Vol. 10(7), pp. 90-99, August 2018
DOI: 10.5897/IJWREE2018.0781
Article Number: 9BDEEE758031
ISSN: 2141-6613

http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Quantifying the impact of integrated watershed management on groundwater availability in Gerduba watershed, Yabello district, Ethiopia

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Received 3 May, 2018; Accepted 20 June, 2018

Integrated watershed management has a positive impact on groundwater balance. However, most parts of the study area particularly, Borana is the one which is suffering from severe rangeland degradation. Among others, heavy grazing, bush encroachment, gully expansion, topsoil fertility loss, sedimentation and less adequate water availability account for the greatest noticeable rangeland degradation phenomena. Due to these, water remains the most limiting resource for the pastoral and agro-pastoral communities of Borana (Coppock et al., 2006). To overcome these problems, efforts have been made to launch integrated watershed management programs; however, knowledge to quantify the impact of integrated watershed management on groundwater availability has been limited to date. The hydrology of the area was characterized based on its land use, land cover, soil type, slope position, rainfall, humidity, wind speed, temperature, evapotranspiration and runoff. Thornthwaite's soil-water balance model was used to determine the potential and actual evapotranspiration and results were 796.27 and 465.89 mm, respectively. The mean annual runoff from the catchment was computed using the runoff coefficient method. The catchment is characterized by two rainy seasons during the year. The mean annual rainfall of the catchment is 585.1 mm. As the result of soil and water conservation measures, the volume of surface runoff was reduced from 45.98 to 33.44% of the mean annual rainfall of the catchment. Inversely, the groundwater recharge increased from 12.8 to 55.14% of the mean annual rainfall of the catchment. Though, the difference in groundwater level in cistern and hand-dug wells after interventions was found to be 1.1 and 1.3 m, respectively. Thus, construction of additional physical conservation structures is suggested to further improve the groundwater availability in the area.

Key words: Soil and water conservation, surface runoff, groundwater, water balance.

INTRODUCTION

Deforestation, increased runoff and soil erosion are serious problems in Ethiopia (Tireza et al., 2013). Over grazing and improper land resource management are the principal causes of increased runoff and soil erosion in Ethiopia. But it could be reversed through integrated watershed management with a positive impact on groundwater balance as well as ecosystem. According to a study carried out by Singh et al. (2014), at Garhkundar-Dabar watershed in India, treated and untreated watershed were compared in which the treatment decreased rainstorm flow (21 vs. 34%) together with increased base flow (4.5 vs. 1.2%) and groundwater recharge (11 vs. 7%) relative to total rainfall received. These led to regulation of the velocity of surface runoff generation and created opportunities for percolation and recharge of groundwater. Implementing biological and physical conservation measures that restrict runoff and reduce erosion may increase groundwater recharge (Bierman and Rosen, 2005). Nyssen et al. (2010) found that good management of the catchments resulted in a higher infiltration rate and a reduction of direct runoff volume by 81%, which had a positive influence on the catchment water balance, because some of the rainfall is partitioned between the atmospheres via evapo-transpiration and percolates downward, with some re-emerging as stream flow, while the remainder recharges the groundwater as a result of soil and water conservation structures which may balance the recharging and discharging groundwater (Kumar, 2003). However, the knowledge to quantify the impact of integrated watershed management on groundwater availability has been limited till date.

MATERIALS AND METHODS

Study area

The study was conducted in southern Oromiya in the Borana pastoralists' zone (Figure 1). The terrain of the central Borana Plateau includes a central mountain range, scattered volcanic cones and craters and flat plains (Coppock, 1994). The temperatures (19-24°C) (Table 3) and mean annual rainfall range from 300 to 1000mm (Figure 3). Rainfall is bimodal, rains are expected between March and May and the short rains in October and November (Upton, 1986).

Soil sample and analyses

The collected soil samples were passed through a 6-mm sieve to remove unnecessary materials. The pits were opened at the aforementioned interval based on the type of soil profile. In order to determine the available water-holding capacity (WHC) of the soil, average root depths of the dominant vegetation were measured in the field using a meter stick. The collected soils were analyzed using the hydrometric method (Table 1).

The moisture or water content of the soil at PWP and FC were determined from collected soil samples. In this case, the soils samples were saturated and after all pore spaces are filled with water, the pressure of 0.33 bars and 15 bars were applied for FC and PWP, respectively. The samples were then placed in an oven to dry at 105°C for 24 h and weighed to estimate the water content in the soil at FC and PWP. The available water content was estimated according to Thompson (1999) as cited in Tireza et al. (2013).

$$AWC = FC - PWP \qquad 1$$

Where, FC = water content at the field capacity; PWP = water content at the permanent wilting point. In this case, different soil layers with different AWC were summed following Stephen (1999):

$$TWC = (AWC_1)(L_1) + (AWC_2)(L_2) + \ldots (AWC_n)(L_n) \qquad 2$$

Where, L = thickness of the soil layer, 1, 2 and n represents each successive soil layer; TWC = total water content. The average root depths of dominant vegetation in the catchment area were taken, and the soil WHC (Water Holding Capacity) up to the root zone was estimated in order to determine the actual evapotranspiration. The mean annual rainfall was computed using the arithmetical mean method.

$$STOR = AWC \times e \frac{APWL}{AWC} \qquad 3$$

Where, AWC = the moisture storage capacity, also known as available water capacity of the soil.

Computing surface runoff before and after integrated watershed management

Primary and secondary data such as land use, runoff coefficient and rainfall data were used to compute surface runoff before and after intervention in the study area.

$$Q = CPA \qquad 4$$

Where, Q = runoff volume from the catchment (m^3); P = average precipitation (m); A = catchment area (m^2) and C = Runoff coefficient.

The runoff coefficient (Ci) was determined based on the land use, hydrological soil group and slope. The four HSGs described by Suresh (2002) were used as standards. Slope, land use, infiltration capacity and soil type data were used to determine soil hydrologic groups of the study area. The land cover classifications adopted by Cord et al. (2014), were used as standard to classify land use type. The infiltration rate data were collected in the field using a double-ring infiltrometer. To measure moisture availability, the disturbed and undisturbed soil samples were taken at the depths of a 1.4 m profile opened at 0-0.4, 0.4-0.8 and 0.8-1.4 m horizon intervals (Figure 2). Soil samples were taken from a pit 1.4 m deep opened

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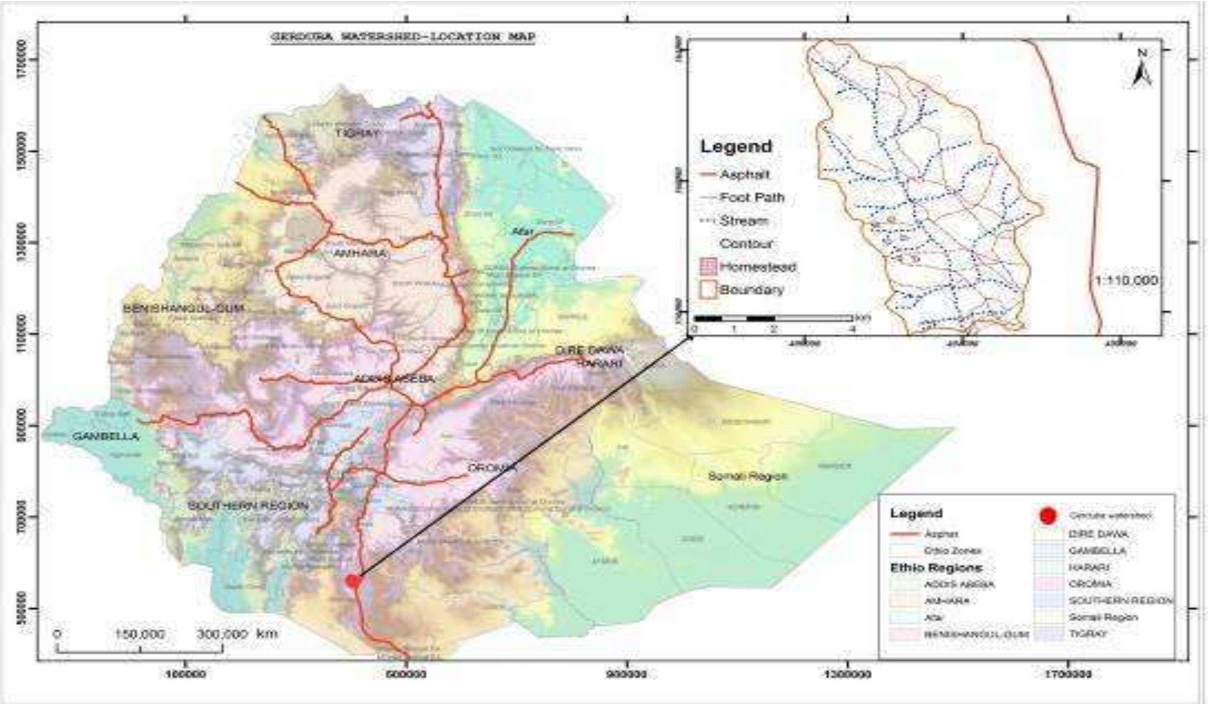

Figure 1. Location map of the study area.

Table 1. Soil analysis report.

Land use/land cover	Textural classes at different slope positions			Bulk density at different slope classes		
	0-5%	6-10%	>10%	0-5%	6-10%	>10%
Bush land	Clay loam	Sandy clay loam	Sandy clay loam	1.15	1.18	1.21
Cultivated land	Sandy clay loam	Sandy clay loam	Sandy clay	1.25	1.29	1.36
Grazing land	Sandy loam	Sandy loam	Sandy loam	1.18	1.21	1.26
Woody land	Clay loam	Clay loam	Clay loam	1.08	1.16	1.21
Homestead	Sandy clay loam	Clay loam	Clay loam	1.03	1.25	1.39
Bare land	Sandy clay	Sandy clay	Sandy clay	1.33	1.35	1.40
Ex-closure	Sandy clay	Sandy clay	Sandy clay	1.19	1.21	1.29

All bulk density values are in g/cm^3.

Figure 2. Taking soil samples from dug wells.

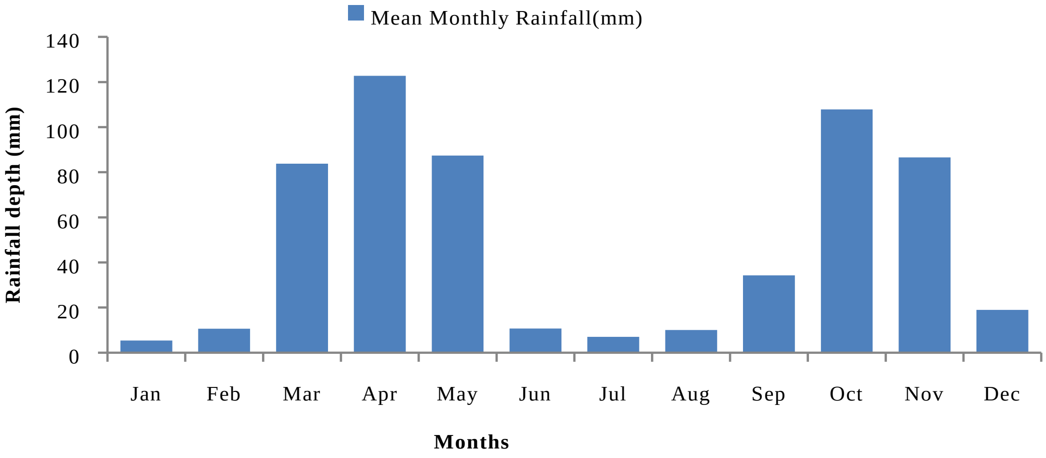

Figure 3. Mean monthly rainfall of study area from 1998 to 2016.

at 0-0.3, 0.3-0.7 and 0.7-1.4 m horizon intervals.

Potential evapotranspiration's were calculated using Penman-Monteith and Thornthwaite methods.

This in turn was used to determine actual evapotranspiration for the study area. The equation is:

$$PET = 16C\left(\frac{\bar{T}10}{I}\right)^{a} \text{mm} \qquad 6$$

Where, PET = potential evapotranspiration (mm/month); $\bar{T}$ = mean monthly air temperature (°C); n = the number of months; C = daylight correction factor for potential evapotranspiration (latitude dependent); I = annual heat index and it is given by the equation:

$$i = \sum_{n=1}^{12} I \qquad 7$$

I is the month heat index and expressed as:

$$I = \frac{T^{1.514}}{5} \qquad 8$$

After the whole potential evapotranspiration has been computed, the Actual evapotranspiration was calculated by Thornthwaite's soil-water balance model.

$$\text{SMmonth} = \text{STOR month} - \text{STORpreviousmont} \qquad 9$$

A negative value of ΔSM means discharge of water from the storage because of evapotranspiration, whereas a positive value of ΔSM implies infiltration of water into the soil that contributes to the soil moisture storage. The method described by Thornthwaite and Mather (1957) for successive approximations to determine a starting value of accumulated potential water loss from which to start the monthly computations was used. This involves (1) estimating the potential water deficiency at the end of the wet season, (2) estimating the accumulated potential water loss at the end of the dry season by adding all the negative potential percolation values, (3) determining the associated soil moisture using the soil moisture retention tables, (4) adding the positive potential percolation values for the wet season to estimate the soil moisture at the end of the wet season, (5) converting that soil moisture back to accumulated potential water loss, and then repeating the process until convergence is achieved. The total mean AET that occurs in the catchment was determined by the arithmetic mean of the annual AET from each land use weighted by their area coverage:

$$AET_T = \sum \frac{AET_i a_i}{A} \qquad 10$$

Where, AET_T = total actual evapotranspiration; AET_i = mean annual actual evapotranspiration from each land use; a_i = drainage area of each land use; A = total catchment area.

Groundwater changes after and before watershed managements

Water balance equations were used to estimate groundwater recharging of the study area. All water balance equations are based on the premise that the difference between water inflow and outflow over a given time period for the hydrologic system must be equal to the change in water storage in that system (Ellah, 2009). This means:

$$\text{inflow} \pm \text{change in storag} \qquad 11$$

The main purpose of this computation is to make a quantitative evaluation, the amount of water percolated deep into the ground in the investigated area before and after integrated soil AND water conservation measures. GWR:

$$p - AET - Q - GWR = C \qquad 12$$

$$P - AET - QB = GWR\ldots\ldots\ldots\ldots\text{before}$$

$$P - AET - QA = GWR\ldots\ldots\ldots\ldots\text{afte}$$

Table 2. Descriptive statistics of water level data.

Years	WTPT	N	Mean± Std.	CV (%)	Minimum	Maximum
2012	CSN	8	5.29±0.48	9.12	4.80	6.00
	HDW	8	7.60±0.26	3.45	7.20	7.90
2013	CSN	8	4.90±0.63	12.81	3.50	5.50
	HDW	8	7.35±0.26	3.49	7.00	7.70
2014	CSN	8	4.68±0.73	15.71	3.00	5.30
	HDW	8	7.13±0.22	3.12	6.90	7.50
2015	CSN	8	4.43±0.70	15.83	2.80	5.00
	HDW	8	6.68±0.18	2.74	6.50	7.00
2016	CSN	8	4.30±0.65	15.22	3.00	5.00
	HDW	8	6.34±0.13	2.01	6.20	6.50
2017	CSN	8	4.99±0.81	16.20	3.30	6.00
	HDW	8	7.48±0.10	1.40	7.30	7.60

CSN = Cistern; HDW = hand dug well; WTPT = water point.

Table 3. Mean monthly temperatures at Yabello pastoral dry land and Agricultural Research Center Meteorological Station (°C).

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MMMxT	28.4	29.1	28.2	26.0	24.9	24.7	24.0	25.0	26.3	25.6	25.9	26.8
MMMiT	12.7	14.2	15.7	16.2	15.5	14.7	14.1	14.2	14.9	15.6	14.4	13.1
MMAT	20.5	21.5	21.6	21.0	20.1	19.2	19.1	20.0	20.3	20.4	20.1	19.8

MMMxT = Mean monthly maximum temperature; MMMiT = mean monthly minimum temperature; MMAT = mean monthly air temperature.

Where, P = precipitation; AET = actual evapotranspiration; QB = surface runoff before intervention from the catchment; QA = the surface runoff after intervention from the catchment; GWR = groundwater recharge.

Some indicators showing an increasing groundwater table in cisterns and hand-dug wells were identified through key informants and experts to describe the depth of water level from the surface. More than 95% of permanent water-point supply is from hand-dug wells (Coppock et al., 2006). Though, both cistern and hand-dug wells were selected as appropriate indicators. Eight water-points were measured using measuring tape and assessed through key informants and watershed experts. Six years of water levels of eight water-points were measured using a measuring tape. The structural data monitoring of descriptive statistics used is presented in Table 2. Model used under data analysis:

$$Y_{ij} = \mu + YRS_i + WP_j + e_{ij} \qquad 13$$

Where, $Y_{ij} = {}_{ij}^{th}$ observation, μ = overall mean of observed data; YRS_i = effects of i^{th} years on water levels; WP_j = effects of j^{th} water point on water levels and e_{ij} = ij^{th} random error.

RESULTS AND DISCUSSION

Hydrometeorology of the watershed

Catchment estimated based on the basic climatological data, land use type and soil data.

Potential evapotranspiration

The potential evapotranspiration of the study area was estimated using the FAO Penman-Monteith method and Thornthwaite system (Tables 5 and 6).

Actual evapotranspiration

The actual evapotranspiration of the catchment area was determined based on the estimated potential evapotranspiration by using the Thornthwaite soil-water balance model. Accordingly, the mean annual actual evapotranspiration for the entire catchment was found to be 465.89 mm (Table 7).

The actual evapotranspiration of the study area was collected from National Meteorological Agency (Table 4 and 8). Soil hydrologic groups (SHG) of the study area was estimated using different standard such as basic infiltration rate, soil texture, soil bulk density and runoff coefficient (Table 9).

Table 4. Mean monthly wind speed, relative humidity and sunshine hours (NME).

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WS (m/s)	1.4	1.6	1.7	1.4	1.1	1.0	1.0	1.2	1.4	1.2	1.2	1.2
RH (%)	35.4	36.9	42.0	60.0	64.7	60.7	57.8	53.0	51.3	58.8	58.4	44.2
SH (h)	8.8	8.4	7.7	5.7	5.1	4.0	2.6	3.7	4.9	4.8	6.1	7.9

WS = Wind speed; RH = relative humidity; SH = sunshine hours.
Source: National Meteorological Agency.

Table 5. Estimated PET using FAO Penman-Monteith method

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
MMMxT	28.4	29.1	28.2	26.0	24.9	24.7	24.0	25.0	26.3	25.6	25.9	26.8	
MMMiT	12.7	14.2	15.7	16.2	15.5	14.7	14.1	14.2	14.9	15.6	14.4	13.1	
WS (km/d)	135	158	170	140	102	98	101	118	140	118	118	115	
RH (%)	35.4	36.9	42.0	60.0	64.7	60.7	57.8	53.0	51.3	58.8	58.4	44.2	
SH (h)	9.9	9.4	8.7	6.4	5.7	4.5	3.0	4.2	5.5	5.4	6.9	8.9	
SR	23	23.3	23	19.2	17.5	15.3	13.3	15.5	17.8	17.3	18.7	21.1	
Eto (mm/d)	5.0	5.4	5.5	4.3	3.7	3.4	3.1	3.7	4.2	3.9	4.0	4.4	1533.6

MMMxT = Mean monthly maximum temperature (˚C); MMMiT = mean monthly minimum temperature (˚C); WS = wind speed; RH = relative humidity; SH = sunshine hours; SR = solar radiation (MJ/m^2/d) and Eto = evapotranspiration (mm/d).

Table 6. Estimated PET calculated using Thornthwaite system.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
T	20.5	21.5	21.6	21.0	20.1	19.2	19.1	20.0	20.3	20.4	20.1	19.8	
J	8.47	9.12	9.19	8.79	8.23	7.68	7.63	8.14	8.37	8.42	8.23	8.01	100.28
CF	0.94	0.97	1	1.04	1.07	1.08	1.08	1.05	1.02	0.98	0.95	0.93	
CPET	64.9	72.3	75.3	72.4	67.6	62.3	61.1	66.0	66.5	65.8	62.5	59.6	796.3

T = Mean monthly air temperature (ºC); J = monthly heat index; LCF = latitude correction factor at 10° N; CPET = corrected potential evapotranspiration (mm).

Table 7. Calculated available water capacity of the soil at the root zone.

S/N	Soil type	Root depth (m)	CAWC at root (mm/m)
1	Sandy clay loam	0.9	158
2	Clay	0.9	202.97
3	Sandy loam	0.7	155.98
4	Clay loam	1.9	249.98
5	Clay loam	0.9	85.5

CAWC = Calculated available water capacity; mm = millimeter; m = meter.

Runoff generation before and after implementations of soil and water conservation measures

The amounts of surface runoff generation and leaving the catchment before and after the implementation of integrated soil and water conservation measures varied as presented in Tables 10 and 11.

Accordingly, the volume of surface runoff generation before implementations of integrated SWC measures was found to be 45.98% of the mean annual rainfall of

Table 8. Total amount of AET of the catchment.

S/N	Soil type	Area(m^2) ('000)	AET(m)	AET(m^3)	MAAET(mm)
1	Sandy loam	21800	0.4692	10228560	
2	Clay	280	0.4313	120755.32	
3	Clay loam	8370	0.4709	3941433	
4	Clay	405	0.4745	192172.5	
5	Sandy clay loam	1250	0.4149	518625	
6	Rocky	95	0	0	
Total		32200		15,001,546	465.89

AET = actual evapotranspiration, MAAET = mean annual actual evapotranspiration

Table 9. Standard used to assign soil group of different land use types.

Land use	SHG	Basic IR (in/hours)	Soil texture	Intermediate bulk density (g/cm^3)	Relative runoff potential	RC
Cultivated land	A	0.30-0.45	Course sand, sand, loamy sand	1.35-1.40	Low	0.12-0.15
	B	0.15-0.30	Sandy loam, loam	1.30-1.35	Moderate	0.15-0.20
	C	0.05-0.15	Silt loam, sandy clay loam	1.20-0.30	High	0.20-0.25
	D	0-0.05	Clay loam, sandy clay, silty clay, clay	0.90-1.20	Very High	0.25-0.50
Bush land	A	0.30-0.45	Course sand, sand, loamy sand	1.25-1.30	Low	0.13-0.15
	B	0.15-0.30	Sandy loam, loam	1.20-1.25	Moderate	0.15-0.20
	C	0.05-0.15	Silt loam, sandy clay loam	1.15-1.20	High	0.20-0.30
	D	0-0.05	Clay loam, sandy clay, silty clay, clay	1.00-1.15	Very High	0.30-0.40
Homestead	A	0.30-0.45	Course sand, sand, loamy sand	1.50-1.60	Low	0.15-0.20
	B	0.15-0.30	Sandy loam, loam	1.30-1.50	Moderate	0.20-0.25
	C	0.05-0.15	Silt loam, sandy clay loam	1.20-1.30	High	0.25-0.30
	D	0-0.05	Clay loam, sandy clay, silty clay, clay	1.00-1.20	Very High	0.30-0.35
Grazing land	A	0.30-0.45	Course sand, sand, loamy sand	1.30-1.50	Low	0.17-0.20
	B	0.15-0.30	Sandy loam, loam	1.25-1.30	Moderate	0.20-0.23
	C	0.05-0.15	Silt loam, sandy clay loam	1.20-1.25	High	0.23-0.38
	D	0-0.05	Clay loam, sandy clay, silty clay, clay	1.00-1.20	Very High	0.37-0.40
Bare land	A	0.30-0.45	Course sand, sand, loamy sand	1.50-1.60	Low	0.30-0.40
	B	0.15-0.30	Sandy loam, loam	1.40-1.50	Moderate	0.40-0.43
	C	0.05-0.15	Silt loam, sandy clay loam	1.30-1.40	High	0.43-0.50
	D	0-0.05	Clay loam, sandy clay, silty clay, clay	1.20-1.30	Very High	0.50-0.60
Woody land	A	0.30-0.45	Course sand, sand, loamy sand	1.30-1.50	Low	0.15-0.20
	B	0.15-0.30	Sandy loam, loam	1.25-1.30	Moderate	0.25-0.30
	C	0.05-0.15	Silt loam, sandy clay loam	1.20-1.25	High	0.30-0.45
	D	0-0.05	Clay loam, sandy clay, silty clay, clay	1.00-1.20	Very High	0.45-0.50
Ex-closure	A	0.30-0.45	Course sand, sand, loamy sand	1.25-1.30	Low	0.18-0.20
	B	0.15-0.30	Sandy loam, loam	1.20-1.25	Moderate	0.20-0.25
	C	0.05-0.15	Silt loam, sandy clay loam	1.15-1.20	High	0.25-0.28
	D	0-0.05	Clay loam, sandy clay, silty clay, clay	0.90-1.15	Very High	0.28-0.31

IR=infiltration rate**, RC=** runoff coefficient**, in/hr=**inch per hour**, g/cm^3=**gram per centimeter cubic**;** Based on the bulk density and soil infiltration rate data, the nearest numbers to the maximum or minimum between the RCs were taken; low=A, moderate=B, high=C, very high=D.

the study area (Table 10). But the calculated amount of surface runoff after integrated SWC measures were implemented was found to be 6,299,538 m^3, which is 33.44% of total rainfall (Table 11). These integrated

Table 10. Runoff generation before implementation of integrated SWC measures.

Land use type	Area (m^2) ('000)	*HSGs	Slope (%)	RC*	MAR	ROG (m^3)	ROG (%)
Homestead	500	B	2-6	0.25	0.5851	61435.5	
Crop land	300	A	2-6	0.14	0.5851	24574.2	
Bare land	20000	D	>6	0.6	0.5851	7021200	
Grazing land	10900	C	2-6	0.23	0.5851	1466846	
Woodland	400	B	>6	0.35	0.5851	81914	
Bush land	100	A	>6	0.13	0.5851	7606.3	
Total	32200					8663576	45.98

*HSGs = Hydrologic soil groups, RC = runoff coefficient, MAR = mean annual rainfall, ROG = runoff generated.
*Source: Skinner et al. (2009).

Table 11. Changes in the catchment runoff induced by implementation of SWC measures.

Land use	Area (m^2) ('000)	*HSGs	Slope (%)	RC	MAR	ROG (m^3)	ROG (%)
Homestead	500	B	2-6	0.21	0.585	61435.5	
Crop land	180	B	2-6	0.19	0.585	20010.42	
	120	C	2-6	0.21	0.585	14744.52	
Bare land	9000	C	>6	0.5	0.585	2632950	
Grazing land	10900	B	2-6	0.34	0.585	2168381	
Wood land	400	A	>6	0.18	0.585	42127.2	
Bush land	60	A	>6	0.13	0.585	4563.78	
	40	B	>6	0.16	0.585	3744.64	
Ex-closure	11000	B	2-6	0.21	0.585	1351581	
Total	32200					6299538.06	33.44

watershed management enhancements decrease surface runoff by 12.5% points. These create an opportunity for surface runoff to infiltrate and percolate deep to groundwater as it gets time for infiltration. This finding was in line with the previous results that after implementation of SWC measures, surface runoff leaving the watershed is reduced by 9.96% of the mean annual rainfall of the catchment (Tireza et al., 2013).

Effects of integrated SWC measures on groundwater availability

The portion of precipitation available groundwater recharges before and after implementations of integrated SWC measures was estimated by using the water balance equation stated in equation (14).

$$GWRB = P - AET - QB = 18{,}840{,}220\ m^3 - 7{,}763{,}655\ m^3 - 8{,}663{,}576\ m^3 = 2{,}412{,}989\ m^3$$

Where, P = precipitation; Q = surface runoff before the implementation of soil and water conservation measures; AET = actual evapotranspiration; GWRB = groundwater recharge before implementations of SWC measures in the study area.

The amount of water that percolates deep into the groundwater before the interventions were found to be 2,412,989 m^3 which are 12.81% of the mean annual rainfall of the study area. However, the amount of surface runoff deep percolated down to replenish groundwater after the implementation of integrated watershed management was found to be 4,777,027 m^3 annually, which is 25.36% of the mean annual rainfall of the catchment. As a result, the groundwater recharges increased by 12.55% of mean annual rainfall of the study area. This may solve the shortage of groundwater availability problems as it is the main source of drinking for both humans and livestock. This finding is in line with the previous results that groundwater recharges increased by 12-28% of the annual rainfall of the study area due to SWC measures implemented in Ronquillo watershed in the Northern Andes of Peru (Krois and Schulte 2013). This study also confirms the report by Singh et al. (2014), on Garhkundar-Dabar watershed in

Table 12. Measured average water level from surface at the end of dry season

Water points	Years					
	2012	2013	2014	2015	2016	2017
Cistern	5.5	5.2	4.9	4.7	4.4	5.1
HDW	7.8	7.5	7.2	6.8	6.5	7.6

All numbers in the above table are in meters; HDW- Hand dug well.

Table 13. Mean of water level comparison for different water points evaluated.

Factors	Years						Water points	
Level	2012	2013	2014	2015	2016	2017	Cistern	HDW
Mean± SE	6.44 ± 0.12^{a}	6.13 ± 0.12^{ab}	5.90 ± 0.12^{b}	5.55 ± 0.12^{c}	5.32 ± 0.12^{c}	6.23 ± 0.12^{ab}	4.76 ± 0.07^{b}	7.09 ± 0.07^{a}

HDW-hand dug well; LSD value =0.35; Means with different letters are significantly different.

India which compared treated and untreated watershed in treatment together with increased base flow (4.5 vs. 1.2%) and groundwater recharge (11% vs. 7%) relative to total rainfall received. Cisterns and hand-dug wells are the major water sources for human and livestock during dry seasons in the study area. The depth of water level from the surface at the end of dry season or before start of long rainy season (March-June) over six years was estimated (Table 12). The average water levels for 2012, 2014, 2015, 2016 (Table 13) give a good indication of variation in both water-points at the end of the long dry season.

Since there was a shortage of rainfall during the long rainy season of 2016 that replenishes the groundwater, the depth of water-point level in 2017 increased. This decreasing depth of water level is by default due to rising of the groundwater table which may be caused by an integrated watershed management project conducted in the study area. The main case for rising of groundwater table is a reduction of surface runoff generation tackled by integrated SWC measures conducted in the study area (Table 10). Some stored water in different *in-situ* water harvesting structures replenishes the cisterns and hand dug wells at a lower elevation. The difference in groundwater level in cistern and hand-dug wells after interventions was found to be 1.1 and 1.3 m, respectively (Table 12). To test the impact of catchment management on depth of water-points, a comparison was made between the years not preceding catchment management for 2012, and after preceding it (2013, 2014, 2015, 2016 and 2017). The depth of water level before interventions (2012) is significantly different from 2014, 2015 and 2016 among the means as compared at $p<0.05$ (Table 13). These results show that in 2014, 2015 and 2016, the decreasing depth of water level as compared to 2012 is due to rehabilitation of the watershed to its original potential.

Similar suggestion by Nyssen et al. (2010) regarding soil and water conservation measures (SWC) showed that they increased infiltration capacity of soil and caused a rise in the water table and improved water availability over time. A report by Mekonen and Tesfahunegn (2011) shows that after the implementation of soil and water conservation (SWC) measures, the groundwater level in the wells was augmented by up to 2.5 m.

Conclusion

The study area is characterized by high intensity and short duration of rainfall. Integrated watershed management reduces surface runoff generation by 12.55% of annual rainfall of the study area. The impacts of integrated watershed management measures on the hydrology of the catchment enhance an opportunity infiltration, and thereby reduce surface runoff generation which leads to an incremental rise of groundwater by 2,364,038 m^3. In this case, after conducting integrated watershed management, more than half of the rainfall is supposed annually to be conserved either on the surface or underground. Consequently, the yearly increasing water depths from the surface in cisterns and hand-dug wells were reduced with little change. The difference evident in groundwater level in the reservoirs after interventions increase was by 1.1 and 1.3 m, respectively. Critical criteria such as slope, rainfall type and raw materials availability should be considered seriously when planning watershed management. Since the study area is characterized by high intensity and short duration of rainfall events in two seasons that may produce high surface runoff with the probability of it not raining again in the same season, additional physical SWC structures are suggested to store all produced surface runoff. Research and development work should complement each other and at the same time be focused on introducing low-cost, effective and easily applicable soil and water conservation measures with local knowledge and local personnel that can rehabilitate degraded areas to their full potential.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. Brien Norton, Mr. Nago Dembo, Mr. Wondimu Tolcha, Mr. Gebeyehu Elias, Mr. Zerihun Yohannis, Mr. Zelalem Taku, Mr. Isihak Lolo and Mr. Tamirat Tesema for their hearty support and peer editorial review. This work was supported by the Oromia Agricultural Research Institute and Hawassa University.

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