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Modelling rainfall runoff for identification of suitable water harvesting sites in Dawe River watershed, Wabe Shebelle River basin, Ethiopia

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Abstract

Scarcity of freshwater is one of the major issues which hinders nourishment in large portion of the countries like Ethiopia. The communities in the Dawe River watershed are facing acute water shortage where water harvesting is vital means of survival. The purpose of this study was to identify optimal water harvesting areas by considering socioeconomic and biophysical factors. This was performed through the integration of soil and water assessment tool (SWAT) model, remote sensing (RS) and Geographic Information System (GIS) technique based on multi-criteria evaluation (MCE). The parameters used for the selection of optimal sites for rainwater harvesting were surface runoff, soil texture, land use land cover, slope gradient and stakeholders' priority. Rainfall data was acquired from the neighbouring weather stations while information about the soil was attained from laboratory analysis using pipette method. Runoff depth was estimated using SWAT model. The statistical performance of the model in estimating the runoff was revealed with coefficient of determination (R^2) of 0.81 and Nash–Sutcliffe Efficiency (*NSE*) of 0.76 for monthly calibration and R^2 of 0.79 and *NSE* of 0.72 for monthly validation periods. The result implied that there's adequate runoff water to be conserved. Combination of hydrological model with GIS and RS was found to be a vital tool in estimating rainfall runoff and mapping suitable water harvest home sites.

Key words: *Geographic Information System (GIS), rainfall runoff, rainwater harvesting, soil and water assessment tool (SWAT), the Dawe River watershed, the Wabe Shebelle River basin*

INTRODUCTION

One of the utmost noteworthy natural resources that supports life, economy, and social development is water [Huang, Cai 2009; Ramakrishnan *et al.* 2009]. Water plays a key role for human beings, plants, animals and also for the functioning of the ecosystem. Africa and, particularly, in Ethiopia, the existing water resources are influenced by synthetic activities, urbanization, industrial use and irrigation, all of them are leading to freshwater dearth and food insecurity. Studies indicate that the global water consumption rate doubles as fast as the population [FAO 2015]. Hence, optimum and effective use and theoretically informed management of water is indispensable in the face of exponential rise in population and the aforementioned factors. Communities in semi-arid areas such as the Dawe River watershed, experience low and erratic rainfall which is unevenly distributed spatially and temporally. These results the recurrent droughts that affects the success of rainfed agriculture and general water availability in the area, coupled with high water demands mainly due to dynamic population growth [East Hararghe Irrigation Development Authority [2016]. This makes them vulnerable to insufficient water and often live under insecure livelihoods. Therefore, for such communities the ability and skills to effectively manage the resulting runoff by using rainwater harvesting methods is extremely important [MBILINYI *et al*. 2007].

Rainwater harvesting (RWH) is assumed to be one of the viable approaches to combat water shortage and it has been in use for thousands of years. It can be defined, in its broad sense, as all methods that ponder, stock up and collect effective runoff from rainwater [ROCKSTRÖM 2000]. It used either for surface water pondage or for ground water replenishment since this aid for sustainable water resources management [BAKIR, XINGNAN 2008].

Indeed, RWH is extremely valuable in addressing the water shortage challenge and it reduces groundwater abstraction or cropping risks yet increases crop production subsequently. Furthermore, harvested rainwater can be used to foster grassland, enhances afforestation, improves food insecurity, decrease top soil loss and erosion, and to improve the exploitation of freshwater. What's more, RWH is used to increase groundwater reserves which amplifies water potential and also boosts job opportunities or improves socio-economic situations [ADHAM *et al*. 2016a].

The two key determinant factors for effective use of RWH systems are whether optimal sites are selected and the nature of the technical design [AL-ADAMAT *et al*. 2012]. The identification of appropriate areas to harvest rainwater relies, in turn, on numerous factors [MAHMOUD, ALAZBA 2014], which can be grouped in two, namely biophysical and socio-economic. The former focuses on biophysical factors like precipitation, stream order, slope gradient, land use/cover, soil texture [KADAM *et al*. 2012; KUMAR *et al*. 2008], and the latter, however, focuses on integrating socio-economic factors (e.g., land tenancy, distance to settlement/streams/roads/agricultural area, population density) with the biophysical components [BULCOCK, JEWITT 2013; KROIS, SCHULTE 2014].

In estimating rainfall runoff, numerous hydrological models are available. Of these models, the soil and water assessment tool (SWAT) was applied in this research owing to its availability, convenience, friendly interface, and simple operation; it can be obtained from the official website [ABDO *et al*. 2009].

Integration of remote sensing (RS) and Geographic Information Systems (GIS) with hydrological model provides ideal tools for the simulation of surface runoff and peak discharge. RS can be used to deliver real data with high temporal and spatial resolution whereas GIS is a device for gathering, storing, and examining spatial and non-spatial data [MATI *et al*. 2006]. Also, it is advantageous in areas where there is scarcity of data, which is common in developing countries like Ethiopia [MAHMOUD 2014]. Hence, GIS and RS are valuable and time-saving approaches in identifying optimal water harvesting sites.

The present study endeavors to identify appropriate site for surface rainwater harvesting structures in Dawe River watershed by using SWAT model, RS data and GIS techniques. The results of this research can benefit decision makers as they establish water management plans for the watershed and also suggests areas for water harvesting in the conservation and better utilization of water for the people practicing the unplanned manner to store the water.

MATERIALS AND METHODS

STUDY AREA

Dawe River watershed is situated in middle the Wabe Shebelle River basin in the range of 41°44'34" E to 41°47'58" E longitude and 9°13'37" N to 9°26'39" N latitude in the eastern part of Ethiopia. Its area coverage is about 368 km^2 (Fig. 1). It is bordered by mountain and plateaus in its southern part. Higher mountains exist at the upper margin while there are low landforms at the lower. The altitude ranges from 1655 to 3358 m a.s.l. According to the Harmonized World Soil Database (HWSD) [DEWITTE *et al*. 2013], five soil types are distinguished in the watershed, namely chromic luvisols, eutric leptosols, humic nitosols, lithic leptosols and rendzic leptosols. The eutric leptosols cover the steep hilly slopes whereas chromic luvisols and rendzic leptosols are found on flat and milder slopes. The weather condition of the watershed is described by a humid to sub-humid with majority falling in sub-humid zone receiving a yearly average rainfall of 723.36 mm and 534 mm, respectively. The yearly average maximum and minimum temperatures are 27.14°C and 10.59°C, respectively with mean annual potential evaporation of 1962 mm.

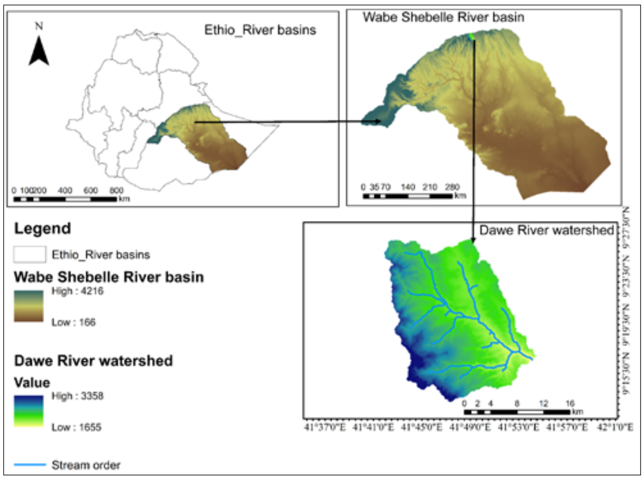

Fig. 1. Location and elevation map of study area;
source: own elaboration

DATASETS

In the present study, Landsat image, digital elevation models (DEM), soil type maps and climate data are extracted to be used for assessing runoff evaluation and water harvesting practices. Landsat imaging is used to express the land use and land cover maps. The Landsat 8 are acquired from the United States Geological Survey (USGS) website with geo-reference to UTM zone 37, WGS 1984, and was taken in April 2019 with a 30 m resolution. It is processed using ERDAS IMAGINE 14 software. DEM's generate drainage layer, slope, and topographic maps. The soil map is expressed by the texture, colour, and by its depth. The daily meteorological data are delivered by the Ethiopia Meteorological Agency for the years 1992 to 2013 as measured by four meteorological stations.

METHODS

The key parameters used in selecting optimal water harvesting areas are surface runoff, soil texture, land use and land cover, slope gradient and socioeconomic data [FAO 2003; Frasier, Myers 1983]. These were done using multi criteria evaluation (MCE) process for suitability site analysis [Eastman *et al*. 1995]. Accordingly, during the survey work in the watershed, formal and informal discussions with farmers and community representatives were done to gather information (suitable water harvesting site) and to consider the interest of stakeholders' priority.

Field-level soil samples data for soil texture mapping were collected from catchment and was determined in the laboratory using pipette method [Martin 1993]. This is based on direct sampling of the density of the solution. The analyses were conducted at Haramaya University central laboratory. In addition, to adjust the meteorological data for further analyses, the missing values were filled using arithmetic mean method [McCuen 2004], and the consistency and homogeneity of rainfall was checked by double mass curve technique [Subramanya 1998] and by standard normal homogeneity test using XLSTAT (ver. 2019.1) software respectively. Theissen polygon method is used to estimate areal rainfall. Four stations of rainfall within the vicinity of the boundary of the watershed were used for areal rainfall estimation. ArcGIS 10.5 was used to combine and analyse the parameters as a part of the procedure for determining the site of potential runoff areas and the appropriate locations for runoff water harvesting. Also, soil and water assessment tool (SWAT) model was used to estimate runoff depth in the study catchment. Figure 2 indicates the methodological flow chart to detect suitable site for harvest rainwater.

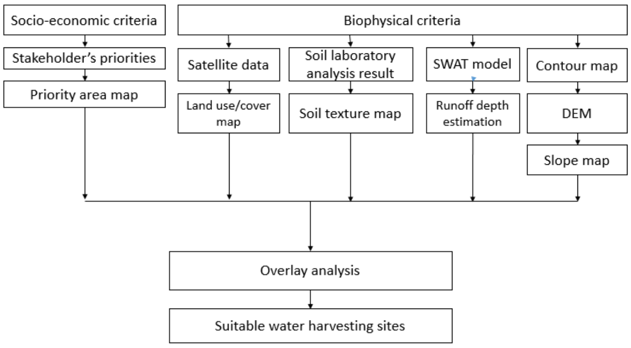

Fig. 2. Methodological flow chart for identifying the suitable runoff water harvesting sites; SWAT = soil and water assessment tool, DEM = digital elevation model; source: own elaboration

Data input and processing

Land slope gradient. The slope gradient is a crucial parameter in identifying the best site for water harvesting. It influences exhaustively the value of the time of concentration and directly, the runoff and its speed of flow, sedimentation and recharge [Adham *et al*. 2016b; Prinz *et al*. 1998]. Critchley *et al*. [1991] and FAO [2003] revealed that the areas with slopes of greater than 5% were not apposite to harvest rainwater as they are vulnerable to high soil erosion rates. Hence, slope map was generated with 30-m resolution DEM (Fig. 3a) and were classified to develop the map (Fig. 3b).

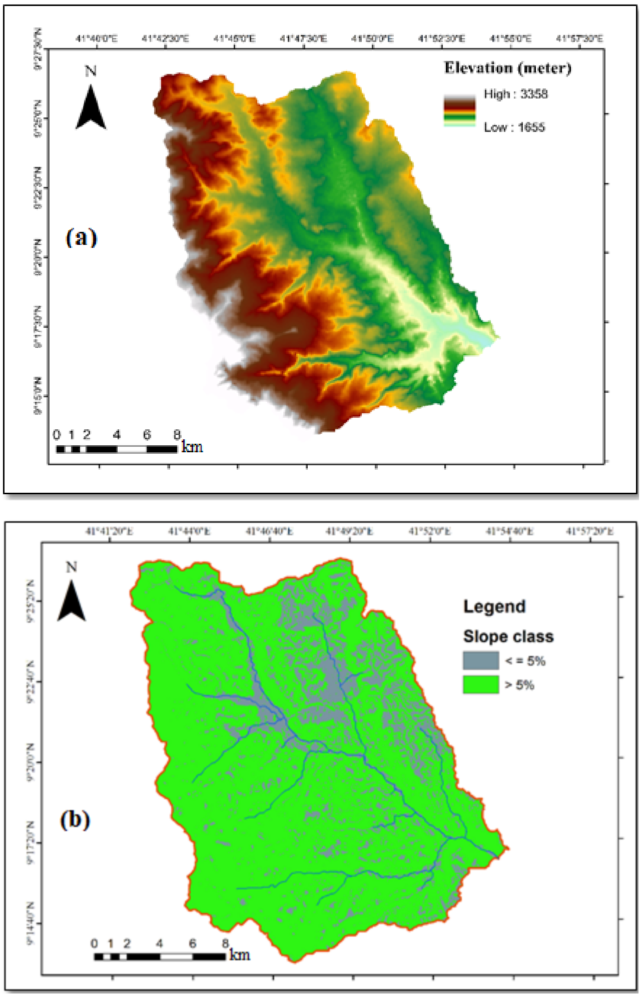

Fig. 3. Elevation (a) and slope class (b) map for suitable water harvesting site selection; source: own elaboration

Soil textural map. Soil texture affect overland flow by affecting the rate of infiltration. Generally, medium to fine scale textural soil are more appropriate for RWH due to their high water retention capacity Mbilinyi *et al*. [2007]. Adham *et al*. [2016b] also indicates soils with less infiltration rate are more suitable for RWH. Soils with high clay content are preferable for water storage because of impermeability of clay and its capacity to retain the collected water, especially if the aim is to pond the water for domestic and agricultural uses [Mbilinyi *et al*. 2007]. Based on laboratory analysis, soil texture revealed in the watershed is loam, clay loam, and sand clay loam across the horizons. Hence, soil texture mapped as shown in Figure 4.

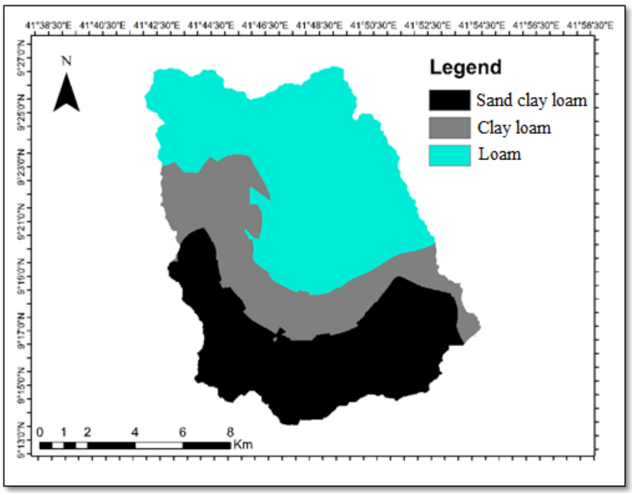

Fig. 4. Map of soil texture for suitable water harvesting site selection; source: own elaboration

Land use and land cover (LULC). The land use and land cover of a catchment influences runoff and is a key parameter to selection appropriate water harvesting sites. For instance, surfaces with denser land cover is associated with higher rates of interception and infiltration and thus have lower runoff [KAHINDA *et al*. 2008]. Seven major LULC types have been identified: agricultural land, shrub land, grazing and forest land, bare land, water body, and settlement (Fig. 5).

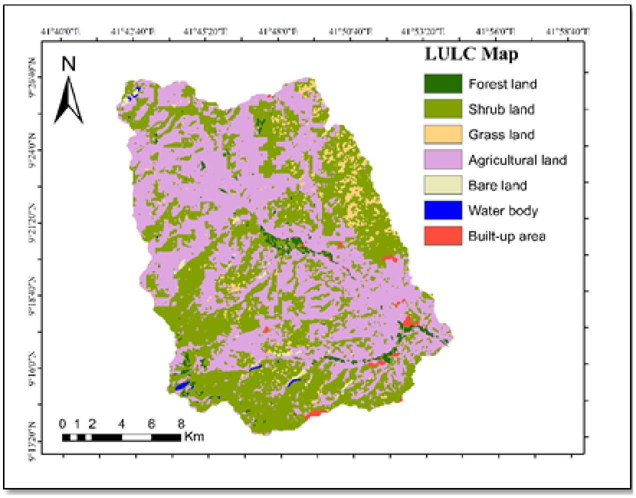

Fig. 5. Land use land cover (LULC) map for suitable water harvesting site selection; source: own elaboration

Stream order. The spatial analysis tools were developed to produce the stream order map based on the DEM data mainly in order to identify hydrological parameters. Surface water is the prime source of water in the watershed. During short rainy season, collecting water is vital for domestic, and other purposes. The stream order refers to the hierarchical linking between the flow sections and allows the drainage basins to be classified based on their size. Its arrangement depends on the linkage of tributaries. Additionally, for mapping RWH, order analysis is important and, hence, conducted because the higher stream orders have lower absorptivity and infiltration. The map of stream order is indicated in Figure 6.

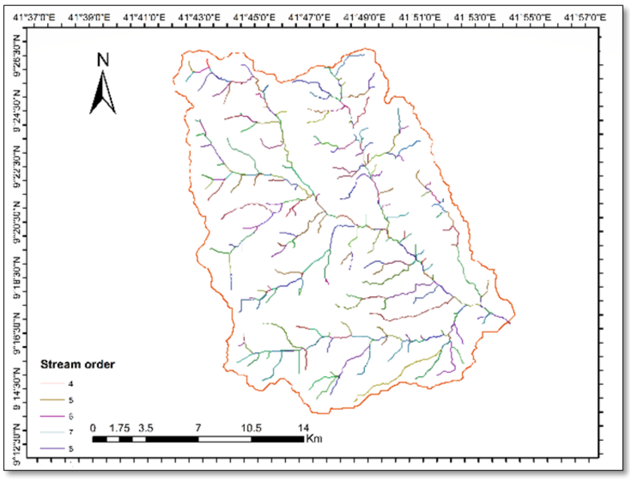

Fig. 6. Stream order map for suitable water harvesting site selection; source: own elaboration

Stakeholders' priority. The community representatives inhabiting in the catchments were participated in selecting sites of rainwater harvesting considering their own criteria and interest. They follow the criteria like distance to settlement/farming area/animal stocking, land tenure, possibility of river diversion and existence of overflow water. This coincides with FAO [CRITCHLEY *et al*. 1991] which report that stakeholders' priority is a significant parameter in identifying sites to conserve rainwater. The selected sites by the representative is delineated and mapped in Figure 7 as suitable, moderately suitable and not suitable.

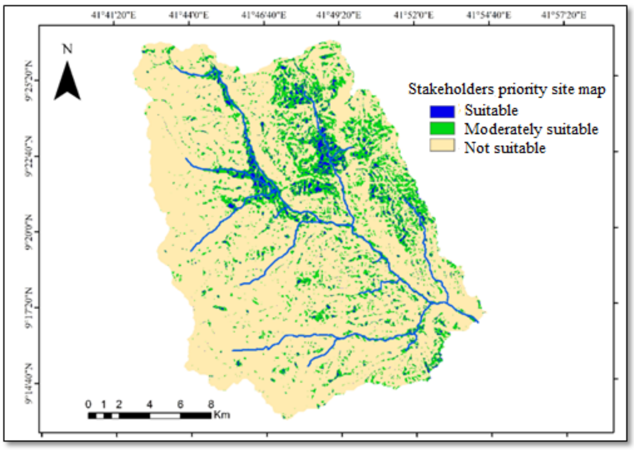

Fig. 7. Stakeholders' priority water harvesting site map in the study area; source: own elaboration

Surface runoff depth estimation. Surface runoff depth is another significant key parameter in identifying optimal sites for rain water harvesting. Potential water supply during runoff is assessed using runoff depth. Runoff depth was estimated using soil and water assessment tool (SWAT) hydrological model. SWAT is a physically-based model for continuous estimation of discharge, sediments, and nutrients on daily/sub-daily basis. It divides the watershed into sub-watersheds, which are made from drainage patterns using DEM, and defines the minimum drainage area to form a stream by using a threshold value. These sub-watersheds are further divided into hydrologic response units (HRUs).

Accordingly, the modelled hydrological processes were discretized into land phase and channel courses. The land phase was estimated on the HRU level and summed up for each sub-watershed in order to determine the overall water balance with the combination of climate station data and the channel courses [Neitsch *et al.* 2011]. A comprehensive picture of the model is described by Arnold *et al.* [2012; 2000] and Neitsch *et al.* [2011].

SWAT model setup. In SWAT model, the watershed is divided into various small sub-watersheds, which are then discretized into HRUs as per Arnold *et al.* [2012] (Tab. 1). Land use/land cover and soil area thresholds can be used that assured the number of HRUs in individual sub-watershed. Thus, threshold value as a default values of the model were used for land use (20%), soil (10%) and slope (20%) respectively [Winchell *et al.* 2009]. These values resulted 25 sub-watersheds and 321 HRUs. Flow accumulation is summed through all HRUs in sub-watersheds, and the resulting value are then flow through channels, and reservoirs to the catchment outlet.

Table 1. Spatial coverage of different soil types, land use land cover (LULC) types, and slope classes of the study area after defining the hydrologic response units (HRUs)

Specification	Proportional area (%)
LULC types (2019s land use)	
Agricultural land	48.00
Shrub land	33.02
Grass land	8.50
Forest land	6.50
Bare land	0.98
Water body	1.40
Built-up area	1.60
Soil types	
Chromic luvisols	33.93
Eutric leptosols	24.46
Humic nitosols	1.36
Lithic leptosols	0.04
Rendzic leptosols	40.21
Slope classes (%)	
0–5	30.15
5–10	27.26
10–15	17.78
15–20	11.47
>20	13.34

Source: own elaboration.

For this analysis, Penman–Monteith approach [Monteith, Moss 1977] was used to determine the potential evapotranspiration using meteorological data like: maximum and minimum temperature, relative humidity, wind speed and solar radiation. Also, in order to carry out the model result, and thus to realize its performance in the watershed, 26 flow sensitivity analyses parameters were done.

Soil Conservation Service (SCS) curve number technique [SCS 1972] were used to determine surface runoff and infiltration for this study. Sequential Uncertainty Fitting version-2 (SUFI-2) algorithm in SWAT-CUP (ver. 5.1.6.2) as per Abbaspour *et al.* [2015]; Arnold *et al.* [2012] within Arc SWAT 2012 (revision 664) was used to calibrate and validate using Latin Hypercube sampling simulations.

As indicated in Table 2 Nash–Sutcliffe efficiency (*NSE*) was selected as objective function [Nash, Sutcliffe 1970]. Another criterion to evaluate the quality of the model were coefficient of determination (R^2) Table 2 [Gupta *et al.* 1999]. Global sensitivity design method was used in SWAT-CUP built-in tool. Indices such as *t*-test and *p*-value were used to bring a measure and significance of sensitivity, respectively [Abbaspour 2015]. The higher *t*-test in absolute values brings high sensitivity while a *p*-value of 0 is more significant.

Table 2. Performance indicators of model streamflow simulations

Formula	Name of indicator	Simulation value
$R^2 = \frac{(\Sigma[X_i - X_{av}][Y_i - Y_{av}])^2)}{\Sigma[X_i - X_{av}]^2 \Sigma[Y_i - Y_{av}]^2}$	regression coefficient	1
$NSE = 1 - \frac{\Sigma[X_i - Y_i]^2}{\Sigma[X_{av} - Y_{av}]^2}$	Nash–Sutcliffe efficiency coefficient	1

Explanations: R^2 = linear regression coefficient between observed and simulated data; X_i and Y_i = the observed and simulated discharge values, respectively, X_{av} and Y_{av} = the mean of observed and simulated discharge values.
Source: own study

DETERMINATION OF RELATIVE WEIGHTS AND SUITABILITY FOR RAINWATER HARVESTING SITES

Determining relative weights for each criterion

After surface runoff depth amount using SWAT model was estimated in line with other indicated parameters, all processes for the creation of a suitable rainwater harvesting map were applied in a suitability model developed in ArcGIS 10.5. The suitability model creates rainwater harvesting compatibility maps by merging different criteria using a weighted linear combination process [Hopkins 1977; Malczewski 2000]. The weight linear combination is a widely used multi-criteria evaluation process for suitability site analysis [Eastman *et al.* 1995]. This model includes the standardization of suitability maps, the weighting of the comparative significance of suitability maps, and the merging of weights and uniformity maps to achieve a suitability value [Al-Hanbali *et al.* 2011].

In selecting optimal water harvesting sites, all parameters are not considered equally the same. Several methods are suggested for the determination of these weights. A pair wise comparison method, mostly known as analytic hierarchy process (AHP) is the commonly used and hence has been adopted for this study. It involves the evaluation of each criterion against each other criteria and this is done in pairs to identify which criterion is more substantial than the other for a given objective [Drobne, Lisec 2009].

The parameters like runoff depth, slope, stakeholders' priority, soil texture, stream order, land use/cover were assigned weights on a scale of 1 to 9 [Drobne, Lisec 2009]. While assigning the weights, the influence of each factors on the suitability of rainwater harvesting was considered.

Table 3. Pairwise comparisons among parameters for rainwater harvesting

Criterium/factor	Runoff depth	Slope	Stake holders priority	Soil texture	Stream order	LULC	Weight
Runoff depth	1.00	2.00	3.00	4.00	5.00	6.00	0.38
Slope	0.50	1.00	2.00	3.00	4.00	5.00	0.25
Stake holders priority	0.33	0.50	1.00	2.00	3.00	4.00	0.16
Soil texture	0.25	0.33	0.50	1.00	2.00	3.00	0.10
Stream order	0.20	0.25	0.33	0.50	1.00	2.00	0.07
Land use	0.17	0.20	0.25	0.33	0.50	1.00	0.04

Explanation: LULC = land use land cover.
Source: own elaboration.

Once the weights of the six parameters were finalized, pairwise comparison matrices of the assigned weights were constructed using the AHP method. The consistency ratio of the study was three percent, which is less than ten percent and thus shows that the comparison between the parameters is acceptable. The pairwise comparison matrix for identifying rainwater harvesting (RWH) sites and the weight of each criterion are shown in the Table 3.

Then, perception of weighted averages in the model, and reliable relationship is prepared by multiplying the weight of the factor as indicated in Equation (1):

$$S = \sum Wn\, Xn \tag{1}$$

Where: S = suitable site, Wn = weighting of factor n, Xn = the relationship value of criteria n.

Determining suitability for each criterion

Site selection is the most significant activity in planning and implementing a successful surface RWH. It should be appropriate on both biophysical and socio-economic grounds. Tab. 4 shows the suitability level for each parameter affecting rainwater harvesting sites for this study. The suitability level was nominated based on literature review, expert judgment and local knowledge experiences. This site selection analysis approach considered FAO guidelines for both socio-economic and biophysical to select successful RWH sites.

Table 4. Criteria, classification, suitability levels, and scores for each criterion for identifying suitable sites of RWH

Criteria	Class	Value	Score
Runoff depth (mm)	Suitable	60–70	4
	moderately suitable	80–90	8
	not suitable	<50	1
Slope (%)	Undulating	<5	9
	Hilly	>5	1
Land use/cover	farmland and grass	very high	9
	moderately cultivated	high	7
	bare soil	medium	5
	Mountain	low	1
	water body, urban area	restricted	restricted
Soil texture	high suitability (loam)	>20	7
	moderately suitability (clay loam)	11–15	4
	low suitability (sandy clay loam and sandy loam)	8–11	3
Stream order	high suitability	7	8
	medium suitability	6	3
	very low suitable	<4	1

Source: own elaboration based on: ADHAM *et al*. [2018].

RESULTS AND DISCUSSION

CALIBRATION AND VALIDATION OF SWAT MODEL

The Dawe River watershed streamflow gauged near Gara Muleta was used to calibrate SWAT model for a period of ten years (January 1, 1995 to December 31, 2005) using SWAT-CUP. In the model setup, this study tracked calibration techniques given by ARNOLD *et al*. [2012] and ABBASPOUR *et al*. [2015], by observing the model parametrization within the requirements of stinginess [BEGOU *et al*. 2016]. The hydrograph (Figs. 8, 9), and the model performance analysis in Tables 5 and 6 all shows a good performance for the simulation period and consistent with the study of MUTENYO *et al*. [2013]. But, some points are not captured well, and for some years the streamflow is overvalued e.g., 2005 in Figure 9 due to rise of rainfall during main rainy season. This brings to the slightly lower NSE (Tab. 6) related to the other evaluation criteria due to the sensitivity of the NSE to high runoff as indicated by MA *et al*. [2008]. The model calibration and validation for monthly flow in Figure 8 shown a good fit among measured and simulated results. Depend on the *p*-value and *t*-test (Tab. 5), which indicates the significance of surface runoff for the watershed, six most sensitive parameters are ranked chronologically and related to runoff. The remaining two affects the base flow generation. These parameters are characteristically used in SWAT to calibrate base flow, which was confirmed by ABBASPOUR *et al*. [2015]. Also, these parameters, which mostly govern the existence (Gwqmn), and recession (Gw_Delay) were calibrated within the default ranges depicted in SWAT-CUP. Therefore, it was revealed that the model showed strong performance in indicating the hydrological phenomena of the watershed.

The study found that 47 and 59.9% of runoff watershed was base flow respectively for both measured and simulated flow. This result is consistent with GEBRE *et al*. [2016] which indicated that on a yearly basis, 45.2–52.0% of runoff from the watershed was base flow for measured and simulated flows.

Spatially, the variability of each sub-watershed (SW) runoff rate is shown in the Figure 10 and average annual watershed was estimated 863 mm for the indicated years. As shown in the Figure 10 the maximum rate of runoff was occurred at the north-eastern and central part of the watershed at SW2, SW8, SW9, SW10, SW12, and SW18, whereas the minimum runoff had mainly occurring at the southern part of the watershed at SW22, SW23, SW24, and SW25 for the corresponding period. Clay loam was the

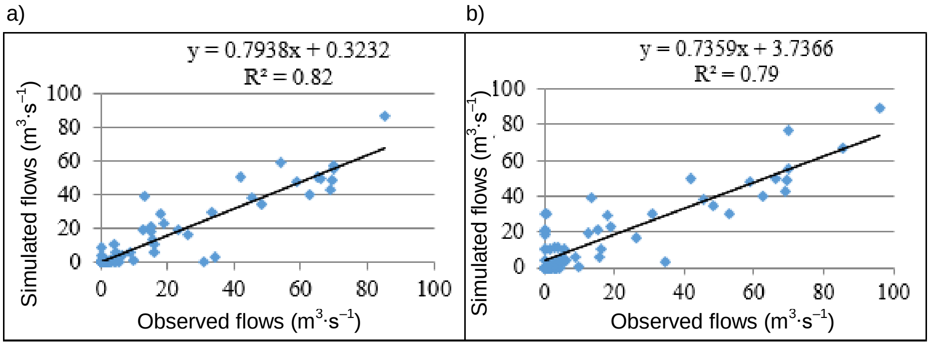

Fig. 8. Scatter plot of simulated versus observed flow monthly: a) calibration, b) validation; source: own study

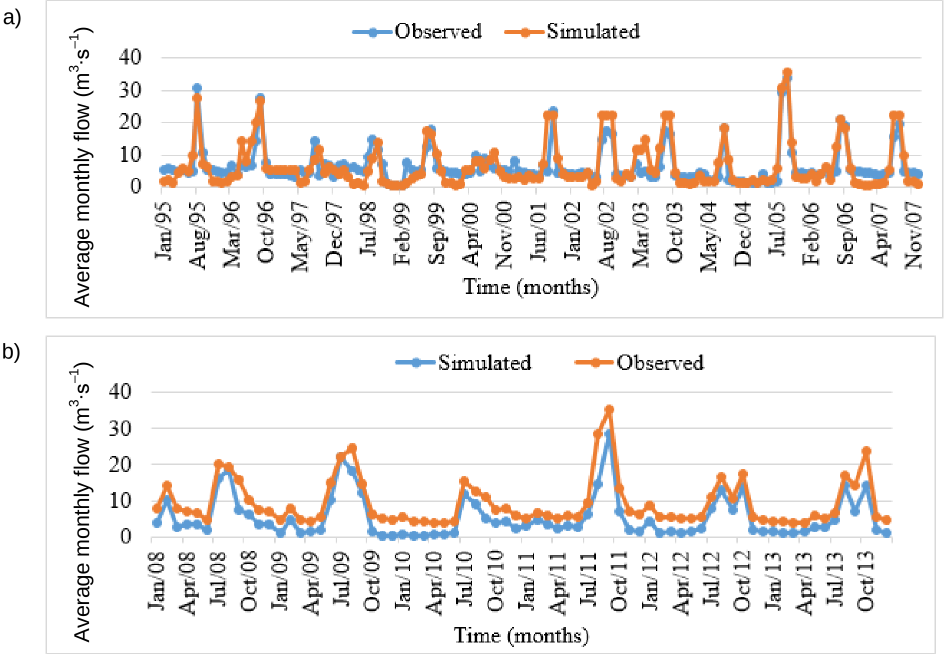

Fig. 9. Observed and simulated daily runoff in comparison with areal rainfall for Dawe River watershed for: a) calibration, b) validation periods; source: own study

Table 5. Ranking of the calibrated parameters, according to their sensitivity and significance

Rank	Parameter	Description	*t*-test	*p*-value	Final range	Method[1)]
1	R_CN2.mgt	SCS runoff curve number for moisture condition II	–44.020	0.00	–0.20–0.2	r
2	R_OV_N.hru	Manning's "*n*" value for overland flow	13.432	0.00	0.01–300	v
3	ESCO.hru.	soil evaporation compensation factor	–4.080	0.00	0.01–1.00	v
4	SOL_AWC ().sol	available water capacity of the soil layer (mm H_2O per mm of soil)	3.898	0.0076	–0.20–0.20	r
5	SOL_Z().sol	depth from soil surface to bottom of layer (mm)	2.612	0.069	–25.00–25.00	r
6	Surlag.bsn	surface runoff lag coefficient	–1.362	0.086	0.05–23.00	v
7	SOL_K().sol	saturated hydraulic conductivity (mm·h^{-1})	1.136	0.840	0.4–0.7	r
8	Gw_delay.gw	groundwater delay time (days)	0.814	0.984	0.00–10.00	v
9	Gwqmn.gw	threshold depth of water in the shallow aquifer for return flow to occur (mm)	–0.519	1.289	0.00–4000.00	v

[1)] A "v" in method implies a replacement of the initial parameter value with the given value in the final range, whereas an "r" indicates a relative change to the initial parameter value.
Source: own study.

Table 6. Summary of the model performance analysis for the calibration and validation period

Criteria	Calibration (1995–2007)	Validation (2008–2013)
Coefficient of determination (R^2)	0.82	0.79
Nash–Sutcliffe efficiency (*NSE*)	0.77	0.73

Source: own study.

major dominant soil type in the area where the maximum runoff was occurred; while in the case of sand it was lowest. According to ADHAM *et al.* [2018] and MBILINYI *et al.* [2007] clay loam is characterized as depth in soil, higher water holding capacity, moderate drainage and having ground water at shallow depth.

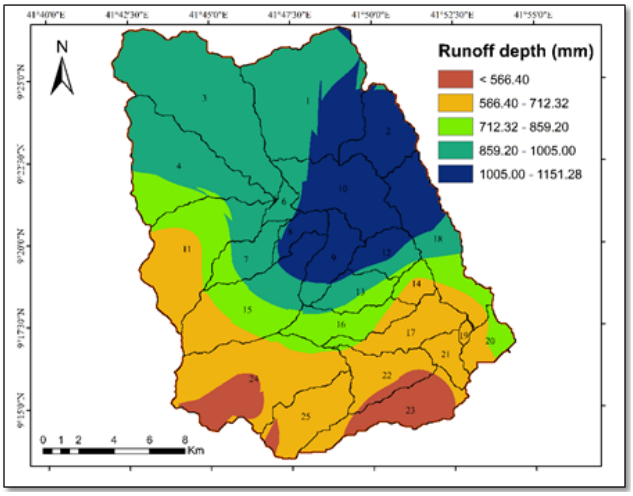

Fig. 10. Spatial distribution of runoff in the study area;
1–25 = sub-watersheds (SW); source: own study

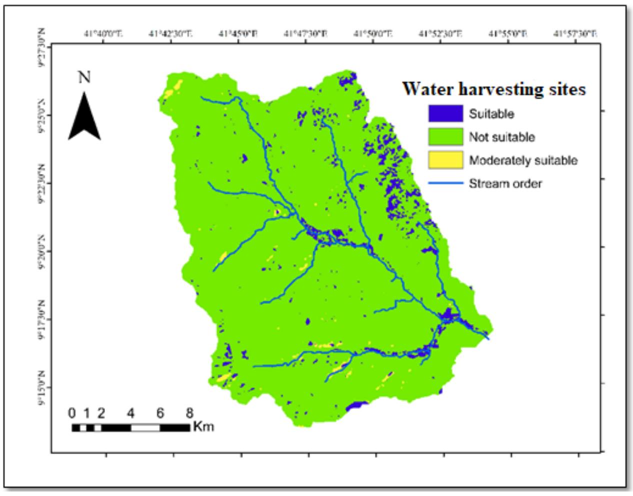

Fig. 11. Suitable water harvesting site map of the study area;
source: own study

SUITABLE SITES FOR HARVESTING RAINWATER

The study conducted by preparing all input data required in identifying suitable sites for RWH viz. slope gradient, soil texture, surface runoff depths, LULC map and stakeholders' priority. The appropriate site for RWH was specified using GIS and RS in combination with SWAT model and multi-criteria evaluation (MCE) by considering six thematic layers. In the study process, satellite image and a 30-m DEM pixel were used to generate the key parameters with their spatial analysis as shown in the Figures 3, 4, 5, 6, 7 and 10. Seven land use types were identified; of this agricultural land covers 48% of the study area. Bare land and water bodies covers slight percentage of the watershed (Fig. 5).

The slope gradient is a key limiting factor to RWH. The slope of the study area (Fig. 3b) has been classified into three classes, as nearly flat (0–3%), milder slope (3–5%), steep slope (>5%). The relation between surface runoff and slope were found out that increment of surface runoff with slope were revealed in the Figs. 3b and 10 and rugged area of the watershed relies in the range of steep slope. At the central to north-eastern part of the watershed, high accumulation of surface runoff depth was shown (Fig. 10). The places with a milder slope is essential for rainwater harvesting.

Three comparable class are used as indicators for suitable areas for water harvesting suitability: suitable, moderately suitable, and not suitable as shown in Figure 11. These results indicate that some of the central and North Eastern stream part of the study area was suitable for RWH site which had milder slopes and number of tributaries. This ranges texturally between loam and clay loam, and the surface runoff depth within 712.32 to 1151.28 mm. Among the six key parameters, slope gradient and surface runoff depth are essential factor in identifying suitable to moderately suitable RWH areas. These findings are consistent with ADHAM *et al*. [2018] which shown that, RWH site are suitable for areas with milder to moderate slopes joint with soil texture which have a high water-retaining, for instance clay and clay loam.

Beside biophysical factors, stakeholders' priorities are other key parameters used to identify rainwater harvesting sites. These can be influenced by the parameters like settlement and agricultural area. Certain sites were not considered in suitable water harvesting area map even though they were chosen by community representative because of technical aspects. As a result, the integration of biophysical with stakeholders' priorities criteria are the most significant for enhancing the optimality of RWH schemes and developing future water storage sites.

CONCLUSIONS

The communities in the Dawe River watershed are facing acute freshwater water sources. This is mainly due to unpredictable rainfall. Hence, the study strives to identify possible areas for conserving rainwater. In this study, suitable rainwater harvesting areas were selected by applying SWAT model, GIS and remote sensing techniques. The key parameters considered in the study are soil texture, LULC, slope gradient, surface runoff depth, stakeholders' priorities and stream order. Multiple criteria evaluation which acquired by means of weighted linear combination of dependable approaches were used to evaluate the plans for suitable rainwater harvesting.

The finding indicates that, central and north-eastern stream part of the study area was suitable for rainwater harvesting site which had milder slopes and number of tributaries. This ranges texturally between loam and clay loam, and the surface runoff depth within 712.32 to 1151.28 mm. The outcomes verified that suitable to moderately suitable sites cover from central to north-eastern part of the watershed. And also, it available at some corners of the study area.

The result implied that there's sufficient runoff water to be ponded. Combination of SWAT hydrological model with GIS and RS was found to be a vital tool in estimating rainfall runoff and mapping suitable rainwater harvesting sites.

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REFERENCES

ABBASPOUR K. C., ROUHOLAHNEJAD E., VAGHEFI S., SRINIVASAN R., YANG H., KLØVE B. A. 2015. Continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. Journal of Hydrology. Vol. 524 p. 733–752. DOI 10.1016/j.jhydrol. 2015.03.027.

ABDO K.S., FISEHA B.M., RIENTJES T.H.M., GIESKE A.S.M., HAILE A.T. 2009. Assessment of climate change impacts on the hydrology of Gilgel Abay catchment in Lake Tana basin, Ethiopia. Hydrological Processes. Vol. 23 p. 3661–3669. DOI 10.1002/hyp.7363.

ADHAM A., RIKSEN M., OUESSAR M., RITSEMA C. 2016a. Identification of suitable sites for rainwater harvesting structures in arid and semi-arid regions: A review. International Soil and Water Conservation Research. Vol. 4. Iss. 2 p. 108–120. DOI 10.1016/j.iswcr.2016.03.001.

ADHAM A., RIKSEN M., OUESSAR M., RITSEMA C.J. 2016b. A methodology to assess and evaluate rainwater harvesting techniques in semi-arid regions. Water. Vol. 8. Iss. 5 p. 198–221. DOI 10.3390/w8050198.

ADHAM A., SAYL K.N., ABED R., ABDELADHIM M.A., WESSELING J.G., RIKSEN M., FLESKENS L., KARIM U., RITSEMA C.J. 2018. A GIS-based approach for identifying potential sites for harvesting rainwater in the Western Desert of Iraq. International Soil and Water Conservation Research. Vol. 6. Iss. 4 p. 297–304. DOI 10.1016/j.iswcr.2018.07.003.

AL-ADAMAT R., ALAYYASH S., AL-AMOUSH H., AL-MESHAN O., RAWAJFIH Z., SHDEIFAT A., AL-HARAHSHEH A., AL-FARAJAD M. 2012. The combination of indigenous knowledge and geo-informatics for water harvesting siting in the Jordanian Badia. Journal of Geographic Information System. Vol. 4. No. 4 p. 366–376. DOI 10.4236/jgis.2012.44042.

AL-HANBALI A., ALSAAIDEH B., KONDOH A. 2011. Using GIS-based weighted linear combination analysis and remote sensing techniques to select optimum solid waste disposal sites within Mafraq city, Jordan. Journal of Geographic Information System. Vol. 3. No. 4 p. 267–278. DOI 10.4236/ jgis.2011.34023.

ARNOLD J.G., MORIASI D.N., GASSMAN P.W., ABBASPOUR K.C., WHITE M., SRINIVASAN R., SANTHI C., HARMEL R.D., VAN GRIENSVEN A., VAN LIEW M.W., KANNAN N., JHA M.K. 2012. SWAT: Model use, calibration, and validation. Transactions of the ASABE. Vol. 55. Iss. 4 p. 1491–1508. DOI 10.13031/ 2013.42256.

ARNOLD J.G., MUTTIAH R.S., SRINIVASAN R., ALLEN P.M. 2000. Regional estimation of base flow and groundwater recharge in Upper Mississippi River basin. Journal of Hydrology. Vol. 227 p. 21–40. DOI 10.1016/S0022-1694(99)00139-0.

BAKIR M., XINGNAN Z. 2008. GIS and remote sensing applications for rain water harvesting in the Syrian Desert (Al-Badia). Proceedings of the 12th International Water Technology Conference, March 2008. Alexandria, Egypt p. 73–82.

BEGOU J., JOMAA S., BENABDALLAH S., BAZIE P., AFOUDA A., RODE M. 2016. Multi-site validation of the SWAT model on the Bani catchment: Model performance and predictive uncertainty. Water. Vol. 8. Iss. 5, 178. DOI 10.3390/w8050178.

BULCOCK L.M., JEWITT G.P.W. 2013. Key physical characteristics used to assess water harvesting suitability. Physics and Chemistry of the Earth. Vol. 66 p. 89–100. DOI 10.1016/ j.pce.2013.09.005.

CARTER M.R. 1993. Soil sampling and methods of analysis. Boca Raton. Lewis Publishers. ISBN 9780873718615 pp. 823.

CRITCHLEY W., SIEGERT K., CHAPMAN C. 1991. Water harvesting. A manual guide for the design and construction of water harvesting schemes for plant production [online]. Rome. FAO. [Access 20.09.2019]. Available at: www.fao.org/docrep/u3160e/u3160e07.htm

DEWITTE O., JONES A., SPAARGAREN O., BREUNING-MADSEN H., BROSSARD M., DAMPHA A., …, ZOUGMORE R. 2013. Harmonization of the soil map of Africa at the continental scale. Geoderma. Vol. 211–212 p. 138–153. DOI 10.1016/ j.geoderma.2013.07.007.

DROBNE S., LISEC A. 2009. Multi-attribute decision analysis in GIS: Weighted linear combination and ordered weighted averaging. Informatica. Vol. 33. p. 459–474.

East Hararghe Irrigation Development Authority 2016. Participatory rural appraisal annual report of East Hararghe. [05.09.2019 Harar, Ethiopia]. [unpublished].

EASTMAN R.J., JIN W., KWAKU KYEM K.A., TOLEDANO J. 1995. Raster procedures for multi-criteria/ Multi-objective decisions. Photogrammetric Engineering and Remote Sensing. Vol. 61. No. 5 p. 539–547.

FAO 2003. Land and water digital media series, 26. Training course on RWH [CD-ROM]. Planning of water harvesting schemes, unit 22. Rome, Italy. Food and Agriculture Organization.

FAO 2015. Cities of despair – or opportunity? [online]. [Access 10.09.2019]. Available online: http://www.fao.org/ag/agp/greenercities/en/whyuph/

FRASIER G.W., MYERS L.E. 1983. Handbook of water harvesting. Washington DC. USDA, Agricultural Research Service. Handbook. No. 600 pp. 51.

GEBRE S.B., TENA A., MERKEL B.J., ASSEFA M.M. 2016. Land use and land cover change impact on groundwater recharge: The Case of Lake Haramaya watershed, Ethiopia. In: Landscape dynamics, soils and hydrological processes in varied climates. Ed. M.M. Assefa, A.Wossenu. 1st ed. Switzerland. Springer International Publishing p. 93–110.

GUPTA H.V., SOROOSHIAN S., YAPO P.O. 1999. Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. Journal of Hydrologic Engineering. Vol. 4. Iss. 2 p. 1093–1120. DOI 10.1061/ (ASCE)1084-0699(1999)4:2(135).

HOPKINS L.D. 1977. Methods for generating land suitability maps: A comparative evaluation. Journal of the American Institute of Planners. Vol. 43. Iss. 4 p. 386–400. DOI 10.5822/ 978-1-61091-491-8-30.

HUANG Y., CAI M. 2009. Methodologies guidelines: Vulnerability assessment of freshwater resources to environmental change. United Nations Environment Programme. Nairobi, Kenya. ISBN 978-92-807-2953-5 pp. 19.

KADAM A.K., KALE S.S., PANDE N.J., SANKHUA R.N., PAWAR N.J. 2012. Identifying potential rainwater harvesting sites of a semi-arid, basaltic region of western India, using SCS-CN method. Water Resource Management. Vol. 26 p. 2537–2554. DOI 10.1007/s11269-012-0031-3.

KAHINDA M.J., LILLIE E.S.B., TAIGBENU A.E., TAUTE M., BOROTO R.J. 2008. Developing suitability maps for rainwater harvesting in South Africa. Physics and Chemistry of the Earth, Parts A/B/C. Vol. 33. Iss. 8–13 p. 788–799. DOI 10.1006/j.pce. 2008.06.047.

KROIS J., SCHULTE A. 2014. GIS-based multi-criteria evaluation to identify potential sites for soil and water conservation techniques in the Ronquillo watershed, northern Peru. Applied Geography. Vol. 51. p. 131–142. DOI 10.1016/ j.apgeog.2014.04.006.

KUMAR M.G., AGARWAL A.K., BALI R. 2008. Delineation of potential sites for water harvesting structures using remote sensing and GIS. Journal of Indian Society Remote Sensing. Vol. 36 p. 323–334. DOI 10.1007/s12524-008-0033-z.

MA Z., KANG S., ZHANG L., TONG L., SU X. 2008. Analysis of impacts of climate variability and human activity on streamflow for a river basin in arid region of northwest China. Journal of Hydrology. Vol. 352 p. 239–249. DOI 10.1016/j.hydrol.2007.12.022.

MAHMOUD S.H. 2014. Delineation of potential sites for groundwater recharge using a GIS-based decision support system. Environmental Earth Sciences. Vol. 72. Iss. 9 p. 3429–3442. DOI 10.1007/s12665-014-3249-y.

MAHMOUD S.H., ALAZBA A.A. 2014. The potential of in situ rainwater harvesting in arid regions: Developing a methodology to identify suitable areas using GIS based decision support system. Arabian Journal of Geosciences. Vol. 1 p. 1–13. DOI 10.1007/s12517-014-1535-3.

MALCZEWSKI J. 2000. On the use of weighted linear combination method in GIS: Common and best practice approaches. Transactions in GIS. Vol. 4. Iss. 1 p. 5–22.

MATI B., DE BOCK T., MALESU M., KHAKA E., ODUOR A., NYABENGE M., ODUOR V. 2006. Mapping the potential of rainwater harvesting technologies in Africa: A GIS overview on development domains for the continent and ten selected countries. United Nations Environmental Programme, World Agroforestry Centre. Nairobi, Kenya. Technical Manual. No. 6. ISBN 92 9059 2117 pp. 116.

MBILINYI B.P., TUMBO S.D., MAHOO H., MKIRAMWINYI F.O. 2007. GIS-based decision support system for identifying potential sites for rainwater harvesting. Physics and Chemistry of the Earth. Parts A/B/C. Vol. 32 p. 1074–1081. DOI 10.1016/jpc.2007.07.014.

MCCUEN R.H. 2004. Hydrologic analyses and design. 3rd ed. Englewood Cliffs. New Jersey. ISBN 978-0131424241 pp. 888.

MONTEITH J.L., MOSS C.J. 1977. Climate and the efficiency of crop production in Britain [online]. Philosophical Transactions of the Royal Society B: Biological Sciences. Vol. 281 p. 277–294. [Access 15.10.2020]. Available at: https://jstor.org/stable/2417832

MUTENYO I., NEJADHASHEMI A.P., WOZNICKI A., GIRI S. 2013. Evaluation of SWAT performance on mountainous watershed in tropical Africa. Hydrology: Current Research. Vol. 4. DOI 10.4172/2157.S14.001.

NASH J.E., SUTCLIFFE J.V. 1970. River flow forecasting through conceptual models part I – A discussion of principles. Journal of Hydrology. Vol. 10. Iss. 3 p. 282–290. DOI 10.1016/0022-1694(70)90255-6.

NEITSCH S.L., ARNOLD J.G., KINIRY J.R., WILLIAMS J.R. 2011. Soil and water assessment tool. Theoretical documentation version 2009 [online]. Texas Water Resources Institute Technical Report. No. 40. Texas A&M University system. Texas, USA. [Access 15.10.2020]. Available at: https://swat.tamu.edu/media/99192/swat2009-theory.pdf

PRINZ D., OWEIS T., OBERLE A. 1998. Water harvesting for dry land agriculture developing a methodology based on remote sensing and GIS. Proceedings of the 13th International Congress Agricultural Engineering. 02–06.02.1998 Rabat, Morocco p. 1–12.

RAMAKRISHNAN D., BANDYOPADHYAY A., KUSUMA.K.N. 2009. SCS-CN and GIS-based approach for identifying potential water harvesting sites in the Kali Watershed, Mahi River Basin, India. Journal of Earth System Science. Vol. 118. No. 4 p. 355–368. DOI 10.1007/s12040-009-0034-5.

ROCKSTRÖM J. 2000. Water resources management in smallholder farms in eastern and southern Africa: An overview. Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere. Vol. 25. No. 3 p. 275–283. DOI 10.1016/S1464-1909(00)00015-0.

SCS 1972. National engineering handbook. Section 4: Hydrology. USDA, Washington DC. Soil Conservation Service pp. 126.

SUBRAMANYA K. 1998. Engineering hydrology. 3rd ed. Tata McGraw Hill, New Delhi, India. ISBN 9780070648555 pp. 445.

WINCHELL M., SRINIVASAN R., DI LUZIO J.M. 2009. Arc SWAT 2.3.4 Interface for SWAT2005: User's guide manual. Black Land Research Center, Texas Agricultural Experiment Station, Texas, USA pp. 484.