academicJournals

Vol. 11(6), pp. 472-479, 11 February, 2016
DOI: 10.5897/AJAR2015.10304
Article Number: 95D585757122
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Effects of catchment characteristics and climatic conditions on reservoir water capacity in a drought prone area

Darwin Dodoma Singa[1]*, Siza Donald Tumbo[1], Mahoo, Henry Fatael[1], Rwehumbiza, Filbert[1] and Lowole, Maxi[2]

[1]Sokoine University of Agriculture, BP: 3003, Morogoro, Tanzania.
[2]Lilongwe University of Agriculture and Natural Resources, Box 219, Lilongwe, Malawi.

Received 17 August, 2015; Accepted 29 October, 2015

Crop production in semi-arid sub-Saharan Africa (SSA) is limited by over-reliance on erratic and inadequate rainfall, which often results in yield reduction or total crop failure. The effects of frequent droughts and dry spells need to be circumvented by water conservation. Where rainwater is harvested, research recommendations are based on direct use of the water without relating it to catchment characteristics, climatic conditions and long term storage. A study aimed at predicting sizes of seasonal open surface reservoir based on rainfall and runoff rainwater was conducted from 2012 to 2013 at Ukwe Area, Malawi. The work premised on assessment of land and hydrological factors as they impinge on runoff water storage. Rainfall-runoff relative analysis showed runoff trend following the magnitude of rainfall. Findings showed that runoff water harvested, under the Ukwe area landscape conditions, is linearly related to seasonal rainfall amount with coefficient of correlation of greater than 0.75, demonstrating vitality of rain and timing of rain harvesting for reservoir sustenance. Runoff amount was almost four times that of infiltrated amount, highlighting the fact that drought prone areas can be flood prone as well. Results further demonstrate that weekly reservoir balance using crop, livestock and domestic consumption, and losses through evaporation and seepage, as dry season progresses are critical for reservoir sizing during dam construction or crop field sizing at the onset of dry season.

Key words: Semi-arid, rainwater, reservoir, Malawi, runoff, coefficient.

INTRODUCTION

Unpredictable rainfall, droughts, long dry season and Floods in Sub-Saharan Africa severely disrupt crop production. There is, hence, need to efficiently harvest and use the scarce rainwater resources (Mloza-Banda and Banda, 2003). In Malawi, the water is conveyed to the field through integrated rainwater harvesting and irrigation production systems (Ibraimo and Munguambe, 2007). Several reports in Malawi have shown that runoff rainwater harvest from catchments and stored in small earth dams, for subsequent supplemental or sole dry

*Corresponding author. E-mail: dodoma1mwasinga@yahoo.com, dodomamwasinga@live.com

season irrigation is an appropriate antidote to this phenomenon. It is further reported that harvested and stored runoff water can be used for irrigation through supplementation during dry spells and as sole water source during the dry season (ITDG, 2015; ICARDA, 2014). Yet the technology is not fully tapped to provide full crop-water productivity at a micro-catchment level for farmers in Malawi.

Currently there is unprecedented decline in per caput amount of irrigated land from 1 to 2.3% per year from early 1960s to 1975, and to less than 1% from 1990s. The decrease has been due to, among other bottlenecks, high environmental and social costs and poor irrigation performance (Rosegrant and Svendsen, 1993). Use of irrigated agriculture indicators signified role of agricultural water management as one of the contributing factors (Valipour, 2015, 2011). Agricultural Water Management impinges on water use in relation to water source capacity. When reservoirs are used for dry season irrigation, water storage should be below the calculated yield of the catchment in a dry year or based on an acceptable average minimal yield over a period of years (FAO, 2010). The foregoing research outcomes were, however, all based on single system entity without establishing appropriate variable combinations of catchment area runoff attributes and long term open surface reservoir water volume in relation to the envisaged crop field area.

Valipour (2015) provided an estimation of areas equipped for irrigation and desirability of water management previously not researched in European countries. The relative estimation was based on water management, crop, cultivated area, irrigation equipped area, active rural population (RP) and total population, human development index, Gross Domestic Product and National Rainfall Index (NRI), and Irrigation Water Requirement Indices (IWR). Estimation results showed that to obtain relationships among the indices, each country must be treated separately. Index prioritization indicated that difference between NRI and IWR; RP per total population and permanent crops per cultivated area had significant effects on estimation of area equipped for irrigation per cultivated area. Research in the United States of America (USA) by Valipour (2013) showed that the effect of geographic condition on climate was more than hydrology. The Surface Water Supply Index (SWSI) was found to be one of the most important hydrologic parameters for study of drought and flood periods in basins. Use of the SWSI further revealed that the stream-flow component or the reservoir component is the predominant driving force for water use and management at any given time.

From the foregoing findings for Europe and the USA, based on parameters of rainfall, population cultivated area, irrigation forecasted area and surface water management the currently reported research work was conducted to cater for SSA region on significance of rainfall, catchment characteristics, runoff, water reservoir, and irrigated crop and area. The aim of the research was, therefore, to provide the vulnerable crop growing communities and other stakeholders relationships of the parameters as they impinge on bean crop water productivity. The objective of the study was, therefore, to quantify seasonal open surface reservoir capacity based on runoff amounts as influenced by rainfall and catchment characteristics.

MATERIALS AND METHODS

Study location

Ukwe Area is in Lilongwe North-West of Central Malawi. The area is about 20 km from the Lilongwe city. The area, in which the research site was located, is about 1150 m above sea level, 13° 46’ S and 33 ° 37’ E to 13° 55’ S and 33° 38’ E, extending 13° 46’ S and 33 ° 31’ E to 13 ° 50’ S and 33 ° 32’ E, occupying flat *dambo* margins. The area has a small Kalembe Dam, also called *Mphetsankhuli* dam (for its support of production of appetite satisfying food crops) fed an ephemeral Kalembe stream. The stream is seasonal, flowing only in the rainy season (December to April).

The Kalembe stream and Mphetsankhuli dam catchment lies on a gentle slope (2 to 5%) towards the dam with savannah woodland vegetation regenerated shrubs and scattered trees (mostly exotic cassia type) (Figure 1). Temperatures range from 18 to 24°C rising to 29°C just before the start of rains (October to November). Cultivated fields have soil organic matter content of 1.75%, pH of 5.5 and soil bulk density of 1.35 g/cm^3. The area is drought-prone and farmers have a bean irrigation club using flat *dambo* margins with alluvium and uplands soils. The catchment area is composed of Savannah woodland vegetation regenerated shrubs and scattered trees.

Instrumentation and data collection

Catchment area and rainfall

Catchment area and topographic determinations were carried-out using the Differential Global Position System (DGPS) – Leica model G509. A total catchment area of 1.03 km^2 (103 ha), including the reservoir whose maximum rainy season area is 0.08 km^2 or 8 ha were identified. But physical observations showed only 16 ha to be the actual catchment that contributed runoff water to the reservoir, with the rest areal runoff being intercepted by some physical (bunds) and biological conservation (woodlot) measures.

The dominant vegetation type and intensity were identified using the Food and Agriculture Organization grouping with each vegetative category given a percentage value (FAO, 2014). The dam catchment area is proportionally composed of 26% cultivated land, 11% tree bush, 20% heavy grass, 22% scrub or medium grass, 21% settlements.

Daily rainfall data for 2012/2013 were collected using nine rain gauges, three in the upper catchment area, three in the middle slope (arable area) and three in the *dambo* area. Thiessen method was used to obtain a real rainfall means, to avoid inaccuracy that would occur if data of direct gauge point rainfall means were used to represent the site daily rainfall values. The mean areal rainfall Ř was calculated using equation 1.

$$\bar{R} = \sum_{i=1}^{n} \frac{R_i a_i}{A} \quad (1)$$

Where *Ř* is mean areal rainfall, R_i is rainfall measurements at each

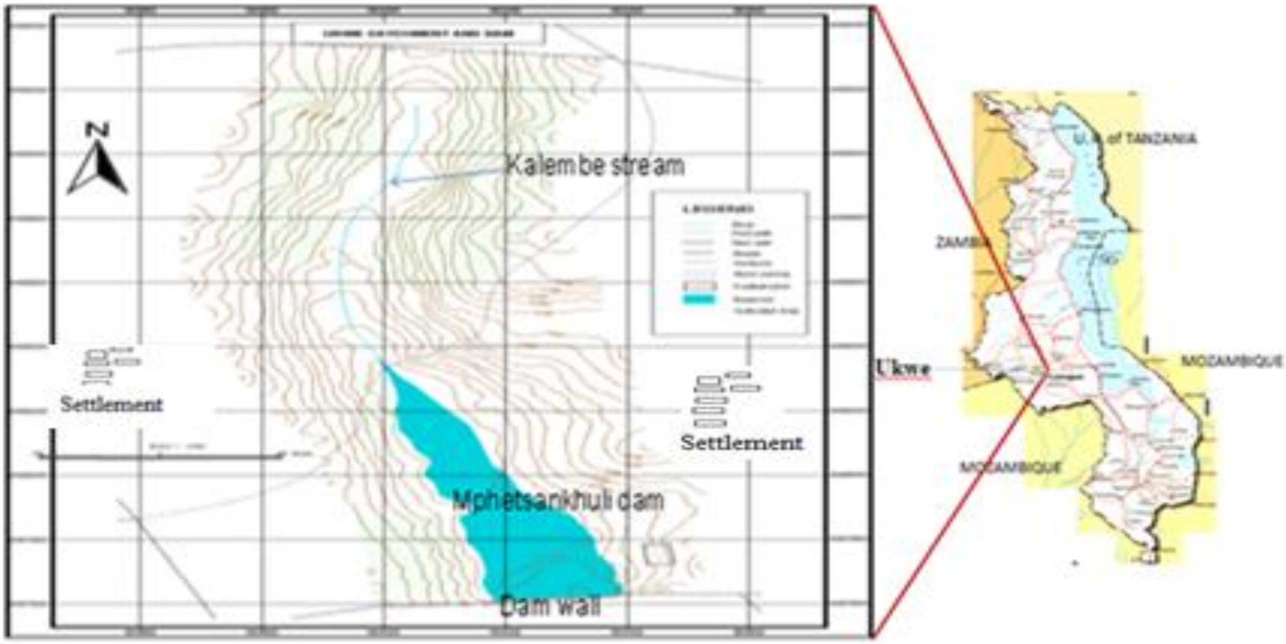

Figure 1. Ukwe site-catchment, stream and dam.

rain gauge station, A is total area of catchment, and a_i is polygon area corresponding to rain gauge station. Since runoff into the reservoir from the catchment area, and the stream, is non-point specific flow from each area polygon (a) contributes to the change in volume of the reservoir as monitored by the calibrated gauge installed at the stream mouth portion of the reservoir (Njoloma, 2009).

The daily gauge rainfall data were correlated with the areal rainfall to compute a correlation coefficient, which is a statistical parameter determining the extent of correlation between the two variables. Low level of correlation would depict poor representation of the areal computed rainfall data to the measured rainfall values (Mair and Fares, 2012).

The data were, therefore, subjected to a Double Mass Analysis (DMA) to investigate gauge data errors or inconsistencies. Accumulated values of monthly mean rainfall from the nine gauge stations of Ukwe site were plotted against the accumulated areal mean values of the other stations namely, Bunda and Kandiya stations, 50 km South and 12 km South-east respectively. The basis for this theory is that rainfall for stations in the Ukwe reservoir catchment, which is in the same climatic region with the other two stations, should be related in a long run. Any inconsistencies would result in spurious trend (not real trend).

Reservoir water

Depth of water in the reservoir was measured using a staff gauge, vertically installed, (using a builder's level) from a boat and height determined by the DGPS rover. The reservoir has a 45 by 30 cm concrete outlet (30 cm 'dead base') on the western edge that is regulated to drain water into an iron pipe through the embankment to the common dwarf bean crop (Kalima variety) plots downstream. Common bean irrigation complemented all agronomic and pathological practices to avoid allelopathy, and biocides for the crop's potential growth and protection as recommended by the Ministry of Agriculture and Food Security (MAFS, 2012). 'Dead base' was the depth of water retained in the reservoir (dead storage) that could no t be accessed since it was below the outlet.

The reservoir water was used for irrigating 1.2 ha of beans downstream and also consumed by 102 heads of cattle and 143 goats. All domestic water is supplied by shallow wells hence reservoir water is not used for domestic chores. This paper reports on the rainfall, runoff and reservoir components as a hydrological system only – it does not cover the subsequate use of water on the crop and crop water productivity.

Analysis of data

Rainfall-runoff analysis

Seasonal rainfall was graphically compared to runoff values. Rain fall linear regression was used to establish relationship between rainfall and runoff into the reservoir.

Runoff-reservoir analysis

Since rainfall and evaporation were expressed in mm/day the surface runoff in m^3/s was also converted into mm/day. The procedure used in this research to convert m^3/s to mm/day was

$$Q = 1000\left(\frac{86400V}{A}\right) \quad (2)$$

where Q = flow rate in mm/day, V is runoff in m^3/s reservoir inflows (daily discharges from the catchment area) measured by calibrated gauge installed in the reservoir (MIWD, 2011), and A is the catchment area (m^2). Measured data of daily area discharges into the reservoir were verified by data made available from the Water Department, Surface Water Division of the Ministry of Irrigation and Water Development obtained by using a calibrated gauge in the reservoir from 1959 to 2000.

The amount of runoff water accumulated in the reservoir was estimated using the derivation method from direct measurement as depicted by Sawunyama (2005). The method is based on actual determination of reservoir characteristics in the field involving measurement of throwback, maximum depth and maximum width of reservoir water, using 1/6 reservoir shape constant, thus

$$C = DWT/6 \tag{4}$$

where C is the reservoir water volume (m^3), D is the water depth (m), W is the average dam width (m), and T is the throwback distance (m) (Hudson, 1998 cited in FAO, 2010). The equation estimates capacity of a reservoir by assuming a reservoir to be a pyramid whose base is the water surface, other than being the dam wall. Apart from being recommended for Zimbabwe, the method has also been proved valid and is also used in Malawi (Kambuku, 2010).

Evaporation from reservoirs was calculated using the equation

$$EV = \frac{2}{3}\frac{RA_{max}E}{1000} \tag{5}$$

where EV is the volume of water evaporated (m^3), E is the open water evaporation (mm), RA_{max} is surface area of the reservoir at full supply level (m^2) (Kambuku, 2010). A relationship between evaporation from a calibrated standard (Class 'A') open pans installed at the site and evaporation from the reservoir was established to verifiably quantify the water loss from the reservoir, as the season progressed. The pans were calibrated with $E_{pan}/E_{reservoir}$ ratio for small reservoirs of 0.7.

Reservoir water, crop water requirement

The volume of water in the reservoir was equated to the seasonal field crop water use. This was related to actual and potential water use yields. Reservoir water balance (ΔC) was based on losses due to seepage, evaporation and livestock consumption. The reservoir water volume balance (after losses through evaporation and seepage, and abstraction by livestock, up to crop harvest week) divided by total seasonal crop water requirement over a hectare provided the total area (ha) the reservoir water could irrigate. The foregoing relationship in turn established optimum sizing of either area or reservoir for maximizing crop productivity based on the runoff generating catchment attributes and climatic conditions. The procedure is supported by the NCEA (2012) after conducting a number of research projects. The reservoir water balance due to irrigation was hence calculated by:

$$C = I \times (Ni) \tag{6}$$

where, I is application rate (m^3/week) and Ni is the number of applications per week, for weekly applications of 5 cm at different ΔC values. Quantification of the reservoir balance in line with water use was achieved using the water balance equation

$$\Delta C = IV + P - E - Q - GW - I \tag{7}$$

where, ΔC is new water balance, IV is balance from previous week, P is precipitation = 0, E is evaporation, Q is surface runoff = 0 during the dry season, and GW is seepage. All measurements in the equation were in millimeters.

Crop yield and crop-water productivity

A common method of 'water can' irrigation was used. A relationship between applied water and bean water productivity *(P)* was established,

$$P = Y/W \tag{8}$$

where P = Crop water productivity (kg yield/volume of water), Y = grain yield (kg), W = unit of applied water (L). Grain yield was determined as weight per hectare basis at 14% grain moisture content.

RESULTS AND DISCUSSION

Areal rainfall consistency and homogeneity tests

Following regression between the measured gauge rainfall means and the Thiessen computed means the following linear equation was established, which enabled the prediction of areal rainfall from the data,

$$Y = 1.616X - 0.0386 \tag{9}$$

where, Y is the mean areal rain and X is the observed rainfall.

Rainfall-runoff analyses

Runoff into the reservoir is non-point; it is distributed into the reservoir by the whole catchment area from diverse points, is based on changing catchment land use and varies from year to year. The best way to measure runoff inflow to the reservoir, therefore, was to measure the change in the reservoir water capacity as the season progressed. The unimodal rainfall pattern in Ukwe area commences as heavy storms in December when the soil is dry and highly absorbent resulting to negligible runoff. Runoff relatively peaks up between January and February but again rescinds as the season progresses due to both vegetative cover and reduction in rain amounts. Relative analysis showed runoff trend following the magnitude of rainfall (Figure 2). This is the duration when runoff harvesting should be at its peak, that is, 20 to 70 mm/day of rainfall and 10 mm to 20 mm /day of runoff.

Regression between runoff and rainfall for Ukwe area, using runoff as a response variant and precipitation as fitted term constant is shown in Figure 3. There is strong positive relationship between precipitation and runoff with 95% confidence limit. The results indicate the relationship line within the Upper Limit (UL) and Lower Limit (LL) indicating the authenticity of the data sets, with the following relationship:

$$Q = 0.165P + 0.408 \tag{10}$$

The relationship demonstrates that without precipitation (P) in form of rain, annual surface (including stream) and subsurface mean flow rate feeding the reservoir is only 0.408 mm/day. For every 1 mm rainfall at Ukwe, 0.165 mm runoff is generated. This demonstrates vitality of rain

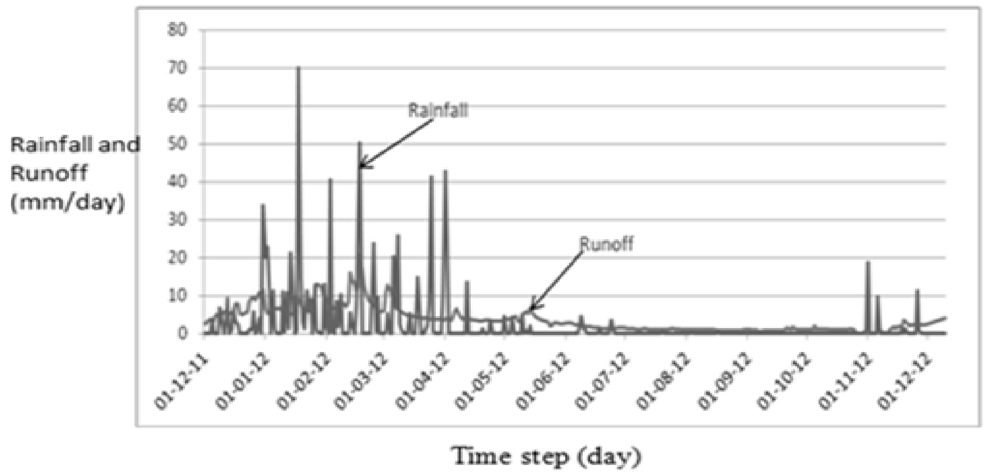

Figure 2. Relationship between rainfall and runoff.

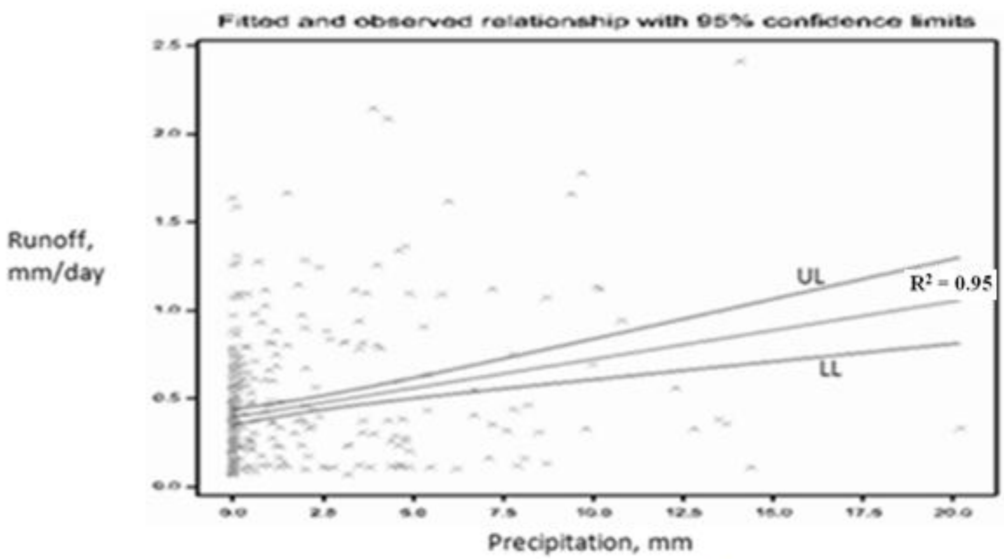

Figure 3. Regression between rainfall and runoff for Ukwe reservoir-catchment.

towards reservoir sustenance, and that there is a definite relationship between the frequency of rainfall occurrence and the magnitude of runoff. The catchment runoff to the reservoir comprised overland flow; interflow and groundwater flow from the upper and the lower aquifer. Overland flow runoff coefficient determined the extent to which excess rainfall run off as overland flow and the quantity that infiltrated, became groundwater inflow to the reservoir.

Figure 4 shows the results of rain intensity, infiltration rates and runoff obtained from the catchment based on highest and longest annual rainfall for the year 2012 for storm duration of 7 h (420 min). The intensity went up to 140 mm within 10 min before rescinding to 18 mm after 6 h. The soil became saturated, resulting in runoff within 3 min lasting 5 h. Runoff amount was almost four times that of infiltrated amount. This highlights the fact that drought prone areas can sometimes be flood prone as well and that under long duration high intensity rainfall, surface runoff start early and tails off late as rainfall intensity rescinds.

At the onset of a rainstorm rains in following hours of dry day or week the soil is dry and water absorbent hence high infiltration rate was evident. As the rainy storm progressed, infiltration rate decreased and surface run-off increased with increasing rain intensity. This was the time when effects of conservation measures and topography became crucial; more of the former increased

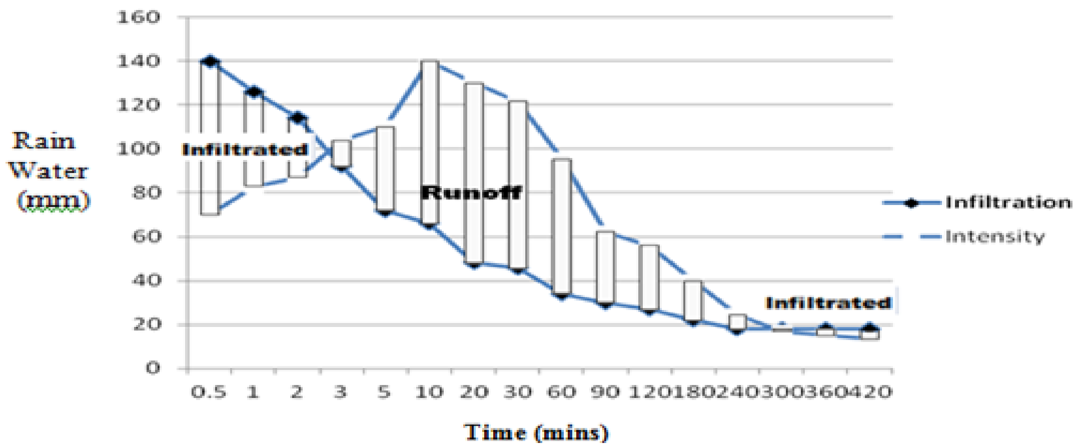

Figure 4. Rain intensity, infiltration and runoff at Ukwe.

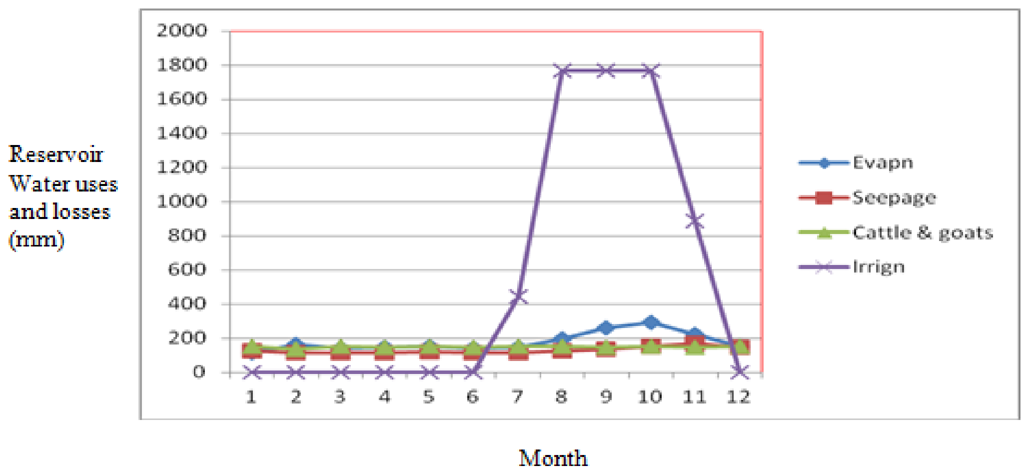

Figure 5. Reservior water abstraction and losses for the Mphetsankhuli reservoir.

infiltration and reduced run-off while it was vice-versa with the latter. The situation reverses again at the end of the storm, as the rain intensity declines.

Reservoir water

Reservoir evaporation and seepage

Onset of rains in October or November tended to make the reservoir more effluent. During the dry season, monthly evaporation rate from the reservoir was lower (150 mm) from April to August, when temperature was low and wind speed high, than from September to December (250 to 300 mm) when temperature was high and wind speed is low. This indicates that evaporative water loss from the reservoir in Malawi is more related to temperature than wind speed. Relationship between evaporation from calibrated standard (Class ‘A’) pan and reservoir confirmed a coefficient of 0.75 - the value helped in estimating evaporative losses from the reservoir. In addition to evaporation, contributors to the reservoir water balance were losses through deep seepage, consumption by cattle and goats and irrigation (Figure 5).

Seepage losses ranged from 150 mm per month in the rainy season (January - June) to as high as 200mm per month for the hottest month of November. Reservoir water seepage tended to be lower during the months of low rainfall, likely due to low hydraulic potential, demonstrating how influent the reservoir becomes as the dry season progresses. Seepage and evaporation intensities were both responsive to prevailing climatic conditions. Water consumption for livestock similarly picked-up (150 to 180 mm) during the hot dry season (August to November). The highest water withdrawal from the reservoir was by the dry season bean crop irrigators, that is, from 0 mm in June when the dry irrigation season commences to about 1750 mm per

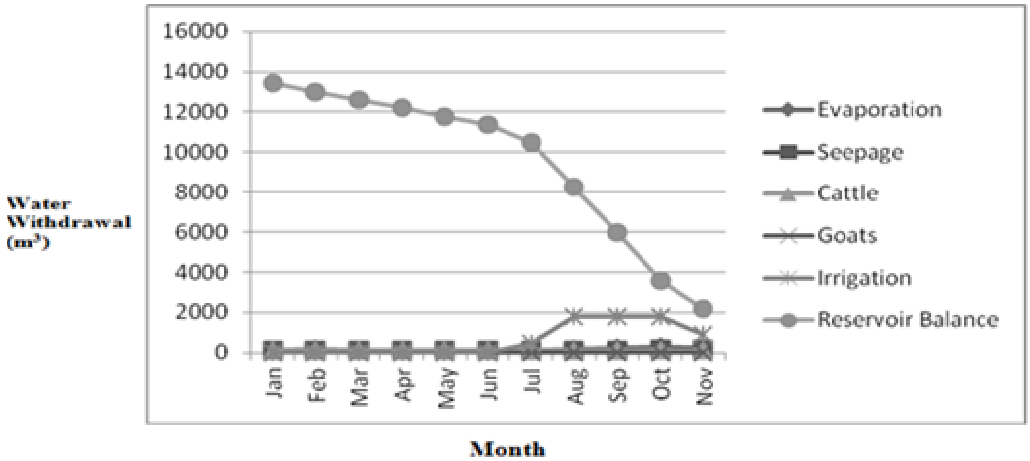

Figure 6. Monthly reservoir water balance, Mphetsankhuli Dam, Ukwe, 2013.

month during the peak irrigation months of August to November, before tailing-off end of the month as the unimodal rainfall commences. This needs to be taken into account, in reservoir water balance computation, based on the number and daily consumption by each animal (Ward, 2014). This is critical for reservoir sizing during dam construction or crop field sizing at the onset of dry season as it dictates weekly and monthly reservoir balance as season progresses (Figure 6).

Volume change was based on the weekly water amount that remained in the dam after deep ground losses and evapotranspiration. The amount gradually declined from about 13500 m^3 in January to about 10500 m^3 during non-irrigation season to about 2000 m^3 by end of November when irrigation ceases and temperature starts declining hence reducing evaporation and livestock water consumption.

Statistical crop yield analysis for three bean crop irrigation regimes, 2.5, 5.0 and 7.5 cm per week after pre-planting week application of 10 cm gave best biomass and grain yield from the 5 cm per week irrigation regime. Similar results had been reported by El-Tohamy et al. (2013). Results further indicated potential crop command field area of 1.5 ha with crop water productivity, which was 0.7 g/L, slightly lower than values of 1g/L reported from experiments elsewhere (Hashim et al., 2012).

Conclusion

The study has demonstrated that relatively runoff hydrograph responses follow the magnitude of rainfall but as the rainy season progressed the runoff rate is reduced by increasing catchment vegetative cover. Regression between the two factors augments the vitality of rain towards reservoir sustenance, and the definite relationship between the frequency of rainfall occurrence and the magnitude of runoff. It is illustrated that drought prone areas are sometimes flood prone as well.

During long duration rainfall, with high intensity, surface runoff starts early and tails off late as rainfall intensity rescinds. Hydrological researchers, such as Elsebaie (2012) also found strong relationship that exists between frequency and intensity of rainfall on one hand and magnitude of runoff on the other. Evaporative pressure from the reservoir is more influenced by rise in temperature than increase in wind speed. The proportion of water available for the crop, with respect to evaporative losses, is hence more during cool season than during the hot dry season. The reservoir water seepage tends to be lower during the months of low rainfall, likely due to low hydraulic potential, a demonstration of how influent the reservoir becomes as the dry season progresses.

Results have also demonstrated that through field measurements and computation verifications, it is possible to determine water reservoir capacities, irrigation water requirement and crop water productivity and potential crop command field area to be availed in Sub-Saharan drought prone areas.

Conflict of Interests

The authors have not declared any conflict of interest

ACKNOWLEDGEMENT

Special appreciation goes to the Regional Universities Forum for Capacity Building (RUFORUM), the International Development and Research Centre (IDRC) and Carnegie Corporation of New York, USA for research funding support. The technical and administrative guidance as well as fuel assistance by the Lilongwe University of Agriculture and Natural Resources is highly appreciated; also to all the Sokoine University of Agriculture and Total Landcare staff, who made contributions towards expected research achievement.

REFERENCES

Elsebaie IH (2012). Developing rainfall intensity – duration – frequency relationship for two regions in Saudi Arabia, J. King Saud Univ. Eng. Sci. 24(2):131-140.

El-Tohamy WA, El-Abagy HM, Badr MA, Gruda N (2013). Drought tolerance and water status of bean plants (*Phaseolus vulgaris* L.) as affected by citric acid application, J. Appl. Bot. Food Qual. 86:212-216

FAO (2010). Manual on Small Earth Dams, A Guide to Siting, Design and Costruction 64 Rome.

FAO (2014). Crop Water Information: http://www.fao.org/nr/water/cropinfo_bean.html Accessed: Feb. 16, 2015.

Hashim MAA, Shiam AA, Asl-Gaad KA, Patil VC, Tola EHM, Rangaswamy M, Samdany MS (2012). Determination of Water Requirement and Crop Water Productivity of Crops Grown in the Makkah Region of Saud Arabia, Australian J. Basic Appl. Sci. 6(9):196-206.

Ibraimo N, Munguambe P (2007). Rainwater Harvesting Technologies for Small Scale Rainfed Agriculture in Arid and Semi-arid Areas, Department of Rural Engineering, Faculty of Agronomy and Forestry Engineeng, Uni-versity Eduardo Mondlane, Mozambique.

Intermediate Technology Development Group (ITDG), Run off Rainwater Harvesting: the Path to Enhanced Livelihoods South Asia, Colombo and Sri Lanka. http://www.itdg.org/southasia. Accessed: February 15, 2015.

International Center for Agricultural Research in the Dry Areas (ICARDA) (2014). Supplemental Irrigation - More Crop per Drop. http://www.icarda.cgiar.org/tools/supplemental-irrigation. Accessed: Feb. 14, 2015.

Kambuku D (2010). Conjunctive use of small earth dams and boreholes for sustainable rural livelihood in a semi-arid area: Case of Lilongwe West Rural Groundwater Project area, Malawi.

Ministry of Agriture and Food Security, MAFS (2012). Guide to Agricultural Production and Natural Resources Management in Malawi, Lilongwe 3:132-136.

Mair A, Fares A (2012). Comparison of Rainfall Interpolation Methods in a Mountainous Region of a Tropical Island - Case Study, J. Hydrol. 10.1061/(ASCE)HE.1943-5584.0000330

Ministry of Irrigation and Water Development, MIWD (2011). Annual Report of Daily Runoff for Lingadzi at S111, 40502, 1959-2000. Water Department, Surface Water Division, Lilongwe, Malawi.

Mloza-Banda HR, Banda JW (2003). The agro-ecological role of *dambo* Ecosystems and Sustainable Livelihoods in Malawi. 19 – 58. In: Edriss AK (Ed) (2003). The Dynamics of Food Production Systems and Adoption of Technologies in a Village Economy: Case studies from Malawi. Bunda College of Agriculture Lilongwe, Malawi.

Njoloma MH (2009). Synchronizing Irrigation Development with Hydrology of the Local Catchment Areas by Use of Rainfall – Runoff Modelling in Lilongwe in Malawi, PhD Thesis, Tottori University, Japan.

Rosegrant MW, Svendsen M (1993). Asian Food Production in the 1990s. Food Policy 18(2):13-32.

Sawunyama T (2005). Estimation of Small Reservoir Storage Capacities in Limpopo River Basin Using Geographical Information Systems (GIS) and Remotely Sensed Surface Areas: A Case of Mzingwane Catchment, An MSC Thesis, Integrated Water Resources Management, Department of Civil Engineering, University of Zimbabwe.

Valipour M (2015). Assessment of Importance of Water Resource Management for European Agriculture, J. Water Resour. Hydraulic Eng. 4(2):171-180.

Valipour M (2013). Use of Surface Water Supply Index to Assessing of Water Resources Management in Colorado and Oregon, US. J. Adv. Agric. Sci. Eng. Res. Sci. Educ. Dev. Instit. 3(2):631-640.

Valipour M (2011). Variations of irrigated agriculture indicators in different continents from 1962 to 2011. J. Adv Water Sci. Technol. 1(1):01-14.

Ward D (2014). Water Requirement of, Poultry and Other Livestock, Min. of Agriculture, Food and Rural Affairs, Ontario, Canada. http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm#1