptions, the data were analyzed using non-parametric methods (Wilcoxon signed rank test and Kruskal-Wallis test).

Results

Seven subsections were presented sequentially to discuss the performance of specific water conservation practices and overall hydrologic, environmental and social benefits that would be accrued to all study watersheds. Factors limiting the effective management are then identified and ranked and the inter-relationship between the most important factors are explored by correlating the scores. Finally, future perspectives for watershed sustainability under continued, integrated administration are presented.

Performance of Watershed Conservation Practices

A critical element in developing an effective watershed conversation program is determining the relative effectiveness of various practices for use and the programs that are available. This analysis compares the effectiveness of five key practices (rain water harvesting, check dams, farm ponds, afforestation and community based watershed management) based on the same criteria to determine significant differences in the hydrological improvement effect and degradation of overall sustainability.

Overall sustainability of the watersheds managed by the communities was the highest among all with composite sustainability index as 93 as tabulated in Table 1. This best performance was a side benefit of the highest recharge contribution results (at 205 mm yr-1) and the highest agricultural productivity contribution results (at 34% increase), and was the most severe of the decreases in surface runoff (at 47%). This further confirms previous studies that pointed out the need for a combination of structural interventions and creation of enabling institutional arrangements by effectively supporting local stewardship and adaptive management (Tesfaye et al., 2018). These benefits of community based management can be explained by the regular up-keep work and greater social equity in water allocation and knowledge share of operational information through local ecological knowledge with more emphasis on each intervention made physically (Wani et al., 2003).

Table 1. Comparative Performance of Watershed Conservation Practices

Practice	Groundwater Recharge (mm yr^{-1})	Runoff Reduction (%)	Agricultural Productivity Increase (%)	Sustainability Index
Rainwater Harvesting	168	34	24	84
Check Dams	191	42	29	89
Farm Ponds	175	36	26	86
Afforestation	162	31	22	82
Community-based Watershed Management	205	47	34	93

The second most successful practice was check dams with a sustainability of 89 and 42% reduction in runoff, except the community based management. As has been reported for watersheds in more semi-arid environments (Sharda et al., 2005) a large groundwater recharging potential in a watershed (191 mm per year estimated) is expected from this structural intervention. Overall, farm ponds also showed to be very effective albeit not as effective as check dams (36% runoff reduction, 175 mm yr-1 recharge) when taking their role in storing water for supplemental irrigation combined with their role in regulating peak flows, as measured in their sustainability at 86. Rain water harvesting had moderate increase in all the parameters with a sustainability index of 84 and being a decentralised initiative, supported the bigger structures. The vegetative practices had the lowest sustainability index but still resulted in an enhancement of agricultural productivity (+ 22%) and in reduction of runoff (- 31%), showing long term benefits of vegetative practices in soil stabilization and micro climate control. (Yudono, 2021)

The varying effectivness of these practices supports the hypothesis that no single intervention treatment is optimally effective, but rather, a suite of intervention treatments that is well suited to the local context has the most impact. This is especially true for the superiority of community-based watershed management which further emphasizes the fact that in addition to physical infrastructure, social capital and institutional mechanisms remarkably contribute to achieve sustainable watershed outcomes (Meshesha & Khare, 2019). The results could then be applied to the environmental and hydrological benefits study at a larger scale of all the watersheds covered in the following sections.

Hydrological Improvements Across Watersheds

There were much better large-scale improvements in the majority of watersheds with the delivery of interventions within watersheds.Interventions within watersheds resulted in large-scale, significant improvements in mainly hydrological parameters across all five types of watersheds. The changes are due to simple variation in water balance due to improved infiltration, decreased run-off or increased soil water holding capacity. These are significant gains and reflect the type of gains that could be made by applying a collective effort approach at the watershed level in structuring, vegetating and implementing improvements.

The groundwater recharge is given in Table 2 before and after intervention, and the average values were respectively 118 mm yr^{-1} and 186 mm yr^{-1} that corresponds to a 57.6% improvement. The major rehabilitation is the combined effect of infrastructure that promote recharge (percolation, check dams and farm ponds), which increases the time water spends on the landscape surface resulting in more time for infiltration to deep soils, and likely limits bank erosion that leads to surface degradation (Tesfaye et al., 2018). The increase observed is in tune with the findings of the groundwater augmentation in similar groundwater study conducted in a semi-arid zone (20-35%) observed by Sharda et al. (2005). Multiple rather than single interventions were used in the various watersheds, yielding improved results than the top of the range estimates of results which had been made earlier based on single interventions.

Table 2. Hydrological Response Before and After Intervention

Parameter	Before Intervention	After Intervention	Improvement (%)
Groundwater Recharge (mm yr^{-1})	118	186	57.6
Surface Runoff (mm)	452	296	34.5
Soil Moisture (%)	18.6	29.4	58.1
Water Use Efficiency (kg m^{-3})	1.42	2.08	46.5

The amount of surface runoff decreased significantly by 34.5% from 452 mm to 296 mm. This decrease is due to the opportunities provided by contour bunding, terracing and vegetative barriers to increase the infiltration opportunity time, ability of the check dams and percolation tanks to retain and capture the overland flow, which would otherwise have left the watershed (Wani et al., 2003). The reduction in runoff also results in attenuation of peak flows during periods of storminess, "curbing" the potential for flooding downstream and sedimentation. This magnitude reduction is comparable with previous meta-analyses of single-unit runoff reduction which ranged from 9-24% (Jiang et al., 2011, Qi & Altinakar, 2011) and is evidence for integrating management being an amplifying measure.

Relatively soil moisture showed the greatest improvement among the hydrological parameters, improving from 18.6% to 29.4% (+58.1%). The increased infiltration and decreased runoff (Davis, 2007) will mean more water will remain in the form of soil moisture to benefit the plant life. The use of vegetative barriers and afforestation was also a factor in soil moisture gains, which was caused by a higher organic matter content and better soil structure, subsequently enhancing soil water holding capacity (Yudono, 2021). This improvement would be particularly significant in rain fed agriculture which is the principle livelihood in the study regions as it may reduce the frequency of time buckets when the crop is under water stress due to deprivation of soil moisture between rainfalls and increase the period when it has available soil moisture.

Earlier there was a water use efficiency of 1.42kg/m3; it was increased by 46.5% to 2.08kg/m3 which is attributed to availability of more water for irrigation and efficient irrigation methods such as drip irrigation. Water offsets within the watershed that allowed for water to be stored within the system, and then applied more selectively and effectively with the crop resulted in even greater productivity per unit of water used. The findings are in line with the already done studies which indicate that water productivity can be improved by 30-50% with integrated solutions in water stressed farming systems (Meshesha & Khare, 2019). Moreover, the observed gains in water use efficiency are expected to have direct impacts on food security by granting higher gains of water productivity and leading to less fluctuation in food production even with the interannual fluctuations in rainfall.

Once these results have been compared with the results obtained from literature, this results in remarkable coherence. The higher groundwater recharge observed (25–30%) and observed lower runoff compared to before the participatory integrated management (PIM) (15–20%) is less intensive participatory integrated management, although still consistent with other research reported in the Somodo watershed in Ethiopia (Tesfaye et al., 2018). Reductions of about 9-24% in runoff and increments of recharge of 20-35% occurred in research conducted in Tamil Nadu (India) with a similar set of check dams and farm ponds, with values similarly low end of range values in the current range of runoff reduction and recharge increase values. The large magnitudes noted here could be due to deliberate planning for interventions to take place at several locations in the hydrological cycle so it is not a one-size-fits-all approach, but rather a combined effort among components of the surface storage, infiltration enhancement, and vegetative interventions. Further, one approach was the integration of a community cadre that would help to solve problems and provide flexibility for adapting changes in a structure during its monitoring period that would maintain hydrologic function (Wani et al. 2003).

There was not even a geographical equalization between hydrologic gains and types of watershed. The rate of change of groundwater recharge was greatest for the semi-arid watersheds (68%) and least for the forest watersheds (42%) perhaps due to already relatively high base flow infiltration rates and relatively low runoff coefficients for the forest watersheds (Aliaga, 2002). The opposite was observed in the upper watersheds whose watersheds exhibited the maximum percentages decrease in surface runoff (41%) as a result of effective implementation of contour bunding and terracing on steep slopes. These spatial variations stress the need for individual intervention portfolios, depending on the geomorphological and climatic situations. This characteristic of the individual will be further discussed. The numerous hydrological responses described throughout all the watersheds lay the groundwork for the environmental and socioeconomic benefits described in the following sections.

Environmental Benefits

The efforts of the integrated watershed management program led to significant gains for all tested environmental parameters, offering evidence of the ability of combined activities to rehabilitate functions and improve environmental services in the study watersheds. As shown in Table 3, the structural, vegetative, and institutional measures positively affected vegetation cover, sediment loss, water quality, and biodiversity all noticeably following intervention implementation, demonstrating synergies in how actions positively affected landscape health.

Table 3. Environmental Indicators Before and After Intervention

Indicator	Before	After	Improvement (%)
Vegetation Cover (%)	34	52	52.9
Sediment Loss (t ha^{-1} yr^{-1})	15.2	8.6	43.4
Water Quality Index	69	86	24.6
Biodiversity Score	58	77	32.8

The vegetation cover jumped up from 34% to 52% with an increase of 52.9%. The major contribution to this substantial growth was attributed to afforestation programmes and the creation of vegetative barriers – which provided much area of permanent vegetation on degraded slopes and riparian areas (Wani et al., 2003). An improvement in vegetation also resulted from the improved soil moisture conditions and decreased surface runoff at the plantation which led to better micro-climatic conditions for seedling establishment and growth (Tesfaye et al., 2018). Those field-based observations agreed with the normalized difference vegetation index (NDVI) measured from satellite-borne data and calibrated using the field plot measurements, with greening visible consistently in all the watershed types, with a stronger increase in NDVI in the semi-arid and upper watershed regions.

The sediment loss reduction varied significantly from 15.2 to 8.6 t ha^{-1} yr^{-1}, which represented a 43.4% reduction. All of the soils' degradation had been rectified by several soil conservation practices such as contour bunding, terracing, planting vegetation to stabilize banks, creating check dams, which have the effect of trapping and retaining sediment and nutrient runoff from the watershed (Sharda et al., 2005). These lower rates of sediment loss are important for soil fertility and long-term productivity of farming operations, because erosion takes away the nutrient capital base for the crops. In addition to this, sediment is a reduced cause in the impacts downstream including the siltation and degradation of the aquatic habitats which increases the useful life of water storage infrastructure (Yudono, 2021). The observed reduction in sediment in this study was consistent with previous studies conducted by integrated watershed interventions in like agro-climatic settings that reported a reduction of 35–55% depending on the intensity of the intervention and the site-specificities (Sharda et al., 2005).

The improvement in the water quality in the watersheds has been significant, with the Water Quality Index (WQI) showing a significant improvement from 69 to 86 (24.6%). This enhancement may be due to several mechanisms. Check dams and percolation tanks act as sedimentation tanks, which capture particulate pollutants, lower the turbidity of the flow in the downstream section (Meshesha & Khare, 2019). Vegetative barriers and riparian afforestation mediate agricultural runoff and important nutrients, pesticides and organic matter are not discharged to stream channels. The production of reduced surface runoff volumes (Section 4.2) is also assisting to lower loading of surface runoff pollutants because of the reduction of the overland flow transport capacity (Tesfaye et al., 2018). Upstream and downstream water samples were collected and analyzed in the laboratory, showing consistent reductions in biochemical oxygen demand (BOD) and total suspended solids (TSS) parameters and in nitrate concentration (NO_3^-) which in turn improved the water quality index (WQI) scores. This result is consistent with previous studies in Indonesia's Krueng Aceh watershed which found that multiple different interventions applied together resulted in improvements of 18–30% (Yudono, 2021) in stream water quality metrics.

There was an increase in Biodiversity score from 58 to 77, (32.8% increase). This is a measure based on a designated species based on field surveys measuring both species richness and abundance of flora and fauna at representative sampling plots within each watershed. Habitat restoration and habitat diversification as part of the watershed interventions, is a direct outcome that is the enhanced biodiversity. The afforestation of native tree species led to the development of new forest patches and expansion of existing ones thus shelter and food was provided for wildlife (Wani et al., 2003). Linear habitat corridors were created using vegetative barriers and/or contour bunding, which allowed movement of species throughout the landscape. Better soil moisture conditions and water availability, recorded in the hydrological results, also provided a broader variety of plant species, such as those needing relatively more moisture that were not present or only sparsely distributed in the water-stressed semi-arid watershed areas. The changes were found to be beneficial for the environment as evidenced by the 41% rise in species richness in bird surveys and 35% increase in small mammal trapping indices, post intervention (Tesfaye et al., 2018).

The hydrological improvements described in the previous subsection are not necessarily distinct from the environmental benefits that are documented here; these improvements and benefits are closely tied together. Building healthy vegetation resulted in less runoff and greater infiltration, which allowed the vegetation to grow even more, and thus facilitated continued ecological restoration (Davis, 2007). Likewise, increased water quality due to decreased sediment loss was an indirect benefit of this and increased habitat area was an indirect factor in improving biodiversity. The strong inter-relationships that exist between these environmental indicators (quantified formally later in Section 4.6) demonstrate the integrated nature of the environmental improvements that have been facilitated by a 'one watershed one plan' approach and the need for a multi-faceted approach to tackling many environmental concerns at the same time rather than one single objective at a time.

Socioeconomic Benefits

The integrated watershed management interventions led to significant socioeconomic benefits for the study households, converting the hydrological and environmental benefits discussed in the previous sections into tangible human well-being and agricultural livelihood gains. The application of coordinated conservation measures resulted in significant improvements in all the variables analyzed as presented in Table 4: household water availability, agricultural productivity, annual farm income and cropping intensity.

There was an improvement in the amount of water available at the household field, from 124 L day-1 to 196 L day-1, or a 58.1%. It is a significant improvement attributable to cascading benefits of improved ground water recharge and surface water storage, thereby improving the water availability for domestic uses (Tesfaye et al., 2018). Household farm pond and percolation tank construction also resulted in smaller distances and time for obtaining water for various needs, hence serving to mitigate exposure to water collection, especially for women and children, who are traditionally the most vulnerable to such exposure (Wani et al., 2003). Better groundwater levels also extended the service to community hand pumps and dug wells during dry periods, helping to reduce the impact of dry seasons on water availability previously when families had to use other sources of water, such as far distances, or poor quality water. This is consistent with the results of participatory watershed interventions in Ethiopia where integrated interventions increased domestic water security by 40–60% (Tesfaye et al., 2018).

The agricultural productivity increased by 41.2% from 3.4 t ha-1 to 4.8 t ha-1. This improvement came about when a number of factors interacted. As stated in Section 4.2, soil moisture holding capacity was improved, which resulted in better crop water status during dry spells and yielded consistent crops from one season to another (Sharda et al., 2005). Likewise, the adoption of drip irrigation systems also enhanced productivity boost by supplying water directly near the root zone of crops and reduced the evaporative losses while the water use efficiency went up from 1.42kg m-3 to 2.08 kg m-3. Minimal sediment loss and soil erosion, described in Section 4.3, ensured the maintenance of top soil depth and its nutrient content, both of which play an important role in determining potential yield of crops (Meshesha & Khare, 2019). Raising the productive land under cultivation and offsetting previously degraded land or marginal lands through contour bunding and terracing were also linked to an increase in overall productivity. The productivity gain observed here is similar to that observed in Integrated Watershed Programmes implemented in Tamil Nadu, India where productivity increased by 30–50% after implementing soil and water conservation measures (Sharda et al., 2005).

Annual farm income grew from \$1,560 ha^{-1} to\$2,340 ha^{-1}, representing a 50.0% increase. The resulting high income was due to improved water availability both as far as increased productivity and changes in cropping pattern. Farmers could benefit from the increased agro-production through adding value to their products in higher food value crops such as vegetables and pulses during the dry season, replacing the previously idle seasons (Qi & Altinakar, 2011). The cropping intensity grew from 128% to 162% as an improvement of 26.6%, indicating that farmers were able to grow a two or three crop cropping tenure, instead of letting their land lie fallow during the drought prone post-monsoon spell. The intensity of these was possible due to the availability of stored water from the farm ponds and percolation tanks for supplemental irrigation, enabling the growing period to be extended beyond the rainy season (Yudono, 2021). The increase in income from this study was similar to the annual household income increase of 35–60% in integrated watershed management schemes conducted in Mayurakshi watershed, India where the income improved after introducing integrated watershed management practices (Qi & Altinakar, 2011).

Table 4. Household and Agricultural Outcomes Before and After Intervention

Indicator	Before	After	Improvement (%)
Household Water Availability (L day^{-1})	124	196	58.1
Agricultural Productivity (t ha^{-1})	3.4	4.8	41.2

Indicator	Before	After	Improvement (%)
Annual Farm Income (USD ha^{-1})	1,560	2,340	50.0
Cropping Intensity (%)	128	162	26.6

Not all watershed types saw the same relative benefits of the social and economic benefits across watershed, the semi-arid watersheds having the biggest relative increase in both household water availability (from water conservation programmes) and farm income (58%): possibly due to the poor underlying status of these watersheds relative to other watersheds and the consequent scope for further improvement from water conservation activities. On the other hand, forest watersheds exhibited smaller increase in agricultural productivity (28%), because in fact they have relatively good moisture conditions and higher baseline productivity (Aliaga, 2002). The improving sequence highlights the need to prioritize and target integrated watershed interventions to those most vulnerable areas in terms of water stress conditions, where transformative socio-economic impacts are more likely to have a substantial effect. This significant transformation of household water security, agricultural production and farm incomes highlighted in this paper confirm that IWM is a means to restore ecosystem function and rehabilitate hydrological processes to provide tangible benefits and measurable impacts for the livelihoods and well-being of rural communities in the broader context of sustainable development and poverty reduction.

Major Challenges in Watershed Management

However, although the various benefits of integrated watershed management proved to be remarkable in terms of hydrology, environment and socio-economic outcomes, the actual setting up and sustainability of the interventions were limited by a cluster of interconnected structural, social and climatic challenges. Characterization and quantification of these constraints is a critical part of developing more resilient management frameworks and will help guide decision on policies to overcome the constraints with greatest threat to success. Six major challenges were specifically identified and assessed by the respondent households, mean scores on a scale of between 1 (not a constraint) and 5 (severe constraint) and in this way the relative importance of the each challenge was quantified.

Table 5. Constraints Affecting Watershed Conservation

Challenge	Mean Score (1–5)	Rank
Insufficient Funding	4.58	1
Poor Community Participation	4.33	2
Climate Variability	4.18	3
Weak Institutional Coordination	3.97	4
Lack of Technical Expertise	3.84	5
Maintenance Issues	3.69	6

In terms of financial resources, it was determined that this factor is the most significant problem with a mean score of 4.58/5. This is a testament to a very real fact that in general, watershed management schemes, especially in developing regions, are underfunded compared to the extent of degradation and the ambition of watershed restoration goals (Yudono, 2021). Program effectiveness is hindered by the large costs needed to construct and maintain structural interventions like check dams, percolation tanks, or farm ponds and a limited government budget and competing development priorities. According to the household surveys, 72% of respondents felt that the financial allowances provided to them were not enough for them to implement the interventions that they intended, and 64% of respondents indicated that lack of funding has caused construction to be delayed and/or the use of less high quality materials which reduces the structural strength. This restriction is more severe in upland and semi-arid watersheds where slopes are steep and there are high rates of runoff (Sharda et al., 2005).

The second most important constraint was poor community participation with a mean score of 4.33. The establishment and the change and maintenance of a meaningful community-based involvement (CBS) was challenging at various implementation areas, although it had the highest sustainability index when compared to all sustainable interventions (Section 4.1). The involvement of local communities was mainly centered on consultation meetings rather than decision-making or even in the maintenance and monitoring process; local elites or external actors had the last voice in decision making (Tesfaye et al., 2018). Some of the reasons for low involvement were the difference in interests between upstream and downstream areas in terms of water allocation, the lack of trust in the implementing agencies, and the lack of immediate economic benefit of time investment in management activity. Community members were more willing in the lower watersheds, where productivity of agricultural lands were higher and jobs were available to small farms, and participation was significantly lower in the upper watershed where situations in people lives were more marginal, with scarce means of livelihood. This is a spatial variability that reflects the need to design engagement strategies specific to local socioeconomic contexts and create individual benefits for participation that brings stable engagement over time (Wani et al., 2003).

Climate variability was the third most important, scoring a mean of 4.18, as it has become a critical issue that affects the effectiveness of the watershed interventions due to the changing rains patterns and/or the delayed dry spells and heavy rainfall events. Insufficient rainfall to produce sufficient runoff, or too much water in short intense periods leading to siltation and structural damage reduces the effectiveness of structures like check dams and percolation tanks (Davis, 2007). The portion of the watersheds in the semi-arid regions was most affected by climate variability; these areas have relatively limited margins of hydrological balance and are very sensitive to the variability in the rainfall regime. Using the historical weather data for the study period, it was determined that 40% of the years were below average for rainfall volume and that the years with below-average rainfall were often followed by consecutive years with below-average rainfall, which in turn decreased the recharge capacity of aquifers and the fill rates of farm ponds. However, this limitation highlights the need to consider climate resilience in the design of water supplies systems in watersheds, including the use of oversized storage, diversified water supplies, and adaptive planning protocols such as adjustment to weather events and opportunities for managing water quantities and qualities flexibly. (Qi & Altinakar, 2011).

Weak institutional coordination was given a mean score of 3.97 which put it fourth in the list of constraints. While it is recognized that intersectoral cooperation (between multiple government departments, such as water resource, agriculture, forestry and rural development) and interadministrative cooperation are important for effective management of the watershed, effective coordination is often hindered by fragmented mandates, conflicting priorities, and poor inter-sectoral communication between various government departments (Meshesha & Khare, 2019). Concurrently with planned interventions conducted in a number of the study watersheds by the agriculture department, the public works department was active in road construction, which affected the drainage and added sediment loads to the watersheds. Likewise, there were no formal mechanisms in place for sharing hydrological data with forest departments and water resource departments to optimize afforestation strategies for water resource management for groundwater recharge. To overcome this limitation, it is necessary to create inter-agency coordination committees, standardize data sharing procedures, and have departmental planning cycles in sync so the interventions are complementary rather than contradictory.

The fifth most important reason was lack of technical expertise with a score of 3.84. Much of the work involved in implementing small-scale measures, such as the use of vegetative barriers and contour bunding, was carried out by members of the local community without good engineering advice and guidance. This led to suboptimal geometry, improper placement and ineffectiveness of these interventions (Sharda et al., 2005). Inappropriate species selection for afforestation was occurring in forest watersheds, partly resulting from an absence of ecological skill in species selection, leading to high seedling mortality rates and delay in vegetation cover gain. Lack of skilled watershed specialists in rural areas and high staff turnover further contributes to this lack of skill, resulting in low quality of implementation. Small, user-friendly technical guidelines, which explain technical processes with pictures, and capacity building programs with long-term training for local technicians and members of the community, would help reconcile this constraint in the long term.

The same trend emerged when it came to maintenance issues, which had a mean score of 3.69 and were closely related to the funding and participation issues above. Yudono (2021) states that the performance of watersheds decline quickly if they are not properly maintained, even if the watersheds are initially well-built, like the need to reseed planting areas in afforestation, replacing seedling mortality, repairing eroded bunds, and desilting check dams. Sediment buildup, overgrowth of vegetation, or from minor damage caused by storm events, showed evidence of degradation in 58% of the structures during defined surveys within 2 years of construction. There is no separate budget for maintaining these, and responsibility for maintaining them, where relevant, is not clearly assigned: either to a dedicated volunteer group or to local government or a third party. This meant that many of them fell into disrepair before their design life. This limitation was especially severe in the upper watersheds where the rugged landscape increases the erodibility and structural damage of hills. These measures are crucial to the long-term functioning and sustainability of watershed interventions: setting up community-managed maintenance funds; creating formalized maintenance plans and pitching costs from the beginning into program budgets.

All of these constraints are ranked in order of importance, of which financial and social constraints are more important than technical and institutional constraints. Also, from this pattern it can be argued that the key challenges to achieving success in watershed management are not purely technical but are largely entangled in the governance and resources allocation context in which watershed management programmes are being implemented (Tesfaye et al., 2018). The combination of constraints make management even more challenging; inadequate funding makes maintenance even more a problem, because if there is money, there is not much to maintain; the lack of community participation hampers the sustainability of even a well financed intervention, because if the community participates, they are not the ones who maintain. These are multifaceted problems which need to be tackled through multifaceted solutions, involving at the same time a greater allocation of financial resources, reinforcement of community involvement structures, development of climate variability resilient capacity, institutional coordination, investments in technical learning and training on maintenance mechanisms. Correlation among these constraints within each watershed is further detailed in the next section and the combined impact of these constraints on these watersheds' overall sustainability.

Correlation Analysis

Pearson correlation was performed in order to measure the interdependency between important watershed performance indicators, and to test the hypothesis that if the watershed management is successfully integrated, then there is synergy between the hydrological, environmental, and socioeconomic dimensions. Groundwater recharge, agricultural productivity, vegetation cover, and a composite sustainability index formed by a linear combination of the three variables were selected as the focus of the analysis. The correlation matrix (Table 6) showed strong positive correlations between all the pairs of variables ranging from to $p < 0.001$.

Table 6. Pearson Correlation Matrix of Key Watershed Performance Indicators

Variable	Groundwater Recharge	Agricultural Productivity	Vegetation Cover	Sustainability Index
Groundwater Recharge	1.00	0.91	0.86	0.93
Agricultural Productivity	0.91	1.00	0.82	0.89
Vegetation Cover	0.86	0.82	1.00	0.88
Sustainability Index	0.93	0.89	0.88	1.00

The most significant relationship noted was that between groundwater recharge and the composite indicator of watershed health (), where areas with improved groundwater recharge had the best watershed health scores. This relationship is intuitively sound because inclusion of hydrological variables in the sustainability index was direct (groundwater recharge, surface runoff reduction and soil moisture) and should thus have a strong association with the other variables (Tesfaye et al., 2018). The near unity of this correlation is quite encouraging, however, as it implies groundwater recharge is a good indicator of not just watershed resilience and sustainability, but perhaps the entire watershed. This could make future monitoring far easier—allowing a practitioner to monitor a single parameter on the groundwater recharge list instead of the entire array of parameters needed for the overall watershed resilience indicator.

The correlation between groundwater recharge and agricultural productivity was almost as high as (0.90), and represents the direct connection between improving subsurface water available and improving agricultural productivity as described in Section 4.4. Groundwater recharge results in an increase in water-table level; shallow wells and springs for supplemental irrigation are sustained; consequently, water-stress affects the crop production seasonally, resulting in its stabilization across seasons (Sharda et al., 2005). This correlation coefficient (–) is comparable to the previous study in India's semi-arid watersheds that reported groundwater level negative correlation with the agricultural production after the establishment of check dams and percolation tanks (Sharda et al., 2005). The link between these variables at the biological level is the extension of the growing period provided by supplemental irrigation leading to completion of reproductive phases of crops though the monsoon rains have ended, and thereby to increased filling of the grains and final yield.

Vegetation cover showed high correlations with groundwater recharge () and sustainability index (). Vegetation cover has improved with afforestation and natural regeneration, which improved soil structure, infiltration capacity and enhanced recharge of the ground water resources (Wani et al., 2003). Conversely, improved soil moisture and groundwater availability enhance the survival and growth of vegetation, which further reinforces soil moisture and water quality improvements as well as ecological improvements. The relationship between agricultural productivity (using CPI data) and vegetation cover (using NDVI data) is also found to be statistically significant, indicating that the same vegetation-related amelioration of soil moisture and microclimate that favours natural vegetation has a positive effect on crop production. This is in line with the result obtained with agroforestry followed by inter-cropping of trees and crops that has been known to enhance soil fertility and water holding capacity, thus enhancing productivity of farm businesses (Yudono, 2021).

Agricultural productivity is well related with the sustainability index () which clearly shows the dominant importance of agricultural livelihood in the performance of the watershed in these mostly agrarian communities. Farm income and farm intensity improvement (which are related to the productivity levels) heavily influence the overall sustainability index because these were considered and weighted alongside hydrological and environmental factors.Farm income improvement and farm intensity improvement are both socioeconomic indicators that have been evaluated among the other hydrological-environmental ones and given equal weighting which substantially affect the overall score of the sustainability index (Meshesha & Khare, 2019). The finding suggests that interventions not providing tangible agricultural gains are unlikely to score high sustainability outcomes, even if they have good hydrological or environmental outcomes, underscoring the need to design watershed programs that provide explicit examples of how they support livelihoods, as well as ecological restoration.

The correlation between agricultural productivity and vegetation cover (,) was still high but the smallest of all the variable pairs examined. This slightly lower association could be due to the status of only part of the vegetation variable having been captured, because agriculture production would not only be affected by the level of vegetation cover, but also by a number of other factors, such as soil fertility, pest infestation, improved seeds, and farm management practices (Davis, 2007). In addition, in intensively cultivated areas, agriculture land is by definition characterized by low natural vegetation cover, thereby potentially dampening the relationship at the plot scale, even though a positive relationship exists on the landscape scale.

The correlation structure was further validated by using principal component analysis (PCA) and any hidden factors which originate in the observed relationships were also identified. The first principal component accounted for 78% of the total variance with positive and high loadings for all four variables, from 0.84 to 0.96, indicating that a single overall dimension (probably reflecting overall watershed management effectiveness) explains much of the covariation among these indicators. The result is a confirmation of the hypothesis that implementing the intervention on the watershed results in synergies and improvements in multiple areas, and that the selected index of sustainability is able to measure this multidimensional synergism. The second principal component—that accounted for another 11% of variance—mainly accounted for the contrast of vegetation cover with agricultural productivity, implying that very high cover can also result in a corresponding drop in agricultural productivity levels, and vice versa, invoking the inherent trade-off in land use between conservation and productivity that integrated management aims to balance.

The statistics of strong intercorrelations obtained in this analysis have significance for watershed monitoring and evaluation. They argue that a limited number of key indicators, such as groundwater recharge or sustainability index can be suitable sentinel indicators to measure program performance, alleviating the monitoring load for implementing agencies facing resource limitations (Qi & Altinakar, 2011). Moreover, the intensity of the links reflects the synergic approach of integrated watershed management, and shows that gains in one aspect of a watershed are not likely to be won without gains in the other, but rather in addition to them. It is this synergy that is one of the reasons for continuing to maintain that integrated approach should be preferred rather than sectoral approaches and serves as a quantitative basis for what lies on the horizon in terms of watershed sustainability in the next subsection.

Discussion

The results of this study have far-reaching and meaningful theoretical and practical relevance for water management and sustainable development. Theoretically, the strong linkage between the groundwater recharge, vegetation cover, agricultural productivity, and the composite sustainability index support the hypothesis that, from the conceptual point of view, IWM is based on synergy rather than considering the watershed management interventions separately (Tesfaye et al., 2018). The interdependency posed by this connects this to the idea that hydrological restoration, ecological conservation and livelihood improvements are inter-dependent, meaning that to achieve lasting results all of these areas should be worked on simultaneously and not only one at a time as is acknowledged by the sectors. The strong percentage of the variance that was explained by the first principal component (78%) in our analysis supports the empirical validity of a theoretical framework that delivers a unified conceptualization of watershed health as a single latent construct that is operationalized across a number of observable domains.

The action implications of these findings are as well alluring. Polis and planning, which incorporated increased capacity building, collective action, and institutional mechanisms to guide watershed use, play an important role in sustainability as illustrated by higher levels of sustainability for this approach compared to investments in physical infrastructure; for polis and planning, the achieved index value is 93. This implies that financial resources of an allocated budget should be remallocated by investing considerable amounts on mobilization and training of communities and maintenance funds instead of being spent on the construction phase alone (Wani et al., 2003). A similar strong relationship exists between groundwater recharge and the sustainability index () and, as such, would be a convenient monitoring shortcut for agencies with limited resources, which would not have to measure all of the parameters necessary to create the sustainability index, but could monitor instead groundwater recharge, a parameter that, while not in itself diagnostic, would survive the measuring process and result in resource savings. In addition, the pathway for continued improvement (up to 2035) from a sustainability index of 72 to 94 and from 150 to 212 mm per year for groundwater recharge offers a strong reason to continue investing in watershed programs, while funding cycles are jumping from one priority to another before a benefit has been fully realized (Sharda et al., 2005).

There are some methodological limitations which need to be noted in interpreting these results. The selection by stratified random sampling of 25 micro-watersheds and 350 households only covers the within the micro-watersheds biophysical and socioeconomic heterogeneity but may not reflect the full biophysical and socio-economic heterogeneity within a larger landscape. Results may not be entirely transferable to areas with similar interventions, similar watershed types and extreme aridity, for example, parts of Sub-Saharan Africa, or a completely different land tenure system, as may be found in parts of Central Asia (Aliaga, 2002). The monitoring period (post-intervention data collection during two to three years), provides a sufficient timeframe to capture initial responses in hydrology and ecology but may be insufficient to capture long-term dynamics such as the maturing of afforested stands, the gradual improvement in soil structure as a result of organic matter build-up, and delayed socioeconomic benefits of increased water security on household asset accumulation and the reduction of intergenerational poverty. Self-reported information from households is crosschecked with field measures and secondary records; however, because it is heaving on self-report data, there is a risk of recall bias and social desirability bias may play a role in the estimates of water availability and income. Also, certain parameters (e.g., livestock distribution and sources of non-agricultural incomes) were missing or were only available at a very low resolution, which may have resulted in incomplete characterisation of the livestock livelihood strategies and their interaction with management outcomes of watersheds.

Conclusion

This study examined the sustainability of integrated watershed management (IWM) for sustainable water resources conservation, using integrated watershed management as the main tool and target of assessment to study its impact on changes in the hydrological, environmental and socioeconomic status of various agro-climatic zones. Based on the discussion, the main conclusion reached in this study is that IWM can be seen as a synergic improvement strategy on all dimensions measured in this study and that watershed management by communities is the worst performing single approach (with a sustainability index of 93). All watersheds had groundwater recharge increases of 57.6%, surface runoff decreases of 34.5%, and agricultural production increased by 41.2%, clearly establishing a causal pathway that connects hydrological restoration to livelihood improvements. Groundwater recharge, vegetation cover, agricultural productivity and the composite sustainability index are all strongly correlated with each other, with increasing positive correlation values greater than —0.5, quantitatively supporting the hypothesis that these dimensions are not mutually exclusive but mutually reinforcing, which directly impacts the theories and paradigms of sectoral management, and provides empirical evidence for integrative approaches to sustainable development. The identification of insufficient funding and poor community participation as the most significant constraints both with scores of > 4.3 out of 5, again confirms that rather than technical the primary barriers to watershed sustainability are governance-related and financial, pointing to a need to address institutional capacity and government

References

Aliaga, J. (2002). *Peasant rationality and land cover changes in the central drylands of chile*. search.proquest.com.

American Water Works Association, and et al. (1989). *Standard methods for the examination of water and wastewater*. oaktrust.library.tamu.edu.

Davis, M. (2007). Integrated water resource management and water sharing. *Journal of Water Resources Planning and Management*.

Meshesha, T., & Khare, D. (2019). Towards integrated water resources management considering hydro-climatological scenarios: An option for sustainable development. *Environmental Systems Research*.

Qi, H., & Altinakar, M. (2011). A conceptual framework of agricultural land use planning with BMP for integrated watershed management. *Journal of Environmental Management*.

Sharda, V., Samra, J., & Dogra, P. (2005). Participatory watershed management programmes for sustainable development: Experiences from IWDP. *Indian Journal of Soil Conservation*.

Tesfaye, G., Debebe, Y., & Yakob, T. (2018). Impact of participatory integrated watershed management on hydrological, environment of watershed and socio-economic, case study at somodo watershed …. *The International Journal of Earth and Environmental Sciences*.

Wani, S. (2021). Death valley of impacts in agriculture: Why and how to cross it with scaling-up strategy? *Scaling-Up Solutions for Farmers: Technology, Partnerships and Convergence*.

Wani, S., Maglinao, A., Ramakrishna, A., & Rego, T. (2003). *Integrated watershed management for land and water conservation and sustainable agricultural production in asia: Proceedings of the ADB-ICRISAT-IWMI …*. oar.icrisat.org.

Yudono, H. (2021). A review on sustainability of watershed management in indonesia. *Sustainability*.