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Full Length Research Paper

Assessment of impact of climate change on runoff in the Kainji lake basin using statistical methods

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This paper presents the assessment of impact of climate change on the runoff in the Kainji Lake basin. Hydro-meteorological variables within River Niger sub-basin in Nigeria and upstream countries were obtained from Nigerian Meteorological Agency (NIMET), Nigeria Inland Waterways (NIWA) and hydrological unit of Kainji hydropower station. The variables were subjected to regression and standardized anomaly indices (SAIs) analyses. The trend analyses revealed that all the hydro-meteorological variables in the locations exhibit fluctuations of different patterns. Precipitation, evaporation, minimum and maximum temperature depict upward trend, while the runoff and the water level depict downward trend in almost all the selected locations. The downward trends of runoff from upstream gauging stations confirm the continual reduction in the water resources of the River Niger sub-basin and the inflow into Kainji dam over the years, which eventually affect water availability for energy generation and other uses. The multiple regression model for Kainji hydropower station and other downstream stations such as Lokoja, Baro and Idah show that for every 1°C rise in temperature, runoff decreases by 4.45, 534.76, 12.72 and 159.05 m^3/s respectively. SAIs also confirms significant decrease in runoff trend for the locations. The results also reveal that changes in climatic variables cause a tremendous fluctuation in runoff. The variation in runoff contributed by temperature, precipitation and evaporation for the stations ranged between 0.22 and 0.45 m^3/s.

Key words: Climate variability, impact assessment, runoff, catchment management, Kainji Lake.

INTRODUCTION

Climate change is change in the meteorological parameters such as temperature, precipitation, humidity, wind and seasons. It can be referred to as seasonal change of weather over a long period of time as a result of global warming. It is widely accepted that climate change is already happening and in the last century between 1906 and 2005 the average global temperature rose by about 0.74°C. The Intergovernmental Panel on Climate Change (IPCC) observed that over the past century changes are occurring in the amount of intensity, frequency and types of precipitation globally (IPCC, 2007). It was also revealed that this has occurred in two

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phases between the period 1910s and 1940s and more strongly from the 1970s to the present (IPCC, 2007). Many studies into the detection and attribution of climate change have found that most of the increase in average global surface temperature over the last 50 years is attributable to human activities (IPCC, 2001). It is estimated that for the 20th century the total global mean sea level has risen between 12 and 22 cm. This rise has been caused by the melting of snow cover and mountain glaciers both of which have declined on average in the northern and southern hemispheres (IPCC, 2007).

It was predicted that climate change will lead to an intensification of the global hydrological cycle and can have major impacts on regional water resources. Changes in the total amount of precipitation and in its frequency and intensity directly affect the magnitude and timing of run-off and the intensity of floods and droughts (Immerzeel, 2008). A change in climate affects the usual timing and intensity of precipitations and temperatures, which in turn affects all other means of livelihood such as agriculture, hydropower generation, domestic and industrial water supply. Climate change can have a profound impact on water resources, agriculture, small and large scale hydroelectric power production. Therefore water managers must be aware of potential impacts of climate change on their river system (Robert, 2008).

The developing nations of Africa, Asia and South America are seriously affected by climate change, therefore there is need to adapt necessary measures to mitigate climate change impact on water resources (Madueme, 1999). Salami et al. (2011) carried out study on the impact of global warming on the rainfall and temperature for some selected cities in the Niger Delta of Nigeria using nonparametric Man-Kendall test to detect monotonic trends and the Sen’s slope estimator to develop models for the variables. The study reveals that there is evidence of global warming in Owerri and rainfall has significantly increased in Calabar over the years. Though the trends in rainfall of Owerri and Port-Harcourt were not significant, plots of the developed models reveal a positive trend in the rainfall of the stations.

McBean and Motiee (2008) assessed the impact of climate change on the water resources of North America. Seventy years of historical trends in precipitation, temperature and stream flows in the Great Lakes of North America were developed using long term regression analyses and Mann-Kendall statistics. MINITAB and Microsoft Excel were used to calculate the trend lines, statistical values and plot the figures. The result obtained demonstrated statistically significant increases in some precipitation and stream flows over the period 1930-2000. Odjugo (2011) carried out study on climate change and global warming in some selected locations in Nigeria using climatic data and statistical tools. The results showed that while temperature in Nigeria is increasing, the rainfall is generally decreasing. Odjugo (2010) studied regional evidence of climate change in Nigeria using Mean annual air temperature from 30 synoptic stations between 1901 and 2005. Statistical tools were used to analyze the data. The results showed that air temperature is steadily increasing.

Various statistical analysis such as Mann-Kendall, Sen Slope, reduction method, standardized anomaly indices (SAIs), simple and multiple regression analysis (MRA) have been used to assess fluctuations and trends analysis of hydro-meteorological variables in order to establish the impact of climate change on runoff. SAIs and MRA have been established to produce a good result in the assessment of fluctuation, trend and linear modeling of climate change impact on runoff (Ojoye, 2012). Selections of these methods become imperative due their effectiveness in assessing climate change impact.

Impact of climate change on River Niger is a very crucial issue due to its importance to countries in which it flows through. Olomoda (2011) indicated that since the past five decades, the Niger basin has been affected by series of climatic changes causing extreme low flows along the river. For example in June 1985 River Niger was completely dry at Niamey, Niger republic. This phenomenon was almost repeated in June 2002 when the flow recorded fell among the lowest in 50 years. The Niger basin theoretical area of about 2 million km^2 has also been reduced to an active catchment area of about 1,500,000 km^2. Ojoye (2012) stated that study had shown that impact of climate change was noticed in River Niger when the annual yield of the River at Kainji reservoir had steadily decrease from 46×10^9 m^3 in 1970 to 26×10^9 m^3 at the peak of 1973 drought. Also there has been drastic reduction in electricity generation at Kainji hydropower station over the year and this may be due to shortage of water in the reservoir among other factors. It is imperative to assess the impact of climate variability on runoff in the Kainji Lake using statistical tools like standardized anomaly indices (SAIs) and regression analysis.

MATERIALS AND METHODS

Description of the study area

River Niger has total length of about 4,200 km and is the 3rd longest river in Africa and the 9th world largest river basin. It has original catchment area of about 2 million Km^2 covering 10 Countries namely Algeria, Benin Republic, Burkina Faso, Cameroon, Chad, Ivory Coast, Guinea, Mali, Niger and Nigeria as shown in Figure 1. The river is the source of water for over 100 million people and is also the major sources of hydropower to most of the countries in its basin. Two out of the three hydropower stations in Nigeria were built on the river namely: Kainji and Jebba hydropower stations. The third is Shiroro hydropower station that was built on river Kaduna which is also a tributary of River Niger. Nigeria is the downstream country through which the River Niger flows and contains 28.3 percent (424,500 km^2) of the basin area (Andersen et al., 2005). Niger basin extends across 20 of the 36 states of Nigeria

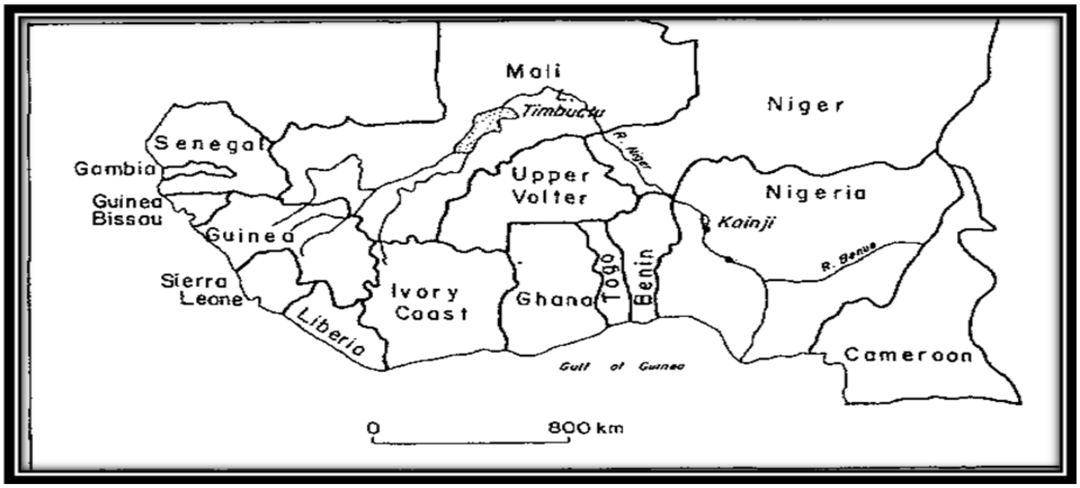

Figure 1. River Niger basin showing Kainji dam in Nigeria.

Table 1. Meteorological stations in the study area.

Location	Coordinate		Year of records
	Latitude (°N)	Longitude (°E)	
Sokoto (Nigeria)	13° 03' 46"	5° 14' 46"	1960-2010
Gusau (Nigeria)	12° 08' 43.4"	6° 42' 45.5"	1960-2010
Yelwa (Nigeria)	12° 27' 40.5"	4° 11' 38.5"	1960-2010
Minna(Nigeria)	9° 36' 17.3"	6° 34' 01.5"	1960-2010
Lokoja (Nigeria)	7° 48' 30.7"	6° 44' 14.5"	1960-2010
Ilorin (Nigeria)	8° 29' 42.6"	4° 32' 54"	1960-2010
Kainji (Nigeria)	9° 50' 00"	4° 40' 00"	1970-2010

and comprises two main rivers: Niger and Benue with 20 tributaries. More than half of the major rivers in Nigeria are in the Niger River Basin and almost 60% of Nigeria's population live in the basin. Kainji hydroelectric power station is located in New Bussa, Borgu local government area of Niger State. River Niger is divided into upper Niger, middle Niger and lower Niger. Kainji dam is located on the lower Niger and was built between 1964 and 1968. It is being fed by many tributaries such as Malando, Danzaki and Sokoto-Rima Rivers. The reservoir is located on latitude 9° 51'45" N and longitude 4° 36'48" E. The operation of hydroelectric power was commenced in 1969. The length of the Kainji Lake is 136 km, width of 24 km and maximum head elevation of 141.73 m and maximum tail elevation of 104 m.

Data collection

The data required for this study are hydro-meteorological data spanning for a period of 30 to 50 years. The meteorological data include precipitation, evaporation, minimum and maximum temperature, while the hydrological data are the runoff and water level.

The required meteorological data were obtained from Nigerian Meteorological Agency (NIMET) Oshodi, Lagos State and meteorological unit of Kainji hydropower station. The hydrological data such as runoff and water level for River Niger at various gauge stations were obtained from the National Inland Waterways Agency (NIWA) in Lokoja, Kogi State and hydrological unit of Kainji hydropower station. The available hydrological data was collected for some selected gauge stations on the river such as: Idah, Baro, Lokoja, Kainji and Koulikoro, Bamanko (Mali) and Jiderebode (Benin Republic) at upstream countries. The data for upstream countries are available at Kainji hydropower, Nigeria. In this study the stations shown in Table 1 were used as data sampling points for the meteorological data, while Table 2 shows the selected gauge stations for the hydrological data on the River Niger.

Data analysis

All the parameters were subjected to trend and fluctuation analysis using Standardized Anomaly Index (SAI) and Regression Analysis.

Multiple regression models

Multiple regression model is a statistical tool for modeling variables with one independent and two or more dependent variables. It can be used to model the impact of climate change on river hydrology (Xia, 2011). Equation (1) is a multiple regression model that was used to assess the effect of climate change on river runoff. Ojoye (2012) used multiple regression model to assess the overall impact of meteorological parameters

Table 2. Hydrological stations on River Niger.

Location	Coordinate		Year of records
	Latitude (°N)	Longitude (°E)	
Kainji (Nigeria)	9° 50' 00"	4° 40' 00"	1970-2010
Baro (Nigeria)	8° 35 ' 27"	6° 27 ' 41"	1960-1994
Lokoja (Nigeria)	7° 48' 30.7"	6° 44' 14.5"	1960-2010
Idah (Nigeria)	7° 05 ' 00"	6° 45 ' 00'	1960-1995
Koulikoro (Mali)	12° 52' 53.3"	7° 32' 51.4"	1960-2003
Banankoro (Mali)	13° 24' 00"	6° 07' 00"	1967-2003
Jiderebode (Benin)	-	-	1969-2004

Table 3. Variance analysis for Lokoja.

Sample	DF	SS	MS	F	F significant
Regression	3	2.65E9	8.82E8	38.55	8.16E-23
Residual	608	1.39E10	2.29E7		
Total	611	1.66E10			

Table 4. Variance analysis for Kainji.

Sample	DF	SS	MS	F	F significant
Regression	3	3.54E7	1.18E7	32.74	1.03E-18
Residual	356	1.28E8	3.60E5		
Total	359	1.64E8			

such as precipitation, temperature and evaporation on the runoff in some selected locations in Sudano-Sahelian ecological zone of Nigeria.

$$Y = a_1 + b_1 X_1 + b_2 X_2 + b_3 X_3 + ... + b_n X_n + \varepsilon \quad (1)$$

Where: X_1, X_2,…,X_n = set of independent; Y = dependent variable; a_1, b_1, b2,…,b_n= constant;ε = error term (negligible). Multiple regression analysis (MRA) in Microsoft Excel was used to assess the overall impact of meteorological parameters such as precipitation, temperature and evaporation rate on runoff for the selected hydro-meteorological stations. The locations considered are: Lokoja, Kainji, Baro and Idah gauge stations. Equation 1 was re-written with Y representing runoff (m^3/s) and X_1, X_2 and X_3 representing temperature (^oC), evaporation (mm) and precipitation (mm) respectively, while a_1, b_1, b_2 and b_3 are the parameter constants as presented in Equation 2.

$$Y = a_1 + b_1 X_1 + b_2 X_2 + b_3 X_3 \quad (2)$$

The multiple regression models obtained for runoff at Lokoja, Kainji, Baro and Idah were presented in Equations (3) to (6) respectively.

$$Y = -534.76 X_1 - 436.92 X_2 + 7.54 X_3 + 23148.33 \quad (3)$$

$$Y = -4.45 X_1 - 111.72 X_2 - 1.83 X_3 + 4438.58 \quad (4)$$

$$Y = -12.72 X_1 - 99.89 X_2 - 0.54 X_3 + 3255.87 \quad (5)$$

$$Y = -159.05 X_1 - 541.71 X_2 + 4.18 X_3 + 14297.22 \quad (6)$$

Microsoft excel output also gave the variance analysis (ANOVA) as presented in Tables 3 to 6 for Lokoja, Kainji, Baro and Idah multiple regression model respectively.

Standardized anomaly index (SAI)

Standardized anomaly index (SAI) was used to depict the fluctuation exhibited by the hydro-meteorological parameters. SAI was first used by Kraus (1977) to provide a synthesis of the average area behavior of precipitation at a specified time. The index was found to be effective for rainfall variability in the Niger basin area (Babatolu, 1998). SAI was used to test for the fluctuation of hydro-meteorological parameters in the study of climate change impact on water resources and adaptation strategies in the Sudano-Sahelian Ecological Zone (SSEZ) of Nigeria (Ojoye, 2012). SAI was used to investigate the annual precipitation trends in homogeneous precipitation of sub-divisions of Western Iran in order to assess the variability during the last thirty-five years (Raziel, 2008). Liu et al. (2011) analyzed past and predicted future drought with comprehensive drought indices for Arkansas-Red river basin. Historical climate data from 1900-2009 was analysed.

The results from the SPI and PDSI showed that widespread

Table 5. Variance analysis for Baro.

Sample	DF	SS	MS	F	F significant
Regression	3	9.38E7	3.12E7	30.06	1.32E-17
Residual	416	4.33E8	1.04E7		
Total	419	5.26E8			

Table 6. Variance analysis for Idah.

Sample	DF	SS	MS	F	F significant
Regression	3	1.10E9	3.67E8	13.30	2.57E-17
Residual	428	1.18E10	2.76E7		
Total	431	1.29E10			

DF = Degree of freedom; SS = Sum of square; MS = Mean of square; F = F-test statistic; Fsiginificant = p-value.

drought took place in the 1910s, 1930s, 1950s and 1960s, which agreed with the historical climate record. Rimkus et al. (2013) study the dynamics of meteorological and hydrological droughts in the Neman river basin, Lithuania using standardized anomaly index. Meteorological and hydrological warm period droughts were analyzed in this study. Meteorological droughts were identified using the standardized precipitation index (SPI) and hydrological droughts using the streamflow drought index (SDI). The whole river basin was analyzed over the period from 1961 to 2010. It was found that the total dryness area has decreased over the last 50 years. A statistically significant increase in standardized precipitation index values was observed in some river sub-basins. An analysis of drought recurrence dynamics showed that there was no indication that the number of dangerous drought was increased.

Gebrehiwot and van der Veen (2013) assessed the evidence of climate variability in the northern part of Ethiopia. This study attempts to investigate the temporal and spatial variability of climate parameters such as precipitation and temperature for the period 1954-2008. Standardized precipitation anomaly was used to examine the temporal characteristics of climate variability and determine the prevalence of droughts. Analysis of variance was also employed to establish significant differences in rainfall characteristics amongst different in-situ stations. The temporal analysis indicated an overall slight decrease in precipitation and an overall increase in the mean annual minimum and maximum temperatures over the study period. This showed that the northern part of Ethiopia is warming faster than the national average of 0.25°C per decade. It was also observed that the average annual minimum temperature is increasing faster than average annual maximum temperature, which is an indication of warming nights over the years.

Marinela and Irina (2012) used standardized precipitation anomaly (SPA) to assessed variability of precipitation and liquid flow in the Desnăţui, Romania. Monthly hydro-meteorological data from 1965-2009 was used in this study. The results revealed that the annual rainfall variability analysis showed the existence of some cyclical with positive values of SPA in the first period analyzed, negative in the second half and again positive in the last part. Ekwe et al. (2014) studied the monthly and annual rainfall trends in Nasarawa State, Nigeria. Monthly rainfall data for the State for 20 years (1993-2012) was used in the study. Time series analysis, standardized anomaly index and linear regression analysis were employed in this study to illustrate the rainfall trend and seasonal variation. The results revealed that there was a slight high value of mean annual rainfall recorded in 1996 while least value was obtained in 2008. The anomalous departures from the mean were observed to be very small with the highest positive departure from the mean of approximately 12% in 1996. The standardized anomaly results showed a fluctuating rainfall pattern across the years over the State.

The SAI can be used for any hydro-meteorological parameters. The name of the index is adopted to suit the parameter under consideration (Ojoye, 2012). Equation (7) presents a typical SAI.The anomaly index for fluctuation analysis with line bar above the reference zero line means that the year has a positive (or surplus) anomaly while those with line bars below the reference zero line means negative (or deficit) anomaly (Valt et al. 2005).

$$X_{xy} = \frac{1}{N_y}\sum_{i=1}^{Ny}\left(E_{xy} - E_x\right)\sigma \tag{7}$$

Where: X_{xy} = parameter for the y^{th} year; E_{xy} = year total parameter; E_x = mean parameter for the base year; σ = standard deviation, and N_y = number of years when data are available.

All the hydro-meteorological variables for the selected gauging stations were analyzed by estimating their SAI. The values of SAI obtained were plotted against year as presented in Figures 2 to 12 as an illustration for hydro-meteorological variables at Kainji hydropower station and runoff for upstream and downstream locations of the study area. The Equations expressing the relationship between variables and time (year) are presented in Tables 7 and 8. The variables with positive slope indicate an upward trend, while those with negative slope show a downward trend.

RESULTS AND DISCUSSION

Multiple regression

The multiple regression models for runoff at Lokoja, Kainji Baro and Idah were presented in Equations (3) to (6) respectively and the ANOVA results were presented in Tables 3 to 6 respectively. The multiple regression model for Lokoja indicates -534.76 coefficient of the mean temperature which implies that runoff will decrease by

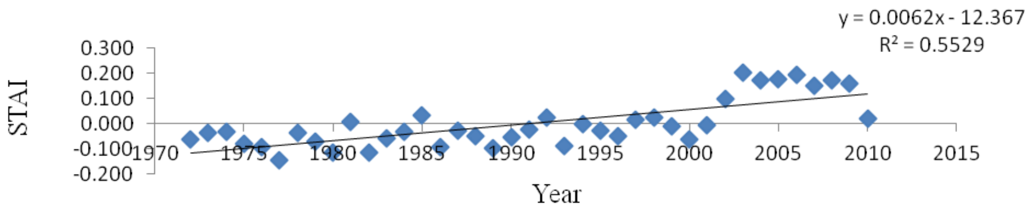

Figure 2. Minimum temperature trend for Kainji.

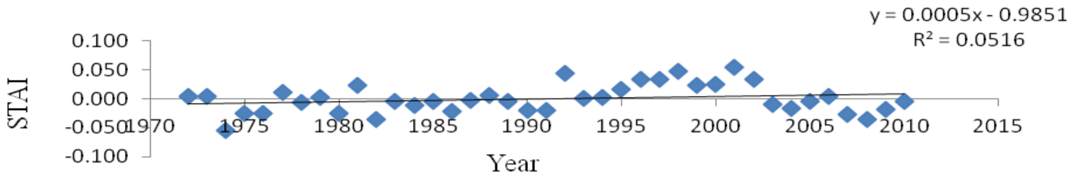

Figure 3. Maximum temperature trend for Kainji.

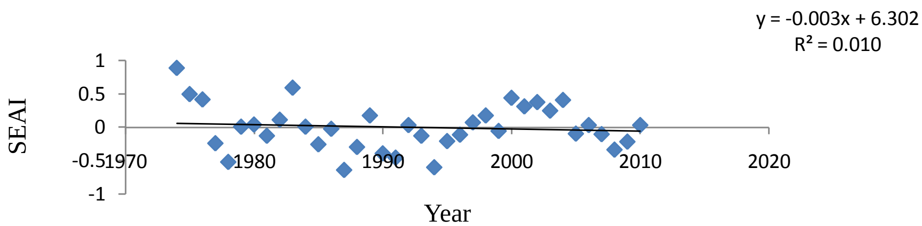

Figure 4. Evaporation trend for Kainji.

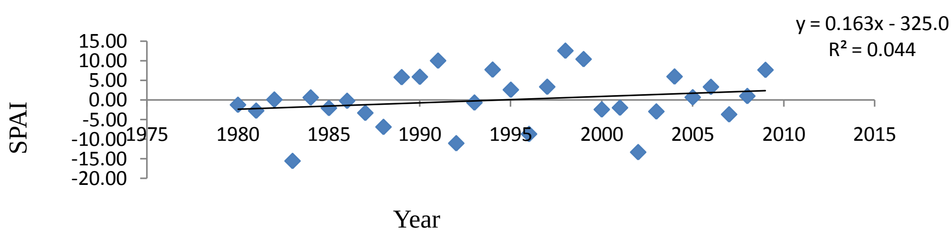

Figure 5. Precipitation trend for Kainji.

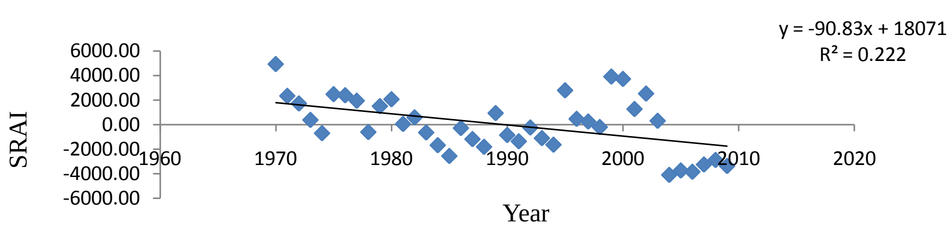

Figure 6. Runoff trend for Kainji.

average of 534.76 m^3/s per month for 1°C rise in temperature. The coefficient of evaporation is -436.92 showing that runoff will decrease on average by 436.92 m^3/s per month for 1 mm rise in evaporation. The coefficient of precipitation is 7.45 implies that runoff will increase by 7.45 m^3/s per month for 1 mm rise in

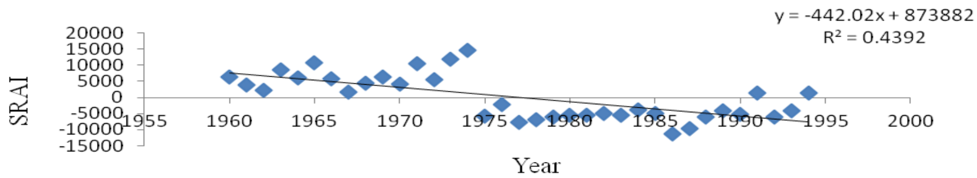

Figure 7. Runoff trend for Baro.

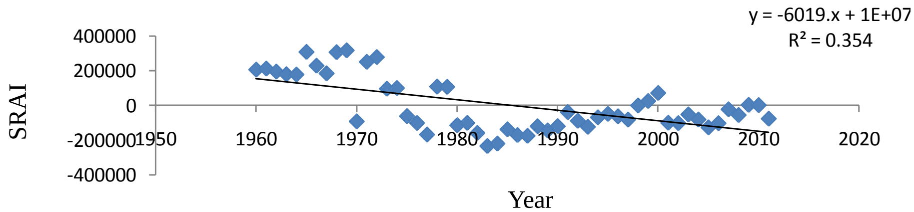

Figure 8. Runoff trend for Lokoja.

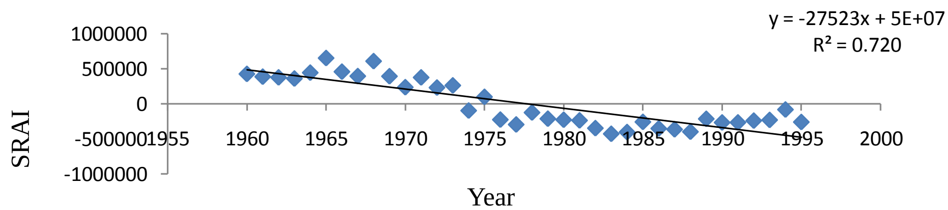

Figure 9. Runoff trend for Idah.

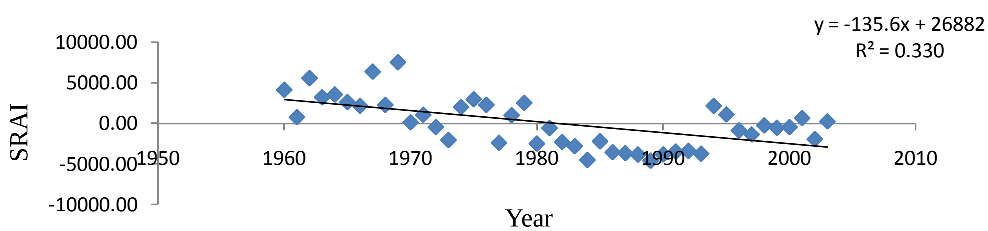

Figure 10. Runoff trend for Koulikoro (Mali).

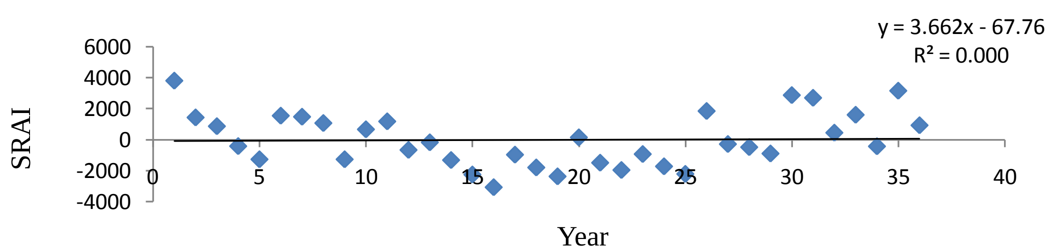

Figure 11. Runoff trend for Jideribode.

precipitation. The model intercept is 23148.33 m^3/s indicating estimated average runoff. The coefficient of determination (R^2) reveals that 0.16 variation in runoff is contributed by temperature, precipitation and evaporation.

The multiple regression model for Kainji shows -4.45

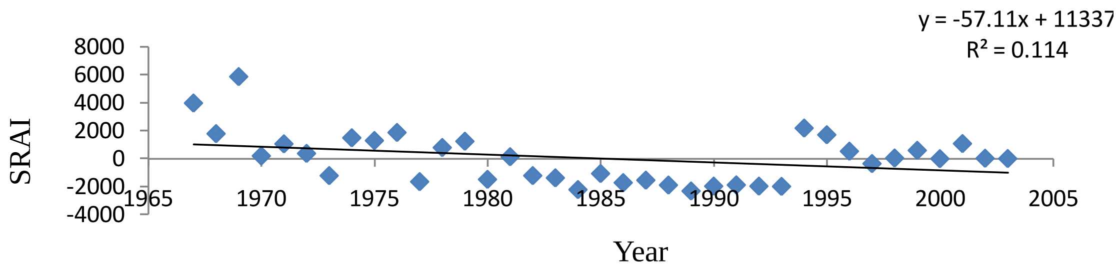

Figure 12. Runoff trend for Banankoro (Mali).

Table 7. Relationship between SAI of climatic variables and time.

Location	Minimum temperature (°C)	Maximum temperature (°C)	Evaporation (mm)	Precipitation (mm)
Yelwa	Y = 2E-07x - 0.0009	Y = 0.0001x -0.2455	Y = 0.0023x - 4.6608	Y = 0.0228x -45.301
Sokoto	Y = 0.0009x - 1.7686	Y = 0.0002x - 0.4892	Y = 0.0123x-24.4	Y = 0.0281 - 55.697
Gusau	Y = 0.0002x - 0.3548	Y = 0.0001x - 0.2181	Y = 0.001x-1.9534	Y = 0.0677x -1.726
Ilorin	Y = 0.002x - 4.0473	Y = -7E-05x+0.1352	Y = 0.0004x-0.7535	Y = -0.1256x +249.38
Minna	Y = 6E-05x - 0.117	Y = 0.0001x - 0.2772	Y = 0.0002x-0.33	Y = 0.0123x - 24.465
Kainji	Y = 0.0062x - 12.37	Y = 0.0005x - 0.9851	Y = -0.0032x +6.3027	Y = 0.163x - 325.04
Lokoja	Y = 0.000x - 0.3091	Y = 4E-05x -0.0857	Y = -0.0002x + 0.3287	Y = 0.0325x - 64.532

Table 8. Relationship between SAI of hydrological variables and time.

Location	Runoff (m^3/s)
Kainji	Y = -90.834x + 180715
Lokoja	Y = -6019.8x +1E+07
Baro	Y = -442.02x +873882
Idah	Y = -27523x + 5E+07
Koulikoro (Mali)	Y = -135.67x + 268827
Bamanko (Mali)	Y = -57.117x + 113378
Jideribode (Benin)	Y = 3.6628x – 67.761

Y = SAI of hydro-meteorological variables and x = time (Year).

coefficient of the mean temperature thus the runoff will decrease on average by 4.45 m^3/s per month for 1°C rise in temperature. The coefficient of the evaporation is -111.72 which reveals that the runoff will decrease on average by 111.72 m^3/s per month for 1 mm rise in evaporation. The coefficient of the precipitation is -1.83 revealing that the runoff will decrease by 1.83 m^3/s per month for 1 mm rise in precipitation. The model intercept 4438.58 m^3/s indicates the estimated average runoff. R^2 reveals that 0.22 variations in runoff is explained by temperature, precipitation and evaporation.

The multiple regression model for Baro indicates -12.72 coefficient of the mean temperature which shows that the runoff will decrease on average by 12.72 m^3/s per month for 1°C rise in temperature. The coefficient of the evaporation is -99.89 revealing that the runoff will decrease on average by 99.89m^3/s per month for 1 mm rise in evaporation. The coefficient of the precipitation is -0.54 which shows that the runoff will decrease by 0.54 m^3/s per month for 1mm rise in precipitation. The model intercept is 3255.87 m^3/s and the estimated average runoff. R^2 shows that 0.18 variations in runoff is contributed by temperature, precipitation and evaporation.

The multiple regression model for Idah indicates -159.05 coefficient of the mean temperature which means that the runoff will decrease on average by 159.05 m^3/s per month for 1°C rise in temperature. The coefficient of the evaporation is -541.71 meaning that the runoff will decrease on average by 541.71 m^3/s per month for 1 mm rise in evaporation. The coefficient of the precipitation is 4.18 revealing that the runoff will increase by 4.18 m^3/s per month for 1mm rise in precipitation. The model intercept is 3255.87 m^3/s implies the estimated average runoff. R^2 shows that 0.08 variations in runoff is explained by temperature, precipitation and evaporation.

The ANOVA test from the multiple regression analysis shows p-value of 8.16E-23, 1.03E-18, 1.32E-17 and 2.57E-17 for Lokoja, Kainji, Baro and Idah stations respectively. These values are all less than 0.05 at 95% significant level. The null hypothesis is rejected while accepting the alternative hypothesis and hence concluded that all the independent variables affect the runoff.

Trends in hydro-meteorological parameters

Minimum and maximum temperature

The minimum temperature at Yelwa has a positive trend with negligible coefficient of determination (R^2). Sokoto, Gusau, Ilorin, Minna, Lokoja and Kainji stations show positive trend with R^2 of 0.68, 0.09, 0.07, 0.054, 0.016 and 0.55 respectively. The maximum temperature at Yelwa, Sokoto, Gusau, Minna, Lokoja and Kainji stations show positive trend with R^2 of 0.018, 0.32, 0.1, 0.28, 0.01 and 0.05 respectively. The maximum temperature at Ilorin station shows a negative trend and R^2 of 0.07. There is an indication of upward trend in temperature in most of the stations.

Evaporation

The evaporation at Yelwa, Sokoto, Gusau, Ilorin and Minna stations show a positive trend with R^2 of 0.26, 0.16, 0.56, 0.15 and 0.018 respectively. The evaporation at Lokoja and Kainji stations reveal positive trend with R^2 of 0.09 and 0.01 respectively.

Precipitation

The precipitation at Yelwa, Sokoto, Gusau, Minna, Lokoja and Kainji stations reveal low positive trend with R^2 of 0.005, 0.02, 0.04, 0.002, 0.005 and 0.04 respectively. Ilorin station has low negative trend with R^2 of 0.035. Low positive trend in most of the selected locations indicates reduction in precipitation and seasonal variation in quantity of water available in the Kainji Lake basin which subsequently affected hydropower generation at the Kainji hydropower station among other factors.

Runoff

The runoff at Lokoja, Baro, Idah, Kainji, Koulikoro and Banankoro stations show negative trend with R^2 of 0.35, 0.44, 0.72, 0.22, 0.33 and 0.11 respectively. Jideribode station shows a low positive trend with negligible R^2 value. This implies that the variation in runoff contributed by temperature, precipitation and evaporation ranges between 0.22 and 0.45.

Conclusion

The hydro-meteorological parameters within Kainji Lake basin and upstream countries along River Niger were analyzed. The parameters were subjected to MRA and SAIs. The precipitation, evaporation and temperature show an increasing trend, while the runoff shows a decreasing trend in almost all the selected locations. The hydro-meteorological variables in all the locations exhibited fluctuations of different patterns. The multiple regression model for Kainji hydropower station and other downstream stations such as Lokoja, Baro and Idah show that for every 1°C rise in temperature, runoff decreases by 4.45, 534.76, 12.72 and 159.05 m^3/s respectively. SAI also indicates a significant decrease in runoff for the locations. The results reveal that changes in climatic variables cause a tremendous fluctuation in runoff. The variation in runoff contributed by temperature, precipitation and evaporation for the stations ranged between 0.22 and 0.45. In conclusion, the downward trends in runoff indicate a continual reduction in the water resources of the reservoir and eventually affect water availability for hydropower generation at Kainji station.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Andersen I, Dione O, Jarosewich-Holder M, Olivry J (2005). The Niger River Basin: A Vision for Sustainable Management. Edited by Golitzen, K.G. www.worldbank.org/INT/Resources/4602114-1206643460526 (assessed on 25/11/2011).

Babatolu JS (1998). Climate change and its implications for water supply in the Niger River Basin Development Authority Area of

Nigeria. A P.hD Thesis, Department of Geography and Environmental Management, University of Ilorin, Ilorin, Nigeria.
Ekwe MC, Joshua JK, Igwe JE, Osinowo AA (2014). Mathematical Study of Monthly and Annual Rainfall Trends in Nasarawa State, Nigeria. IOSR J. Math. 10(1):56-62.
Gebrehiwot T, van der Veen A (2013) Assessing the evidence of climate variability in the Northern Part of Ethiopia. J. Dev. Agric. Econ. 5(3):104-119.
Immerzeel W (2008) Historical trends and future predictions of climate variability in the Brahmaputra Basin. Int. J. Climatology 28:243-254.
IPCC (2001). Climate Change: The Scientific Basis. Technical Summary of the Working Group I Report [Houghton, J.T., Y. Ding, D.J. Griggs, M.Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. CambridgeUniversity Press, Cambridge, United Kingdom and New York, NY, USA, pp. 94. http://www.csun.edu/climate%20change_2001 (assessed on 21/10/2011).
IPCC (2007). Fourth Assessment Report: Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Summary for Policy Makers.
Kraus EB (1997). Subtropical Droughts and cross-equatorial energy transports Mon. Wea. Rev. 105:1009-1018.
Liu L, Hong Y, Hocker JE (2011) Analyzing past and predicting future drought with comprehensive drought indices for Arkansas-Red River Basin, Symposium on Data-Driven Approaches to Droughts. Purdue University. pp. 1-7.
Madueme TC (1999). The Need for Long Term Studies on Regional Climate Change to Ensure Adequate Electric Power Production. Global Climate Change.
Marinela CA, Irina O (2012). Variability of precipitation and liquid flow in the Desnăţui Hydrographical Basin. Water resources and wetlands Conference Proceedings. pp. 367- 371.
McBean E, Motiee H (2008). Assessment of impact of climate change on water resources: A Long Term Analysis of the Great Lakes of North America. Hydrology Earth Syst. Sci. 12:239-255.
Ojoye S (2012). Climate Change Impact on Water Resources and Adaptation Strategies in the Sudano-Sahelian Ecological Zone of Nigeria. A Ph.D Thesis, Department of Geography and Environmental Management, University of Ilorin, Ilorin, Nigeria.
Odjugo PAO (2011). Climate Change and Global Warming: the Nigerian Perspective. J. Sustainable Dev.Environ. Protect. 1(1):6-17.
Odjugo PAO (2010). Regional evidence of climate change in Nigeria. J. Geography Regional Planning 3(6):142-150.
Olomoda IA (2011). Impact of Climatic Change on River Niger Hydrology. Water Resources Development, Niger Basin Authority Niamey, Niger Republic. pp. 1-9.
Raziel T (2008). Investigation of Annual Precipitation Trends in Homogeneous Precipitation Sub-Divisions of Western Iran. BALWOIS Ohrid, Macedonia Republic. pp. 1-7.
Rimkus E, Stonevicius E, Korneev V, Kažys J, Valiuškevicius G, Pakhomau A (2013). Dynamics of meteorological and hydrological droughts in the Neman River Basin. Environ. Res. Lett. 8:1-10.
Robert W (2008). Climate Change Impact on Hydro Electric Water Resources Management. A Technical Workshop Organized by CEATI International. Montreal, Q C. Canada. http://wwwceati.com/Meetings/WW2008/program (assesses on 23/12/2011).
Salami AW, Olofintoye OO, Sule BF (2011). Modeling global warming impact on the rainfall of some selected cities in the Niger Delta of Nigeria. J. Eng. Res. 16(2):1-12.
Valt M, Cagnati A, Crepaz A, Marigo G (2005). Snow precipitation in the Last Years on Italian ALPS. 654-657. http://www.map.meteoswiss.ch/mapdoc/icam2005/pdf/poster.../E26.pdf.
Xia R (2011). A parametric modeling study of the climate change impact on river eutrophication and water quality. A Master of Applied Science Thesis Submitted to the Department of Building, Civil and Environmental Engineering, Concordia University. Montreal, Quebec, Canada. pp. 1-141.

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Rainwater harvesting: An option for dry land agriculture in arid and semi-arid Ethiopia

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Subsistence rain-fed agriculture has been widely practiced for many centuries in Ethiopia and this sector has been highly dependent on rainfall. Thus, rainfall remains the crucial component of the weather elements for improving agricultural productivity. Extreme climatic conditions and high inter-annual or seasonal variability of this weather element could adversely affect productivity, because rainfall controls the crop yields and determines the choice of crops that can be grown. One of the reasons for low crop production in semi arid areas is marginal and erratic rainfall exacerbated by high runoff and evapotranspiration losses. Rainfall in terms of amount and frequency in a growing season is essential for planning and management of agricultural practices. To avert this problem, the successive Ethiopian government (from the time of Aksumite kingdom to the present) and the local community practiced different water harvesting techniques. The *in-situ* and *ex-situ* rainwater harvesting techniques have shown significant impact on improved soil moisture, runoff and ground water recharge; and increased agricultural production, which in turn reduces risks and deliver positive impacts on other ecosystems. Besides, rainwater harvesting has a potential of addressing spatial and temporal water scarcity for domestic consumption, agricultural development and overall water resources management. High water loss through seepage, lack of awareness and being very labor intensive to irrigate the whole fields by pumping the water manually from the pond and applying directly to the crop has been the main challenges of adopting harvested water technologies.

Key words: Rainfall, runoff, semi-arid Ethiopia, soil moisture, water harvesting, yield.

INTRODUCTION

Agriculture is the main economic activity in sub-Saharan Africa (SSA) supporting over 67% of the population, out of which 60% depends on rainfed agricultural practices; generating 30-40% of the country's Gross Domestic Product (Rockström, 2002). However, rainfall is poorly distributed in these countries (Ngigi, 2003). High losses occur due to high surface runoff during high intensity rains, poor crop rooting conditions, past and present soil erosion and evaporation losses from soil, and crop canopy in particular during pre-planting and early crop stages (Rockström, 2003). Uncontrolled runoff can cause damaging flash floods; severe erosion; increased water

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turbidity and substantial water loss. These losses of valuable water resources increase food insecurity and societal poverty, which are the greatest threats to sustainable development in the region (Ngigi, 2003; Temesgen et al., 2007). This implies that erratic rainfall patterns has been the serious challenge of food production in these areas (Fischer et al. 2004), and this will be further worsened by climate change which is expected to increase rainfall variability in many African countries that are already at least partly semi-arid and arid (Ngigi, 2003).

The primary limiting factor for crop-yield stabilization in semi-arid regions is the amount of water available in the crop rooting zone (Lal, 2001). Rainfall intensity in Sub-Saharan Africa can often be greater than the infiltration rate and the water holding capacity of the soil, which can trigger an excess of runoff (Rockström, 2002). In Sub Saharan Africa where rainfall is low, unpredictable and also expected to decline due to climate change, rainwater storage in farm ponds, water pans, subsurface dams, and earth dams is gaining importance as a supplement to irrigation and livestock watering (Ngigi, 2009). It is also an effective strategy to manage floods *in-situ* and *ex-situ*, particularly in high rainfall areas like the Ethiopian highlands. Hence, rainwater harvesting (RWH) could be used to satisfy water demands during dry spells and to create opportunities for multiple uses. De Fraiture and Wichelns (2010) estimated that 78% of water consumed by crops comes directly from rainfall. It is believed that rainfall, if managed properly, is the remaining potential source for feeding the current huge population of the world as there are limitations to further increase of the area under irrigation (Rockström, 2003). This calls for increased attention towards rain fed agriculture or a green revolution (Rockström et al., 2009).

Subsistence rain-fed agriculture has been widely practiced for many centuries in Ethiopia and over 80% of the population's livelihood is contingent upon this sector which contributes ~45% to the national GDP, on average (Bewket, 2009). The Ethiopian agriculture is characterized by extreme dependence on rainfall, low use of modern agricultural inputs and low output levels. The sector is highly vulnerable to drought (Bewket, 2009), which is the single most important climate related natural hazard impacting the country from time to time for many decades. Ethiopia has significant rainfall and it is the ultimate source of water with surface water, ground water and other water sources. Based on grid-based average annual rainfall and the land area, the study estimates that Ethiopia receives about 980 billion (~1 trillion) m^3 of rainfall a year (Awulachew, 2010). While Ethiopia has abundant annual rainfall, the rainfall varies spatially, temporarily and inter-annually (yearly cycles). About 80 percent of rainfall occurs between June and September, while yearly variability can also be significant (e.g., about 30% average variation year over year). Consequently, increasing rainwater storage capacity and improving water control and rainwater management techniques, especially rain water harvesting, are critical to ensure that Ethiopia gets maximum use of its rainfall (Awulachew, 2010).

The term rain water harvesting (RWH) is used in different ways and, thus, no universal classification has been adopted (Ngigi, 2003). However, it can be defined as capturing and storing seasonal excess runoff and diverting it for household and agricultural uses (Hatibu and Mahoo, 1999). RWH refers to all technologies where rainwater is collected to make it available for agricultural production or domestic purposes (Liniger et al., 2006). Nigigi (2003) also defined rain water harvesting as a method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions. It is considered as the single most important means to increase agricultural productivity and provide a source of domestic water supply in drought prone areas (Getaneh and Tsigae, 2013). This makes cultivation of crops twice or more a year possible, as well as the possibility for supplementary irrigation when rains stop early. Rain water harvesting includes roof water harvesting, *in-situ* water harvesting, run-off harvesting, flood water harvesting and subsurface water harvesting (Finkle and Sergerros, 1995).

The sustainability of RWH is based on reliable water supply and production, effectiveness of water use (increase rainwater productivity) and minimal negative impacts on natural resources (Pachpute et al., 2009). RWH systems are generally categorized into two; *in-situ* water conservation practices, small basins, pits, bunds/ridges; and runoff-based systems (catchment and/or storage) (Awlachew et al., 2005) (Figure 1). The storage system is usually used in supplemental irrigation. The *in-situ* systems, which enhance soil infiltration and water holding capacity, have dominated over storage schemes in Ethiopia until recently. Surface runoff from small catchments and roadside ditches is collected and stored in farm ponds holding an average of about $60m^3$ of water. *In-situ* rainwater harvesting techniques (IRWHT) that aims at maximizing benefits of rainfall where it falls are tremendously used and produce good results, especially in semi arid zones (Li et al., 2000; Tian et al., 2003; Li et al., 2006; Ito et al., 2007; Oloro et al., 2007; Rockström et al., 2009 and Vohland and Barry, 2009). Ngigi (2003) attributed the dominant use of IRWHT to its simplicity, low cost and can be practiced in all land use systems.

Improved rainwater management for agriculture has many potential benefits in efforts to reduce vulnerability and improve productivity (Awulachew et al., 2005). As a result of RWH and irrigation development, Ethiopia's agricultural sector has witnessed consistent growth since 2003. For instance maize production has expanded at 6% per annum and the aggregate export value across all commodities has grown at 9% per annum as well as underpinning an 8% annual growth rate in GDP

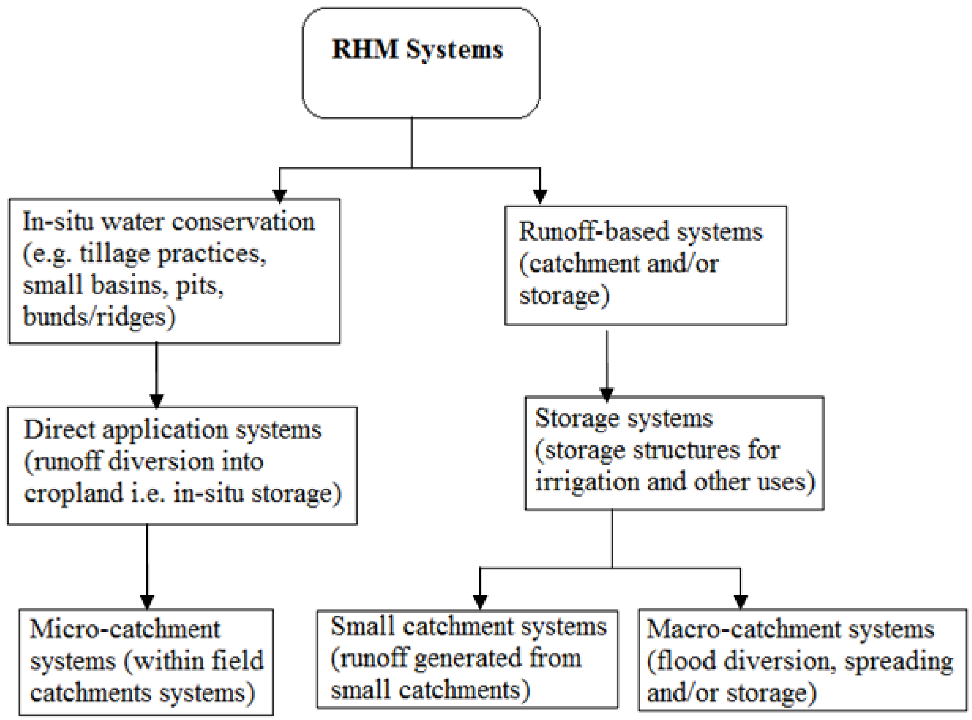

Figure 1. Adopted classification of RWH systems (Ngigi, 2003).

(Awulachew, 2010). In terms of increasing irrigation potential incrementally to the formal irrigation component, through RWH and better water management, the study estimates that RWH can provide an additional 0.5 M ha in irrigation. Thus, *in-situ* agricultural water management including RWH is crucial to improve smallholder livelihood and income in Ethiopia.

Frequent dry spells and droughts exacerbate the incidence of crop failure and hence food insecurity and poverty (Awlachew et al., 2005). The need to improve food production in Ethiopia cannot be overemphasized. In addressing the problems of rainfall variability, the recurrent droughts and food insecurity, the government of Ethiopia has given top priority to a variety of water harvesting programmes to supplement the rain-fed agriculture. Therefore, rainwater harvesting has been recognized as a promising way for improving the water availability for crop production, domestic use and water for livestock in the arid and semi-arid parts of the country. This paper therefore, reviews the present status of RWH researches in the light of an option for dry land agriculture in the arid and semi-arid Ethiopia.

RAINWATER HARVESTING TRENDS IN ETHIOPIA

Over centuries, generations of farming communities in Ethiopia have developed different farming technologies that can provide a basis on which to build improved land husbandry (Alamerew et al., 2002). The history of water harvesting in Ethiopia dated back as early as the pre Axumit period (560 BC) (Habtamu, 1999). It was a time when rainwater was harvested and stored in ponds for agricultural and water supply purposes. Anthropologist Fattovich (1990) have documented evidences of the remains of ponds that were once used for irrigation during this period. A roof water harvesting set-up is still visible in the remains of one of the oldest palaces in Axum; the palace of the legendary Queen of Sheba. Other evidences include the remains of one of the old castles in Gondar, constructed in the 15-16th century, which used to have a water harvesting set up and a pool that was used for religious rituals by the kings.

In south of the country, the Konso people have had a long and well established tradition of building level terraces to harvest rainwater to produce sorghum successfully under extremely harsh environment; low, erratic and unreliable rainfall conditions (Hailemichael, 2011). It is indeed one of the wonders of this country and it has been practiced for millennium; a symbol of struggle for survival by the Konso people against the adversaries of nature (Figure 2). Hailemichael (2011) shows, everyone in the farming system acquires the skill of terrace construction as part of routine farming practices. Thus, rainfall is simply redirected through carefully constructed walls and channels. Researchers noted that this is a country where indigenous knowledge and practices are acknowledged to the extent that the ‘Konso

Figure 2. Indigenous hillside stone terracing and mixed cropping *in-situ* soil and water conservation practices at Konso southern Ethiopia (A) (Hailemicael, 2011) and Half-moon ponds, promoted for water resources conservation in Tigray, northern Ethiopia (B) (Mekonnen and Haile, 2010).

cultural landscape' has been recognized as a UNESCO World Heritage Site (Alamerew et al., 2002.). Efforts over the last decades to promote water harvesting have produced some bright spots particularly with micro-watershed interventions, which include water harvesting as part of an integrated participatory approach to sustainable land management. In addition to that, there are different half-moon ponds, promoted for water resources conservation in Tigray, northern Ethiopia (Figure 2B) (Mekonnen and Haile, 2010)

Ethiopia's agriculture is predominantly rainfed with a potential of nearly 3.5 million ha of land suitable for irrigated agriculture (Awulachew et al., 2005; Awulachew and Merrey, 2007). The population has grown dramatically over the last three decades, increasing from 25 million in the 1960s to nearly 90 million in 2014 leaving a pressure on the agricultural land, forests and the environment at large. Thus, rainwater harvesting and management (RHM) play paramount roles for increasing gain yields and support the growing population (Awulachew, 2010). The RWH techniques most commonly practiced in Ethiopia today are runoff irrigation (run-off farming), flood spreading (spate irrigation), *in-situ* water harvesting (ridges, micro basins, conservation tillage, etc.) and roof water harvesting.

The importance of these techniques, though dates back in the antiquity, has not been recognized until very recently, following the devastating drought and famine of the 1980s (Alem, 1999). RWH is a simple low-cost technique that requires minimum specific expertise or knowledge and offers many benefits. It has regained importance as a valuable alternative or supplementary water resource in Ethiopia (Desta, 2003). Utilisation of rainwater is now an option along with more 'conventional' water supply technologies, particularly in rural areas, but increasingly in urban areas as well. RWH has proven to be of great value for arid and semi-arid countries or regions like Ethiopia where more than 66% of the country is categorized as arid and semi-arid (Georgis, 2000; 2002; Rockström, 2000; Rockström, 2001).

The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climactic volatility in any country (Awulachew, 2010). Although Ethiopia has abundant rainfall and water resources, its agricultural system does not yet fully benefit from the technologies of water management and irrigation (Georgis, 2000; 2002). The majority of rural dwellers in Ethiopia are among the poorest in the country, with limited access to agricultural technology, limited possibilities to diversify agricultural production given underdeveloped rural infrastructure and little or no access to agricultural markets and technological innovations (Awulachew, 2010). A field experiment was conducted under natural rainfall conditions to investigate the effects of farmyard manure and straw mulch on runoff, soil loss, *in-situ* water conservation and yield and yield components of an improved bread wheat variety (HAR-1480) grown on vertisol of Sinana area, south- eastern Ethiopian highland. The results revealed that there was a highly significant difference ($P<0.0001$) between the treatments regarding their effect on runoff depth, soil loss and *in-situ* water conservation (Birru et al., 2012).

TYPES OF RAINWATER HARVESTING

In-situ rainwater harvesting

In-situ RWH, a technique which involves the use of methods that increase the amount of water stored in the soil profile by trapping or holding the rain where it falls (Alamerew et al., 2002; Ngigi, 2003). This may involve small movements of rainwater as surface runoff in order to concentrate the water where it is most wanted. It is sometimes called water conservation and is basically a prevention of net runoff from a given cropped area by holding rainwater and prolonging the time for infiltration. This system works better where the soil water holding capacity is large enough and the rainfall is equal or more than the crop water requirement, but moisture amount in the soil is restricted by the amount of infiltration and or deep percolation (Hatibu and Mahoo, 1999). *In-situ* water harvesting methods that concentrate soil water in the rhizosphere for more efficient use by plants are critically needed for moisture stress areas. It means rainwater is conserved where it falls, whereas *ex-situ* water harvesting systems involve transfer of runoff water from a “catchment” to the desired area or storage structure (Critchley and Siegert, 1991). Land and water conservation interventions on sloping lands include bench/fanya juu terraces, retention ditches, stone lines, vegetative buffer strips, contour bunds, contour farming and other activities that reduce loss of runoff water. They are primarily used to reduce soil erosion and to improve rainfall infiltration and conservation in the soil profile (Bossio et al., 2007).

In-situ rainwater conservation technologies are distinct from runoff farming systems in that they do not include a runoff generation area; instead it aims at conserving the rain where it falls in the cropped area or pasture (Alem, 1999). The most commonly implemented technology is conservation tillage which aims to maximize the amount of soil moisture within the root zone. A number of cultural moisture conservation practices such as mulching, ridging, addition of manure, etc could fall under this category. Small field/farm structures such as tied ridges/bunds within cropped area that conserve direct rainfall without ‘external’ outside cropland boundary, that is, no distinct catchment area, except overflow from upstream sections also falls under this category. *In-situ* rainwater conservation technology is one of the simplest and cheapest and can be practiced in almost all the land use systems. *In-situ* water conservation systems are by far the most common (Rockström, 2000) and are based on indigenous/traditional systems (Reij et al., 1996; Leisa, 1998). The primary objective has been to control soil erosion and hence, manage the negative side effects of runoff soil and water conservation measures, that is, to ensure minimal runoff is generated. The positive effect of *in-situ* water conservation techniques is to concentrate within-field rainfall to the cropped area (Rockström, 2002).

In a semi-arid context, especially with coarse-textured soil with high hydraulic conductivity, this means that *in-situ* conservation may offer little or no protection against the poor rainfall distribution (Rockström, 2000). In such cases, the farmers will continue to live at the mercy of the rain. In effect, the risk of crop failure is only slightly lower than that without any measures. However, soil improvements and management would enhance realization of better yields.

Agronomic practices such as the use of farm yard manure (FYM), timely weeding and mulching are used to enhance water availability in the soil by improving the water holding capacity and reducing soil water evaporation. Mulch and manure treatments had a highly significant effect ($P<0.0001$) on *in-situ* rainwater retention (Birru et al., 2012). The results demonstrated that *in-situ* soil moisture conservation increased significantly for 6 ton ha^{-1} mulch as compared to the control treatment. Soil moisture storage in the 6 ton ha^{-1} mulch treatment was 216.11 mm, which was 39.15 mm higher in comparison to the control. However, the mean soil moisture storage for 4 ton ha^{-1} straw mulch (STR) was 215.40 mm, which was statistically at par in comparison to that retained at 6 ton ha^{-1} straw mulch treatment.

The average rainwater depth retained for 6 ton ha^{-1} farmyard manure application (181.81 mm) was significantly higher than that retained under control treatment (176.96 mm). The results further indicated that soil moisture storage was increased by 22.1, 21.7, 19.0, 2.7, 0.74 and 2.53% for STR-6, STR-4, STR-2, FYM-6, FYM-4 and FYM-2, respectively, as compared to the control (Birru et al., 2012). From these results one can understand that leaving crop residues could have the potential to conserve much of the incoming rainfall and contribute towards sustainable crop production by alleviating the impacts of drought spells which frequently occur in the growing season. The main limitation of this technique is its high labour demand, especially on steep slopes where proper structural measures are required. Some amount of training and site-specific design/layout is also needed. In one example from the Anjenie watershed of Ethiopia (Akalu and Adgo, 2010), long-term terracing increased yields of teff, barley and maize significantly. In contrast, cultivation on steep un-terraced hillsides had negative gross margins.

Similarly, Vancampenhout et al. (2005) obtained positive yield results and increased soil water holding capacity using stone bunding on field crops in the Ethiopian highlands. Rockstrom (2003) reported that in-situ RWH had a significant effect on grain yield and by using this system in Burkina Faso they were able to increase the yield of sorghum from 715 kg ha^{-1} to 1,057 kg ha^{-1}. Micro-basin water harvesting structures (e.g., half-moons, eyebrow basins and trenches) have also been proven to be effective in improving tree survival and growth in degraded lands. Experiences from northern Ethiopia have shown that these structures improved tree survival and growth significantly compared to non-treated landscapes (Derib et al., 2009). The seedlings grown in micro-basins were thicker, taller and more productive than those grown in normal pits, suggesting a need to integrate tree planting with soil water management.

Tillage normally assists in increasing the soil moisture holding capacity through increased porosity, increasing the infiltration rates and reducing the surface runoff by providing surface micro-relief or roughness which helps in temporary storage of rain water. Previous research results have shown that the depth of tillage is the most important factor controlling or affecting soil moisture characteristics (Hudson, 1987). Deep tillage helps to increase porosity, reduce surface sealing of the soil and permits roots proliferation to exploit soil water and nutrients at deep horizons (Kidane et al., 2012). Significant reduction of surface runoff and increase in crop yields have been shown to occur with increased depth of tillage.

Temesgen et al. (2012) conducted an experiment on the impact of conservation tillage on hydrology and agronomy on famer's fields from the year 2009-2010. The soil moisture measurements had been taken continuously at the lower and upper sides of each plot, for a period of one month only (due to vandalism). Although the measurement period is short, the sampled results clearly revealed that soil moisture in traditional tillage (TT) (average 34.6%vol.) is significantly higher ($\alpha = 0.05$) than that of conservation tillage (CT) (average 31%vol.) at 0-15 cm depth while the reverse holds true at 15-30 cm layer (33.5 and 31.6%vol.), in CT and TT, respectively. Similar studies have been conducted in an on-farm experiment in the northwestern highlands of Ethiopia (Kidane et al., 2012). There were significant differences ($P< 0.0001$) in soil moisture content between tillage treatments as well as in the upper and lower sides of the plots. Significantly, ($P \leq 0.05$) different soil moisture contents between the upper and lower sides of the *fanya juus* were observed under traditional tillage practice 0.305±0.003 and 0.323±0.003 m^3, respectively.

Temesgen et al. (2007) observed field trial on conservation tillage compared with traditional tillage in a moisture deficit area in Ethiopia. Sub-soiling along the same lines (STS) resulted in the least surface runoff (Qs =17 mm-season^{-1}), the highest transpiration (T =196 mm-season^{-1}) and the highest water productivity using total evaporation (W_{PET}=0.67 kg-m^{-3}) while TT resulted in highest surface runoff (Qs=40 mm-season^{-1}), least transpiration (T =158 mm-season^{-1}) and low water productivity (W_{PET}=0.58 kg-m^{-3}), respectively. Araya et al. (2011) reported runoff values of 46.3, 76.3 and 98.1 mm from *derdero* (DER), *terwah* (TER) and conventional tillage, respectively. There were significant differences ($P < 0.0001$) in infiltration rates in the soils between winged subsoiler (WS) and traditional tillage (TT) treated plots (Kidane et al., 2012). The initial and steady state infiltration rates under WS plots were 0.84±0.005 and 0.1±0 cm m^{-1}, respectively.

On the other hand, 0.54±0.006 and 0.05±0.004 cm m^{-1} at 01 and 60 m were observed under the TT treated plots. The infiltration rate in the WS treated plots was twice higher than the TT tilled plots and this implies that implementation of conservation tillage is more important for *in-situ* moisture conservation. Temesgen et al. (2012) evaluated the hydrological and grain yield impact of conservation tillage on field experiment and they identified that more surface runoff occurred for traditional tillage compared to conservation tillage, and that the differences between the two was more in the wheat plot than in *tef*. The average reduction of surface runoff was 48% in the wheat plot due to the application of CT, with the daily averages of 4.8 and 2.5 mm d^{-1} in TT and CT, respectively. In *tef* crop, the surface runoff reduction was 15% with an average of 4.5 and 3.8 mm d^{-1} in TT and CT, respectively.

***Ex-situ* water harvesting**

Water harvesting ponds

The occurrence of repeated drought and dependence on rainfall which has been erratic and uneven in Ethiopia over the past decades has resulted in a widespread crop failure which in turn has brought a growing awareness of the importance of small-scale water harvesting at both household and community levels (Haile, 2007). In order to alleviate the problem of recurrent drought and household food security, the government of Ethiopia has taken household level water harvesting ponds and shallow wells development as one strategy of the country's irrigation development (Haile, 2007). In Ethiopia, particularly in moisture deficit areas, irrigation development is considered. Therefore an absolute necessity and not an option has been adopted as the frontline strategy to bring about sustained food security due to its profound role in boosting agricultural productivity in highly rain dependent agricultural farming systems.

Moreover, since 2002, household level water harvesting irrigation development has attracted the attention of the policy makers due to the small initial investment, low government recurring cost, short development period, relative freedom of organization and freedom from management difficulties (Alem, 1999: Mekonnen and Haile, 2010). In an effort to address the problems of recurrent droughts and food insecurity, the government of Ethiopia has given top priority to a variety of water harvesting programs to supplement rain fed agriculture of which water harvesting ponds have been widely implemented (Alem, 1999).

Although advanced water harvesting systems has been introduced to Ethiopia, traditional ponds have been widely used for many centuries; some estimates it as early as 560 BC (Fattovich, 1990). Its inhabitants are used to harvesting rainwater for both human and livestock watering in most rural areas, particularly in the arid and semi-arid regions where annual rainfall is less than 600 mm (Alem, 1999). Ponds are simple to construct and can be managed by the community. Approximately 15 to 20 % of the people and over 80% of

Figure 3. Water harvesting ponds using Geomemmbrane and micro basins in Ethio-Somali Region (A) and Amhara region (B-D) Ethiopia, respectively (www.gcca.eu/2014).

the livestock in Ethiopia uses water from either rivers/streams and ponds (Alem, 1999). Currently, the Ethiopian government promotes the use of water harvesting technologies such as geomambrane in different parts of the country especially in the semi-arid and arid regions (Figure 3). However, the adoption and its successfulness have been disappointing due to lack of awareness of development agencies and farmers.

The distribution of these ponds generally, is in the arid and semi-arid areas where the Sahelian climatic condition prevails. Traditional ponds are the major sources of water in the Ethiopian rift valley where ground water is deep and other sources of water are not feasible. These days, the use and promotion of ponds even for livestock watering is increasingly becoming difficult and challenging by the spread of deadly child-hood malaria, and for this reason most NGOs are unable to promote and support pond construction due to environmental constraints (Mekonnen and Haile, 2010).

Roof water harvesting

Roof water harvesting is a system of collecting rainfall water from the roof of a building and storing it in some storage facilities for future use when there is shortage of water (Haile and Merga, 2002). Large scale and modern water supply schemes in rural Ethiopia remains a challenge owing to the unique and rugged terrain and the scattered settlement pattern of the rural people. One technique that appeals today that can be of significant importance in the development of the subsector is roof water harvesting at household level. This technique is so important in the rural highland areas where the terrain is rugged and the villages and hamlets are scattered. In such areas, it is difficult to think that communities can be served by centralized water supply schemes, at least it is expensive. Other sources require long walk and time for women and children to fetch water (Alem, 1999).

The roof water harvesting in Ethiopia has the advantage of being low cost, relatively simple in design (household technology), less laborious and time saving (Alem, 1999). It provides adequate water during the rainy season, a period when the rural people are busy with the farm activities and when there is shortage of labor. They are more appropriate in areas where there are no rivers, ground water sources and where rainwater is the only feasible means of water supply. The emergence of this technique these days is due to the increasing shortage of water from the conventional sources, shallow wells, perennial springs, rivers/streams. In earlier times, roof water harvesting practices were confined to urban areas only. However, its use in the rural areas are increasingly becoming important these days as more people in the rural areas are having corrugated roof houses.

EFFECTS OF RAINWATER HARVESTING

Soil moisture

Globally, the total volumes of water stored within the soil are huge, but at any given locality they are relatively small and quickly depleted through evapotranspiration. Because of this, in recent decades there has been increased interest in various *in-situ* rainwater management techniques that enhance infiltration and water retention in the soil profile (World Bank, 2006). It is important to note that RWH can be used to rehabilitate degraded land and retain moisture (FAO, 2001). Water harvesting retains moisture in-situ, through structures that reduce runoff from fields and hold water long enough to allow infiltration (Rockström, 2002). Improved in-field water harvesting can increase the time required for crop moisture stress to set in and thus can result in improved crop yields and have resulted in positive effects on soil fertility, moisture conservation and agricultural productivity (Alemu and Kidane, 2014, Kidane, 2014, Kidane et al., 2012).

These are techniques for improving the soil moisture by enhancing infiltration and reducing runoff and evaporation (Ngigi et al., 2005; SEI, 2009). An important potential of in -situ water harvesting is to limit nutrient leakage from the fields by controlling soil erosion (Herweg and Ludi, 1999; Gebremichael et al., 2005; McHugh et al., 2007; Gebreegziabher et al., 2009). Water can be stored in artificial constructions (e.g. water tanks, drums, jars, jerry cans, cisterns), in surface reservoirs (ponds, dug-outs, artificial reservoirs) and in the sub-surface as soil moisture or groundwater. Soil moisture conservation (recharge of shallow aquifers) is the key to high productivity (Herweg and Ludi, 1999). Hence, RWH is efficient in increasing the soil moisture for crops in water scarce areas (Ngigi, 2003). In addition, in the dry lands of the Tigray Regional State in northern Ethiopia, the regional government and the general population have been making efforts to control the degradation of natural resources since 1991. As a result, many soil and water conservation measures have been initiated, particularly for soil erosion control, including the construction of stone bunds to conserve *in-situ* soil moisture (Alemu and Kidane, 2014).

Surface runoff

During rainy season, rainwater is collected in large storage tanks which also help in reducing floods in some low lying areas. Apart from this, it also helps in reducing soil erosion and contamination of surface water with pesticides and fertilizers from rainwater run-off which results in cleaner lakes and ponds (Rockström, 2002). The main characteristic of flood water harvesting is a turbulent channel of water flow harvested either by diversion or spreading within a channel bed/valley floor where the runoff is stored in soil profile (Critchley and Siegert, 1991). Harvesting runoff water for supplemental irrigation is a risk-averting strategy, pre-empting situations where crops have to depend on rainfall whose variability is high both in distribution and amounts. By using underground spherical tanks in cascades and having a combined capacity of 60 m^3, seasonal water for supplemental irrigation for an area of about 400 m^2 is guaranteed (Mtisi and Nicol, 2013). Indirect benefits of RWH in terms of reduced incidence of downstream flood damage had been noted (Johnson et al., 2001; Gleick, 2002).

Run-off harvesting from a catchment using channels or diversion systems and storing it in a surface reservoir-water pans/ponds (Rockstrom, 2000) has shown that, the yields and reliability of agricultural production can be significantly improved with water harvesting. In this system, surface runoff from small catchments or adjacent road runoff is collected and stored in manually and/or mechanically dug farm ponds. Although, this technique requires relatively high investment costs compared to *in-situ* systems. Evaluation of RWH in a surface reservoir in the four Great Horn of African (GHA) countries (Ethiopia, Kenya, Tanzania and Uganda) revealed that, it was slowly being adopted with high degree of success (Kiggundu, 2002). In northern Shewa of Ethiopia, runoff from farm lands is stored down streams in large pits for later use, for irrigating plants using watering cans (Alem, 1999).

Ground water recharge

Methods for increasing groundwater recharge include pumping surface water directly into an aquifer and/or enhancing infiltration by spreading water in infiltration basins (World Bank, 2006). There are two main techniques of rain water harvesting namely storage of runoff on surface for future use and recharge to groundwater and shallow aquifer (MacDonald and Davies, 2000). Water harvesting can also have a positive impact on soil conservation, erosion prevention, groundwater replenishment and the restoration of ecosystems. Options for increasing groundwater recharge include constructing small dams or bunds, terracing, contour trenching, sub-surface dams and planting trees or planting vetiver grass (Gebremichael et al., 2005).

Soil storage has more advantage as it does not require lifting and water application to the root of each plant. It also contributes to the recharge of the ground water (Oweis et al., 2001; William et al., 1992). By deep ponding, moisture deficit for crops such as cereal grains, which are more needed by the farmers for their food security, is tackled. Soil storage has more traditional base and lower cost so that its adoption rate can be faster compared to deep ponding. Therefore, more emphasis needs to be given in the future (Desta, 2005). The same trend was also observed for available soil water for rain-fed crops. Water availability from rehabilitated gullies using check dams was the main source of surface irrigation water, which was supplemented by shallow and deep ground water wells. Groundwater levels in the wells increased up to 2.5 m, while the irrigated areas are increased and the number of hand-dug wells also significantly increased. Newly emerging springs and irrigated fields as well as increasing crop diversity and yields were some of the indicators of the improved water resources and supply (Mekonen and Brhane, 2011).

Yield increment

One of the reasons for low crop production in semi-arid areas is marginal and erratic rainfall exacerbated by high runoff and evapotranspiration losses. The in-field RWH techniques has been shown to improve the yield of maize and sun flower on some benchmark ecotypes in South Africa (Henslley et al., 2000). RWH can be used to re-establish vegetation cover to improve crop growth in order to alleviate poverty and enhance food security. Successful interventions in rain-fed

Figure 4. RWH pond picture to prove the point that RWH facility can promote yields (Lemma, 2005 (B); Woldearegay, 2012 (A)).

agriculture in Somali Region Ethiopia have transformed the livelihoods of many poor farmers (FAO, 2001). Improved RWH may result in improved crop yields, food security and livelihood among households (Rockström, 2002). Supplementary irrigation increased crop yields by 20%. With RWH, farmers have diversified to include horticultural cash crops and the keeping of dairy animals. For instance US$ 735 (per ha) compared to US$ 146 normally is now earned from rain-fed maize (Mtisi and Nicol, 2013). This has contributed to food security, better nutrition and family income.

Most of the future growth in crop production in developing countries is likely to come from intensification, with irrigation playing an increasingly strategic role (Postel, 2003; IAASTD, 2009; FAO, 2011). Access to irrigation water is critical to raising and stabilizing crop production (Postel, 2003). Irrigation has direct benefits in terms of production and income. However, there have also been associated impacts whose costs may at times outweigh the benefits of production (Johnson et al., 2001; Gleick, 2002). One of the promising breakthroughs for upgrading rain-fed agriculture in the semi-arid lands remains on how efficiently small scale farmers can utilize practices such as RWH. It is viable in areas with annual rainfall as low as 300 mm (Ngigi, 2003). Besides increased yields, Ngigi et al. (2005) reports that RHM is also aimed at stabilizing variations in crop yields and ensuring food security. Lemma (2005) noted that the survival rate of trees in the irrigated areas of home gardens (84%) had shown a better result when compared to home gardens without pond. This implied that the availability of supplementary irrigation in the backyard has significant contribution on the survival of trees (fruit trees) in the home garden. For instance, about 75% additional yield could be obtained for green pepper and onion crops as compared to tomato crop, which had up to 83% yield increment obtained by using the effective water application method (Lemma, 2005) (Figure 4).

According to the study by Rämi (2003) in Tigray region, Wukro district boasts 30 ponds, mainly clay and plastic-lined serving a total of 80 households. Small gardens with peppers, tomatoes, maize and root crops, which were planted during the rainy season and freshly planted fruit and coffee trees were found around most of the ponds. In the Amhara region (north-western part of the country) from the total completed water harvesting structures, reaching 242,000 in number, over 42,000 have started production, as a result 21,194 ha of land is under irrigation and 148, 244 farm households are benefiting. Of this 14%, 21,194 are women headed households. Irrigated area in the region is primarily aggregated from shallow well, river diversion and spring development (Desta, 2005). In addition to that, according to the participatory rural appraisal (PRA) findings, sorghum yield in Kobo District, Northern Ethiopia doubled with availability of flood water. Similarly, pepper yields increase by up to 400% with application of floodwater (Alamerew et al., 2002).

In Oromia region (central, eastern and western part of the country) the total irrigated land is 65,508 ha, when the plan was 68,565 ha (95.5% achievement). By this 343,953 (92%) households have become beneficiaries. Again 379 ha traditional irrigation through river diversion is under establishment on top of 31,311 ha that already exists. Of the total planned 216,290 ponds, 75% is in food insecure districts and the remaining 25% is in non-food insecure districts. The stored water apart from drinking and crop production, have been used for selling, making mud for house construction, making soil blocks and raising seedlings at the nursery (Desta, 2005). RWH has the potential to increase the productivity of cropland by increasing the yields and by reducing the risk of crop failure (Tesfay, 2011). Alemie et al. (2005) also reported 20,000, 10,000 and 12,000 kg/ha yield of tomato, pepper and onion respectively, due to efficient use of RWH technologies in Wukro and Mehoni Destricts, northern Ethiopia. The farmers managed RWH structures to increase the farm household's agricultural yield by improving the availability of water during the dry spell periods (Amha, 2006).

CHALLENGES AND OPPORTUNITIES OF RAINWATER HARVESTING

The main challenges of adopting RWH technologies are that much of the harvested water is lost through seepage and thus it is not sufficient and it is very labor intensive to irrigate the whole fields by pumping the water manually from ponds and applying directly to the crops (Moges, 2009). The other challenge is to find ways of selecting and promoting appropriate RWH interventions that are well matched to the site-specific, biophysical and socio-economic circumstances (Gowing et al., 2003). The use of on-farm storage reservoirs faces evaporation and seepage losses and silting (Thome, 2005). It is important to minimize the adverse effects of these problems in the design of a surface-water storage facility. Silting may be minimized by arresting the silt and sand on the catchment area itself, mainly through controlling catchment erosion but also by installing silt-traps (Thome, 2005).

Rainfall distribution is another natural challenge of RHM systems. During extreme drought years, very little can be done to bridge a dry spell occurring during the vegetative crop growth stage, if no runoff producing events occur during early growth stages (Rockström, 2000). Despite significant efforts by the Government of Ethiopia and other stakeholders, improving agricultural water management from RWH is hampered by constraints in policies, institutions, technologies, capacity, infrastructure, and markets. Addressing these constraints is vital to achieve sustainable growth and accelerated development of the sector in Ethiopia (Awulachew, 2010). The challenge for agriculture in Sub-Saharan Africa is the variability in rainfall, characterized by high intensity storms, and high frequency of dry spells and droughts. RWH systems can turn these inherent challenges into opportunities.

Where there is no surface water, or where groundwater is inaccessible due to hard ground conditions, or where it is being over exploited, recharge alternatives should be implemented. In a very simplified sense, if a society is threatened or subjected to water scarcity it should respond by attempting to get and store more water using simple, inexpensive and traditional concepts of rain water harvesting technologies (Mupenzi et al., 2011). RWH systems operate on different scales (plot, field and catchment) to modify the water balance in order to increase the rainfall use efficiency (Gowing et al., 2003). RWH is one option to irrigate and produce high value crops to reduce poverty and food insecurity. The assumption is that producing high value crops enables farmers to get returns from selling the product and thus increasing their ability of generating income. For example, in Aleaku Gubantaboke Kebele (Bulbula District) some farmers ability of generating

income. For example, in Aleaku Gubantaboke Kebele (Bulbula District) some farmers have clearly confirmed the importance of RWH as best option for pepper (seedling) production. Realizing the importance of pepper in terms of cash returns, some farmers have already shifted from maize, teff and wheat to pepper and they reported a net return of US$502.26 per quarter hectare (Moges, 2009).

The Ethiopian highland has a large potential for RWH implementation on open woodland land use types to improve the water availability for livestock which has a nexus effect on water productivity. Other benefits of rain-water harvesting are that it makes water available at the point of consumption and reduces the need to pump or haul it over long distances thus saves time and human labour. The experience of RWH activities indicates that they could be used as catalysts for development in a bid to alleviating poverty and promoting socio-economic well-being of the rural people (Mbugua and Nissen-Petersen, 1995).

CONCLUSION AND RECOMMENDATION

RWH has been implemented in many parts of Ethiopia since the time of Aksumite Civilization (560 BC) to the present. However, the adoption of the technology had been disappointing due to many challenges. The sustainability of RWH techniques largely depends on the livelihood improvements of farmers, especially those who practice traditional rain fed agriculture. The adopted RWH techniques had enhanced soil moisture, recharge ground water, reduced runoff and increased yield which in turn preserve the ecosystem.

The benefits of RWH technologies extend beyond rain fed farming to the whole ecological system. Therefore, external catchment based RWH had eminent potential of mitigating rainfall-related crop production risks in the arid and semi-arid regions in Ethiopia. Site specific well-managed RHM therefore, as well as irrigation application are keys in helping Ethiopia overcome major challenges including population pressure; food insecurity; soil and land degradation; high climate variability and low agricultural productivity.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Akalu TF, Adgo ET (2010). Water harvesting with geo-membrane lined ponds: Impacts on household incomes and rural livelihoods in Minjar

Shenkora district of Ethiopia. In Mati, B.M. Agricultural water management interventions delivers returns on investment in Africa. A compendium of 18 case studies from six countries in eastern and southern Africa. VDM Verlag, pp. 42-52.

Alamerew E, Fentaw B, Ali S (2002). Traditional rainwater harvesting systems for food production: the case of kobo Wereda, Northern Ethiopia.

Alem G (1999). Rainwater harvesting in Ethiopia: An overview. Integrated development for water supply and sanitation. 25th WEDC Conference. Addis Ababa, Ethiopia. pp. 387- 390.

Alemie A, Gebrie A, Teka D (2005). Pond water productivity under the present use in Tigray region, Northern Ethiopia. MU-DCG project Technical Report Number 4, Mekelle University, Mekelle.

Alemu B, Kidane D (2014). The Implication of Integrated Watershed Management for Rehabilitation of Degraded Lands: Case Study of Ethiopian Highlands. J. Agric. Biodivers. Res. 3(6):78-90.

Amha R (2006). Impact Assessment of Rainwater Harvesting Ponds: The Case of Alaba Woreda, Ethiopia. MSc Thesis, Addis Ababa University.

Araya T, Cornelis WM, Nyssen J, Govaerts B, Gebregziabher T, Oicha T, Getnet F, Raes D, Haile M, Saire KD, Deckers J (2011). Effects of conservation agriculture on runoff, soil loss and crop yield under rainfed conditions in Tigray, Northern Ethiopia. Soil Use and Manage. 27:404-414.

Awulachew SB (2010). Irrigation potential in Ethiopia: Constraints and opportunities for enhancing the system. International Water Management Institute (IWMI).

Awulachew SB, Merrey DJ (2007). Assessment of Small Scale Irrigation and Water Harvesting in Ethiopian Agricultural Development. International Water Management Institute (IWMI).

Awulachew SB, Merrey DJ, Kamara AB, Van Koppen B, Penning de Vries F, Boelee E, Makombe G (2005). Experiences and opportunities for promoting small–scale/micro irrigation and rainwater harvesting for food security in Ethiopia. Colombo, Sri Lanka: IWMI. v. (Working paper 98). P. 86.

Bewket W (2009). Rainwater harvesting as a livelihood strategy in the drought- prone areas of the Amhara region of Ethiopia. Organization for Social Science Research in Eastern and Southern Africa (OSSREA).

Birru O, Quraishi Sh, Bedadi B (2012). Effects of straw mulch and farmyard manure on runoff, erosion, *in-situ* water conservation, and yield and yield components of wheat at the highlands of Bale, south eastern Ethiopia. African Journal of Agricultural Research 7(44):5879-5886.

Bossio D, Critchley W, Geheb K, van Lynden G, Mati B (2007). Conserving landprotecting water. In: Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture, London: Earth scan and Colombo: International Water Management Institute, pp. 551-583.

Critchley W, Siegert K (1991). A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production. FAO Corporate Document Repository. http://www.fao.org/docrep/U3160E/u3160e00.htm#Contents.

De Fraiture C, Wichelns D (2010). Satisfying future water demands for agriculture. Ag. Wat. Manag. J. 97:502-511.

Derib SD, Assefa T, Berhanu B, Zeleke G (2009). Impacts of micro-basin water harvesting structures in improving vegetative cover in degraded hillslope areas of north-east Ethiopia. The Rangeland J. 31(2):259-265.

Desta L (2003). Comparative advantage of soil storage (runoff farming) for crop production over structural storage in the current effort of rainwater harvesting in Ethiopia. Proceeding of ‘Rainwater Harvesting Stakeholders' Workshop. Addis Ababa, 27th May, 2003.

Desta L (2005). Concepts of Rainwater Harvesting and its Role in Food Security – the Ethiopian Experience. Ministry of Agriculture and Rural Development, Department of Water Harvesting, Small Scale Irrigation and Rural Infrastructure Development. P. 5.

FAO (2001). Water Harvesting in Western and Central Africa. RAF/Publication, FAO, Rome, Italy.

FAO (2011). The State of the World's Land and Water Resources for Food and Agriculture Organization. Food and Agriculture Organization of the United Nations, Rome.

Fattovich R (1990). Remarks on the PreAxumite Period in Northern Ethiopia. J. Ethiopian Studies 23:1-33.

Finkle M, Sergerros M (1995). Water Harvesting. Proceedings of the SADC ELMS practical Workshop held in Windhock and Okakarara, Namibia, 10-28 May, 1993. Report series No. 33.

Fischer T, Turner N, Angus J, McIntyre L, Robertson M, Borrell A, Lloyd D (2004). "New Directions for a Diverse Planet: Proceedings of the 4th International Crop Science Congress," Brisbane, Australia, 26 September–1 October 2004.

Gebreegziabher T, Nyssen J, Govaerts B, Getnet F, Behailu M, Haile M, Deckers J (2009). Contour furrows for in situ soil and water conservation, Tigray, Northern Ethiopia. Soil, Tillage Res. 103:257-264.

Gebremichael D, Nyssen J, Poesen J, Deckers J, Haile M, Govers G, Moeyersons J (2005). Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray Highlands, northern Ethiopia. Soil Use Manag. 21:287-297.

Georgis KW (2000). Conservation tillage research findings: The Ethiopian experience. In Conservation tillage for dryland farming. Technological options and experiences in Eastern and Southern Africa. eds.E.K. Biamah, J. Rockstrom and G.E. Okwach. RELMA, Workshop Report No. 3:148-151.

Georgis KW (2002). Water harvesting, the key to successful crop production and resource management in water stress environments: Eastern African experience. In Workshop on the experiences of water harvesting in drylands of Ethiopia: Principals and practices, eds. M. Haile and S.N. Merga. Dryland Coordination Group. DCG Report No. 19:55-64.

Getaneh M, Tsigae A (2013). Comparative analysis of lining materials for reduction of seepage in water harvesting structures, Adet, Ethiopia. Int. J. Dev. Sust. 2(2):1623-1635.

Gleick PH (2002). Soft water paths. Nature 418: 373.

Gowing JW, Young MDB, Hatibu N, Mahoo HF, Rwehumbiza F, Mzirai OB (2003). Developing Improved Dry land Cropping Systems for Maize in Semi-Arid Tanzania. Part II. Use of a Model to Extrapolate and Add Value to Experimental Results. Expl. Agric. 39: 293-306.

Habtamu G (1999). Rainwater harvesting concepts and issues. Paper presented at the Founding Conference of the Ethiopia Rainwater Harvesting Association (ERHA). December 17, 1999. Addis Ababa.

Haile M, Merga SN (2002). Workshop on The Experiences of Water Harvesting in the Drylands of Ethiopia: Principles and Practices December 28-30 2001, DCG Report No. 19, Mekelle, Ethiopia.

Haile T (2007). Assessment of Institutional Setup and Effect of Household Level Water Harvesting in Ensuring Sustainable Livelihood. Dry lands Coordination Group Report No. 52, Oslo, Norway.

Hailemicael A (2011). Indigenous talents of Konso people to cope up climate change susceptibility, Ethiopia. Arba Minch University, Ethiopia.

Hatibu N, Mahoo H (1999). Rainwater harvesting technologies for agricultural production: A case for Dodoma, Tanzania.

Henslley M, Botha JJ, Van Staden PP, Du Tota A (2000). Optimizing Rainfall Use Efficiency For developing Farmers with Linited Acccess to Irrigation Water, WRC report No 878/1/100. Water Research Commission, Pretoria, South Africa.

Herweg K, Ludi E (1999). The performance of selected soil and water conservation measures-case studies from Ethiopia and Eritrea. Catena pp. 99-114.

Hudson N (1987). Soil and Water Conservation in semi-arid areas. FAO Soils Bulletin No. 57. FAO, Rome. P. 172.

IAASTD (2009). International Assessment of Agricultural Knowledge, Science and Technology for Development: Summary for Decision Makers of the Sub-Saharan Africa Report. Assessment. International Assessment of Agricultural Knowledge, Science and Technology for Development, Johannesburg. P. 24.

Ito M, Matsumoto T, Quinones M (2007). Conservation tillage practice in sub-Saharan Africa: The experience of Sasakawa Global 2000. Crop Prot. J. 26:417-423.

Johnson N, Revenga C, Echeverria J (2001). Managing water for people and nature. Science 292:1071-1072.

Kidane D, Temesgen M, Abdelkadir A (2012). Effect of Winged Subsoiler and Traditional Tillage Integrated with *Fanya Juu* on

Selected Soil Physico-Chemical and Soil Water Properties in the Northwestern Highlands of Ethiopia. E. Afr. J. Sci. 6(2):21-32.

Kidane DA (2014). Conservation tillage implementation under rainfed agriculture: Implication for soil fertility, green water management, soil loss and grain yield in the Ethiopian Highlands. Int. J. Agric. Sci.4(9):268-280.

Kiggundu N (2002). Evaluation of rainwater harvesting systems in Rakai and Mbarara Districts, Uganda. GHARP case study report. Greater Horn of Africa Rainwater Partnership (GHARP), Kenya Rainwater Association, Nairobi, Kenya.

Lal R (2001). World cropland soils as source or sink for atmospheric carbon. Adv. Agron. 71:145-191.

Leisa (1998). Challenging water scarcity [Editorial]. ILEIA Newslett. Low Ext. Input Sustain. Agric. 14:1.

Lemma G (2005). The role of Household Ponds on the expansion of Homegardens in Tigray, Ethiopia. MSc Thesis. Department of Tropical Land Resource Management, Mekelle University, Ethiopia.

Li X, Gong J, Wei X (2000). *In-situ* rainwater harvesting and gravel mulch combination for corn production in the dry semi-arid region of China. J. Arid Env. 46:371-382.

Li X, Shi P, Sun Y, Tang J, Yang Z (2006). Influence of various in situ rainwater harvesting methods on soil moisture and growth of *Tamarix ramosissima* in the semiarid loess region of China. J. Hydrol. 328:338-346.

Liniger H, Schwilch G, Hurni H (2006). Soil and Water Conservation, Global Change, and the Millennium Development Goals –An Evaluation by WOCAT. 14th International Soil Conservation Organization Conference. Water Management and Soil Conservation in Semi-Arid Environments. Marrakech, Morocco, May 14-19, 2006 (ISCO 2006).

MacDonald AM, Davies JK (2000). A brief review of groundwater for rural water supply in sub-Saharan Africa. British Geological Survey Technical Report WC/00/33pp. BGS Keyworth UK.

Mbugua JK, Nissen-Petersen E (1995). Rain water an underutilized resource-SIDA, Nairobi, Kenya.

McHugh OV, Steenhuis TS, Fernandes ECM (2007). Performance of in situ rainwater conservation tillage techniques on dry spell mitigation and erosion control in the drought-prone North Wello zone of the Ethiopian highlands. Soil and Tillage Research 97: 19-36.

Mekonen K, Brhane G (2011). Impact assessment of soil and water conservation measures at Medego watershed in Tigray, northern Ethiopia. Maejo Int. J. Sci. Technol. 5(03): 312-330.

Mekonnen Y, Haile M (2010). The Potential of in situRain Water Harvesting for Water Resources Conservation on Malaria Transmission in Tigray, Northern Ethiopia. MEJS 2(2):49-63.

Moges G (2009). Identification of potential rain water harvesting areas in the Central Rift Valley of Ethiopia using a GIS based approach. MSc Thesis, Wageningen University, Netherland.

Mtisi S, Nicol A (2013). Good Practices in Water Development for Dryland Regions of Ethiopia, Kenya, and Uganda. P. 99.

Mupenzi JP, Lahai L, Tafadzwa LM, Lie Y, Jiwen G (2011). Rain water harvesting and Artificial Recharge in Africa. Nature Sci. 9(4): 41-45.

Ngigi SN, Savenije HHG, Thome JN, Rockstro J, de Vriesd FWTP (2005). Agrohydrological evaluation of on-farm rainwater storage systems for supplemental irrigation in Laikipia district, Kenya. Agricultural Water Management 73:21-41.

Ngigi SN (2003). What is the limit of up-scaling rainwater harvesting in a river basin? Physics and Chemistry of the Earth 28:943-956.

Ngigi SN (2009). Climate Change Adaptation Strategies: Water Resources Management Options for Smallholder Farming Systems in Sub-Saharan Africa. The MDG Centre for East and Southern Africa, The Earth Institute at Columbia University, New York, P. 189.

Oloro V, Steenhuis T, Abebe B, Fernandes E (2007). Performance of in situ rainwater conservation tillage techniques on dry spell mitigation and erosion control in the drought-prone North Wello zone of the Ethiopian highlands. Soil Till. Res. J. 97:19-36.

Oweis T, Prinz D, Hachum A (2001). Water Harvesting: Indigenous knowledge for the Future of the Drier Environments. ICARDA, Aleppo, Syria. P. 40. ISBN: 92-9127-116-0.

Pachpute J, Tumbo S, Sally H, Mul M (2009). Sustainability of Rainwater Harvesting Systems in Rural Catchment of Sub-Saharan Africa. Wat. Reso. Manag. 23:2815-2839.

Postel SL (2003). Securing water for people, crops, and ecosystems: New mindset and new priorities. Natural Resources Forum 27:89-98.

Rämi H (2003). Ponds filled with challenges, Water harvesting experiences in Amhara and Tigray. UN OCHA, Ethiopia.

Reij C, Scoones I, Toulin C (1996). Sustaining The Soil: Indigenous Soil and Water Conservation in Africa. Earth Scan, London, UK. P. 228.

Rockström J (2000). Water resources management in smallholder farms in Eastern and Southern Africa: An overview. Physics and Chemistry of the Earth 25(3):278-288.

Rockström J (2001). Green water security for the food makers of tomorrow: Windows of opportunity in drought prone savannahs. Water Sci. Technol. 43(4):71-78.

Rockström J (2002). Potential of Rainwater Harvesting to Reduce Pressure on Freshwater Resources. Dialogue on water, food and environment. International Water Conference, Hanoi, Vietnam, October 14-16.

Rockström J (2003). Water for food and nature in the tropics: Vapour shift in rainfed agriculture. *Phil.* Trans. R. Soc. Land, 358:1997-2009.

Rockstrom J, Barron J, Fox P (2002). Rainwater management for increased productivity among smallholder farmers in drought-prone environments. Physics and Chemistry of the Earth. 27:949-959.

Rockström J, Kaumbutho P, Mwalley J, Temesgen M, Mawenya L, Barron J, Mutua J, Damgaard-Larsen S (2009). Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. Soil Till. Res. 103(1):23-32.

Stockholm Environment Institute (SEI) (2009). Rainwater harvesting: A lifeline for human well-being, York. P. 69.

Temesgen M, Rockstrom J, Savenije HHG, Hoogmoed WB (2007). Assessment of Strip Tillage Systems for Maize production in semi-arid Ethiopia: Effects on grain yield and water balance. UNESCO-IHE, Wageningen University, The Netherlands.

Temesgen M, Uhlenbrook S, Belay S, van der Zaag P, Mohamed Y, Wenninger J, Savenije HHG (2012). Impact of conservation tillage on the hydrological and agronomic performance of Fanya juus in the upper Blue Nile (Abbay) river basin. Hydrol. Earth Sys. Sci. 16:4725-4735.

Tesfay G (2011). On-farm water harvesting for rainfed agriculture development and food security in Tigray, Northern Ethiopia. Drylands Coordination Group Report No. 61, 07, 2011, Norway.

Thome JN (2005). Evaluation and design of runoff storage systems for supplemental irrigation in Laikipia District, Kenya. MSc Thesis. Department of Environmental and Biosystems Engineering, University of Nairobi, Kenya.

Tian Y, Su D, Li F, Li X (2003). Effect of rainwater harvesting with ridge and furrow on yield of potato in semiarid areas. Field Crop Res. 84: 385-391.

Vancampenhout K, Nyssen J, Gebremichael D, Deckers J, Poesen J, Haile M, Moeyersons J (2005). Stone bunds for soil conservation in the northern Ethiopian highlands: Impacts on soil fertility and crop yield. Soil Till. Res. 90(1-2):1-5.

Vohland K, Barry B (2009). A review of *in-situ* rainwater harvesting (RWH) practices modifying landscape functions in African dry lands. Agric. Ecosys. Environ. 131:19-127.

William C, Chris R, Alain S (1992). Water Harvesting for Plant Production, Volume II: Case Studies and Conclusions for Sub-Saharan Africa. World Bank Technical Paper No 157, Africa Technical Department Series.

World Bank (2006). Ethiopia: Managing Water Resources to Maximize Sustainable Growth. Washington, DC: World Bank.

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