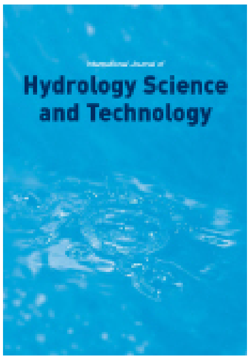

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Investigating the effect of watershed management on land use, groundwater recharge, and irrigation potential in Tigray region, northern Ethiopia

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Abstract: This study was conducted to investigate the effect of watershed management on groundwater recharge and irrigation expansion in northern Ethiopia. The GIS-based water and energy transfer between soil, plants, and atmosphere under the quasi-steady state (WetSpass) hydrological model was implemented. Two scenarios, before watershed management (1997–2007) and after watershed management (2008–2018), were investigated. After watershed management, groundwater recharge increased from 9.7, 44.4, and 54.15 mm for dry, rainy, and annual conditions, respectively, to 9.9, 96.2, and 106.13 mm for these conditions. The relationship between calculated and observed groundwater depths results in a coefficient of determination of 0.81. After watershed management, the water balance system had evapotranspiration, surface runoff, and groundwater recharge of 83.7%, 3.0%, and 13.3%, respectively, of total precipitation. Excess groundwater recharge of 6.51% resulted in extending the irrigation area by 12.7 hectares. Results show that WetSpass is effective in estimating groundwater recharge and irrigation area expansion.

Keywords: groundwater recharge; hydrology; water balance; watershed management; WetSpass; Ethiopia.

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1 Introduction

In brittle and marginal rain-fed areas, groundwater drought is a global issue (Husna et al., 2023) and a watershed management programme is critical to agricultural growth and development and a viable strategy for resolving water scarcity issues (Joshi et al., 2008). Climate variability affects crop yields because rainfall distribution varies greatly over space and time, negatively affecting livelihoods (Georgis et al., 2010). According to Gebregziabher et al. (2016), the degradation of watersheds is caused by the interaction of physiographic structures, climate, and poor land use (deforestation, inappropriate farming, animal movement disturbing slopes and soils, construction of roads, and improperly controlled water diversion, transportation, and use).

According to Aish and Batelaan (2010), groundwater recharge is the downward movement of water to the water table under gravitational force. Groundwater recharge in a watershed depends on a number of variables, including the amount, distribution, and frequency of rainfall across the watershed, as well as the amount of bare soil, the type of vegetation, the type of soil, and the properties of the soil. The hydrological process of groundwater recharge is dynamic and changes over time and space. The depth of the watershed at a given location indicates how much groundwater recharge is taking place there.

Effective groundwater resource management requires an accurate estimation of groundwater recharge. It is crucial in areas with high water supply demands because these areas need these resources to develop economically (Kahsay et al., 2018). However, measuring the rate of groundwater recharge is the most challenging aspect of assessing groundwater resources. This is because groundwater estimation is a complicated function of weather, soil, vegetation, physiographic characteristics, depth of the groundwater table, and the characteristics of the geologic material within the flow paths (Mogaji et al., 2015; Al-Badry and Shamkhi, 2021).

Empirical techniques like chloride mass balance, water balance, well water level fluctuation, or hydrological models can be used to estimate groundwater recharge. In this study, the GIS-based water and energy transfer between soil, plants, and the atmosphere under a quasi-steady-state (WetSpass) hydrological model was used. The CROPWAT software is suitable for calculating irrigation water needs and potential evapotranspiration (PET). The WetSpass model was used in several studies providing reliable results, including those by Gebreyohannes et al. (2013), Kahsay et al. (2018), Meresa and Taye (2018), Yueqiu et al. (2018), and Abdirahman et al. (2023).

Due to its geographic location, topography, reliance on rain-fed agriculture, and underdeveloped water resources, Ethiopia is one of the nations impacted by climate change (Kumar, 2009). Common environmental issues in Ethiopia include land degradation, soil erosion, and deforestation, which reduce agricultural land productivity and result in the loss of vegetation cover (Gashaw et al., 2014; Ahmad and Pandey, 2018; Mena et al., 2018). One of the Ethiopian regions that suffer from severe land degradation is Tigray (Hadush, 2015). Ethiopia started a watershed management programme in the 1970s to address these issues (Gebregziabher et al., 2016). Since the early 1990s, residents and the local government of the Tigray region have started integrated watershed management initiatives (Negusse et al., 2013).

Several researchers, (e.g., Alemayehu et al., 2009; Negusse et al., 2013; Gella, 2018) evaluated the effects of watershed management on land use and cover, hydrological responses, and groundwater availability in Ethiopia. These studies, however, lacked thoroughness because they failed to account for the impact of watershed management on the irrigation expansion. Land degradation was a major issue that had been severely affecting the farmers' farming production in the Tigray region, specifically in the selected study area. To overcome these problems, huge integrated watershed management practices have been implemented since 2008. Some of the structures that were constructed on the managed watershed are afforestation, percolation ponds, field bunds, continuous contour trenches, water absorption trenches, terraces, and check dams. These structures have quite a visible role in groundwater recharge, but it has not been studied how these practices would affect groundwater availability and the expansion of irrigation systems. Chyne et al. (2023) stated that check dams are one of the most common structures to harvest rainwater that collects and stores drained runoff.

A thorough investigation of the catchment's hydrological response to watershed management is needed to identify and comprehend the impact of watershed management practices on irrigation expansion. Significant hydrological studies also support agricultural development because Ethiopia's economy is largely dependent on agricultural production. The investigation of the maximum groundwater recharge availability in relation to soil textures and land uses, which has been taken into account in this study, is also neglected in some other studies. In the Tigray region of northern Ethiopia, this study examines the impact of watershed management on water availability and irrigation expansion. The objectives of this study were to:

1 assess the effect of watershed management on groundwater recharge

2 investigate the contribution of watershed management practices to irrigation area expansion.

2 Study area and data

2.1 Study area description

This research was carried out in the Tigray region of northern Ethiopia's Sheka watershed (Figure 1). The distance between the watershed and Mekelle, the regional capital of Tigray, and Addis Ababa, the capital city of Ethiopia, is approximately 125 km and 905 km, respectively. Geographically, it lies between 38.81° and 38.83° E and 13.69° and 13.72° N in the Kola Temben district of the Tigray region's central lowland zone. The area of the catchments is 4.02 km^2. Even though the catchments area is small, a number of watershed management practices have been implemented there over the past ten years that have become a model for other, larger catchments.

The steep land features are a result of the watershed's highly erodible topography. The catchment's elevation ranges from 1,787 to 2,034 metres above sea level (Figure 1). It is distinguished by a fragile environment, erratic rainfall, and moderately undulating terrain with steep slopes. According to Belete et al. (2013), the majority of the watershed's slopes are very steep (2.06%), steep (18.29%), moderately steep (38.42%), sloping (25.32%), gentle (13.46%), and flat (2.44%). The region experiences a mono-modal rainfall pattern, with December and January having the least amount of rain and June to September having the most. Barley, maize, and soybeans are the main crops grown in the study area during the rainy seasons, while carrots, cabbage, and pepper are grown during the dry seasons.

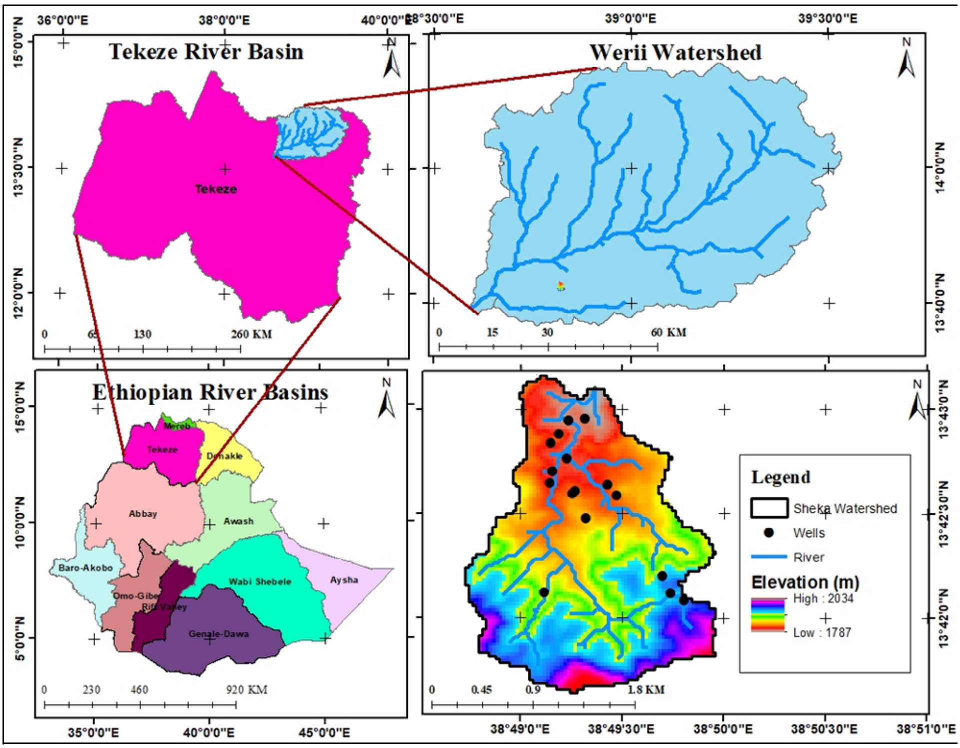
2.2 Data collection and preparation

2.2.1 Time series data

The time series data, including meteorological data (daily rainfall, wind speed, relative humidity, sunshine hours, and minimum and maximum temperature), were collected from the Tigray meteorological service agency. We used historical weather data from four stations: AbiAdi, Axum, Endabaguna, and Hawzen, covering the years 1997 to

2018. The double mass curve was used to assess consistency after some of the missing data had been filled in appropriately. The Tigray Agriculture Bureau supplied the required data for the crops that are commonly farmed in the study area.

Figure 1 Location map of the study area (see online version for colours)



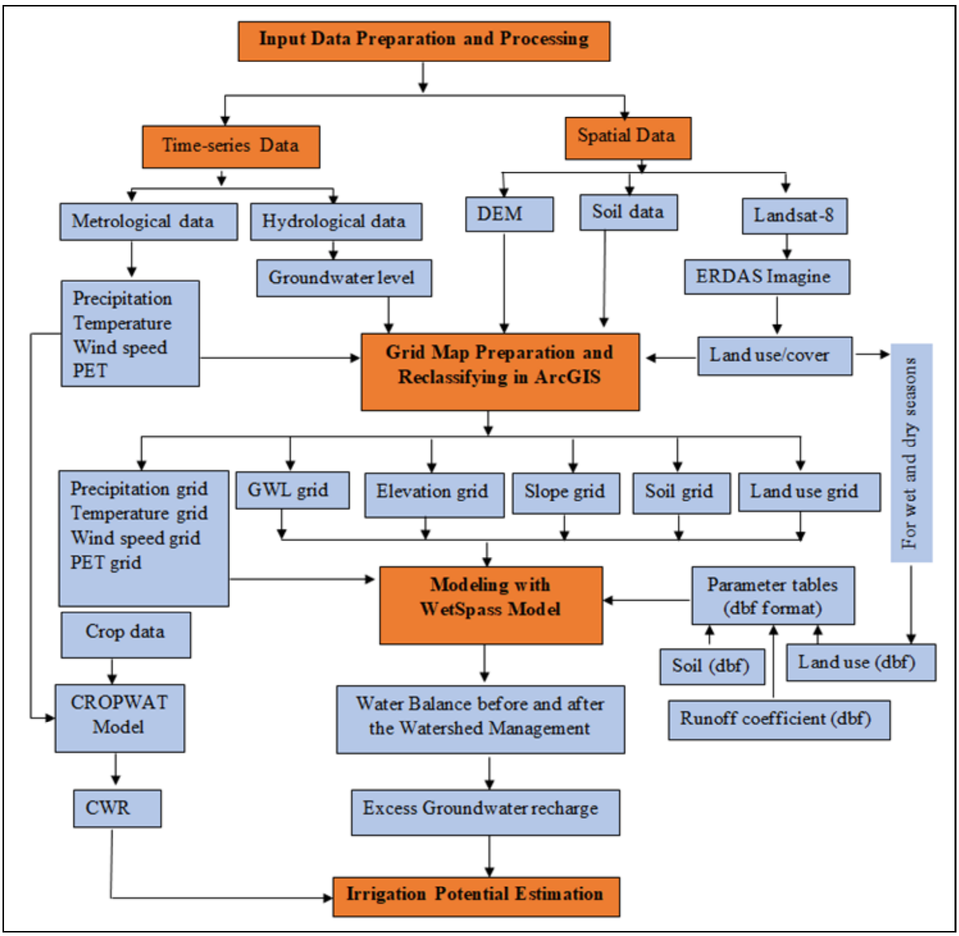
Field surveying was carried out to collect primary data, such as the groundwater depth and locations of the shallow and deep wells. The groundwater levels before watershed management were obtained from the regional bureau of Ethiopian Water Resources, and they were prepared by subtracting the static water level from the surface elevation of the hand-dug shallow and deep wells. The groundwater level after watershed management (current groundwater levels) was measured in the field. The groundwater level and surface elevations were measured using the deep tape meter and GPS. The static water levels of the wells were obtained by subtracting the groundwater level from the surface elevation of the wells.

2.2.2 *Spatial data*

A digital elevation model (DEM) covering the study area with 30 m spatial resolution was downloaded from the open-source website (https://earthexplorer.usgs.gov/) provided by the United States Geological Survey (USGS). Soil data for the watershed was extracted from the digital soil map of Ethiopia and FAO (United Nations FAO, 1998). The soil textures were later classified according to the soil types.

Land use and cover maps for 2007 (before watershed management) and 2018 (after watershed management) were prepared using cloud-free ETM+ Landsat images downloaded from the USGS open-source website. The Landsat images were layer-stacked and then subset (clipped) for the particular watershed. A supervised land use classification method by ERDAS Imagine-2015 and respective recent Google Earth images (2007 and 2018) was used to classify land use. Finally, the land use accuracy assessment was performed to check the correlation between the producer's and the user's accuracy.

Figure 2 Methodological framework of the study (see online version for colours)



3 Methods

A GIS-based spatially distributed hydrological model (WetSpass), CROPWAT software, and other empirical models were used to investigate the rate of groundwater recharge and the amount of groundwater available for irrigation. The methodological framework shown in Figure 2 was used as the foundation for this study's analysis.

3.1 Calculating groundwater recharge

WetSpass, a GIS-based hydrological model, was used to analyse groundwater systems in steady-state conditions and needs long-term average hydro-meteorological data and watershed-based physical layers of spatial patterns as the main inputs. The WetSpass model needs the parameters on a seasonal basis; hence, in the case of the Ethiopian context, the months of June, July, August, and September were considered wet seasons, while the remaining eight months were considered dry seasons. Grid maps and parameter tables such as land use, soil texture, slope, topography, groundwater levels, precipitation, PET, and wind speed were prepared using ArcGIS tools and Erdas Imagine software. The parameter table input files, such as land use, soil texture, and runoff coefficient for the dry and wet seasons, were also prepared in a database file format (dbf).

The groundwater depths collected from the regional water resources office were prepared by subtracting the static water level from the surface elevation of the boreholes and springs (wetlands) found within the watershed. All these parameters were prepared for the dry and wet seasons in 2007 and 2018 as grid maps. The long-term hydro-meteorological data of the watershed was also prepared as a grid map. Each value estimated in an IDW interpolation is a weighted average of the surrounding sample points. These weights are computed by taking the inverse of the distance from an observer's location to the location of the area of interest.

PET is the upper limit of evapotranspiration for a crop in a given climate. The most common method to calculate PET is the Penman-Monteith method (Allen et al., 1998; Asfaw, 2014). The CROPWAT8 was used to calculate PET using equation (1). It was then prepared as a grid map using the inverse distance-weighted (IDW) interpolation method in ArcGIS.

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma \dfrac{900}{T+273} V_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34V_2\right)} \quad (1)$$

where ET_0 is the reference evapotranspiration rate (mm/day), R_n is net radiation at the crop surface (MJ/m^2/day), G is soil heat flux density (MJ/m^2/day), T is the daily temperature at 2 m height (°C), V_2 is the wind speed at 2 m height (m/s), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), $e_s - e_a$ is saturation vapour pressure deficit (kPa), Δ is slope vapour pressure curve (kPa/°C), and γ is psychrometric constant (kPa/°C).

The WetSpass model was used to calculate the watershed's surface runoff, which is dependent on the soil, land use, slope, and precipitation. The groundwater recharge, surface runoff, and evapotranspiration at the catchment level are each estimated by the WetSpass model using equations (2), (3), and (4), respectively.

$$Rraster = avRv + asRs + aoRo + aiRi \quad (2)$$

$$Sraster = avSv + asSs + aoSo + aiSi \quad (3)$$

$$ETraster = avETv + asEs + aoEo + aiEi \quad (4)$$

where *Rraster*, *Sraster*, and *ETraster*, are the total groundwater recharge, surface runoff, and evapotranspiration of a raster cell respectively, each having a vegetated, bare-soil, open-water, and impervious area component denoted by *av*, *as*, *ao*, and *ai* respectively.

3.2 Estimating expanded irrigable area

For the three selected crops (cabbage, carrot, and pepper), the CROPWAT8 model was used to determine the crop water requirement (CWR), irrigation water requirement (IWR), and effective rainfall. Cabbage (covering 30% of the area), carrots (covering 50% of the area), and pepper (covering 20% of the area) were the three crops. Different crop types require different amounts of water, and as a result, different areas of land are irrigated. The increased irrigation area is dependent on the excess groundwater recharge, and equation (5) was used to calculate the duty of the selected crops.

$$A_{\exp} = \frac{R_e * A_{wat}}{Duty} \tag{5}$$

where $A_{\exp}$ is the expanded irrigable area due to excess groundwater recharge (ha), R_e is excess annual mean groundwater recharge (mm/year), A_{wat} is watershed area (ha).

4 Results and discussion

4.1 Changes in land use and evapotranspiration

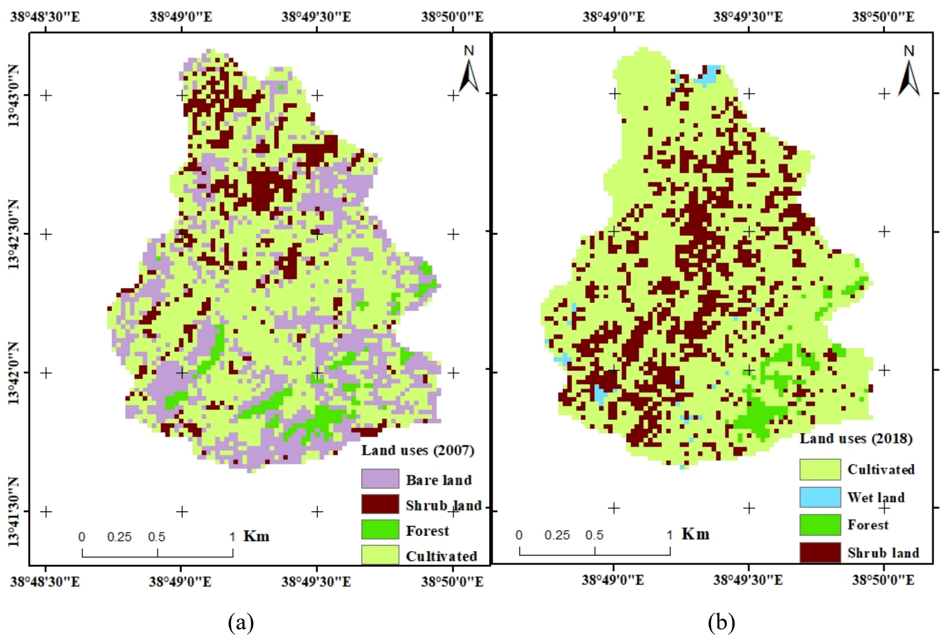
A comparison of the results between before and after watershed management shows that this had an impact on land use and cover (Figure 3; Table 1). Prior to watershed management, the land was mostly undeveloped (Figure 3). After watershed management, there was a noticeable increase in cultivated, forest, and shrublands. Compared to bare land, which decreased to 0%, wetlands increased from 0% to 1.1%. In 2008, techniques for managing watersheds, including afforestation, percolation ponds, field bunds, continuous contour trenches, water absorption trenches, terraces, and check dams, were implemented. Before 2007 (before management), the watershed was highly erodible, but after different watershed management practices were implemented, soil erosion was reduced. The watershed management techniques were more likely to positively impact the gradual change in land use and cover. Figure 5 and Table 2 provide an overview of the water balance of the watershed before and after watershed management.

Table 1 The area coverage of land use/cover before and after the watershed management

Land uses	*2007*				*2018*			
	Winter		*Summer*		*Winter*		*Summer*	
	Area, km²	*Area (%)*	*Area, km²*	*Area (%)*	*Area, km²*	*Area (%)*	*Area, km²*	*Area (%)*
Forest	0.14	3.5	0.14	3.5	0.35	8.7	0.35	8.7
Shrub land	0.8	19.9	1.03	25.6	1.18	29.4	1.18	29.4
Cultivated	2.12	52.7	2.12	52.7	2.447	60.9	2.43	60.4
Bare land	0.96	23.9	0.73	18.2	0	0.0	0	0.0
Wetland	0	0	0	0	0.043	1.1	0.06	1.5

Before watershed management, the annual, wet season, and dry season long-term average evapotranspiration were 673.3, 563.2, and 110.0 mm, respectively; after management, these values were 668.5, 554.07, and 114.43 mm, respectively [Figure 5(a)]. Before management, the mean annual evapotranspiration was 84.4% of the 796.42 mm of annual precipitation, and after management, it was 83.7% of the 797.3 mm of annual precipitation. According to reports from Gebreyohannes et al. (2013) for the Geba basin, Kahsay et al. (2018) for the Raya Valley, and Meresa and Taye (2018) for the Birki basin, the long-term mean annual evapotranspiration was 76%, 84%, and 85% of the corresponding watersheds' annual precipitation, respectively. The output of this study shows good agreement with earlier studies in terms of evapotranspiration estimated using the WetSpass model, indicating a reliable result.

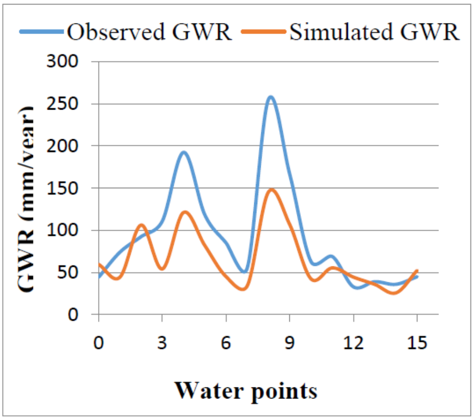
Figure 3 Land use map of the watershed: (a) before watershed management, (b) after watershed management (see online version for colours)



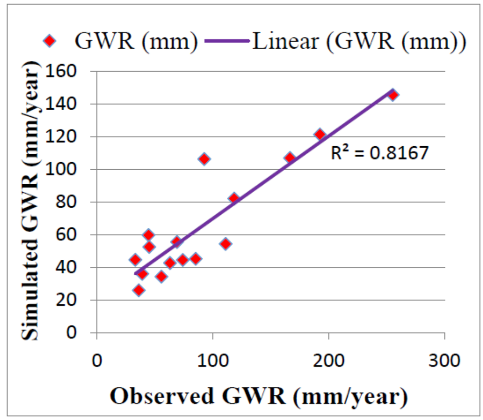
4.2 Computed groundwater recharge

The hydrological model simulated the long-term average seasonal and annual groundwater recharge of the watershed, both before and after management. By contrasting the calculated annual depths of groundwater recharges with the actual annual depths of groundwater obtained from 16 groundwater monitoring points measured in 2018, the results were verified. Results can be seen in Figures 4(a) and 4(b), where a good coefficient of determination (R^2) of 0.81 was observed. When the watershed was managed, the average groundwater recharge increased from 54.15 mm, 44.4 mm, and 9.7 mm for the annual, wet season, and dry seasons, respectively, to 106.1 mm, 96.2 mm, and 9.9 mm [Figure 5(b); Table 2]. Before and after watershed management, the long-term average annual groundwater recharge was 6.8% of the annual precipitation (796.42 mm) and 13.3% of the annual precipitation (797.3 mm), respectively.

Figure 4 Simulated and observed groundwater recharge: (a) the simulated values and observed values of groundwater recharge in 2018 for 16 monitoring points, (b) the linear relationship between simulated and observed groundwater recharge (see online version for colours)



(a)



(b)

Note: GWR: Groundwater recharge.

Table 2 The overall summary of water balance in the watershed

Water balance component	*Before watershed management*								
	Wet season (mm)			*Dry season (mm)*			*Annual (mm)*		
	Max	*Min*	*Mean*	*Max*	*Min*	*Mean*	*Max*	*Min*	*Mean*
Precipitation	675.9	671.6	673.8	123.1	122.1	122.6	799	794.7	796.4
ET	602	470.7	563.2	123.7	95.7	110	722.9	570.5	673.3
GWR	115.6	0	44.4	23.5	0	9.7	138.8	0	54.2
SRO	93.2	0	65.7	5.9	0	4.3	99.1	0	69.9
Water balance component	*After watershed management*								
	Wet season (mm)			*Dry Season (mm)*			*Annual (mm)*		
	Max	*Min*	*Mean*	*Max*	*Min*	*Mean*	*Max*	*Min*	*Mean*
Precipitation	675.9	670.5	673.3	124.2	123.9	124.1	800	794.4	797.3
ET	602.1	533.8	554	337.4	99.7	114.4	938	633.6	668.5
GWR	188.1	0	96.2	23.5	0	9.9	211.6	0	106
SRO	40.1	0	23	0.78	0	0.72	40.8	0	23.7

Note: ET: Evapotranspiration; GWR: Groundwater Recharge; SRO: Surface runoff.

The results of this study were compared with those from other studies that were done to estimate groundwater recharge, and they showed good agreement. In a study of the Geba basin conducted by Gebreyohannes et al. (2013), the groundwater recharge was calculated to be 37 mm (6% of the annual precipitation). According to a study conducted by Kahsay et al. (2018) in the Raya Valley, the annual groundwater recharge was approximately 55 mm (8.3% of the annual precipitation). Meresa and Taye (2018) estimated a groundwater recharge of 24.9 mm (7.4% of the annual precipitation) for the Birki basin. Zeabraha et al. (2020) examined the groundwater recharge for Adigrat, which resulted in a groundwater recharge of 40.5 mm (6.4% of annual precipitation). According to a study by Al-Badry and Shamkhi (2021), the average annual rainfall generated a water balance with evapotranspiration (83.33%), groundwater recharge (10.8%), and surface runoff (5.2%).

Groundwater recharge increased from 6.8% to 13.31% after watershed management was implemented. The difference in groundwater recharge before and after the implementation of the watershed management practices was the excess groundwater recharge. This excess groundwater recharge, or the difference in groundwater recharge value, was 6.51%. The maximum groundwater recharge occurred after watershed management in all seasons. A study by Salem et al. (2023) showed that groundwater recharge was decreased in unmanaged areas with average values of 335 mm and 317 mm per year in 2012 and 2018, respectively. Accordingly, a study on the impact of watershed management on groundwater and irrigation potential (Johnson et al., 2013) concluded that watershed management raises the groundwater level, which also raises irrigation potential. Both Negusse et al. (2013) and Alemayehu et al. (2009) concluded that the effect of integrated soil water conservation increases groundwater recharge. They also reported that integrated watershed management increases groundwater recharge and reduces land degradation. According to Grum et al. (2017), various watershed management techniques increase water availability, which is essential for growing crops, particularly in arid and semi-arid areas.

4.3 Computed surface runoff

The estimated average surface runoff before management was 69.9, 65.7, and 4.29 mm for the annual, wet season, and dry season, respectively. After watershed management, surface runoff was 23.7, 23.0, and 0.72 mm for the annual, wet season, and dry season, respectively [Figure 5(c)].

The increase in losses in direct runoff, such as interception, infiltration, and percolation, which can be safely stored as groundwater resources, is one of the possible causes of the decrease in surface runoff after watershed management. These losses can be safely stored as groundwater resources. Before and after watershed management, the average long-term annual surface runoff was 8.8% of the annual precipitation (796.42 mm) and 3.0% of the annual precipitation (797.3 mm), respectively. About 97% of the annual surface runoff of the watershed occurs during the rainy season, and the remaining 3.0% occurs in the dry season.

The WetSpass model's results indicate that soil type, land use, and rainfall all affect groundwater recharge. Sand-loam soil combined with cultivated land and shrubland showed the highest rate of groundwater recharge, whereas silt-loam soil combined with bare land and wetland showed the lowest rate of groundwater recharge [Figure 6(a)]. In silt loam soils with wet and bare land uses, surface runoff was maximum; in sandy loam soils with shrubland and cultivated land uses, it was minimum [Figure 6(b)]. According to Armanuos et al. (2016), sand soil and heavy rainfall result in the greatest groundwater recharge. The study by Gebreyohannes et al. (2013) found that agricultural land and bare land combined with sandy loam and loam soils provided the greatest groundwater recharge. In a related study, Meresa and Taye (2018) and Al-Badry and Shamkhi (2021) found that agricultural land combined with sandy soil texture resulted in the highest values of groundwater recharge, while bare land combined with clay soils and wet drainage areas resulted in the lowest values of groundwater recharge.

4.4 Expanded irrigation area

Table 3 provides the gross and net IWRs for each crop irrigated in the study area. For pepper, cabbage, and vegetables, the gross IWRs were 411.8, 611.7, and 148.4 mm, respectively. For pepper, cabbage, and vegetables, the net IWRs were 288.4, 428.2, and 103.8 mm, respectively. In response to the duty of these three selected crops, which was 0.52 l/s/h, the irrigation area has been significantly increased. The watershed management resulted in an excess groundwater recharge of 51.8 mm (6.51% of the total precipitation). Thereafter, 12.7 hectares of expanded irrigation area were computed.

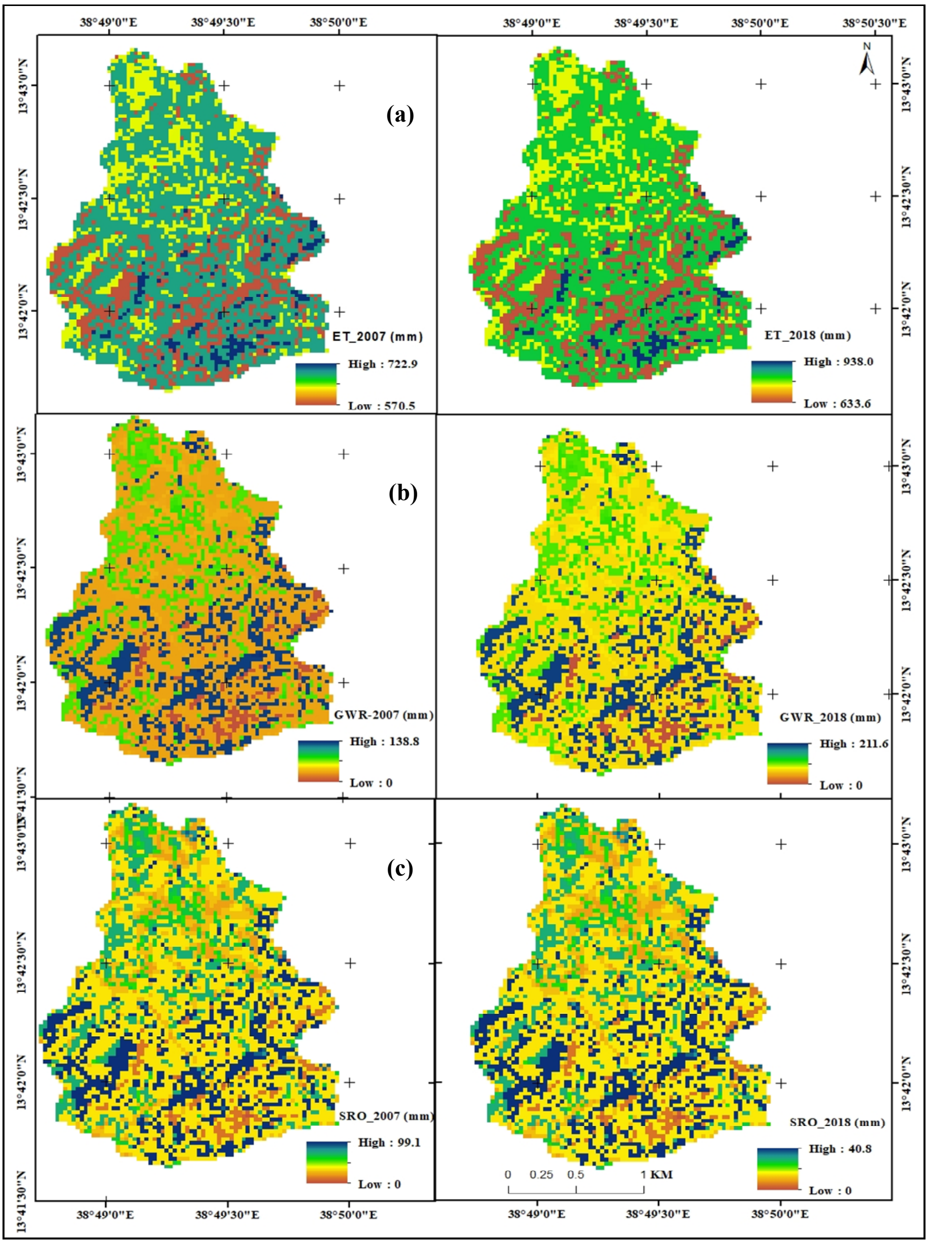
The annual income of the farmers increased significantly as crop productivity rose. The increased annual income also decreased emigration from the area in search of economic opportunity while simultaneously improving both diet and health. According to the statistics of the district, 53 farmers (or 10.56% of the village's total population) had been there before the implementation of watershed management. After watershed management, however, there are 326 farmers (or 64.94% of the population).

Table 3 Gross and net IWR outputs of CROPWAT8 software

Vegetable		*Cabbage*		*Pepper*	
Net Irr (mm)	*Gr. Irr (mm)*	*Net Irr (mm)*	*Gr. Irr (mm)*	*Net Irr (mm)*	*Gr. Irr (mm)*
11.7	16.7	19	27.1	10	14.3
15.3	21.9	21.4	30.6	9.9	14.1
15.3	21.9	23.8	33.9	9.9	14.1
18.4	26.3	28.9	41.3	12.5	17.8
43.1	61.6	31.8	45.5	12.5	17.8
		31.2	44.6	15.1	21.6
		32.3	46.1	20.4	29.1
		33.6	48	34.3	49
		32.5	46.4	35.6	50.9
		31.6	45.1	37.6	53.7
		35.8	51.2	37.9	54.1
		36.1	51.6	52.7	75.3
		36	51.5		
		34.2	48.8		
103.8	*148.4*	*428.2*	*611.7*	*288.4*	*411.8*

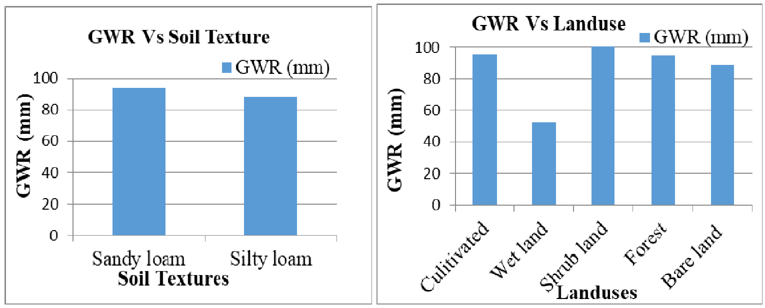
Integrated watershed management is crucial for boosting groundwater recharge and increasing the potential for irrigation, according to Johnson et al. (2013) and Amee et al. (2016). Irrigation practices have been extensively used in the study area over the past ten years. This can be confirmed because the expansion of the irrigation area came after the adoption of several watershed management techniques. From this study, it can be concluded that adopting more integrated watershed management practices has a significant benefit for increasing irrigation area as well as for the efficient use and planning of water resources.

Figure 5 The overall annual water balance for 2007 (before watershed management) and 2018 (after watershed management): (a) evapotranspiration, (b) groundwater recharge, (c) surface runoff (see online version for colours)

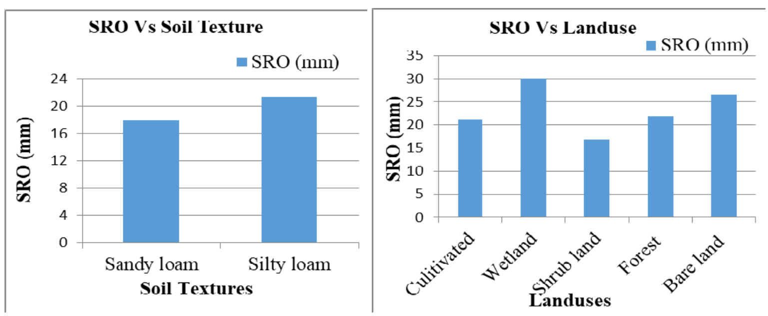


Note: ET, GWR, and SRO are the annual evapotranspiration, groundwater recharge, and surface runoff respectively.

Figure 6 Relationships between (a) groundwater recharge vs. soil textures and land uses, (b) surface runoff vs. soil textures and land uses (see online version for colours)



(a)



(b)

Note: GWR: Groundwater recharge, SRO: Surface runoff.

5 Conclusions

WetSpass, a physically based model that simulates water balance systems of a catchments using spatial and hydro-meteorological data, was used to examine the effect of watershed management on groundwater recharge and irrigation area expansion. For the proper use, management, and planning of water resources, it is essential to estimate the long-term average annual groundwater recharge, evapotranspiration, and surface runoff on a seasonal and annual basis. Before the watershed management, the study area's water balance system consisted of 84.4% evapotranspiration, 8.8% surface runoff, and 6.8% groundwater recharge from the total precipitation, whereas after the watershed management, it consisted of 83.7% evapotranspiration, 3.0% surface runoff, and 13.3% groundwater recharge from the total precipitation.

Within a decade, land use change resulted in an increase in wetlands and a decrease in bare land due to watershed management practices. Because the watershed is managed and has a high coverage of shrublands and cultivated lands, which facilitate infiltration rate and evapotranspiration, resulting in reduced runoff, an increase in groundwater recharge and a reduction in surface runoff have been observed. After watershed management, the catchment's excess groundwater recharge increased by 6.51% of the average annual rainfall, producing 12.7 additional hectares of irrigation space. The output of the

WetSpass model demonstrated a good degree of agreement with the measured depths of groundwater recharge; as a result, it can be used to further research on surface and groundwater resources.

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