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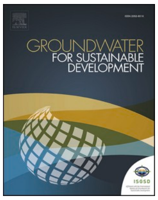

Impact of natural resource management interventions on water resources and environmental services in different agroecological regions of India

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ABSTRACT

Natural resource management is critical for addressing issues of water scarcity, land degradation and poor agricultural and livestock productivity especially in rainfed ecologies. This study was conducted in 13 Gram panchayats (cluster of villages) of three states in India representing different agroecological regions. Natural resource management works undertaken through the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) covering water harvesting, pasture land and orchard development were evaluated between November 2015 and January 2016. Density of water harvesting varied from 10 to 250 m^3 ha^{-1} depending on topography and works completed in different villages. These structures have contributed significantly to harvesting surface runoff, enhancing groundwater recharge, reducing soil erosion, and flood control. Irrigation acreage increased between 4 ha and 95 ha which is about 5–10% of the total cultivable area in study villages. In addition, crop productivity increased from 30 to 50% both in rainy and post-rainy seasons compared to non-beneficiary fields. The study showed that the selected natural resource management works have the potential to generate additional economic gain from US\$ 60 ha^{-1} $year^{-1}$ to US\$ 225 ha^{-1} $year^{-1}$ along with some indirect benefits to strengthen environmental services and rural livelihood. Overall, the MGNREGA has helped in strengthening ecosystem services, viz., provisioning, regulatory, and supporting services in addition to providing employment opportunities. The study also suggests to follow science-led approach in designing and implementation of various NRM works for further improvements and achieving long term sustainability.

1. Introduction

Rainfed ecosystem in Asia and Africa is facing number of challenges including water scarcity, land degradation and poor agricultural and livestock productivity (Dinar et al., 2019; Fitton et al., 2019). These landscapes are also hot spots of poverty and malnutrition (Naschold, 2012; Tittonell and Giller, 2013). Recent FAO report claimed that about 128 million ha of rainfed crop land and 650 million ha of pasture land are facing severe drought frequency. Moreover, 3.2 billion population experiencing very high water scarcity situation. Out of which 1.2 billion people are living under extreme water scarce condition in Asia and Africa (FAO, 2020). Climate change has brought huge uncertainty in resource availability and intensified the risk of crop failure and investment losses (Javed et al., 2019; Prăvălie et al., 2019). The climate change effects are more severe on small and marginal farmers as their coping ability against these challenges is limited (Muluneh, 2020).

Natural resource management (NRM) interventions are considered to be promising to address these challenges and to strengthen rural economy as about 70% population in rainfed ecologies are dependent on agriculture and allied sectors (Rockstrom and Falkenmark, 2015; Singh, 2017; Santos-Montero et al., 2020; Tamagnone et al., 2020; Garg et al., 2020a,b). Number of countries have designed public welfare programs [e.g., Integrated watershed management (IWMP) and Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) in India;

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Sustainable Land Management Program (SLMP) in Ethiopia, etc.] those have targeted to undertake various natural resource management interventions at landscape and farm scale as per the need and investment capability (Garg et al., 2020c; Mezegebu et al., 2020; Abera et al., 2020). These programs are also helpful to address the United Nations sustainable development goals of clean water and sanitation; no poverty, zero hunger, and reducing inequalities (Singh et al., 2014; Karlberg et al., 2015; Singh, 2016; James et al., 2019; Garg et al., 2020a,b).

The MGNREGA is one of the largest public welfare programs in the World has been implemented in India since 2005. The program implemented in three phases, initially in 200 most backward districts in 2005–06. The implementation of the program spread to an additional 130 districts in 2007–08, and to all the districts of India by 2008–09. The Act envisages, for instance, that the works undertaken will strengthen natural resource management and address causes of chronic poverty such as drought, deforestation, and soil erosion, thereby encouraging sustainable development (Government of India, 2015; Fischer and Ali, 2018).

The MGNREGA focuses on four categories of works: (i) public works relating to natural resource management; (ii) individual assets which are largely focusing on improving the productivity of individual households; (iii) common infrastructure development for livelihood improvement; and (iv) rural infrastructure development for easy accessibility of basic amenities to reduce drudgery. Between 2012–13 and 2016–17, a total number of 16.3 million works were completed under this program by investing about US$14.88 billion, out of which 60% works belongs to natural resource category such as drought proofing, flood control and protection, land development, micro-irrigation, renovation of traditional water bodies, water conservation and harvesting (Government of India, 2016; Singh, 2016).

A number of evaluation and impact studies have been undertaken by various agencies to understand the performance of MGNREGA in terms of addressing poverty, unemployment, and climate change. Maiorano (2014) observed that governing mechanism influenced the implementation performance of MGNREGA among different states while some studies also revealed that there is a bias in allocation of benefits, and the beneficiaries are those affiliated to the ruling political party in terms of participation, number of days of work, and earnings from the program (Das, 2015). However, the MGNREGA enhanced savings capability of households along with increased food security and expenditure on food and nonfood consumables (Ravi and Engler, 2015). While most of these studies largely focused on labor dynamics, implementation process and its governance (Girard, 2014; Maiorano, 2014; Amaral et al., 2015; Das, 2015; Ravi and Engler, 2015; Gupta and Mukhopadhyay, 2016; Singh, 2016), very little is known about the impact of natural resource management works on augmentation of water resources, crop intensification, productivity and environmental services. Understanding the impact of various NRM interventions on water balance components and generated ecosystem services is important for effective planning and appropriate designs of interventions. In absence of system level understanding, the resource utilization could be lopsided and investments may not yield desired returns (James et al., 2019).

Recently, few studies reported the impacts of MGNREGA works on environmental services and water resource availability (Tiwari et al., 2011; Aggarwal et al., 2012; Esteves et al., 2013; Verma and Shah, 2012); however, such systematic efforts are relatively less. It is too early for impact of MGNREGA works to be visible; hence the paucity of assessment studies. We have made an attempt to analyze the impact of NRM works undertaken through MGNREGA in 13 Gram Panchayats from three Indian states (viz., Andhra Pradesh, Chhattisgarh, and Rajasthan) having varied agro-ecological characteristics. The specific objectives of the study are to analyze the impact of MGNREGA works on NRM on: (i) water resources; (ii) crop intensification and productivity; and (iii) ecosystem services in low, medium, and high rainfall regions of selected districts in India.

2. MGNREGA and its implementation in the study area

The MGNREGA is the largest public welfare scheme implemented by Government of India since 2005 (Kumar et al., 2017). The aim of the scheme is to enhance livelihoods of rural people by providing at least 100 days employment to households whose adult members volunteer to do unskilled manual labor (Maiorano, 2014). One striking feature of the program is its decentralized nature where administration and allocation of majority of the works are carried out by the elected local authorities of the respective villages. Adult members of a rural household who are willing to do unskilled manual work have to register for work in the Gram Panchayat. After verification of the place of residence and age of the adult members, the household is issued a job card which is mandatory for working under the program. An application for demanding work has to be made to the Gram Panchayat or MGNREGA technical mates/supervisors responsible for implementation of the program in the village (Das, 2015; Singh, 2016). The local authorities have to provide work to the household within 15 days of the application, failing which an employment allowance has to be paid.

2.1. Study area

The study focused on three Indian states, viz., Andhra Pradesh, Chhattisgarh, and Rajasthan representing south, central, and northern parts of the country (Fig. 1). From each state, two districts and further from each district two or three Gram Panchayats were selected based on the rainfall, soil type, land slope, cropping system and irrigation availability such that these should represent study districts (Table 1). Rainfall in the study locations ranged between 550 mm and 1250 mm indicating wide variability from arid to semi-arid tropics. The major soil types in these locations are Alfisols and Vertisols having low to high water-holding capacity. Topography of the study locations also varied from flat (e.g., Sehnva, Rajasthan) to hilly terrain (e.g., Abhaypura, Rajasthan) with significant variation in land use pattern. The major crops are paddy, maize, groundnut, and horticulture crops (mango) in Andhra Pradesh; paddy, pigeonpea, chickpea, and soybean in Chhattisgarh; and wheat, chickpea, mustard, soybean, and pulses in Rajasthan. Out of 13 Gram Panchayats, eight panchayats have access to surface irrigation from medium to minor irrigation projects whereas other panchayats are largely dependent on groundwater resources for agriculture, livestock and domestic use.

2.2. Natural resource management interventions

Based on the secondary information, MGNREGA work portfolio was analyzed for all the selected 13 Gram Panchayats in the study area. Fig. 2 compares different works proposed and completed in selected Gram Panchayats. The data shows that more than 75% works undertaken are related to natural resource management, with main focus on drought proofing; rainwater harvesting, agroforestry and pasture land development. Out of total 404 works, about 73% works are related to natural resource management in selected Gram Panchayats of Chhattisgarh, 76% in Andhra Pradesh, and 88% in Rajasthan. A range of *in-situ* and *ex-situ* water harvesting measures such as restoring traditional water harvesting tanks, desilting tank bed for increasing storage capacity and repair of dilapidated sluices, weirs and weak bunds; construction of earthen embankments for storage reservoirs; check dams; excavation of village and farm ponds; excavation of trench, field bunds were largely undertaken in different Gram Panchayats. Fruit and other trees were planted by following agroforestry or high density model both at common and individual lands. Fodder grasses were cultivated through various *in-situ* measures largely in wastelands/common lands. Focus was also given on farm based interventions such as application of tank silt in agricultural fields and land levelling (e.g., Garida and Tettangi panchayats of Andhra Pradesh; Jhandatalab and Shiwnikala panchayats in Chhattisgarh; and Kankroliya Ghati and Nandrai panchayats in

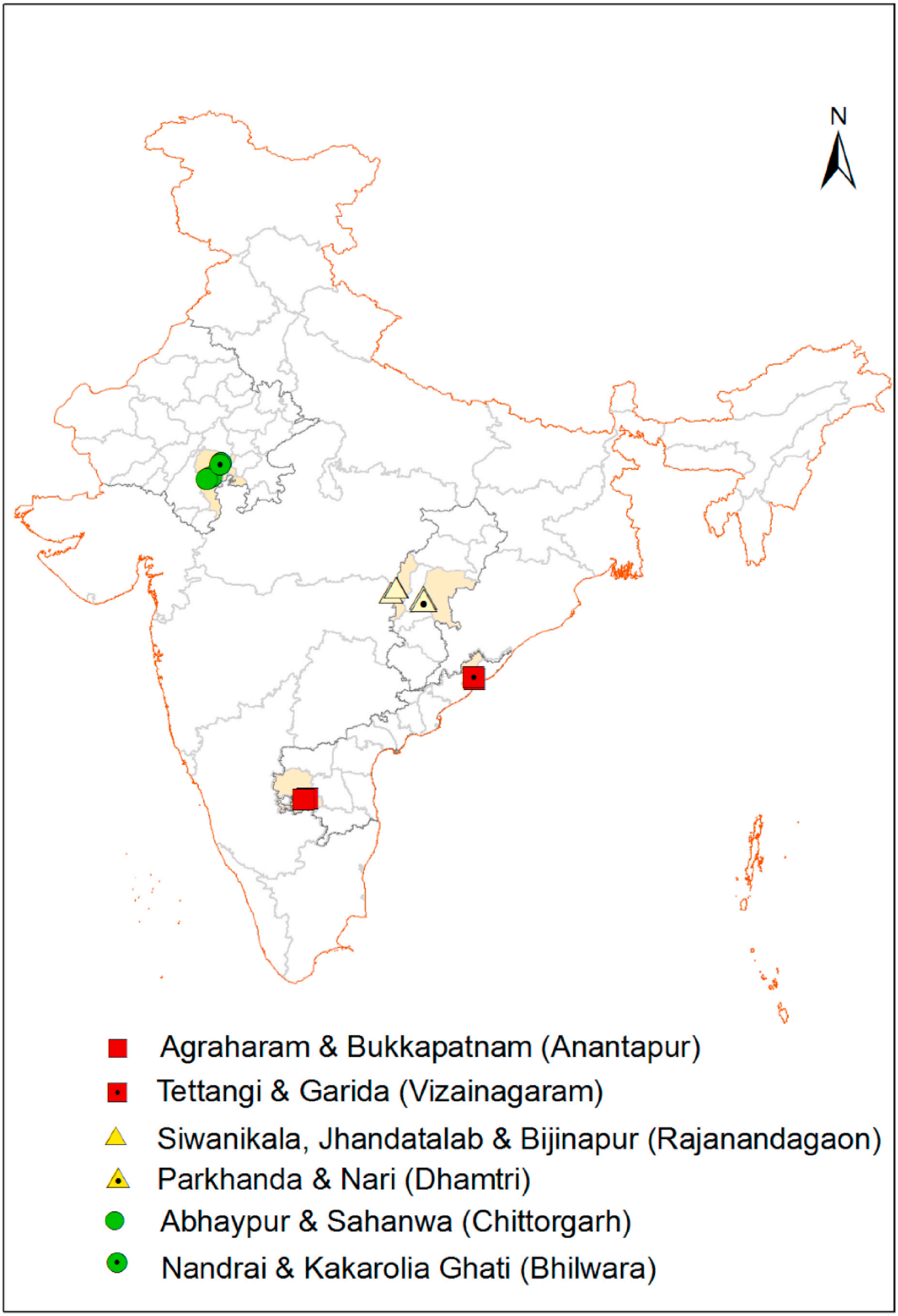

Fig. 1. Location of selected Gram Panchayats in the study area.

Table 1
Basic model inputs provided to hydrological model.

Details	Parameters[a]	Rajasthan			Andhra Pradesh		Chhattisgarh		Source[b]
Gram Panchayat		Abhaypur	Sehnwa	Kakroliya Ghati; Nandrai	Bukkapatnam, Agraharam	Garida, Tettangi	Nari, Parkhand	Jhandatalab, Bijnapur, Shivnikala	
District		Chittorgarh	Chittorgarh	Bhilwara	Anantapur	Vizainagram	Dhamtari	Rajanandagaon	
Water balance components									
Soil and topography	Soil depth (cm)	15–60	15–50	30–75	15–50	30–60	50–80	15–75	Primary data Measured
	Water holding capacity (cm m^{-1})								
	Land slope (%)	5–10	1–3	1–5	1–5	1–5	1–3	1–5	Remote sensing
Cropping system and its management	Major crops	Soybean, sesame, maize (rainy) wheat, chickpea, mustard (post-rainy)			Groundnut (rainy) chickpea (post-rainy)	Rice, maize, groundnut (rainy)	Rice (rainy)	Rice, pigeonpea (rainy) chickpea (post-rainy)	Primary data
	Date of sowing	2nd week of July (rainy); 3rd week of October (post-rainy)			1st week of July (rainy); 3rd week of October (post-rainy)		3rd week of June (rainy); 3rd week of October (post-rainy)		Primary data
Meteorology	Average annual rainfall (mm)	830	830	675	450	1200	950	650	IMD
	PET (mm)	1450	1450	1500	1700	1530	1350	1350	IMD
Impact of water harvesting structures (WHS)									
WHS details	Water harvesting potential created (m^3 ha^{-1})	194	6	12	15	99	183	250	
	Infiltration rate of reservoir bed (mm/day)	30	30	30	30	20	25	25	ICAR-NBSS&LUP
	Average height of WHS (m)	2	1	1	1	1.5	1.5	1.5	Primary data

[a] PET=Potential evapotranspiration.
[b] IMD=India Meteorological Department.

Rajasthan). In addition, in Andhra Pradesh, other works such as comprehensive development of Scheduled caste/Scheduled Tribe colonies and public institutions development were implemented along with rural connectivity and sanitation.

3. Materials and methods

Fig. 3 showed the flow diagram of adopted methodology in current study. Efforts were given on primary and secondary data collection from 13 Gram Panchayats of three states as described in section 3.1. Data was provided as input to the simulation model for computing water balance components and analyzing impact of various NRM interventions on hydrological processes (refer section 3.2). Findings of soil biophysical and rainfall characteristics of respective study sites are shown in section 4.1. Impact of various NRM interventions on various ecosystem services presented in section 4.2 and section 4.3; further potential benefits of various NRM interventions is described in section 4.4.

3.1. Data collection

The data used in this study was collected from a field survey conducted during November 2015 to January 2016 in six selected districts from three states. As much as 30% of the existing and functional natural resource management-based assets were evaluated upon consultation with MGNREGA functionaries in each Gram Panchayats. From 13 Gram Panchayats, 435 households, representing both beneficiaries and non-beneficiaries, were interviewed using a structured pre-tested questionnaire. From these questionnaires, information on socioeconomic and demographic characteristics and MGNREGA participation was collected. To ensure that the study exclusively reflects the impacts of environmental works of MGNREGA, direct beneficiaries of the MGNREGA completed interventions such as farmers with crop fields where silt was applied or those with wells that got recharged as a result of check dams as well as assets created were purposively selected. The selection of beneficiary was based on snowball sampling method. A snowball sample is one in which the researcher collects data on few members of the target population (here the target population is the beneficiary of the structure) he or she can locate, then asks those individuals to provide information needed to locate other members of that population whom they know. The identification of sample was continued till the achievement of sample frame or when the response become homogenous in terms of unit change impact on identified indicators.

To characterize soil physical and chemical properties, 191 samples were collected from agriculture fields, pasture and orchard lands, fields where silt applied, tank bed and respective control fields. Also, soil fertility parameters [organic carbon, pH, electrical conductivity (EC), phosphorous (P), potassium (K); calcium (Ca), magnesium (Mg), sulphur (S), zinc (Zn), boron (B), copper (Cu), iron (Fe), manganese (Mn) sodium (Na)] were analyzed.

A total of 144 water harvesting structures (check dams, storage reservoirs, farm ponds, gully control structures, etc.) and 37 pasture lands and horticulture plantations (community pasture lands and fruit orchards) were evaluated. Various parameters such as water resources availability and change in cropping system and productivity levels were collected. In pasture and horticulture areas, data on total fruit and fodder production and biomass were collected. Moreover, primary data on location and storage capacity of water harvesting structure, and change in water table, cropping system, and productivity were collected. In addition, secondary data on demography, land use, cropping pattern, productivity, daily rainfall and other meteorological information were also collected.

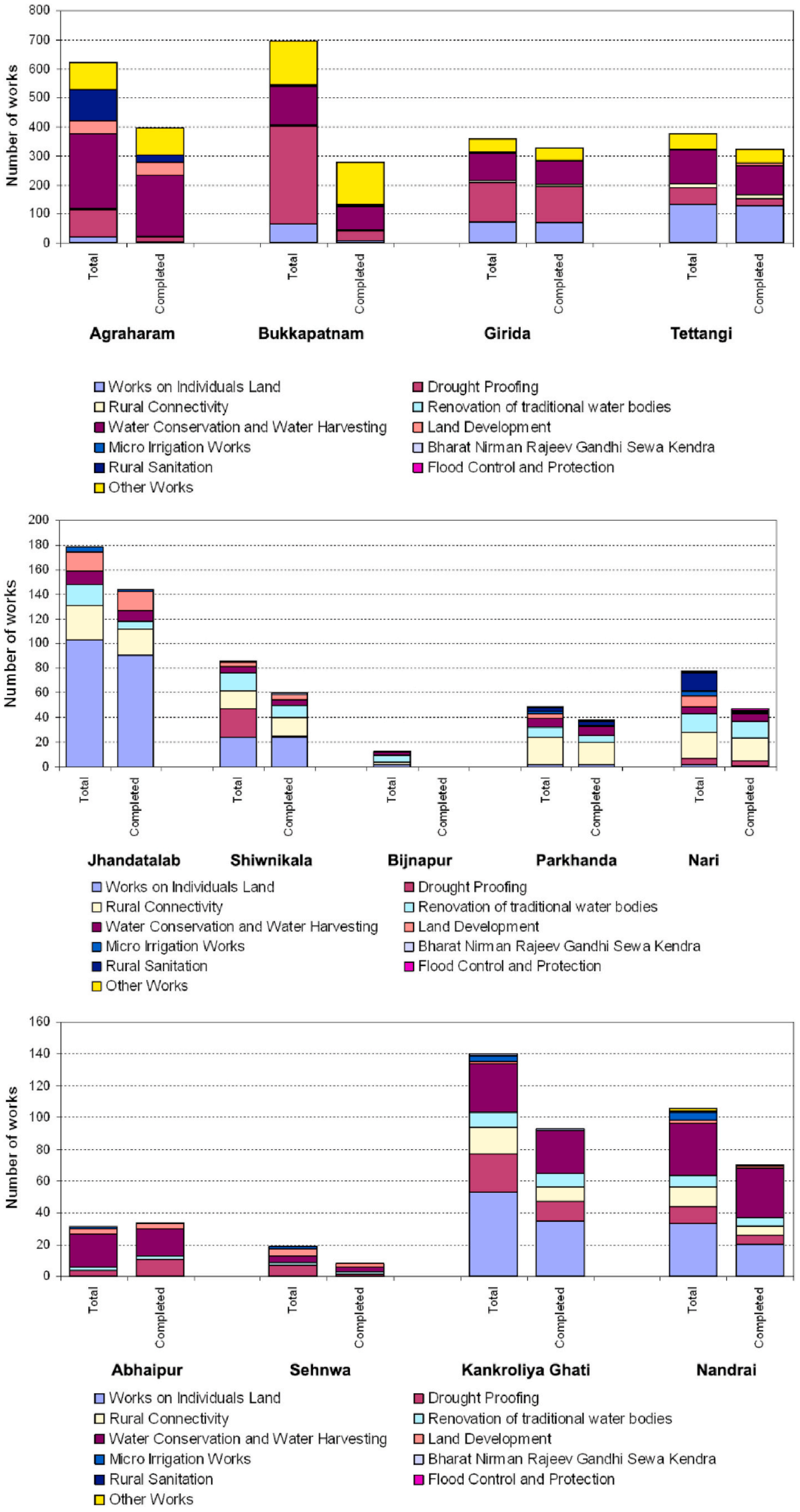

Fig. 2. Status of MGNREGA work implementation in selected Gram panchayats.

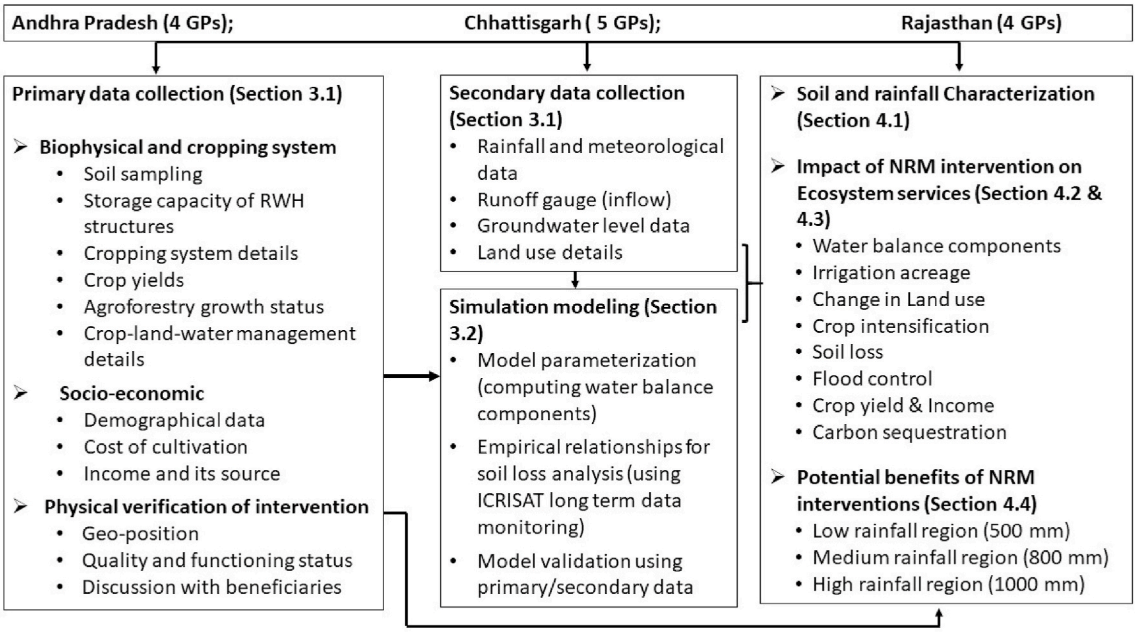

Fig. 3. Flow diagram of adopted methodology.

3.2. Data analysis

3.2.1. Description of simulation model

This study uses a one-dimensional water balance model 'Water Impact Calculator' (WIC) developed by ICRISAT to analyze the water balance components (Garg et al., 2016). The WIC is a generic decision-making tool which could be applied to any land use and cropping system by providing minimum sets of biophysical details and management inputs (Garg et al., 2014, 2016). WIC requires soil (water retention properties and soil layers thickness), weather (Reference evapotranspiration, ETo and rainfall), crop growth (biomass, crop co-efficient, kc and root growth function), topography (land slope, land-form conditions) and crop management (crop sowing and harvesting dates & irrigation method) details as an input. The model calculates the daily water balance as:

$$\begin{aligned}\text{Rainfall} &= \text{Surface runoff} + \text{Groundwater recharge}\\ &+ \text{Evapotranspiration (Evaporation} + \text{Transpiration)}\\ &+ \text{Change in reservoir/pond storage}\\ &+ \text{Change in soil moisture storage} \qquad (1)\end{aligned}$$

In WIC, runoff is estimated based on curve number technique. The Soil Conservation Service Curve Number (SCS–CN) is a simple but popular method for predicting surface runoff and is widely used in many hydrological applications, such as flood estimation and water balance models (Abon et al., 2011; Steenhuis et al., 1995; van Dijk, 2010). It is sensitive to changes in values of curve number parameter, CN, and the antecedent moisture conditions (Michel et al., 2005; Ponce and Hawkins, 1996; Soulis and Valiantzas, 2012).

In WIC, the amount of water in excess of infiltration, after satisfying the soil moisture deficit, is considered deep percolation (Garg et al., 2016). Evaporation and transpiration values are estimated based on the surface boundary conditions and moisture accessibility between surface soil layer and the root zone. Water available in the top 10 cm layer is considered the main layer that is satisfying the bare soil evaporative demand, whereas moisture available within the root zone is used to meet crop water uptake/transpiration demand. The crop water requirement (CWR) for a given day is calculated as:

$$CWR = K_c * ET_o \qquad (2)$$

where Kc is the crop coefficient and ETo (mm/day) is the reference crop evapotranspiration.

The root zone depth is a dynamic variable and is controlled by crop growth stage (days after sowing) as defined by Allen et al. (1998). Usually, evaporation from soil surface is inversely proportional to vegetative growth stage. Thus, after achieving full vegetative crop growth (Kc $\geq$ 1.0), evaporation from the bare soil surface becomes insignificant. If moisture in the root zone was not sufficient to meet CWR, then WIC declares that the crop is under water stress condition. A detailed description of WIC, model development, testing and validation procedure is given by Garg et al. (2016).

3.2.2. Model setup

The model was set up for different land use types in each of the Gram Panchayats. The data on soil properties (water-holding capacity, and soil depth), topography (slope percentage), land use (cropping system and its management), and meteorology (daily rainfall and potential evapotranspiration requirement) were provided and water balance components were estimated for 10-year period. Crop management inputs (e.g., sowing and harvesting date of different cropping systems) (Table 1) were provided in the model based on farmers' practices obtained from the primary survey. Wasteland is modeled as sparse land having relatively shallow soil depth (<15 cm) whereas forest land is considered with perennial tree species of deciduous nature during summer.

The WIC considers variable crop coefficients and root growth as per growth stages/season (Garg et al., 2016) and computes crop water requirements and green water availability in root zone on daily basis whereas runoff is computed based on SCS Curve number method (Arnold and Fohrer, 2005). After initiating the curve number for specified land use/cropping system, WIC computes curve number as per wetness level of surface layer and partitions runoff from rainfall. After removing the excess runoff, remaining rainfall amount is infiltrated from upper to lower soil layers. The model allows the soil to hold maximum water up to field capacity and remaining infiltrated water is distributed consequently in lower layers. At the same time available green water in root zone is utilized for crop/tree water uptake as per crop water demand. Table 1 summarizes the input details, model parameters, and data source used for current modeling.

As the selected Gram Panchayats were not monitored in terms of hydrology, simulation results are validated with available secondary information. For example, simulated surface runoff for Abhaypura Gram Panchayat was compared with available data from water resources department for Berkhedi dam located at upstream of Abhaypura panchayat having similar agroecology and topography. The results showed that WIC simulated runoff coefficient was 30 per cent for Abhaypura Gram Panchayat whereas observed runoff coefficient for Berkhedi dam was 25–30 per cent. This indicated that the model is able to capture landscape hydrology appropriately.

3.2.3. Estimating soil erosion

The study utilized data monitored on surface runoff and soil loss from long-term heritage micro-watersheds of 5–10 ha at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Telangana, India for both Alfisol and Vertisol and established rainfall vs. soil loss relationships (Fig. 4). Same empirical relationships were used to calculate the soil loss in different pilot areas of selected panchayats. Surface runoff (outflow) generated from different rainfall events were derived using WIC and further soil loss estimated using above-mentioned relationships. Soil loss was estimated for two management scenarios: (i) no interventions; and ii) with WHS interventions.

3.2.4. Analysis of impact of WHS on water balance components

To understand the impact of various WHS, two scenarios (non-intervention stage and with intervention) were developed. Based on primary and secondary data, total storage capacity of WHS was estimated for each Gram Panchayat and harvesting density (water storage capacity developed per ha) was estimated. The model was run for each Gram Panchayat with respective “harvesting capacity” to capture the intervention stage. It diverted entire runoff through defined harvesting density and does reservoir balance on daily timescale as defined in Eq. (3).

$$\begin{aligned}&\text{Water volume at day}_i = \text{Water volume at day}_{i-1} + \text{Inflow (runoff)}\\&+ \text{Rainfall over the water body} - \text{Evaporation from the water body}\\&- \text{Spillover} - \text{deep percolation}\end{aligned} \tag{3}$$

3.2.5. Parameterization of pasture land

We developed two scenarios: (i) wasteland; and (ii) pasture land, to understand the impact of pasture land on water balance components and water use efficiency. The “wasteland” scenario represents the situation where the landscape is in a degraded stage. Soils are highly eroded and poor in organic carbon and have poor water-holding capacity. The “pasture land” scenario represents the situation where local species of bushy plants along with grass is cultivated with some soil and water conservation measures (*in-situ* interventions). Leaf fall, stem and other bush/tree biomass is added to the soil mainly at dormancy period. To capture these scenarios, land management and agronomic parameters inputs were provided differently as shown in Table 2. Initial curve number value of land use was assigned with difference of 5; crop coefficient was taken as 0.1–0.5 for wasteland and 0.1–0.9 for pasture land (Garg et al., 2016). With increased *in-situ* water conservation measures and increased organic carbon content, water-holding capacity of soil in pasture land was 10–15% higher than wasteland and same was provided to the model.

3.2.6. Uncertainties of the model results

Modeling natural resources is a challenging task due to spatial and temporal variability of static and dynamic variables. This task becomes further challenging especially in the absence of monitoring data and largely dependent on indirect methods. In the current study, the model simulations were made by considering average land slope and soil types. In addition, major cropping system was only considered while estimating water balance components. Moreover, the model validation was restricted to limited runoff information in project villages. Further, empirical rainfall-soil loss relationship (measured at ICRISAT watersheds as shown in Fig. 4) was integrated with runoff simulation for

Table 2
Parameters to simulate wasteland and pasture land.

Parameters	Wastelands covered by scanty grasses	Protected pasture land with tree plantation	Source
Land management	Open grazing	Protected by live fencing; with *In-Situ* interventions	Primary survey
Runoff estimation	SCS curve number	curve number	Pathak et al. (2013); Garg et al. (2016)
Organic carbon (%)	0.2	0.5–0.8	Measured
Water-holding capacity (mm m^{-1})	80	95	Measured
Crop coefficients (−)	0.1–0.5	0.1–0.9	Literature

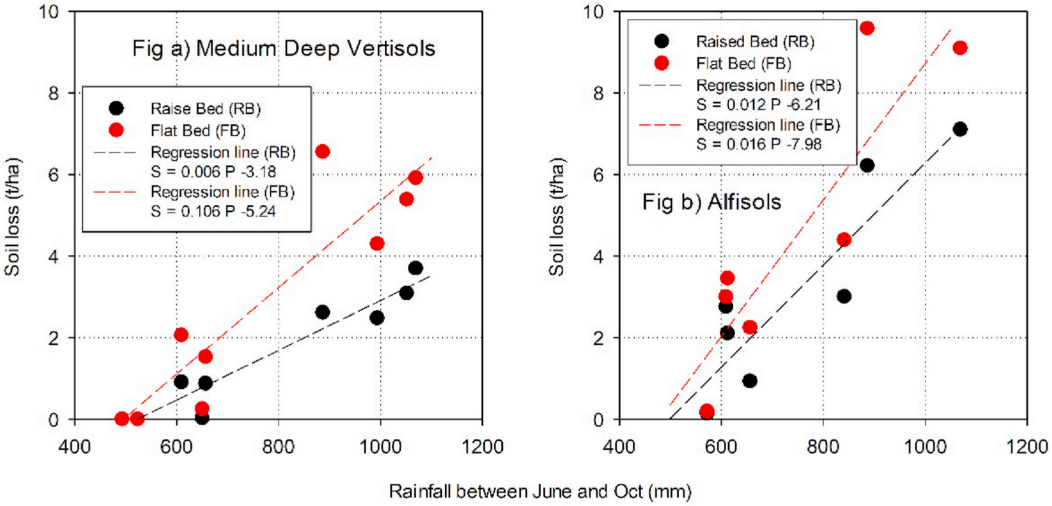

Fig. 4. Rainfall vs soil loss response from Vertisols and Alfisols under different land management conditions on yearly time scale at ICRISAT Patancheru (data from long term hydrological monitoring).

estimating soil loss in different project sites.

4. Results

4.1. Soil biophysical and rainfall characterization

4.1.1. Soil physical and chemical properties

Soils of six districts from three states have diverse physical and chemical properties (Table 3). In general, these soils were poor in organic carbon, available phosphorus and secondary and micronutrients such as sulphur, boron and zinc. Nearly 49–88% fields were found deficient in soil organic carbon in Chhattisgarh, Andhra Pradesh, and Rajasthan in that order which is also a proxy for nitrogen deficiency. In Andhra Pradesh, nearly 38% fields were found deficient in phosphorus whereas the available phosphorus deficiency was highest (70% fields) in Chhattisgarh and Rajasthan. Except few fields in Rajasthan, calcium deficiency in Andhra Pradesh and Chhattisgarh was found in nearly 45–65% fields. Widespread deficiency was observed in important micro and secondary nutrients such as sulphur, boron and zinc as more than 70% fields were found deficient in these nutrients (Table 3).

Further, land use analysis revealed that soil organic carbon in pasture lands developed in Bhilwara, Rajasthan was relatively higher (0.60–0.80%) compared to nearby wastelands (0.20–0.30%). These results indicate that carbon pool increased in top soil layers (0–15 cm) due to pasture land development over four-to five-year period whereas no significant change in soil organic carbon was found in orchard developed sites of Chittorgarh, Rajasthan compared to nearby control fields as soil depth of the landscape is very shallow.

Soil organic carbon was found low (<0.5%) in all the samples collected from tank bed at Chhattisgarh as compared to soils from farmers' fields (0.7–1.0%). Therefore, application of tank silt to farmers' fields may not add additional nutrients in this case. Quality of silt from tank bed collected from Chhattisgarh was similar to the soils from farmers' fields except for exchangeable sodium. Sodium concentration in silt was 70–1090 mg kg^{-1}. However, the level of sodium concentration varied with age of the tank, location of tank, and location of soil sample collected from the tank bed. The sodium concentration in the samples from lower end of the tank was 323–362 mg kg^{-1} as compared to 70–78 mg kg^{-1} at the upper end. This is indicative of the amount of domestic wastewater flow into the tanks and extent of other domestic activities (bathing, washing, etc.) carried out. Samples collected from pilot villages in Andhra Pradesh showed significant higher content of organic carbon (0.5–0.9%) in the fields, where soil and water conservation, plantation, and tank silt application were done as compared to control fields.

4.1.2. Rainfall characterization

Rainfall data of targeted districts collected from Indian Meteorological Department, was analyzed for ten years period and is summarized in Table 4. Data showed that average annual rainfall of different districts ranged between 550 and 1250 mm. Table 4 shows rainfall distribution in terms of number of events and amount of rainfall received. We categorized daily rainfall into three categories, i.e., low intensity (<30 mm day^{-1}), medium intensity (30–50 mm day^{-1}), and high intensity (>50 mm day^{-1}). Nearly 40–50% of total rainfall amount is being received through low intensity rainfall events whereas rest is distributed among medium and high intensity rainfall events. Data also suggested that minimum three rainfall events are likely to be received with higher intensity even in districts like Anantapur and Bhilwara where average annual rainfall is lower than 700 mm, and have potential to generate surface runoff in each monsoon season.

4.2. Impact of MGNREGA on provisioning ecosystem services

4.2.1. Enhanced water resources availability

The study estimated water balance components in 13 selected Gram Panchayats having diverse soil types, land use, cropping pattern, and topography. The geographical area of these panchayats ranged between 200 ha and 4535 ha and average annual rainfall ranged between 550 mm and 1250 mm. Based on model simulation, annual runoff amount varied from 70 mm to 250 mm (14–29% of total rainfall). In most of the cases, August and September were receiving more than 60% of total annual rainfall and accordingly generated runoff was also significant. Primary data on water storage capacity of different WHS was used as a

Table 3
Soil health status in different pilot *Gram Panchayats* [a].

Parameters[b]	Critical limit	Andhra Pradesh			Chhattisgarh			Rajasthan		
		Average	Range	% fields deficient	Average	Range	% fields deficient	Average	Range	% fields deficient
Soil chemical properties										
Organic carbon (%)	0.5	0.39	0.07–1.68	66	0.34	0.03–1.02	88	0.54	0.2–1.25	49
pH	6.5–8.5	7.26	5.03–9.4	–	7.68	5.58–9.36	–	7.26	5.95–8.15	–
EC (uS)	0.8	0.18	0.02–1.23	–	0.18	0.02–0.8	–	0.17	0.03–0.5	–
Avail P (mg kg^{-1})	5.0	8.97	1.14–58.31	38	8.64	1.39–71.53	70	5.67	2.15–34.7	70
Exch K (mg kg^{-1})	50	91.78	18–469	25	146	25–362	7	78	32–263	24
Exch Ca (mg kg^{-1})	1000	939.83	214–4456	66	1001.24	143–1417	47	1211.2	736–1417	13
Exch Mg (mg kg^{-1})	1.0	269.12	58–1094	3	536.43	52–1179	8	253.41	48–573	3
Avail S (mg kg^{-1})	8.0	10.36	0.72–311.6	72	6.53	1.61–28.67	75	8.11	2.6–28.14	64
Avail Zn (mg kg^{-1})	0.75	0.55	0.02–2.84	69	0.45	0.08–2.63	82	2.05	2.6–28.14	61
Avail B (mg kg^{-1})	0.58	0.50	0.11–2.05	75	0.45	0.06–1.43	89	0.57	2.6–28.14	46
Avail Fe (mg kg^{-1})	2.0	19.11	0.03–356.3	9	23.40	4.86–200.34	0	12.62	2.04–211.8	0
Avail Cu (mg kg^{-1})	0.5	1.22	0.16–5.12	10	1.42	0.28–5.86	8	1.23	0.56–5.08	0
Avail Mn (mg kg^{-1})	1.0	10.69	1.16–44.5	0	9.66	0.21–40.6	2	9.90	2.6–28.14	0
Exch Na (mg kg^{-1})	–	117.04	2–1689	–	137.67	20–1090	–	65.22	21–286	–
Soil physical properties										
Coarse sand (%)		51	23–63		26	3–69		18	2–34	
Fine sand (%)		24	15–41		32	11–53		36	11–58	
Silt (%)		8	4–19		16	5–26		22	11–42	
Clay (%)		16	8–36		26	5–45		24	8–52	

Total number of samples is 191

[a] Source: Field survey.

[b] Avail = Available; Exch = Exchangable.

Table 4
Annual rainfall distribution (mm) in selected districts of three states in India[a].

Rainfall category	Andhra Pradesh		Chhattisgarh		Rajasthan	
	Anantapur	Vizianagram	Dhamtari	Rajanandagaon	Chittorgarh	Bhilwara
0–30 mm day^{-1}	300 (60)[b]	488 (54)	441 (44)	376 (41)	352 (42)	299 (33)
30–50 mm day^{-1}	73 (2)	369 (9)	191 (5)	200 (5)	237 (6)	150 (4)
>50 mm day^{-1}	167 (3)	395 (5)	503 (5)	346 (4)	265 (3)	224 (3)
Total rainfall (mm)	540 (65)	1252 (68)	1135 (54)	922 (50)	854 (52)	673 (40)

[a] Source: India Meteorological Department.
[b] No. of events is given in parentheses.

model input to estimate total harvested runoff during monsoon period. The storage capacity of WHS created in different panchayats varied from 10,000 m^3 to 339,000 m^3 and largely depended on topography and total number of works completed. In other words, harvesting density i.e., water storage capacity developed per ha (term used "harvesting density") ranged from 6 m^3 ha^{-1} to 300 m^3 ha^{-1}. Fig. 5 describes the variability in generated surface runoff and soil loss for "no intervention" as well as "with intervention" scenarios for Abhaypaura Gram Panchayat as an example. It shows that runoff generated during June and July was fully captured as storage capacity of the WHS and was sufficient to hold generated runoff. Subsequent rainfall received during August to October was generally spilled over to downstream areas and only less than 5% of the runoff was harvested in available WHS (Fig. 5a). We observed that this variability exists even within the district due to difference in topography and land use.

On an average, these structures got filled 2 to 3.5 times of their storage capacity during the monsoon period depending on number of times inflow was received. The total water harvested from these structures varied from 30,000 m^3 $year^{-1}$ to 678,000 m^3 $year^{-1}$ on average basis. Further, the analysis revealed that total water harvested ranged from 1 to 15% of total inflow generated at selected Gram Panchayats. Some Gram Panchayats have large potential to develop WHS to harness the full potential of runoff generated while other Gram Panchayats have saturated their absorbing capacity.

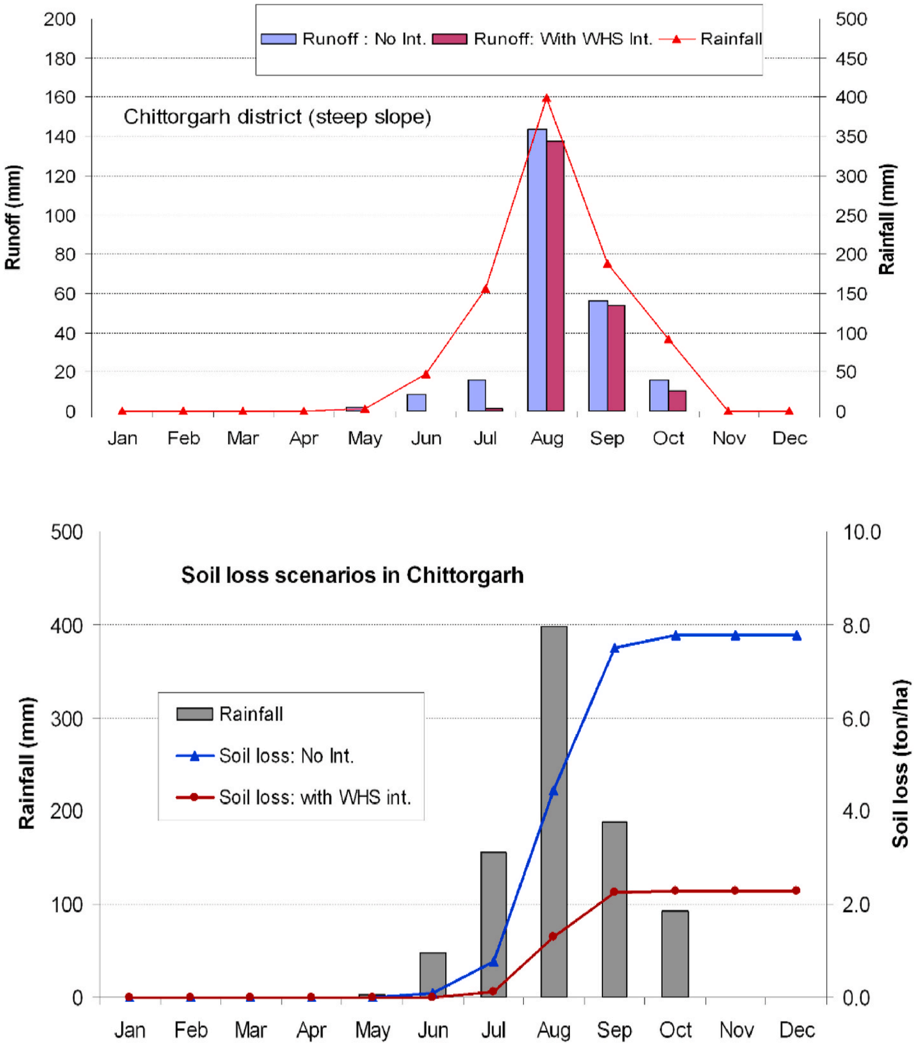

Fig. 5. a) Month-wise runoff generated with response to rainfall in Abhayapura Gram Panchayat - comparing "no-intervention" and "with intervention"; b) Cumulative soil loss with response to rainfall in a selected normal year - comparing "no-intervention" and "with intervention".

4.2.2. *Increased irrigation acreage*

The WHS have been contributed in terms of groundwater recharge which resulted in expansion of irrigated area and change in cropping pattern. Based on crop-water requirement and green water availability, irrigation water requirement was estimated. We found that these structures have contributed to expansion of irrigated area ranging between 4 ha and 95 ha, i.e., 25% of total irrigated area increased in past 10 years on average. The MGNREGA contribution was significant in terms of expansion in area under supplemental irrigation in Gram Panchayats which are completely dependent on rainfall whereas the impact was relatively less in Gram Panchayats having canal networks. For example, in Abhaypura, Rajasthan, the maximum contribution in terms of irrigated area expansion was from WHS whereas in other Gram Panchayats the contribution was less than 10%.

4.2.3. *Change in cropping system*

Due to WHS, increased water availability influenced the cropping system both in *monsoon* and *post-monsoon* as farmers shifted their cropping pattern from low-yielding crops to high value crops. For example, both wheat and mustard, equally dominated in Abhaypura area during *post-monsoon* period in 2005. Limited number of farmers from downstream areas were able to cultivate wheat in 2005 whereas midland farmers were cultivating mustard due to poor groundwater availability. After construction of rainwater harvesting structures, midland farmers also shifted their cropping system from mustard to wheat as more than 90% irrigated farmers are cultivating wheat (Fig. 6).

In addition to expansion in irrigated area, crop productivity was also increased by 20–50% compared to non-beneficiary households (Table 6). This is largely because of availability of the supplemental irrigation water during critical stage of crop.

4.2.4. *Increased fodder availability*

Wasteland was converted to pasture lands which has significantly contributed to meet the fodder requirements in Rajasthan. Fodder production from pasture land was around 4–5 t ha^{-1} after four years of establishment in Bhilwara, Rajasthan. A 25-ha pasture land was sufficient to meet the fodder requirements of about 200 animals for 2–3 months after the rainy season. This has become additional income source to the panchayat as they charge 0.50 US$ per animal per month collectively. The pasture land further contributed to reducing soil erosion; however, there is no measured data available on soil loss from the study area.

4.2.5. *Orchard development*

Orchard developed under MGNREGA has good potential to convert wasteland/degraded land into productive landscape. The success of orchard is found highly dependent on the selection of suitable tree species as per rainfall, soil types and depth and its management. Technical feasibility of orchard plantation in different rainfall and soil condition was analyzed. Total water requirement of different fruit trees (*mango, pomegranate, lemon, black plum, Indian gooseberry, jujube guava, and papaya*) was estimated (considering non-limiting water condition) and was compared with total green water availability of a given landscape under rainfed condition.

Orchard developed under MGNREGA in Chittorgarh, Rajasthan had plants with stunted growth due to shallow soil depth (<30 cm) and degraded landscape. Despite having good to moderate rainfall, moisture supplying capacity of degraded land was low and crop (orchard) water demand was relatively high. Amount of irrigation in orchards selected for the evaluation was nearly 1000 mm per year. In Anantapur, Andhra Pradesh large area was developed with mango orchards which showed good productivity as well as adaptability among the farming community. In Chhattisgarh, orchards were developed on the bank of a river. Water-holding capacity of this landscape is poor. Therefore, frequent irrigations were provided using the conventional irrigation methods which led to huge wastage of water. A proper irrigation scheduling along with improved method of irrigation needs to be undertaken. In Vizianagaram district of Andhra Pradesh, mango orchards were developed in trench-cum-bund and teak plants grown on the bunds. This activity was a potential intervention of agroforestry.

4.3. *Impact of MGNREGA on regulatory and supporting services*

The study results suggest that the MGNREGA works on NRM enhanced not only provisioning ecosystem services but also regulatory and supporting services. Water budget analysis showed that converting

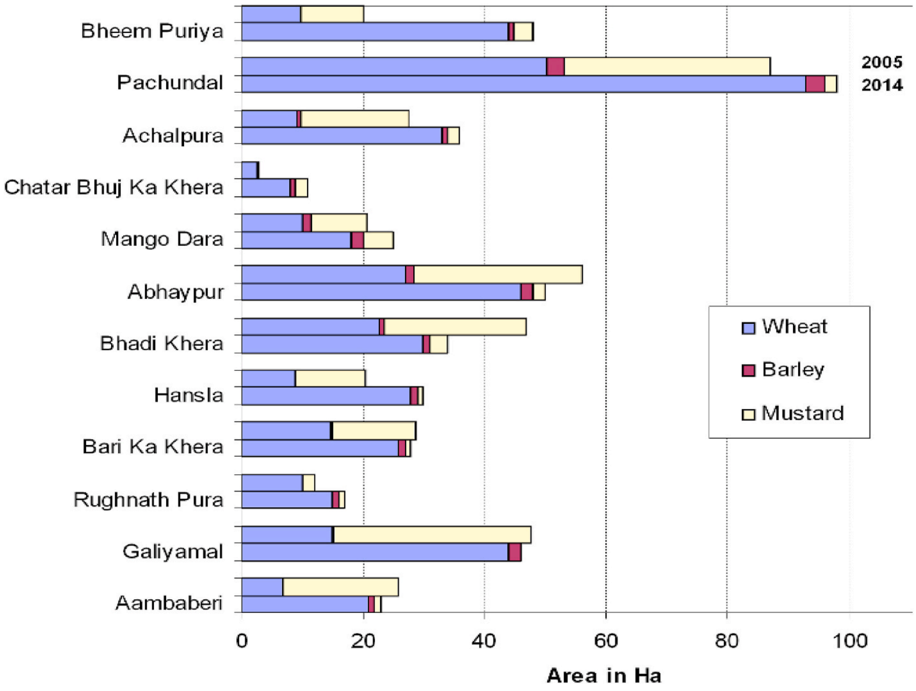

Fig. 6. Change in cropping pattern (*rabi*) in different villages of Abhayapura Gram Panchayat, Chittorgarh district, Rajasthan between 2005 and 2014.

Table 5
Impact of water harvesting structures on water balance components (runoff and groundwater recharge) and increased irrigated acreage in selected panchayats.

District	Panchayat	Geographical area (ha)	Avg. Annual rainfall (mm)	Runoff (mm)	Water yield (Runoff generated) (MCM)[a]	Structure capacity developed (m^3)	Total water harvested (m^3)	Irrigated area Expansion due to MGNREGA (ha)	Water surplus to down-stream location (MCM)	Reduced soil loss (t ha^{-1})
Rajasthan										
Chittorgarh	Abhaypura	1750	832	242	4.24	339,200	678,400	95	3.56	3.1
Chittorgarh	Sehnwa	1555	832	180	2.80	10,000	30,000	4	2.77	2.5
Bhilwara	Nandrai	4535	673	137	6.21	62,500	187,500	28	6.03	2.9
Bhilwara	Kakroliya Ghati	4066	673	137	5.57	37,500	112,500	17	5.46	2.9
Chhattisgarh										
Dhamtari	Nari	1026	1061	147	1.51	223,600	447,200	89	1.06	3.9
Dhamtari	Parkhanda	916	1061	147	1.35	131,400	262,800	52	1.08	3.9
Rajnandgaon	Bijnapur	442	1061	147	0.65	127,500	255,000	51	0.39	3.9
Rajnandgaon	Shiwnikala	616	1061	147	0.91	185,000	370,000	73	0.54	3.9
Rajnandgaon	Jhandatalab	838	1061	147	1.23	161,700	323,400	64	0.91	3.9
Andhra Pradesh										
Anantapur	Agraharam	2836	447	69	1.95	31,600	110,700	22	1.83	1.2
Anantapur	Bukkapatnam	3117	447	69	2.14	57,550	201,400	40	1.94	1.2
Vizianagaram	Tettangi	417	1200	240	1.0	32,000	80,000	16	0.92	2.9
Vizianagaram	Girida	202	1200	240	0.48	29,000	72,500	14	0.41	2.9

[a] MCM = Million cubic meter.

Table 6
Average crop yield of major cropping system in study districts – comparison of beneficiary and control households (HHs)[a].

State	District	Major crops	Yield (kg ha^{-1})		Yield increase (%)
			Control HHs	Beneficiary HHs	
Rajasthan	Chittorgarh	Wheat	3500	4500	29
		Mustard	1100	1400	27
	Bhilwara	Wheat	2200	3000	36
		Mustard	1000	1500	50
Chhattisgarh	Dhamtari	Paddy	4500	5400	20
	Rajnandgaon	Paddy	2100	2900	38
		Chickpea	500	750	50
Andhra Pradesh	Anantapur	Groundnut	450	700	56
	Vizianagaram	Paddy	1900	2800	47

[a] Source: Compiled from primary survey.

wasteland into pasture land significantly changed landscape hydrology as runoff reduced from 32% to 17% and groundwater recharge was equal to 9–10% of total rainfall (Table 7). More than 70% of the nonproductive evaporation in the fallow/barren land shifted into productive transpiration (generating wood biomass and fodder grass) after pasture land development and resulted in increased land and water use efficiency. Similarly, constructed WHS in different Gram Panchayats have helped in flood control in downstream areas and also controlling soil erosion.

Total amount of carbon sequestered by pasture land is presented in Table 8. There were two domains where carbon could be fixed in pasture lands: (i) below the ground as organic matter; and (ii) wood formation in tree biomass. Unlike agricultural land, soils in pasture lands are not exposed by tillage operation; therefore, decomposition of carbon is minimal.

Table 7
Comparison of water balance components among fallow and pasture land.

Parameters	Fallow land	Pasture land with *In-Situ* practices
Rainfall (mm)	673	763
Outflow (mm)	218 (32%)	120 (17%)
Evaporation (Nonproductive losses)	387 (57%)	125 (18%)
Transpiration (Productive use)	–	364 (54%)
Deep percolation (mm)	68 (10%)	64(9%)

Soil analysis showed that there is net gain of 0.3–0.6% organic carbon in pasture land compared to the nearby barren lands at sites visited in Rajasthan and Andhra Pradesh which is equivalent to 7–14 t ha^{-1} carbon sequestration over the four to five years period (Table 8). Tree species (e.g., babul) which established well are producing good biomass and growth (Table 8). With 80% survival rate of tree plants, nearly 2.5–8.0 t ha^{-1} wood mass have been developed in pasture land over the four-year period which is equivalent to 1–3 t ha^{-1} carbon sequestration.

Primary data as well as simulation modeling results indicated that various WHS have contributed to accelerated groundwater recharge. Farmers' perception revealed that the duration of the stream flow has increased by 15–30 days (e.g., Abhaypura, Rajasthan) as base flow increased with higher water table. With reduced flash floods and reduced velocity, soil erosion has reduced by 1–4 t ha^{-1} (Table 5). Fig. 5b compares cumulative soil loss between "no intervention" and "with intervention" stages in Abhaypura Gram Panchayat in one of the normal rainfall years. Soil loss has significantly reduced from 8 t ha^{-1} to 2 t ha^{-1}. Abhaypura is one of the Gram Panchayats where relatively high structure density exists. Despite having a huge runoff, soil loss reduced threefold compared to "no intervention" stage.

Increased surface and groundwater availability supported drinking water needs for domestic purpose as well as livestock. In addition, MGNREGA NRM works have facilitated other income-generating activities such as fish cultivation in rejuvenated tanks and farm ponds. For example, in Chhattisgarh, few village tanks have been taken on lease from Gram Panchayat by local fishermen (*Machwa*) community to

Table 8

Carbon sequestration due to pasture land development in study area[a].

Description	Bhilwara (Rajasthan)	Vizianagaram (Andhra Pradesh)	Anantapur (Andhra Pradesh)
Major tree species grown	Babul/ fodder	Teak/fodder	Mango
Carbon sequestration due to increasing organic carbon			
Soil organic carbon measured from pasture land in top 15 cm soil layer (%)	0.64	0.88	0.55
Soil organic carbon measured from nearby control (barren) field in top 15 cm soil layer (%)	0.20	0.26	0.24
Difference in carbon content (%)	0.44	0.62	0.31
Carbon sequestration in 15 cm soil depth (t ha^{-1})	9.9	12.6	6.28
Carbon fixation in wood			
No. of trees per ha	400	500	160
Survival rate (80%) (no. of trees per ha)	320	450	144
Average wood mass per tree (4–5 years old) (Kg tree^{-1})	25	10	18
Total wood biomass accumulated (t ha^{-1})	8.0	4.5	2.6
Carbon sequestration in wood biomass (40% carbon) (t ha^{-1})	3.2	1.8	1.04
Total carbon sequestration (t ha^{-1})	13.1	14.36	7.32

[a] Source: Sample analysis and biomass estimation.

cultivate fish as additional livelihood source.

4.4. Harnessing the untapped potential of semi-arid tropics–scenario analysis

Intended environmental impacts of MGNREGA works on water conservation and harvesting for three rainfall regions (low = 500 mm; medium = 800 mm; and high = 1000 mm) were developed. In this analysis, major impact indicators used are: enhanced irrigated area, crop yield, per cent crop area saved due to flood control, fodder production, and employment generation due to crop intensification. Amount of harvested runoff in normal year, potential groundwater recharge, and increased irrigated area with WHS were compared with non-intervention stage (Table 9). Further, other anticipated benefits such as flood and soil erosion control, increased crop yield (cereals and fodder) in *rainy season* and *post-rainy* season were estimated considering that only 20–30% cultivable area would be protected from soil erosion at upstream location; and 10–20% cultivable land protected from the flood events at downstream location.

The analysis indicated that WHS have potential to double the groundwater recharge compared to "no intervention" stage. The increased groundwater availability may support 50–150 ha additional irrigated area in 1000-ha geographical extent depending on rainfall regions. Increased irrigated acreage also would influence crop and fodder productivity both in rainy and post-rainy seasons. Increased crop intensification would also provide employment opportunities (~3000–8000 person days on 1000 ha) to skilled and unskilled laborers. The results also suggested that such interventions would reduce soil loss by 40–60 per cent signifying protection of available carbon and nutrients. The *ex-ante* analysis shows that the potential impact of rainwater harvesting was between US$ 50,000 and US$ 190,000 per year compared to no-intervention scenario. This is equivalent to the additional economic gain of US$ 50-200 ha^{-1} year^{-1} in different rainfall regions (Table 9).

Table 9

Potential ecosystem benefits and economic gain due to various water harvesting interventions in three rainfall regions (total geographical area considered = 1000 ha; agriculture area = 800 ha).

Parameters	500 mm		800 mm		1000 mm	
	No int	With Int	No int	With Int	No int	With Int
Quantity						
Runoff yield (mm)	75	75	150	150	200	200
Water harvested (mm)	0	25	0	50	0	70
Increased groundwater recharge (mm)	20	45	30	70	50	106
Supported irrigation acreage (ha)	50	113	75	175	125	265
Soil loss (t ha^{-1})	2	1.2	5.5	2.5	9.0	3.5
Crop yield in *rainy season* (maize)	2000	4500	3500	6000	4000	6500
Crop yield in *post-rainy season* (wheat) (Kg ha^{-1})	2500	3500	3000	4500	3500	5000
Total fodder yield (kg ha^{-1} season^{-1})	6000	9000	7000	10,000	7500	12,000
Increased employment opportunities (person days)		3780		6000		8400
Economic gain						
a) Erosion control						
Impacted area (ha)[a]		160		200		240
Difference in rainy season crop yield due to protected soil loss (Kg ha^{-1})		40		180		385
Difference in post rainy season crop yield (kg ha^{-1})		96		420		825
Total difference (US$ ha^{-1})		26		114		229
Total economic gain (US$ year^{-1})		4146		22,836		55,066
b) *Flood* control						
Impacted land area (ha)**		80		120		160
Difference in rainy season crop yield (Kg ha^{-1}) (assumed 30% yield loss due to flood)		750		900		1050
Equivalent value of Flood control (US$ ha^{-1})		123		148		172
Total economic gain (US$)		9851		17,731		27,582
c) Crop productivity: Cereals						
Additional irrigated area (ha)		50		75		125
Increased income due to higher yield (US$ ha^{-1})		612		713		713
Additional economic gain (US$ year^{-1})		30,597		53,451		89,086
d) *Crop* productivity: *Fodder*						
Additional Fodder gain (US$ ha^{-1})		134		134		201
Increased income due to higher fodder yield (US$ Year^{-1})		6716		10,075		25,187
e) Income generated from farm labour (US$)		14,104		22,388		31,343
Total economic gain in 1000 ha		65,414		126,481		228,263

(*continued on next page*)

Table 9 (*continued*)

Parameters	500 mm		800 mm		1000 mm	
	No int	With Int	No int	With Int	No int	With Int
Quantity						
watershed = **a** + **b** + **c** + **d** + **e** (**US$ year^{-1}**)						
Economic gain (**US$ ha^{-1} year^{-1}**)		65		126		228

[a] Considered 20% of cultivated area; ** considered 10% of cultivated area; 1 US$ = ₹ 67 (In July 2016).

Similarly, scenarios for pasture land development (shallow and moderate deep soil) were also generated for three rainfall regions (low, medium, and high). Various environmental benefits such as consumptive water use, fodder generation, carbon sequestration, timber biomass generation, and soil erosion control were estimated**.** The scenario analysis indicated that developing community wasteland into pasture land holds potential to produce fodder yield ranging from 3 to 7 t ha^{-1} in different rainfall regions which can support 150–375 days to feed a milch animal. Similarly, 5 to 10 t ha^{-1} wood biomass also can be generated in 5 years. This will further enhance organic carbon content in soil pool equivalent to 7 to 11 t ha^{-1} carbon sequestration in 5-year period. In summary, economic gain obtained from pasture land development was between US$ 1270 and US$ 2800 ha^{-1} in the five-year period (Table 10).

5. Discussion

5.1. Building resilience through natural resource management interventions

In view of increasing climate variability and change, NRM plays an important role in strengthening ecosystem services for sustainable development. In this context, MGNREGA, which is one of the largest social welfare schemes, has contributed significantly in terms of rural infrastructure development. A decentralized water harvesting approach along with other NRM interventions was adopted while guaranteeing rural employment to unskilled labor force. Decentralized water harvesting is an effective water utilization approach in which water is partially harvested and utilized at source whereas in centralized water harvesting system (irrigation projects) there are a number of nonproductive losses. In addition, decentralized approach addresses equity issues as all sections of the community get benefit (upstream to downstream users). WHS facilitate to provide one or two supplemental irrigations either from surface water or groundwater reserves. As a result, agricultural productivity has increased minimum by 50 per cent compared to rainfed situation. Sharma et al. (2010) estimated potential of rainfed agriculture through supplemental irrigation for 225 rainfed districts of different agro-ecological regions. They concluded that rainfed system holds large potential to generate surface runoff (114 BCM from 28.5 million ha). Out of generated runoff, nearly 20 per cent of the harvested runoff can meet irrigation requirement (100 mm with one or two supplemental irrigations) of 20.65 million ha area (Sharma et al., 2010). Similarly, in this study we observed if 30 per cent of generated runoff is harvested, the irrigated area can be doubled and facilitate crop intensification and higher agriculture and livestock productivity. Also, NRM interventions have generated wide range of services (provisioning, supporting, regulatory, and cultural services). These works have addressed water scarcity, and agriculture and livestock productivity issues in low and medium rainfall regions while protecting from floods and reducing soil erosion in high rainfall areas.

On the contrary, the present study also observed that few of the NRM works undertaken through MGNREGA did not perform as per the expectation due to lack of technical backstopping and planning. For example, trees in fruit orchards in Rajasthan showed stunted growth as the soil depth was shallow (<30 cm). Continuous irrigation is required to sustain the growth. In some cases, drip irrigation system was laid down in community horticulture plantations through MGNREGA funds. However, these systems have become defunct due to poor maintenance and lack of attention from the community. Frequent irrigation through flood method in such low rainfall regions may not only increase the cost of cultivation but also have negative water and energy footprints. For selection of tree species, soil biophysical properties and rainfall pattern need to be considered while designing the interventions such that plants can grow under rainfed condition or with minimal irrigation application. Further, a protocol should be included in MGNREGA guidelines for maintaining infrastructure and required services such as cleaning drip setup, and fuel and labor cost.

Similarly, few check dams constructed in some places were not getting runoff water as catchment area was negligible. In such a situation, the community used these structures as storage units through lifting groundwater from borehole wells for livestock. Such practices instead of contributing to groundwater recharge, negatively affect water availability and lead to various nonproductive losses. Moreover, some of the structures were found defunct due to piping or damaged outlets. This

Table 10
Environmental benefits from pasture land in shallow and moderate soils in three rainfall regions[a].

Parameters	500 mm		800 mm		1000 mm	
	Shallow	Moderate	Shallow	Moderate	Shallow	Moderate
Quantity						
Fodder yield (Kg ha^{-1})	3000	5000	4500	6000	5000	7500
Timber biomass (Kg ha^{-1})	5000	8000	6000	8000	7000	10,000
Consumptive water use (mm)	300	380	430	470	520	570
Increased organic carbon (OC) in five years (%)	0.35	0.4	0.4	0.45	0.45	0.5
Carbon sequestration due to increased Soil OC (t ha^{-1})	7.9	9.0	9.0	10.1	10.1	11.3
Soil loss from fallow land (t ha^{-1})	2	1.9	5.5	5.4	9	8.5
Soil loss after pasture land development (t ha^{-1})	1.5	1.3	2.5	2.4	3.5	3.4
Erosion control (t ha^{-1})	0.5	0.6	3	3	5.5	5.1
No of days fodder availability to feed a milch animal (days ha^{-1})	150	250	225	300	250	375
Economic gain						
a) Value of fodder (US$ ha^{-1} year^{-1})	134	224	201	269	224	336
Fodder value in five years (US$ ha^{-1})	672	1119	1007	1343	1119	1679
b) Value of timber wood production (US$ ha^{-1})	410	657	493	657	575	821
c) Value of Carbon sequestrated (US$ ha^{-1})	191	218	218	246	246	273
Total economic gain in 5 years **(**US$ ha^{-1}**)** = a+b + c	1273	1994	1718	2246	1940	2773
Economic gain (US$ ha^{-1} year^{-1}**)**	255	399	344	449	388	555

1 US$ = ₹ 67 (In July 2016).

is also observed that number of reservoirs those were developed in these villages by constructing earthen embankments were frequently get breeched due to flash floods and repaired several times. In such case, permanent solutions of introducing masonry core wall could be useful for increasing the life span of the structures. Similar core wall concept was introduced for rejuvenating traditional *haveli* system of Bundelkhand region of Uttar Pradesh, central India (Garg et al., 2020a). Thus, it is essential that works proposed by Gram Panchayats under MGNREGA should be technically validated by qualified technical agencies for their techno-economic feasibility. Similarly, proper awareness need to be created among the community regarding identifying need-based works to generate larger impacts.

5.2. *Rural livelihood*

In addition to strengthening environmental services, MGNREGA is largely contributing to improve the rural livelihood system by: (i) providing employment opportunities for unskilled labor force; (ii) increasing wage employment opportunities in agriculture with crop intensification; and iii) increased crop-livestock-fish production where required NRM works are implemented. The study observed that MGNREGA directly contributes to nearly 10 per cent of total household annual income through wage employment. Several studies claim that implementation of MGNREGA reduced labor availability for agricultural operations (Maiorano et al., 2021). This has significance in terms of labor engagement either in agriculture or in other activities (Girard, 2014). In other words, this has reduced the labor exploitation which extremely prevalent in rural areas. Primary survey indicated that with crop intensification due to increased water availability, migration has reduced significantly and in-migration was observed especially in Chhattisgarh.

The MGNREGA has contributed immensely to the welfare of the rural people by creating different assets and generating wage employment. Several studies observed that there are lacunas in implementation of different works due to lack of technical know-how among the MGNREGA engineers. Therefore, to improve the efficiency of the program, an effective convergence of relevant line departments (watershed, agriculture, horticulture, water resources, forestry, minor irrigation etc.) is needed. It is also important to intensifying field and landscape monitoring to generate quality data base at least in one micro-watersheds of the districts representing landscape topography and agro ecological region to bridge the data gap. This will help to understand the hydrological processes and designing science based natural resource management interventions.

6. Conclusions

The impact of MGNREGA interventions on various environmental services was evaluated in selected Gram Panchayats of Andhra Pradesh, Chhattisgarh and Rajasthan. The study focused mainly on NRM works such as water harvesting, pasture and orchard development, etc. Undertaken through MGNREGA. Primary and secondary data on demography, change in land use, WHS capacity, cropping system, agriculture and livestock productivity, and representative soil samples were collected. Data were analyzed to understand the technical feasibility of various interventions and water balance components using simulation models. There was large variation in amount of rainfall received ranging from 550 mm to 1250 mm among selected Gram Panchayats. Soil test analysis showed most of the selected Gram Panchayats were deficient in soil organic carbon as well as micro and secondary nutrients. Water harvesting density of different Gram Panchayats varied from 10 to 250 m^3 ha^{-1} depending on topography and works completed. The WHS have contributed significantly in terms of harvesting surface runoff, enhancing groundwater recharge, reducing soil erosion, and flood control. Increased irrigation acreage was between 4 ha and 95 ha which is about 5–10% of the total cultivable area. In addition, crop productivity has increased from 30 to 50% both in rainy and post-rainy seasons compared to non-beneficiary fields. Simulation results, further revealed that soil loss reduced by 1–4 t ha^{-1}. Similarly, converting wasteland into pasture land has contributed significantly fodder availability, increasing carbon sequestration, and enhancing land and water use efficiency. *Ex-ante* analysis further showed that the selected NRM works have potential to generate additional economic gain from US$ 60 ha^{-1} $year^{-1}$ to US$ 225 ha^{-1} $year^{-1}$ along with a number of indirect benefits to strengthen environmental services and rural livelihood. The study suggested to follow a science-led approach in designing and implementation for improvements and creating larger impacts in different areas. Overall, the MGNREGA has helped in strengthening ecosystem services, viz., provisioning, regulatory, and supporting services in addition to providing employment opportunities.

Declaration of competing interest

We (Anantha K.H., Kaushal K. Garg, D. Shyam Moses, Mukund D. Patil, and Gajanan L. Sawargaonkar, Prasad J. Kamdi, Sachin Malve, R. Sudi, K.V. Raju, S.P. Wani), hereby declare that there is no conflict of interest among us and partners on submitted manuscript.

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References

Abera, Wuletawu, Tamene, Lulseged, Tibebe, Degefie, Adimassu, Zenebe, Kassa, Habtemariam, Hailu, Habtamu, Mekonnen, Kindu, Desta, Gizaw, Rolf Summer, Vercho, Louis, 2020. Characterizing and evaluating the impacts of national land restoration initiatives on ecosystem services in Ethiopia. Land Degrad. Dev. 31 (1), 37–52.

Abon, C.C., David, C.P.C., Pellejera, N.E.B., 2011. Reconstructing the tropical storm ketsana flood event in marikina river, Philippines, hydrol. Earth Syst. Sci. 15, 1283–1289. https://doi.org/10.5194/hess-15-1283-2011.

Aggarwal, Ankita, Aashish, Gupta A., Ankit, Kumar A., 2012. Evaluation of NREGA wells in Jharkhand. Econ. Polit. Wkly. XLVII (3), 24–27.

Allen, R.G., Pereira, L.S., Smith, M., Raes, D., Wright, J.L., 1998. FAO-56 dual crop coefficient method for estimating evaporation from soil and application extensions. J Irrig Drain E-Asce 131 (1), 2–13.

Amaral, S., Bandyopadhyay, S., Sensarma, R., 2015. Employment programmes for the poor and female empowerment: the effect of NREGS on gender-based violence in India. J. Interdiscipl. Econ. 27 (2), 199–218.

Arnold, J.G., Fohrer, N., 2005. SWAT2000: current capabilities and research opportunities in applied watershed modeling. Hydrol. Process. 19 (3), 563–572.

Das, U., 2015. Does political activism and affiliation affect allocation of benefits in the rural employment guarantee program: evidence from West Bengal, India. World Dev. 67, 202–217.

Dinar, A., Tieu, A., Huynh, H., 2019. Water scarcity impacts on global food production. Global Food Security 23, 212–226.

Esteves, T., Tashina, Rao, K.V., Bhaskar, Sinha B., Roy, S.S., Bhaskar, Rao B., Shashidharkumar, Jha S.K., Ajay, Bhan, Singh, A.B., Patil, Vishal, Sharma, Nitasha, Shashanka, Rao S., Murthy, I.K., Rajeev, Sharma R., Ilona, Porsche I., Basu, K., Ravindranath, N.H., 2013. Agricultural and livelihood vulnerability reduction through the MGNREGA. Econ. Polit. Wkly. XLVIII (52), 94–103.

FAO, 2020. The State of Food and Agriculture 2020. Overcoming Water Challenges in Agriculture. https://doi.org/10.4060/cb1447e. Rome.

Fischer, H.W., Ali, S.S., 2018. Reshaping the public domain: decentralization, the Mahatma Gandhi national rural employment guarantee Act (MGNREGA), and trajectories of local democracy in rural India. World Dev. 120, 147–158.

Fitton, N., Smith, P., Alexander, P., Arnell, N., Bajzelj, B., Calvin, K., Doelman, J., Stehfest, E., Gerber, J.S., West, P.C., Havlik, P., Krisztin, T., Hasegawa, T., Herrero, M., van Meijl, H., Powell, T., Sands, R., 2019. The vulnerabilities of agricultural land and food production to future water scarcity. Global Environ. Change 58, 101944.

Garg, K.K., Anantha, K.H., Barron, J., Singh, Ramesh, Inder, Dev, Dixit, Sreenath, Whitbread, A.M., 2020c. Scaling-up of Agriculture Water Management Interventions for Building System Resilience in Bundelkhand Region of Central India, Background Report for Sustainable Intensification of Rainfed Systems. FAO-SOFA.

Garg, K.K., Anantha, K.H., Nune, R., Akuraju, V.R., Singh, P., Gumma, M.K., Dixit, S., Ragab, R., 2020b. Impact of land use changes and management practices on groundwater resources in Kolar district, Southern India. J. Hydrol.: Reg. Stud. 31, 100732.

Garg, K.K., Singh, R., Anantha, K.H., Singh, A.K., Akuraju, V.R., Barron, J., Dev, I., Tewari, R.K., Wani, S.P., Dhyani, S.K., Dixit, S., 2020a. Building climate resilience in degraded agricultural landscapes through water management: a case study of Bundelkhand region, Central India. J. Hydrol. 591, 125592.

Garg, K.K., Wani, S.P., Patil, M.D., 2016. A simple and farmer-friendly decision support system for enhancing water use efficiency in agriculture: tool development, testing and validation. Curr. Sci. 110 (9), 1716–1729.

Garg, K.K., Wani, S.P., Rao, A.V.R.K., 2014. Crop coefficients of Jatropha (Jatropha curcas) and Pongamia (Pongamia pinnata) using water balance approach. Wires Energy Environ 3 (3), 301–309. https://doi.org/10.1002/wene.88.

Girard, A.M., 2014. Stepping into formal politics: women's engagement in formal political processes in irrigation in rural India. World Dev. 57, 1–18.

Government of India, 2015. Samarthya Technical Training Manual (MGNREGA). Ministry of Rural Development, Government of India, New Delhi.

Government of India, 2016. Master Circulars (2016-17), Guidance for Programme Implementation. Mahatma Gandhi NREGA, 2005. Ministry of Rural Development, Government of India, New Delhi.

Gupta, B., Mukhopadhyay, A., 2016. Local funds and political competition: evidence from the national rural employment guarantee scheme in India. Eur. J. Polit. Econ. 41 (C), 14–30.

James, S., Bernard, V., Karen, M., Nancy, J., Lakshmi, K., Frank, P., David, S., Karl, H., Paul, V., 2019. Farmer adoption of plot- and farm-level natural resource management practices: between rhetoric and reality. Global Food Security 20, 101–104.

Javed, S.A., Haider, A., Nawaz, M., 2019. How agricultural practices managing market risk get attributed to climate change? Quasi-experiment evidence. J. Rural Stud. 73, 46–55.

Karlberg, L., Garg, K.K., Barron, J., Wani, S.P., 2015. Impacts of agricultural water interventions on farm income: an example from the Kothapally watershed, India. Agric. Syst. 136, 30–38.

Kumar, A., Saroj, S., Joshi, P.K., Mishra, A.K., 2017. Institutional versus non-institutional credit to agricultural households in India: evidence on impact from a national farmers' survey. Econ. Syst. 41 (3), 420–432.

Maiorano, D., Shrimankar, D., Thapar-Björkert, S., Blomkvist, H., 2021. Measuring empowerment: choices, values and norms. World Dev. 138, 105220.

Maiorano, D., 2014. The politics of the Mahatma Gandhi national rural employment guarantee Act in Andhra Pradesh. World Dev. 58, 95–105.

Mezegebu, G.D., Anantha, K.H., Garg, K.K., Barron, J., Amede, T., 2020. Scaling-up of water management interventions for rainfed agriculture in Ethiopian Highlands: status, issues and opportunities. In: Background Report for Sustainable Intensification of Rainfed Systems. FAO-SOFA.

Michel, C., Andreassian, V., Perrin, C., 2005. Soil Conservation Service Curve Number method: how to mend a wrong soil moisture accounting procedure? Water Resour. Res. 41, W02011.

Muluneh, A., 2020. Impact of climate change on soil water balance, maize production, and potential adaptation measures in the Rift Valley drylands of Ethiopia. J. Arid Environ. 179, 104195.

Naschold, F., 2012. "The poor stay poor": household asset poverty traps in rural semi-arid India. World Dev. 40 (10), 2033–2043.

Pathak, P., Sudi, R., Wani, S.P., Sahrawat, K.L., 2013. Hydrological behavior of Alfisols and Vertisols in the semi-arid zone: implications for soil and water management. Agric. Water Manag. 118, 12–21.

Ponce, V.M., Hawkins, R.H., 1996. Runoff curve number: has it reached maturity? J. Hydrol. Eng. ASCE 1, 11–18.

Prăvălie, R., Bandoc, G., Patriche, C., Sternberg, T., 2019. Recent changes in global drylands: evidences from two major aridity databases. Catena 178, 209–231.

Ravi, S., Engler, M., 2015. Workfare as an effective way to fight poverty: the case of India's NREGS. World Dev. 67, 57–71.

Rockstrom, J., Falkenmark, M., 2015. Agriculture: increase water harvesting in Africa. Nature 519 (7543), 283–285.

Santos-Montero, L.A.D., Bravo-Ureta, B.E., Cramon-Taubadel, S., Hasiner, E., 2020. The performance of natural resource management interventions in agriculture: evidence from alternative meta-regression analyses. Ecol. Econ. 171, 106605.

Sharma, B., Rao, K.V., Vittal, K.P.R., Ramakrishna, Y.S., Amarasinghe, U., 2010. Estimating the potential of rainfed agriculture in India: prospects for water productivity improvements. Agric. Water Manag. 97, 23–30.

Singh, C., 2017. Is participatory watershed development building local adaptive capacity? Findings from a case study in Rajasthan, India. Environmental Development 25, 43–58.

Singh, S., 2016. Evaluation of world's largest social welfare scheme: an assessment using non-parametric approach. Eval. Progr. Plann. 57, 16–29.

Singh, R., Garg, K.K., Wani, S.P., Tewari, R.K., Dhyani, S.K., 2014. Impact of water management interventions on hydrology and ecosystem services in Garhkundar - dabar watershed of Bundelkhand region, Central India. J. Hydrol. 509, 132–149.

Soulis, K.X., Valiantzas, J.D., 2012. SCS-CN parameter determination using rainfall-runoff data in heterogeneous watersheds – the two-CN system approach. Hydrol. Earth Syst. Sci. 16, 1001–1015.

Steenhuis, T.S., Winchell, M., Rossing, J., Zollweg, J.A., Walter, M.F., 1995. SCS runoff equation revisited for variable-source runoff areas. J. Irrig. Drain. Eng. ASCE 121, 234–238.

Tamagnone, P., Comino, E., Rosso, M., 2020. Rainwater harvesting techniques as an adaptation strategy for flood mitigation. J. Hydrol. 586, 124880.

Tittonell, P., Giller, K.E., 2013. When yield gaps are poverty traps: the paradigm of ecological intensification in African smallholder agriculture. Field Crop. Res. 143, 76–90.

Tiwari, R.H., Somashekhar, I., Parama, V.R., Murthy, I.K., Kumar, M.S.M., Kumar, B.K. M., Parate, H., Varma, M., Malaviya, S., Rao, A.S., Sengupta, A., Kattumuri, R., Ravindranath, N.H., 2011. MGNREGA for environmental service enhancement and vulnerability reduction: rapid appraisal in Chitradurga district, Karnataka. Econ. Polit. Wkly. 46 (20), 39–47.

van Dijk, A.I.J.M., 2010. Selection of an appropriately simple storm runoff model. Hydrol. Earth Syst. Sci. 14, 447–458. https://doi.org/10.5194/hess-14-447-2010.

Verma, S., Shah, T., 2012. Labor market dynamics in post-MGNREGA rural India. Water Policy Research Highlight. http://www.iwmi.cgiar.org/iwmi-tata/PDFs/2012_Highlight-08.pdf.