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The effect of variation of dimensions of solar reflectors on solar enhanced model pond

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Waste water stabilization pond is a simple way of treating waste water but one of its limitations is that it requires large area of land to be efficient. This study employed the use of solar reflectors to improve the efficiency of waste water stabilization pond by investigating the effect of variation of solar reflectors on the physical, chemical and biological properties of the pond. To achieve this, three model ponds were constructed, arranged in parallel and were supplied waste water by an overhead tank. Different sizes of reflectors varying along its height and width were installed at the effluent side of the pond. Effluent samples were collected and tested for BOD, total coliform, temperature, pH, algal count, total suspended solids and dissolved oxygen. The findings showed that when the width of the reflector is longer than the height of the reflector, it was observed to favor increase in pH, decrease in total coliform and total suspended solids while reflectors with longer height than width were observed to favor increase in algal count, temperature, dissolved oxygen and decrease in BOD.

Key words: Waste water stabilization pond, waste water, solar radiation, solar reflectors.

INTRODUCTION

Waste water stabilization pond (WSP) is a basin dug on the earth for removal of organic and pathogenic organisms (Agunwamba, 2001). Not only has it been found to be one thousand times better in destroying pathogenic bacteria and intestinal parasites than the conventional treatment plants (Mara et al., 1983), but also more economical (Arthur, 1983). It is simple to construct, operate and maintain and it does not require any input of external energy (Agunwamba, 2001). However, one of its limitations as stated by Agunwamba (2001) is that WSP system usually requires large area of land which is attributable to its complete dependence on natural treatment process. Therefore, this research is aimed at enhancing the efficiency of WSP without increasing area requirement of the pond by incorporating solar reflectors.

Due to large area requirement of WSP, researchers has been working on this area of study to improve the efficiency of ponds using attached growth system (Shin and Polpraset, 1987; Saidam et al., 2000), step feeding (Shelef et al., 1987), water hyacinth (Mumtaz and Hashim 2012), hydraulic jump (Agunwamba and Ogarekpe, 2010), hydraulic jump and solar reflectors (Agunwamba et al. 2013) and solar reflectors (Agunwamba and Utzev, 2012). Agunwamba et al. (2013) investigated if a solar-enhanced WSP (SEWSP) can increase treatment...
Table 1. Detailed description of ponds and the corresponding size of solar reflectors.

<table>
<thead>
<tr>
<th>Experimental pond</th>
<th>Size of Pond (m)</th>
<th>Size of Reflector (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$2 \times 0.5 \times 0.3$</td>
<td>$0.4 \times 0.1$(wxh)</td>
</tr>
<tr>
<td>B</td>
<td>$2 \times 0.5 \times 0.3$</td>
<td>$0.3 \times 0.1$(wxh)</td>
</tr>
<tr>
<td>C</td>
<td>$2 \times 0.5 \times 0.3$</td>
<td>$0.2 \times 0.1$(wxh)</td>
</tr>
<tr>
<td>D</td>
<td>$2 \times 0.5 \times 0.3$</td>
<td>$0.1 \times 0.1$(wxh)</td>
</tr>
<tr>
<td>E</td>
<td>$2 \times 0.5 \times 0.3$</td>
<td>$0.1 \times 0.2$(wxh)</td>
</tr>
<tr>
<td>F</td>
<td>$2 \times 0.5 \times 0.3$</td>
<td>$0.1 \times 0.3$(wxh)</td>
</tr>
<tr>
<td>G</td>
<td>$2 \times 0.5 \times 0.3$</td>
<td>$0.1 \times 0.4$(wxh)</td>
</tr>
</tbody>
</table>

Figure 1. Schematic diagram of experimental setup due to dimension variation of the solar reflectors.

efficiency and consequently reduce the land area requirement. Their study involved installing reflectors at the sides of the pond and it revealed not only that SEWSP improves treatment efficiency and reduces land area requirement but also reduces the cost of treating wastewater approximately two times lower than the conventional WSP for the same treatment efficiencies.

Therefore, the main objective of this research is to increase the efficiency of treatment of waste stabilization pond with solar reflectors by studying the effect of variation of sizes of solar reflectors in the pond.

MATERIALS AND METHODS

Experimental set up

Different sets of solar enhanced ponds with dimensions are shown in Table 1 and Figure 1. It has a sewage tank ($1.2 \times 1.2 \times 0.6$ m) that receives its influent from sewage that diverted temporary to a ditch. The tank distributes the sewage to the model ponds with the help of control valves and half inches diameter pipes. Each set contain three ponds which are connected in parallel. The inlet and outlet pipes were fitted centrally in the experimental ponds. This setup was situated in the university sewage plant.
Table 2. Sample definition.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Sample</th>
<th>Characteristics of reflector (HxW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>No reflector</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>0.3 x 0.1</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>0.1 x 0.1</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>Influent (A, B &amp; C)</td>
</tr>
<tr>
<td>5</td>
<td>E</td>
<td>0.4x0.1</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>0.2x0.1</td>
</tr>
<tr>
<td>7</td>
<td>G</td>
<td>Influent (H, E &amp; F)</td>
</tr>
<tr>
<td>8</td>
<td>H</td>
<td>No reflector</td>
</tr>
<tr>
<td>9</td>
<td>I</td>
<td>No reflector</td>
</tr>
<tr>
<td>10</td>
<td>J</td>
<td>0.1 x 0.3</td>
</tr>
<tr>
<td>11</td>
<td>K</td>
<td>0.1 x 0.4</td>
</tr>
<tr>
<td>12</td>
<td>L</td>
<td>Influent(I,J,K)</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>0.1 x 0.2</td>
</tr>
<tr>
<td>14</td>
<td>N</td>
<td>0.1 x 0.1</td>
</tr>
<tr>
<td>15</td>
<td>O</td>
<td>Influent (M,N,P)</td>
</tr>
<tr>
<td>16</td>
<td>P</td>
<td>No reflector</td>
</tr>
</tbody>
</table>

Solar reflector setup

The set of three ponds in parallel were constructed with frames at the outlet side of the pond to carry reflector of varying length fixed at angle 90° to horizontal plane. For each set, two different sizes of reflectors are inserted at the outlet side of the first two ponds and the third pond has no reflector (serves as control test). The test is run in batches of three pond per set. The reflectors are made of a flat ceiling board wrapped with foil paper. The foil paper was used as solar reflector.

Sample collection

Influent and effluent samples were collected weekly from the inlet and outlet of the experimental tanks in batches to examine physiochemical and biological characteristic within a period of 4 months. The influent and effluent samples were collected after 6 h detention time. Table 2 shows the samples with regard to their respective characteristics and the sixteen samples were divided into four batches. The parameters that were examined are pH, dissolved oxygen, algal count, total suspended solids, total coli form and biochemical oxygen demand (BOD₅). All the analyses was done using appropriate water testing meters and in accordance with the standard methods (APHA, 1998).

RESULTS AND DISCUSSION

pH

As shown in Figures 10 to 13, sample D, G, L and O have the lowest value of pH in this study and are the influent. Sample B, E, K and M are from ponds with highest area of reflector in their respective batches. It is obvious from the graphs that increased area of reflector increased the respective effluent pH values. It is an established fact that photosynthesis activities in ponds increase pH values in ponds. In fact, high values above 9 in pond due to rapid photosynthesis by the pond alga which consumes CO₂ faster than it can be replaced by bacterial respiration as a result carbonate and bicarbonate ions dissociate (Mara and Pearson, 1998; Kamyambo et al., 2005). It appears that the higher the intensity of sunlight, the higher the pH values in the pond as values of pH up to 11 were recorded in WSPs in the afternoon (Kamyambo et al., 2005). Therefore, increased pH value in sample B, E, K and M is due to increased photosynthesis activities as a result of increased reflected solar radiation in the model pond from the increased area of reflector.

The percentage increase in pH of sample B, C, E, F, J, K, M and N with their respective influent is 2.6, 1.9, 2.5, 1.8, 2.2, 3.3, 3.3 and 2.6, respectively. Figure 31 shows that samples with breadth wise varied reflectors (JKMN) have higher pH value than longitudinal varied reflectors (BCEF). However, apparently, increase in breadth of reflector seems to favor increase in pH value than increase in its height.

Plate count

As shown in Figure 6 to 9, sample B, E, K and M have the highest value of plate count algae throughout the weeks, while sample D, G, L and O (influent of different batches) have the least values of plate count algae. The results show that plate count algae increases with increase in size of the reflectors. The reflectors increase the solar radiation by reflecting solar radiation in the pond. Oswald (1977) reported that 90% of solar radiation is converted into heat and less than 10% to chemical energy. Increase in temperature has been found to favor increase in algal growth (Marvis, 1970). Therefore, increased area of reflector increased the temperature of the pond which favoured the increase in plate count algae.

The increase of plate count alga in percentage of the sample B, C, E, F, J, K and M and N is 168, 137, 86, 63, 33, 48, 104 and 42, respectively. In average, as shown in Figure 30, longitudinal varied reflectors (B, C, E and F) have higher increase in plate count algal than the breadthwise varied reflectors (J, K, M and N) when compared with their respective control test. This indicates that the longer the reflector longitudinally, the higher the plate count algal in the effluent of the pond.

Total coliform

As shown in Figures 18 to 21, sample D, E, L and O are the influents and have the highest total coliform count. Samples B, E, K and M have the lowest total coliform count. These are the samples with the largest size of reflector in their respective batches. It is a well-
The established fact that sunlight reduces the number of bacteria in a medium. In Portugal, it was found that statistically significant relations existed between solar radiation and die off of *Pseudomonas aeruginosa*, *Clostridium perfringes* and fecal streptococcus (Nascimento et al., 1991). Mancini (1978) reported that about half of the lethal effect of light was due to wavelengths below 370 nm and one quarter to wavelengths between 370 and 400 nm (U.V. radiation). Inhibition of Nitrosomonas was achieved by light exposure for 10 min, with the near U.V. range of 410 to 415 nm being particularly effective for this purpose (Alleman et al., 1987). In a more recent study, it was discovered that wavelength above 500 nm damage faecal coliform and this process is enhanced at higher pH values and in the presence of oxygen (Curtis et al., 1992). Hence, increased size of reflector in this study increased the reflected solar radiation in the pond. This resulted to both direct reduction of total coliform by solar radiation of wavelength below 500 and above 500 nm.

The percentage decrease in total coliform of sample B, C, E, F, J, K and M is 82, 79, 86, 74, 81, 86, and 95 respectively. From Figure 32, samples with higher width of reflector seem to reduce total coliform more than samples with higher height of reflectors. It therefore appears that reflector with higher width reduces total coliform than reflectors with higher height.

**Temperature**

As shown in Figures 22 to 25, sample D, G, L, and O have the lowest temperature and are the influents of the ponds. Samples B, E, K and M have the highest values and the highest size of reflector in their respective batches. In the aforementioned figures, sample with larger reflectors gives higher temperature. The reflector increases the solar radiation in the pond and the higher the increase in size of the reflector, the higher the increase in solar radiation in the pond. According to Oswald (1977), 90% of solar radiation is converted to heat energy and the remaining chemical energy. The solar radiation converted to heat increases the temperature of the pond.

The percentage increase in temperature of sample B, C, E, F, J, K and M is 14.5, 10.9, 6.8, 2.5, 8.7, 11.4, 11.9, respectively. Comparing sample BJ, EK and FM with their respective no reflector samples, it appears that reflectors with higher width increases the temperature of effluent of pond more than reflectors with higher width (Figure 33).

**Total suspended solids**

From Figures 14 to 17, samples D, E, L, and O have the highest TSS and they are the influents. Samples B, E, K and M are samples with the largest size of the reflector in their respective batches and showed the least value of total suspended solids. In the above mentioned figures, samples with larger reflectors appear to show lower suspended solids. However, the difference in total suspended solids among samples with reflectors and no reflector appear small, whereas, the difference between samples effluent and influent is high. It appears through observation that majority of the suspended solids were removed by sedimentation. Then, minority of the total suspended solids was removed through biochemical reaction. This biological reaction that reduces organic content is supported by solar radiation (William et al., 1852). Consequently, the higher the solar radiation in a pond, the higher the biochemical process which reduces the organic matters in the waste water. Sample B, E, K and M appear to have the least suspended solids in the model pond because they have the highest reflected radiation in their individual batch.

The percentage decrease in suspended solids of sample (BCEFJKM) is 92.5, 86.9, 75.7, 52.9, 73.4, 77.4, and 80.9 respectively. From Figure 34, comparing samples BJ, EK and FM with the respective control test samples, it appears that reflectors with higher height reduces the suspended solids more than reflectors with higher width.

**Dissolved oxygen (DO)**

As shown in Figures 2 to 5, sample B, E, K and M has the highest DO content and are the samples that have the highest area of reflector in their respective batches. Sample D, G, L, and O are the influents of the pond and have DO content of least value in their respective batches. From the above mentioned figures, it appears that samples with larger reflector have higher dissolved oxygen content despite their slight disparity. The main mechanism of oxygenation in pond systems is the oxygen provided by the algal population (Shilton and Harrison, 2003; Mara and Pearson, 1998). After sunrise, the dissolved oxygen level gradually rises in response to photosynthetic activity, to a maximum in the mid-afternoon, after which it falls to a minimum during the night when photosynthesis ceases and respiratory activity consumes oxygen (Mara and Pearson, 1998). This suggests that increase in solar radiation increases dissolved oxygen content in pond. Pattamapitpon et al. (2013) showed that dissolved oxygen increase with radiation in a quadratic relationship. Sample B, E, K and M have higher values of dissolved oxygen because their reflectors reflected more radiation in the pond which increased the algal activities in the pond and subsequently increased dissolved oxygen content in the pond.

The percentage increase in dissolved oxygen of sample (BCEFJKM) is 28.3, 25.5, 37.3, 13.2, 120, 170 and 130 respectively. In Figure 35, comparing sample BJ,
EK and FM with its respective control test samples, it appears that reflectors with higher height increases the dissolved oxygen in the pond more than reflectors with higher breadth.

**Biological oxygen demand (BOD)**

From Figures 26 to 29, samples B, E, K and M have the least value of BOD content. And they are samples that
Figure 5. Variation of dissolved oxygen of sample MNOP with time in weeks for fourth batch.

Figure 6. Variation of plate count algae of sample ABCD with time in weeks for first batch.

Figure 7. Variation of plate count algae of sample EFGH with time in weeks for second batch.

Figure 8. Variation of plate count algae of sample IJKL with time in weeks for third batch.
Figure 9. Variation of plate count algae of sample MNOP with time in weeks for fourth batch.

Figure 10. Variation of pH of sample ABCD with time in weeks for first batch.

Figure 11. Variation of pH of sample EFGH with time in weeks for second batch.

Figure 12. Variation of pH of sample IJKL with time in weeks for third batch.
Figure 13. Variation of pH of sample MOPN with time in weeks for fourth batch.

Figure 14. Variation of total suspended solids of sample ABCD with time in weeks for first batch.

Figure 15. Variation of total suspended solids of sample EFGH with time in weeks for second batch.

Figure 16. Variation of total suspended solids of sample IJKL with time in weeks for third batch.
have the highest area of reflector in their respective batches. Samples D, G, L and O are the influents of the pond and have the highest value of BOD content. From Figures 26 to 29, it appears that samples with higher area of reflectors have lesser BOD than samples of lower area of reflector though the disparity is slight. Since organic
content in water determines the value of BOD, most of BOD through observation was removed through sedimentation. That was why there is slightly higher disparity between the influents and effluents of the pond. As mentioned earlier, increase in temperature increases biogradation of organic materials in ponds. The samples...
Figure 23. Variation of temperature of sample EFGH with time in weeks for second batch.

Figure 24. Variation of temperature of sample IJKL with time in weeks for third batch.

Figure 25. Variation of temperature of sample MNOP with time in weeks for fourth batch.

Figure 26. Variation of BOD of sample ABCD with time in weeks for first batch.
with higher area of reflectors reflect more solar radiation in the pond and the increased solar radiation in the pond raised the temperature of the pond. The increased temperature increased the rate of degradation of organic content and consequently reduced the BOD in the samples of larger reflectors.

The percentage reduction in BOD of samples BCEFJKM is 19.2, 14.5, 23.3, 20.0, 13.7, 15.3 and 21.3,
Figure 30. Comparison of increase in the plate count algae for different aspect ratios of the reflectors.

Figure 31. Comparison of increase in the pH for different aspect ratios of the reflectors.

Figure 32. Comparison of decrease in total coliform for different aspect ratios of the reflectors.

Figure 33. Comparison of increase in temperature for different aspect ratios of the reflectors.

Figure 34. Comparison of decrease in total suspended solids for different aspect ratios of the reflectors.

Figure 35. Comparison of decrease in dissolved oxygen demand for different aspect ratios of the reflectors.
respective. As shown in Figure 36, by comparing samples BJ, EK and FM with the respective control test samples, it appears that reflectors with higher height favours the decrease in dissolved oxygen in the pond more than reflectors with higher breadth.

Conclusion

Waste stabilization pond is a simple way of treating waste water, but its limitation is that it requires large area of land to operate effectively. As such, this research employed the use of solar reflectors to enhance the efficiency of waste stabilization pond. To achieve this, this study varied different sizes of reflector installed at the effluent side of the pond and studied its effect on the physio-chemical and biological properties of the pond. When the influent and effluent respective parameters of SEWSP were observed, the results showed reduction in BOD, total coliform, total suspended solids and increase in temperature, dissolved oxygen, plate count algae and pH. The observations also showed that variation of the dimension of the reflectors affects the properties of the solar enhanced pond. When the width of the reflector is longer than the height of the reflector, it was observed to favor increase in pH, decrease in total coliform and total suspended solids, while reflectors with longer height than width, were observed to favor increase in algal count, temperature, dissolved oxygen and decrease in BOD.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

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

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²Department of Bio-system and environmental Engineering, Hawassa University, Shashemene, Ethiopia.

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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 atmosphere via evapotranspiration 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).

\[ \text{AWC} = \text{FC} - \text{PWF} \]

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

\[ \text{TWC} = \sum (\text{AWC})(L_k) \]

Where, \(L_k\) = 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.

\[ \text{STOR} = \text{AWC} \times e^{APWL} \]

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.

\[ Q = CPA \]

Where, \(Q\) = runoff volume from the catchment (m³); \(P\) = average precipitation (m); \(A\) = catchment area (m²) and \(C\) = Runoff coefficient.

The runoff coefficient (\(C\)) 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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Table 1. Soil analysis report.

<table>
<thead>
<tr>
<th>Land use/land cover</th>
<th>Textural classes at different slope positions</th>
<th>Bulk density at different slope classes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-5%</td>
<td>6-10%</td>
</tr>
<tr>
<td>Bush land</td>
<td>Clay loam</td>
<td>Sandy clay loam</td>
</tr>
<tr>
<td>Cultivated land</td>
<td>Sandy clay loam</td>
<td>Sandy clay loam</td>
</tr>
<tr>
<td>Grazing land</td>
<td>Sandy loam</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>Woody land</td>
<td>Clay loam</td>
<td>Clay loam</td>
</tr>
<tr>
<td>Homestead</td>
<td>Sandy clay loam</td>
<td>Clay loam</td>
</tr>
<tr>
<td>Bare land</td>
<td>Sandy clay</td>
<td>Sandy clay</td>
</tr>
<tr>
<td>Ex-closure</td>
<td>Sandy clay</td>
<td>Sandy clay</td>
</tr>
</tbody>
</table>

All bulk density values are in g/cm³.

Figure 1. Location map of the study area.

Figure 2. Taking soil samples from dug wells.
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:

\[
PET = 16C \left( \frac{T^{10^1}}{T} \right)^a \text{ mm}
\]

Where, \(PET\) = potential evapotranspiration (mm/month); \(T\) = 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:

\[
i = \sum_{n=1}^{12} l
\]

\(l\) is the month heat index and expressed as:

\[
l = \frac{T^{1.514}}{5}
\]

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

\[\text{SM}_{\text{month}} = \text{STOR}_{\text{month}} - \text{STOR}_{\text{previous month}}\]

A negative value of \(\Delta SM\) means discharge of water from the storage because of evapotranspiration, whereas a positive value of \(\Delta SM\) 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 \(\text{AET}\) that occurs in the catchment was determined by the arithmetic mean of the annual \(\text{AET}\) from each land use weighted by their area coverage:

\[
\text{AET}_T = \sum \frac{\text{AET}_i a_i}{A}
\]

Where, \(\text{AET}_T\) = total actual evapotranspiration; \(\text{AET}_i\) = 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:

\[\text{inflow} \pm \text{change in storage}\]

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:

\[p - \text{AET} - Q - GWR = C\]

The figures and equations below illustrate the annual rainfalls of the study area from 1998 to 2016.
Table 2. Descriptive statistics of water level data.

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

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).

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

MMxMT = 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 points are identified through key informants (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:

\[ Y_{ij} = \mu + Y_{RS} + W_{Pj} + e_{ij} \]

Where, \( Y_{ij} \) = \( i^{th} \) observation, \( \mu \) = overall mean of observed data; \( Y_{RS} \) = effects of \( j^{th} \) years on water levels; \( W_{Pj} \) = 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).

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

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

Table 5. Estimated PET using FAO Penman-Monteith method

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

MMMxT = Mean monthly maximum temperature (ºC); MMMiT = mean monthly minimum temperature (ºC); WS = wind speed; RH = relative humidity; SH = sunshine hours; SR = solar radiation (MJ/m²/d) and Eto = evapotranspiration (mm/d).

Table 6. Estimated PET calculated using Thornthwaite system.

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Ann.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>20.5</td>
<td>21.5</td>
<td>21.6</td>
<td>21.0</td>
<td>20.1</td>
<td>19.2</td>
<td>19.1</td>
<td>20.0</td>
<td>20.3</td>
<td>20.4</td>
<td>20.1</td>
<td>19.8</td>
<td></td>
</tr>
<tr>
<td>CF</td>
<td>0.94</td>
<td>0.97</td>
<td>1</td>
<td>1.04</td>
<td>1.07</td>
<td>1.08</td>
<td>1.08</td>
<td>1.05</td>
<td>1.02</td>
<td>0.98</td>
<td>0.95</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td>CPET</td>
<td>64.9</td>
<td>72.3</td>
<td>75.3</td>
<td>72.4</td>
<td>67.6</td>
<td>62.3</td>
<td>61.1</td>
<td>66.0</td>
<td>66.5</td>
<td>65.8</td>
<td>62.5</td>
<td>59.6</td>
<td>796.3</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Soil type</th>
<th>Root depth (m)</th>
<th>CAWC at root (mm/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sandy clay loam</td>
<td>0.9</td>
<td>158</td>
</tr>
<tr>
<td>2</td>
<td>Clay</td>
<td>0.9</td>
<td>202.97</td>
</tr>
<tr>
<td>3</td>
<td>Sandy loam</td>
<td>0.7</td>
<td>155.98</td>
</tr>
<tr>
<td>4</td>
<td>Clay loam</td>
<td>1.9</td>
<td>249.98</td>
</tr>
<tr>
<td>5</td>
<td>Clay loam</td>
<td>0.9</td>
<td>85.5</td>
</tr>
</tbody>
</table>

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
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
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).

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

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 10. Runoff generation before implementation of integrated SWC measures.

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Area (m(^2)) (‘000)</th>
<th>*HSGs</th>
<th>Slope (%)</th>
<th>RC*</th>
<th>MAR</th>
<th>ROG (m(^3))</th>
<th>ROG (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homestead</td>
<td>500</td>
<td>B</td>
<td>2-6</td>
<td>0.25</td>
<td>0.585</td>
<td>61435.5</td>
<td></td>
</tr>
<tr>
<td>Crop land</td>
<td>300</td>
<td>A</td>
<td>2-6</td>
<td>0.14</td>
<td>0.585</td>
<td>24574.2</td>
<td></td>
</tr>
<tr>
<td>Bare land</td>
<td>20000</td>
<td>D</td>
<td>&gt;6</td>
<td>0.6</td>
<td>0.585</td>
<td>7021200</td>
<td></td>
</tr>
<tr>
<td>Grazing land</td>
<td>10900</td>
<td>C</td>
<td>2-6</td>
<td>0.23</td>
<td>0.585</td>
<td>1466846</td>
<td></td>
</tr>
<tr>
<td>Woodland</td>
<td>400</td>
<td>B</td>
<td>&gt;6</td>
<td>0.35</td>
<td>0.585</td>
<td>81914</td>
<td></td>
</tr>
<tr>
<td>Bush land</td>
<td>100</td>
<td>A</td>
<td>&gt;6</td>
<td>0.13</td>
<td>0.585</td>
<td>7606.3</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>32200</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8663576</td>
<td>45.98</td>
</tr>
</tbody>
</table>

*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.

<table>
<thead>
<tr>
<th>Land use</th>
<th>Area (m(^2)) (‘000)</th>
<th>*HSGs</th>
<th>Slope (%)</th>
<th>RC</th>
<th>MAR</th>
<th>ROG (m(^3))</th>
<th>ROG (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homestead</td>
<td>500</td>
<td>B</td>
<td>2-6</td>
<td>0.21</td>
<td>0.585</td>
<td>61435.5</td>
<td></td>
</tr>
<tr>
<td>Crop land</td>
<td>180</td>
<td>B</td>
<td>2-6</td>
<td>0.19</td>
<td>0.585</td>
<td>20010.42</td>
<td></td>
</tr>
<tr>
<td>Bare land</td>
<td>120</td>
<td>C</td>
<td>2-6</td>
<td>0.21</td>
<td>0.585</td>
<td>14744.52</td>
<td></td>
</tr>
<tr>
<td>Grazing land</td>
<td>9000</td>
<td>C</td>
<td>&gt;6</td>
<td>0.5</td>
<td>0.585</td>
<td>2632950</td>
<td></td>
</tr>
<tr>
<td>Woodland</td>
<td>10900</td>
<td>B</td>
<td>2-6</td>
<td>0.34</td>
<td>0.585</td>
<td>2168381</td>
<td></td>
</tr>
<tr>
<td>Bush land</td>
<td>400</td>
<td>A</td>
<td>&gt;6</td>
<td>0.18</td>
<td>0.585</td>
<td>42127.2</td>
<td></td>
</tr>
<tr>
<td>Ex-closure</td>
<td>60</td>
<td>A</td>
<td>&gt;6</td>
<td>0.13</td>
<td>0.585</td>
<td>4563.78</td>
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</tr>
<tr>
<td>Ex-closure</td>
<td>40</td>
<td>B</td>
<td>&gt;6</td>
<td>0.16</td>
<td>0.585</td>
<td>3744.64</td>
<td></td>
</tr>
<tr>
<td>Ex-closure</td>
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<td>B</td>
<td>2-6</td>
<td>0.21</td>
<td>0.585</td>
<td>1351581</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>32200</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6299538.06</td>
<td>33.44</td>
</tr>
</tbody>
</table>
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 m³. 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

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

<table>
<thead>
<tr>
<th>Water points</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cistern</td>
<td>5.5</td>
<td>5.2</td>
<td>4.9</td>
<td>4.7</td>
<td>4.4</td>
<td>5.1</td>
</tr>
<tr>
<td>HDW</td>
<td>7.8</td>
<td>7.5</td>
<td>7.2</td>
<td>6.8</td>
<td>6.5</td>
<td>7.6</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.44±0.12ab</td>
<td>6.13±0.12ab</td>
<td>5.90±0.12b</td>
<td>5.55±0.12c</td>
<td>5.32±0.12c</td>
<td>6.23±0.12b</td>
<td>4.76±0.07b</td>
<td>7.09±0.07a</td>
<td></td>
</tr>
</tbody>
</table>

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

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REFERENCES

Related Journals: