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Rainfall, Runoff and Soil loss, relationship on different land uses in the Upper Lake Tana Basin

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Abstract: This study aims to assess and develop rainfall, runoff and soil loss relations for free grazing land and area closure land in two large plots in the Gumera Maksgnite district, Ethiopia. Modified Rational Method (MRM) and regression analysis were conducted to establish relations among rainfall, runoff and soil loss. MRM was found to be adaptable to predict runoff for small water harvesting structure. Both MRM and regression model indicated a good correlation with field data; with a value of Nash-Sutcliffe efficiency coefficient in the range of 0.63–0.91 for two land use management types. These indicated a very good model performance for daily runoff data. The model performance showed the applicability of the model to estimate the rainfall, runoff and soil loss relations despite the smaller data size.

Keywords: rainfall, runoff, sediment loss, grazing land, MRM

Introduction

Soil erosion is a hazard traditionally associated with agriculture in tropical and semi-arid areas and is a threat to long-term soil productivity and sustainable agriculture (Morgan, 2005) by 1) reducing soil depth and thereby plant available water (Tessema *et al.*, 2010), 2) silting of small ponds for irrigation, water supply large reservoir systems for hydropower in the Ethiopian highlands (Tamene *et al.*, 2006). This problem of reservoir sedimentation is particularly significant in the Lake Tana basin (Shahin, 1993). Despite those hazards the quantification of runoff and soil erosion is a major challenge; in irrigation and water resources management (Zokaib and Naser, 2012). In most countries little reliable climatic and hydro-meteorological data are available and also poorly maintained. Therefore, the long-term database is needed for the assessment and planning of resource dynamics and its impacts on human life. Data on soil erosion and its controlling factors can be collected in the field or simulated conditions, in the laboratory (Hudson, 1982; Morgan, 1995). For realistic data on soil loss, field measurements are the most reliable because condition varies in both time and space, it is often difficult to determine the causes of erosion or understand the process at work (Hudson, 1982).

Field experiments on large plots are required for evaluating land management practices such as area closure and terracing. Although there is little uniformity on the size of plots for this type of experiment, they are generally in the range of 6 to 13 m wide and 15 to 32 m long (Morgan, 1995). Even if most experiment conducted in the previous wide range, this study is trying to conduct in the range of 0.6 to 2.09 ha of land. In general, the measurement requires funds, long years and well-trained personnel. Consequently, adapting simple empirical model is an option for planning (Hudson, 1982).

The number of models simulating the discharge and sediment yield from watersheds in the upper Blue Nile basin and other river basins in Ethiopia has increased in recent years. Most of these models were originally developed for applications in temperate regions. They range from relatively simple engineering approaches such as the rational method to more complex models such as SWAT, Water Erosion Prediction Project (WEPP), the Agricultural Non-Point Source model, and water balance approaches (Awulachew *et al.*, 2008), and lately the Limburg Soil Erosion Model Grum *et al.* (2017). Here the authors decide to use Modified Rational Method (MRM) considering the availability of data and catchment size because MRM develop for detention and retention of runoff volume and it also applicable for hydraulic design of storage for small watershed. (Xixi Wang *et al.*, 2012) also reported that, the MRM performed better than the SCS-CN and the four improved models in reproducing the runoff of 77 small study watersheds and MRM found to be most consistent and robust performance for the smaller area.

The rational method has been applied to many different watersheds around the world for different purposes and in some cases subjected to different modifications such as (Poertner, 1974; Viessman and Lewis, 2003; Theodroe *et al.,* 2011). The MRM was developed with the intent of using the rational method for hydraulic structures involving storage on small watersheds. However, the application and study of MRM in grazing ecosystems had limited and not sufficiently yet. Though, many studies have been conducted about the application of the rational method and calibration of its parameters for Ethiopian conditions, while no application of MRM has been documented so far. Here the authors decide to use MRM considering the availability of data and catchment size.

This research focused on an extensive field study in the Gumera-Maksegnit watershed conducted by the International Center for Agriculture Research in the Dry Areas (ICARDA) in 2014 on large plot-level for different management on pasture lands (i.e free grazing pasture and control grazing pasture) in the region. The aim of this research was: 1) to find and compare daily runoff and soil losses from two different management; and 2) to develop rainfall, runoff, and soil loss relations.

Materials and methods

Description of the study Area

The study area carried out in Maksegnit district near Gumara River and it locates in the Lake Tana basin of the North West Amhara Regional State, Ethiopia. The watershed is located at about 45 km southwest of Gondar town and cross by Maksegnit - Belesa district road; it is located between 12° 24′ and 12° 31′ north and 37° 33′ and 37° 37′ east. Free grazing plot of approximately 0.62 ha land size, its lowest elevation is 2010 masl at the gauge and maximum 2034 masl at the peak with average land slope of 5.8%. Area closure plot of approximately 2.09 ha land size, its lowest elevation is 2052 masl at the gauge and maximum 2100 masl at the peak with average land slope of 22.8%. The altitude of the big catchment ranges 1933 m to 2852 m above mean sea level. The total annual rainfall varies from 500–733 mm with an annual mean of 621 mm. As local farmers said in every four year unreliable rainfall distribution particularly late onset rain deficiency and early cease of rainfall is an important climatic influence on crop production and livestock husbandry. Average annual rainfall varies over quite short distances due to a variety of local factors, such as nearby topography which is steep and mountainous. The major portions of the two plot soils are very shallow, stony and most soils of the runoff contributing area are unproductive truncates exposed to the sub soils. Soil depth is apparently related to soil type and varies from 10–57 cm. The dominant soil types in the two plots are vertisol and vertisol textural class is loamy.

Figure 1 - FG) vegetation status of free grazing land plot AC) vegetation status of area closure plot. Image was taken on 21 August 2014.

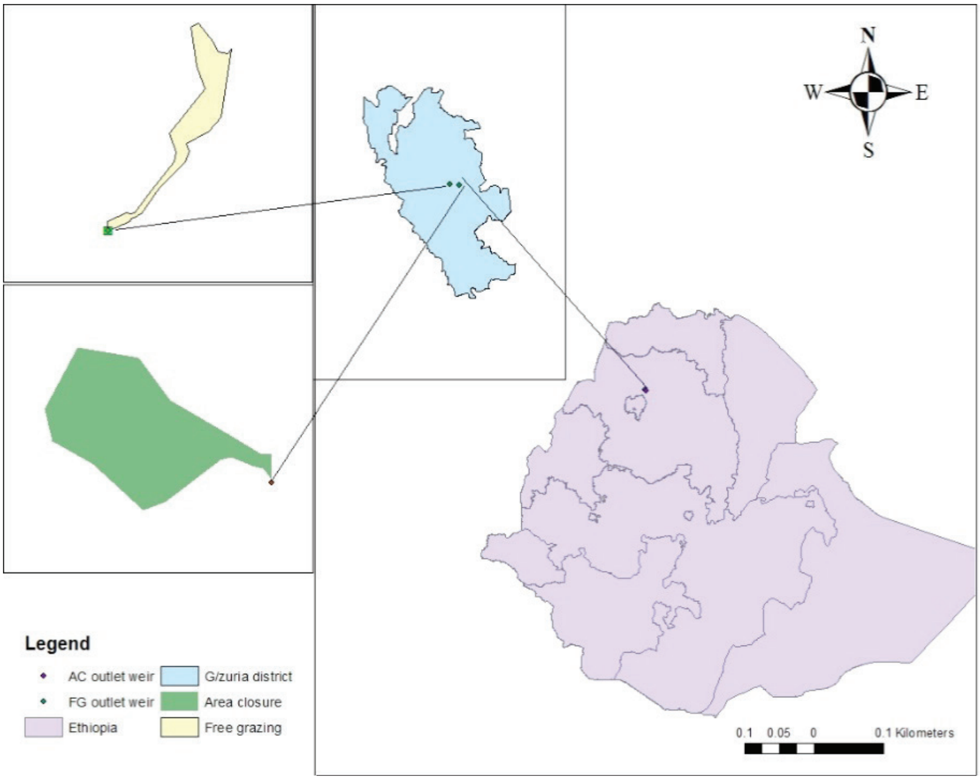

Figure 2 - Location of study area, Ethiopia

Data and methodology

Rainfall intensity and amount

Fieldwork was carried out during the summer of 2014 in Gumera-Maksegnit watershed. A runoff and soil erosion gauge for two management types (area closure and free grazing) plot were established representing soil type and vegetative cover. Data were collected for rainfall, runoff, and soil loss while discovering their impacts and relations for different management. The rainfall data were recorded in the watershed at five-minute intervals with an automatic tipping bucket rain gauge and measuring from June 1 to October 28 in 2014. Automatic rain gauges were installed between two experimental plots and the other two manual rain gauge were installed purposively in each experimental plots. From continuous readings of the automatic rain gauge, rainfall characteristics like amount, intensity, and duration were determined.

Runoff gauging station and data

Earthen Artificial diversion channel was constructed to collect and safely deliver the generated runoff through the intended outlet. Concrete weirs at the outlets of the two experimental plot were constructed by Gonder Agricultural Research Center in 2013. The experimental plot areas were defined using GPS tracking in the field. The size of the experimental plot was 2.09 and 0.62 ha for area closure and free grazing land, respectively. The areas of the experimental plot were used to calculate runoff depth at the outlet location. The experimental plots were treated in the same way as the field on which they were situated.

The depth of runoff stage was taken manually through out the rainy season at the gauged rectangular weir. In addition, one-liter grab samples for sediment measurement were taken every 10 minutes. Together with the sediment samples, velocity and runoff depth were measured to determine the total runoff and to estimate the suspended sediment carried by the flow at that specific time interval. Using a stopwatch and small concrete pond the velocity was determined volumetrically during each runoff collection.

The amount of sediment load within the sample was determined by oven drying the one-liter grab samples then weighing the oven dried soil. Total soil losses for those sampling intervals were then calculated by multiplying total water flow per time by the sediment concentration determined form the one-litre sample. Bed load calculated 10–15% of the suspended load. Total load was a summation of bed and suspended load. The river stage-discharge relationship was determined using stage discharge and volumetrically methods.

Soil Physical Properties

Soil infiltration rates were measured using a 25cm diameter single ring infiltrometer. Texture composition identification was analyzed using a hydrometer and textural triangle. A cylindrical core sampler of 98.2 cm^3 was used to take samples without disturbing the natural structure for bulk density measurement. The soil bulk density was calculated by dividing the mass of the oven-dried sampled soils with the volume of the cylindrical core.

Field Observations and Focus Group Discussion

Field observations and group discussion were held with farmers living in the watershed and field technicians who have been collecting data since the establishment of the station. Further more Gumera Maksginte watershed document was assessed. Those activities were held to better understand rainfall-runoff-soil loss processes at the two experimental watersheds, where and when in the experimental watershed runoff and erosion occur, and the possible reasons for erosion. These discussions helped to understand the runoff erosion process and were an opportunity for the farmers to express their perception and to present questions.

Runoff prediction

The validity of MRM was tested for predicting the runoff of the sub-watersheds. MRM is a method to parameterize simple runoff hydrographs. The MRM produces a runoff hydrograph (and volume) while the original rational method produces only the peak design discharge. The rational method was originally developed for estimating peak discharge for sizing drainage structures, such as storm drains and culverts. The MRM, which has found widespread use in engineering practices since the 1970s, is typically used to size detention/retention facilities for a specified recurrence interval and allowable outflow rate. The MRM was developed with the intent of using the rational method for hydraulic structures involving storage on small watersheds. The MRM hydrograph for the case when the storm duration is less than the time of concentration of the drainage area (Theodroe *et al*., 2011) and stated that Qp can be calculated using Equation;

$$Q=CIA\ D/360Tc \qquad (1)$$

Where
Q = peak discharge, m^3/s, C = rational method runoff coefficient, i = rainfall intensity, m/h, A = drainage area, ha, D = runoff duration (mins), Tc = time of concentration (mins), the time of concentration along our sample hydraulic path is simply the sum of the travel times for the overland flow, shallow concentrated flow, and channel flow.

$$Tc = T1 + T2 + T3 \qquad (2)$$

Overland flow /Sheet Flow: "Sheet flow is flow over plane surfaces". The equation T1 is given by Harlan (2007)

$$T1= (5.48(nL)^{0.8})/(P^{0.5}\ S^{0.4}) \qquad (3)$$

Where T1 = overland sheet flow runoff travel time, mins n= Manning rougness coefficient, dimensionless, L= length of the flow path, M (max. L should be 100m), P = 2 years, 24 hr rainfall, mm, S= ground slope, m/m
Shallow Concentrated Flow: "After a certain distance, sheet flow usually becomes shallow concentrated flow", T2 is obtained by dividing the travel length by the flow velocity of surface water as shown in equation (4) given by (Harlan, 2007).

T2= L/ (60V) (4)

Where V= 4.9178S0.5 for unpaved surface
T2=shallow concentrate flow runoff travel time, min as L= length of flow path, m, V= shallow concentrated flow runoff travel time, min L=length of flow path, m, V=shallow concentrate flow velocity, m/s S= surface slope, m/m
Channel Flow: Channel flow occurs within, channels, streams, ditches and piped storm drainage systems. Velocities are computed for channel flow based upon Manning's open channel flow equation.

T3=L/ (60V1) (5)

Where V1 = q/A, q = (1/n) WR 2/3 S 0.5 V1 = the average open channel flow velocity, q = the flow rate in the open channel, R = the hydraulic radius of the open channel flow (R = W/P), W = the cross-sectional area of the open channel flow, P = the perimeter of the open channel flow.

Size of drainage to be constructed (Sd)

The size of drainage structures to be constructed for each watershed should not be less than the estimated quantity of surface runoff in the watershed. This is to avoid over flooding the drainage structure. The constructed drainage structure should be at least 25% more than the estimated quantity of surface runoff (Al-Handasah, 1982). This is functionally given as equation (6).

d = 125% *Q (6)

Table 1 - Input data for time of concentration and MRM

Parameters	Free grazing land	Area closure	Source
n (sheet flow)	0.13	0.24	NRCS (1986)
n (manning)	0.16	0.16	Chow (1959)
Slope	0.058	0.228	Measured
L (Maximum length of flow path)	278.5	420.8	Measured
Tc (min)	28.3	30	Calculated using eq. 2
Duration (min)	30	27	Measured
C_{lit}	0.1-0.3	0.15-0.45	Schwab and Frevert (1993)

Runoff –soil loss relationship

Linear regression model was used to relate runoff and sediment loss for all land management (area closure and free grazing land management).

Model performance

The statistical criteria select for comparison of the performance of the model in predicting discharge and sediment were Nash and Sutcliffe, (1971), Coefficient of correlation, R2, and RSR (RMSE/$\boldsymbol{\sigma}$) and mean absolute error using excel sheet of statistical analysis techniques.

$$E = 1 - \frac{\sum_{i=1}^{n}(Si - Oi)^2}{\sum_{i=1}^{n}(O - O*)^2}$$

$$R2 = \frac{\sum_{i=1}^{n}(Oi - Oi*)(Si - Si*)}{\sum_{i=1}^{n}(Oi - Oi*)^2 \sum_{i=1}^{n}(Si - Si*)^2}$$

$$RSR = \frac{RMSE}{\sigma} = \left(\frac{1}{\sigma}\right) * \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Si - Oi)^2)}$$

$$MAE = \frac{\sum |s - o|}{n}$$

Where E is Nash Sutcliffe simulation efficiency, R2 is coefficient of determination, RSR is root mean square error over standard deviation, MAE is mean absolute error $\boldsymbol{\sigma}$ is standard deviation n is the number of observations during the simulation period, Oi and Si are the observed and predicted values at each comparison point I, O*i and S*i are the average values of observed and predicted data respectively.

Results and discussion

Average monthly rainfall and its intensity

Figure 3 indicates the four years monthly average rainfall in Gumera Maksginte watershed. Since the area classified under mono modal rainfall distribution, the watershed receives the majority of its rainfall in the monsoon season (July to September). Although the two experimental plots has relatively in the same altitude, area closure received a slightly higher amount of rainfall throughout the four years of the study period.

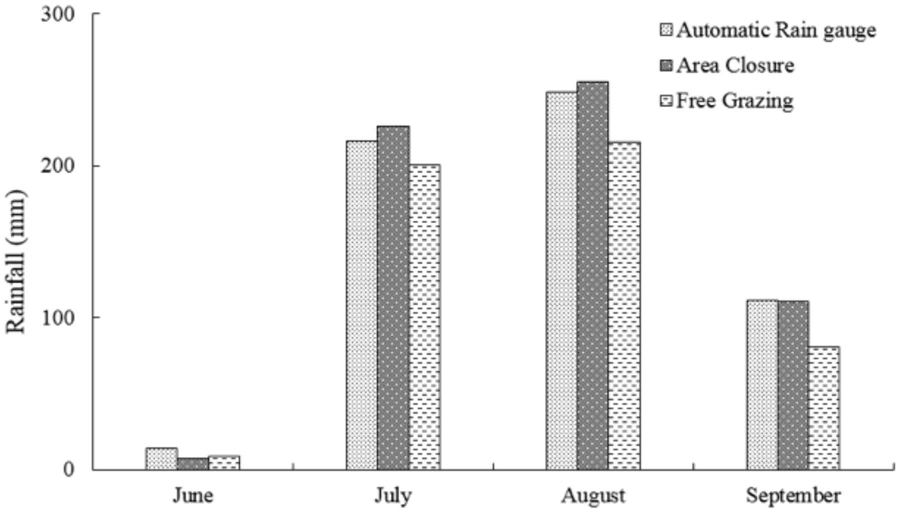

Figure 3 - Average monthly rainfall distribution

In addition, the rainfall data were recorded in the watershed every five-minute interval with an automatic tipping bucket rain gauge in 2014 rainy season. As shown clearly in figure 4, 264 recordings of one-hour interval rainfall intensities with a maximum intensity of 44 mm h^{-1} were recorded. The event rainfall intensities greater than the basic infiltration of the soil (12.12 mm h^{-1}) occurred only 9.1% of the time, while the majority of the event was small. Among the 24 events that are greater than 12.12 mm h^{-1}; 29.1 %, 54.2 % and 16.6 % of the events occur in July, August and September respectively.

Rainfall intensity and soil infiltration rate

Two hundred sixty-four recordings of one-hour interval rainfall intensities with a maximum intensity of 44 mm h^{-1} were recorded during the period of the study. As shown in (Figure 4), the value of rainfall intensities greater than the basic infiltration of the soil (12.12 mm h^{-1}) occurred only 9.4% of the time in 2014. The largest intensities occurred in August. For example, in 2014, from 24 events that are greater than 12.12 mm h^{-1} 29.1% of the events occur in July while 54.2% is in August and 16.6% in September. The value of steady state infiltration rates ranges from 12.1 to 210 mm h^{-1}, since the two land management type had the same soil texture (loam).

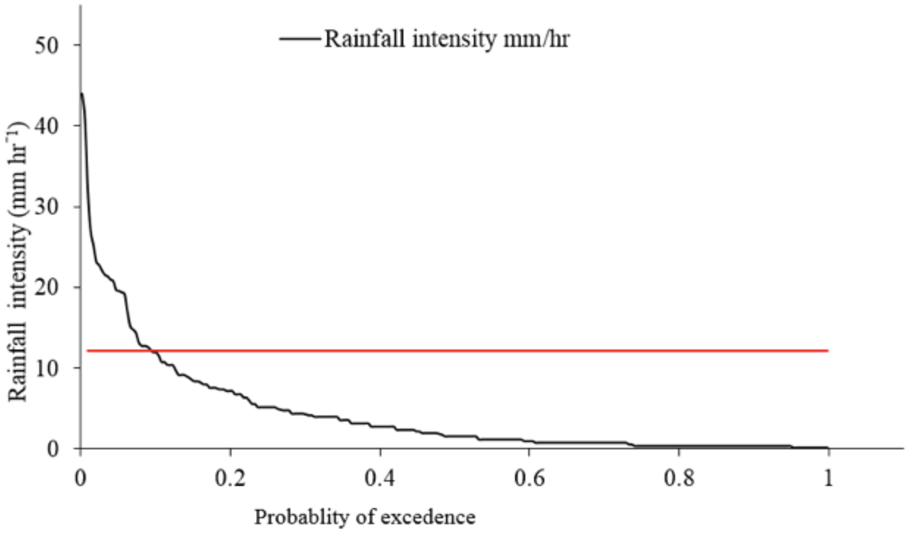

Figure 4 - The excedence probability of rainfall intensities

Event-based rainfall, runoff and soil loss

Table 2 presents event based monthly runoff and soil loss data for the two grazing land management types at large experimental plots. The figure illustrated that the ratio of runoff water from the free grazing land was comparatively higher than that of the area closure throughout the season. The proportion of runoff water was high at the inception of the season (July) when vegetation coverage was normally poor. In later, a combination of good vegetation coverage and high infiltration rate caused small surface runoffs from two management type of grazing land. The average runoff measured on two experimental plots showed that free grazing land had higher run-off losses than area closure.

Sediment concentration shows an increasing trend at the inception; which is similar to the runoff trend and later shows a decreasing trend due to vegetation coverage. The average runoff measured on the two experimental plots showed that free grazing land had higher sediment losses than area closure.

Rainfall and runoff relation

Since analysis of the rainfall-runoff relationship and subsequently an assessment of relevant runoff coefficients should best be based on actual, simultaneous measurements of both rainfall and runoff in the project area. Free grazing experimental plot, small catchment size, and gentle slope, less vegetation coverage. Thirty-two percent of the

Table 2- Event-based runoff and sediment from two management type

Date	FG Runoff (mm)	AC Runoff (mm)	FG sediment load (t/ha)	AC sediment load (t/ha)
8/2/2014	2.70	0.53	0.010	0.002
8/6/2014	2.31	0.74	0.007	0.003
8/9/2014	1.70	0.56	0.004	0.001
8/26/2014	1.63	1.75	0.002	0.009
8/29/2014	1.06	1.48	0.001	0.001
8/31/2014	3.29	0.37	0.002	0.002

long-term precipitation in free grazing experimental plot became discharge at the outlet. Area closure experimental plot the discharges were a smaller proportion of the rainfall, and only twenty-one percent of the long-term rainfall ended up at the experimental plot outlet. Some possible explanations for the observed difference could be slope type (which is mild slope), well vegetation coverage and most importantly, the area closure experimental plot was well protected from livestock and human population.

Despite four kilometers distances between the two experimental plots and the different characteristics, the response was surprisingly similar. Free grazing had some variation in the runoff amounts but on average the same linear response. Linear regressions were generated both for area closure and free grazing land with a value of (R2) (0.78–0.96). The regression slope does not change significantly.

Hence adopting MRM was good for grazing land management. As we all know; many parameters have significant impacts on the runoff rate and thus on the rainfall-runoff relation; such as land-use, vegetative cover, rainfall intensity, soil type, initial soil moisture condition, and slope of the land. This study considered rainfall amount, vegetation cover, rainfall duration and runoff to establish the relations for all management.

Hence the linear regression model shows acceptable E, RSR and MAE of 0.74, 0.42 and 0.82 for area closure and 0.63,1.7 and 0.4 for free grazing land; which indicates a "very good" model performance according to the ratings of Saleh *et al*., (2000) for daily runoff data. This noticeable model performance showed probably due to the applicability of the model to estimate the runoff despite the smaller data size.

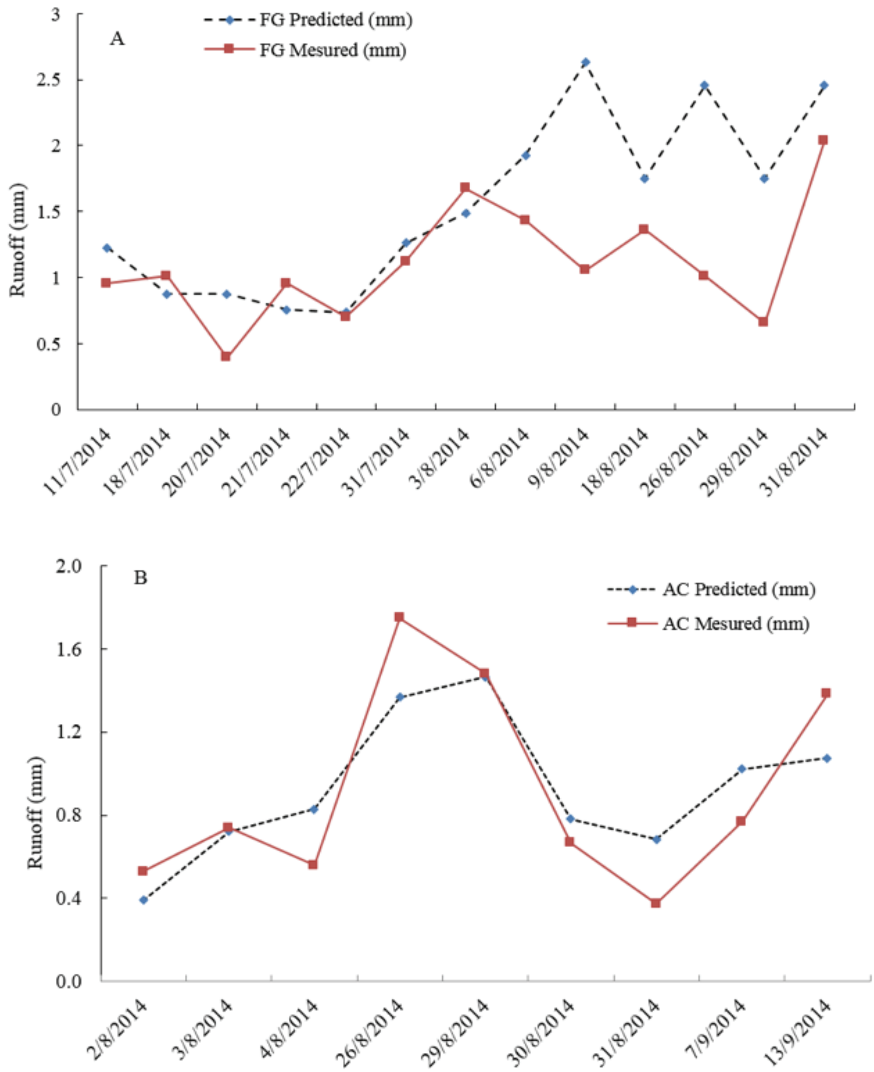

Figure 5- A) predicted and observed runoff for free grazing land; B) predicted and observed runoff for area closure.

Runoff and soil loss relation

Figure 6 presents the field data recorded for runoff and soil loss for two type of land management along with the best regression models. Overall, the correlations for the regression models of all land uses are not very satisfying. As shown in figure area closure plot had the strongest correlation (90%) for runoff-soil loss relation, while as expected the relation was weakest (50%) for the free grazing land due to livestock and human activities, change in vegetative cover at any time.

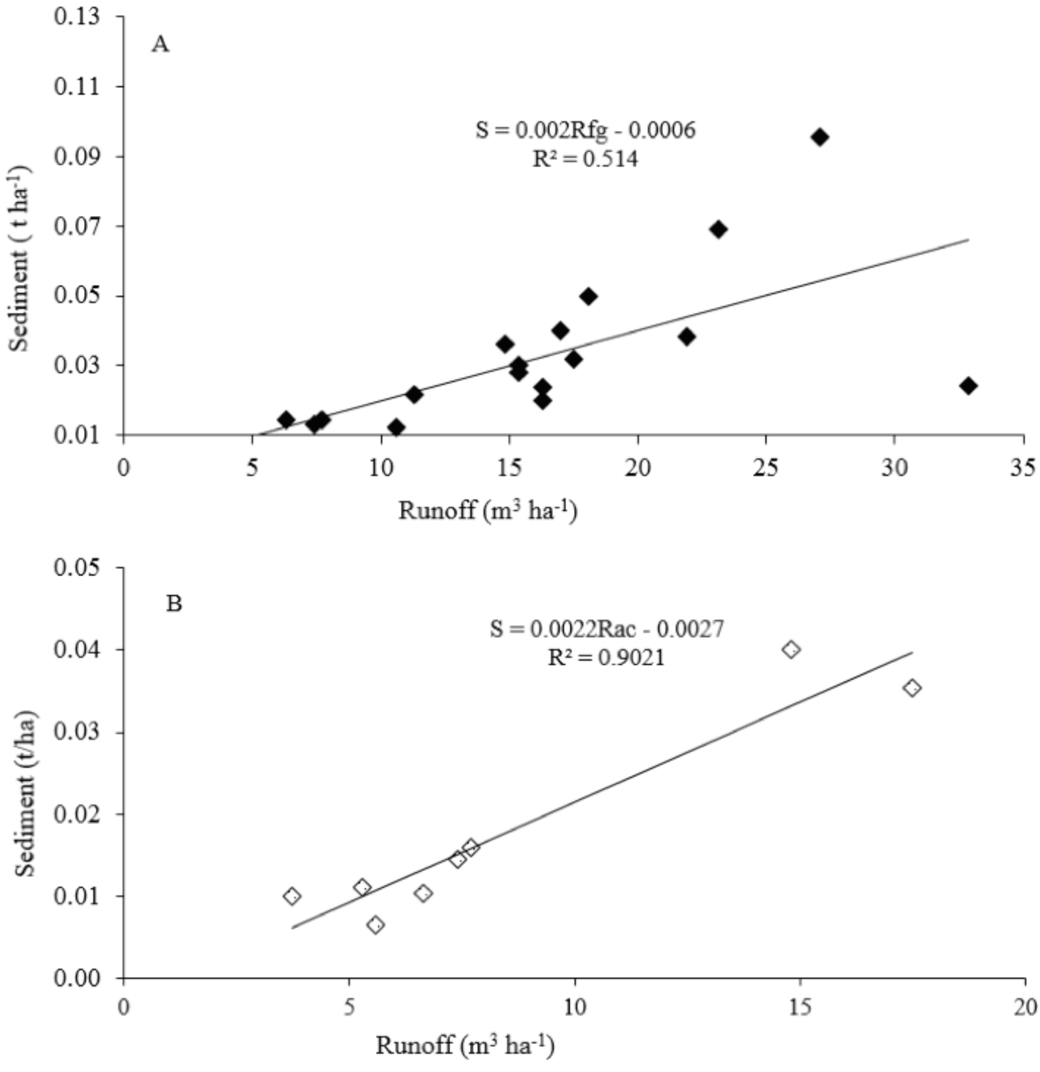

Figure 6 - A) Runoff –sediment relationship for free grazing land and B)

Runoff-sediment relationship for area closure

There are different factors that influence sample value of NSE, RMSE and R2 which includes the sample size, outliers, and bias in magnitude, the topography of gauge, and the sampling interval of hydrological data (McCuen *et al*., 2006). However, the calculated E, RSR and MAE, of observed and simulated runoff is 0.91, 0.4 and 0.004 respectively for area closure and 0.77, 0.89 and 0.01 for free grazing land which indicates a "good" model performance according to the ratings of Saleh *et al*., (2000) for daily runoff data.

Farmers' perception on rainfall, runoff and sediment loss

Based on the secondary data of the project and focus group discussion with selected farmers the following key opinions was summarized.

Farmers reported that unreliable rainfall distribution, particularly late onset, rain deficiency and early finishing of rainfall is an important climatic influence on crop production and livestock husbandry and are some of the main problems farmers face. Good rainfall seasons usually extend from the first week of June to mid of September. But the rainfall until the end of June should not be much higher than moistening the soil. Participants of the discussion started as the rainfall usually fully saturates the soil at the beginning of August. Sometimes rainfall begins the end of June and extends to mid-September and sometimes it begins late June and stops the end of August.

Rainfall-Runoff relations entirely depend on the rainfall condition and catchment characteristics. Intensive rainfall produces high runoff. The flow may change within few minutes if there is heavy rainfall because most of the areas which were compacted and bare due to cattle trampling, stony nature of the soil and shallow soil depth.

All participants of the discussion (farmers and data collectors) agreed as soil erosion is little to moderate problem in the sub watershed. Farmers use to rate the severity of erosion in the area are runoff concentration, overgrazing and slope. According to participants, heavy rainfall events which produce runoff at the beginning of the rainfall season, end of June, produce high soil loss. Since open grazing land in June would be loosely structured and bare soil surface at this time.

Discussion

Rainfall intensity, one of the factors affecting runoff, is a very important parameter to model rainfall-runoff relationships especially in areas where infiltration excess runoff is expected (Beven, 2004). Soil infiltration rate of the experimental plot was compared with the excedance probability of the rainfall intensity as shown in (Figure 4). The steady state infiltration rates ranged from 12.1 to 210 mm h^{-1}. This finding is similar with the study of Blue Nile basin (Derib, 2005, Engeda, 2009, Easton *et al.*, 2012 and Tilahun *et al.*, 2013). Even if loam soil infiltration rate is in the range of 10-20 mm hr^{-1}, this low infiltration rate (12.12 mm h^{-1}) might be caused by the compaction of freely roaming animals for grazing, clay content of the soil and shallow soil depth. Nyssen *et al.*, 2010 stated similarly when the infiltration rate is reduced or in areas with severe degradation, livestock traffic can cause infiltration excess run-off.

Area closure plot improved soil cover, reduced surface runoff and soil loss, increased above-ground biomass, increased soil moisture and water holding capacity as well as surface water availability as compared to free grazing land. It can be concluded that enclosures are an efficient soil conservation tool. Significantly lower runoff coefficients and increased soil moisture availability are demonstrated in area closure sites when compared to free grazing lands that are not closed off. Higher infiltration in enclosures is furthermore creating more favorable conditions for plant growth. On a landscape scale, highly erosive peak flows from steep slopes will be reduced by applying this good practice. WLRC (2015) reported that area closure contributes to the reduction of flood damage caused to reservoirs, villages and communities. Indeed, it is commonly accepted that, a steep slope causes an increase in the lateral hydraulic conductivity of the soils, and thus these soils maintain a greater transmissivity than small slopes, and are able to conduct water out of the profile faster, reducing run-off losses. This is similar with (Bayabil *et al.*, 2010 and Nyssen *et al.*, 2010). Generally low runoff production of area closure plot happened due to the combine effect of high slope steepness, well vegetation coverage and a high time of concentration (Tilahun *et al.*, 2014).

As shown in the table 2 area closure plot had lower sediment loss than free grazing land plot. This might be well vegetation coverage, the stability of soil, low transport capacity and large drainage length of the area closure plot. Vanmaercke *et al.* (2010) reported that the drop and subsequent low sediment concentration was common at the end of the rainy season and they also argued that lower concentrations of sediment are due to sediment depletion. Further more, Descheemaeker *et al.* (2006) suggested that the lower sediment concentrations are a result of the increased plant cover. Generally, the productivity of grazing lands is increased as a result of erosion control, improved soil depths and better soil quality and moisture content (Abnet *et al.*, 2016). In addition, area closure enhanced conservation knowledge of land users, strengthened local community-based institutions than free grazing land. WLRC (2015) also reported that Socio-culturally, area closure has enhanced conservation knowledge, minimized conflicts and increases the aesthetic value of landscapes. Event based runoff coefficients in combination with simple statistical models improve our understanding of rainfall runoff response of catchment with sparse data (Theresa *et al.*, 2010). Overall, the MRM had the best performance in reproducing the observed runoffs of the two experimental study watersheds, as indicated by the highest mean

E, and the smallest RSR and MAE; despite the smaller data size.

In general, the model performances are independent of experimental plot area (as shown Fig. 5 and 6). It was notable that, for the experimental plot with a drainage area of about 0.62 and 2.09 ha, the MRM performed very well. The values of E for the MRM was the best fitted, this model was judged to be most consistent and robust performance for the study of micro catchment. The result was in line with (Xixi Wang et al., 2012), reported that the MRM (E > 0.73) performed better than the SCS-CN (mean E < 0.32) and the four improved models (mean E < 0.56) in reproducing the runoff of 77 small study watersheds.

MRM tend to have a better performance for larger experimental plot and/or events with a runoff to rainfall ratio of between 0.1 and 0.32, a range typical for small watersheds (Hayes and Young, 2005). Also, the model performances exhibit slight variations for watersheds located in the area closure and free grazing land management. This can be attributed to the fact that the runoff-to-rainfall ratios for the experimental plots in these two land management vary noticeably: 0.21 in area closure and 0.32 in free grazing land. Further, for a given experimental plot, the model performances vary greatly from event to event. A model may be able to reproduce well the runoff from one event, but it could have a large prediction error for another, and vice versa. (Zokaib and Naser, 2012) reported that different land uses behaved differently with respect to runoff.

The correlations for the regression models of all land uses are not very satisfying. In fact, the weak correlations indicate that soil loss is not related with runoff amount only. In fact, soil erosion and determining its relation with the runoff is a very complex process as many factors including surface topography, soil type and its moisture condition, rainfall intensity, vegetative cover, and land use can have considerable impacts on it (Zokaib and Naser, 2012). More accurate results can be achieved if all the influential parameters are studied. The Area closure had strongest correlation (90%) for runoff-soil loss relation, while as expected the relation was weakest (50%) for the free grazing land due to livestock and human activities. Interestingly, the figure indicates that, for all the land uses, events of high runoff amount do not always produce high soil loss.

Conclusion

This study presents a comprehensive application of the Modified Rational Method (MRM), developed with the intent of demonstrate the usefulness of hydraulic structures for runoff monitoring on large experimental plots. First, all the collected rainfall amount and characteristics, infiltration rate, rainfall-runoff relations and storm runoff data were analyzed for the two experimental plots. The rainfall intensity was exceeded in the 2014 rainy season as confirmed by other works in the Blue Nile basin. At the beginning of the rainy period, runoff was produced by infiltration excess because of the soil compaction but later in August saturation excess may dominate. In addition, total storm rainfall and total discharge show well correlated through the rainy season. Since the MRM is based on runoff coefficient, rainfall intensity and duration, we found good Nash Sutcliffe efficiencies, RSR and MAE between predicted and observed daily discharges using this method.

Since researching both rainfall-runoff and runoff-soil loss relationship is a large task to be accomplished within a short period, here the presented linear regression model is a very simple one that will be used as an entry for further sediment modelling research in the large experimental plots. Different land uses behaved differently with respect to runoff and soil loss. Despite the research considered only the impacts of runoff amounts on the soil loss, regression analysis performed strong correlation among the three parameters for any land use. In addition to runoff amounts, rainfall amount, rainfall intensity, soil type and its initial moisture condition, slope and vegetative cover may significantly alter the runoff generations and consequently soil loss production. Further research is required to investigate long-term runoff and soil loss relationship in the large experimental plot. And on the basis of new data, the relation could be examined and modified.

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References

Abnet M., Sebastian G., Koen J., 2016. Adapting to climate change through land and water management in Eastern Africa. Ministry of Agriculture and Natural resources, and FAO Sub - regional Office for Eastern Africa, Addis Ababa, Ethiopia. Unpublished document.

Al-handasah D., 1982. Master plan of Michika Local Government 1981-2011. A report presented to the Government of Gongola State, Nigeria

Awulachew S., Mc Cartney M., Steenhuis T., Ahmed A., 2008. A Review of hydrology, sediment and water resource use in the Blue Nile Basin. Colombo, Sri Lanka: International Water Management Institute. 87p. IWMI Working Paper 131.

Bayabil H., Tilahun S., SCollick A., Yitaferu B., Steenhuis T., 2010. Are runoff processes ecologically or topographically driven in the (sub) humid Ethiopian highlands? The case of the Maybar watershed. Ecohydrology 4: 457 - 466.

Beven K., 2004. Infiltration excess at the Horton Hydrology Laboratory. Journal of Hydrology. 293, 219–234.

Chow, 1959. Reference tables for Manning's n values for Channels, Closed Conduits Flowing Partially Full, and Corrugated Metal Pipes.

Derib S., 2005. Rainfall-runoff processes at a hill-slope watershed: case of simple models evaluation at Kori-Sheleko catchments of Wollo, Ethiopia, MSc thesis, Wageningen University, The Netherlands,

Descheemaeker K., Nyssen J., Rossi J., Poesen J., Haile M., Raes D., Muys B., Moeyersons J., Deckers S., 2006. Sediment deposition and pedogenesis in enclosures in the Tigray Highlands, Ethiopia, Geoderma, 132, 291–314.

Easton Z., Fuka D., White E., Collick A., Biruk A., McCartney M., Awulachew S., Ahmed A., and Steenhuis T., 2012. A multi basin SWAT model analysis of runoff and sedimentation in the Blue Nile, Ethiopia, Hydrol. Earth Syst. Sci., 14, 1827–1841.

Engeda T., 2009. Modeling rainfall, runoff and soil loss relationships in the northeastern Highlands of Ethiopia, Andit Tid watershed, MPS thesis, Cornell University, Ithaca,

Harlan H., 2007. Rational method of hydrologic calculations with excels continuing education and development, incorporated New York.

Hayes D., Young R., 2005. Comparison of peak discharge and runoff characteristic estimates from the Rational Method to field observations for small basins in central Virginia. Washington, DC: US Department of the Interior and the US Geological Survey, US Geological Survey Scientific Investigations Report 2005-5254.

Hudson N., 1982. Soil Conservation. B.T. Batsford Ltd. London.324p.

McCuen H., Zachary K., Gillian A., 2006. Evaluation of the Nash–Sutcliffe efficiency index. Journal of Hydrologic Engineering 11.6: 597-602.

Grum B., Woldearegay K., Hessel R., Baartman J., Abdulkadir M., Yazew E., Ritsema C., Geissen V., 2017. Assessing the effect of water harvesting techniques on event-based hydrological responses and sediment yield at a catchment scale in northern Ethiopia using the Limburg Soil Erosion Model (LISEM). Catena, 159, 20-34.

Morgan R., 1995. Soil Erosion and Conservation. Second Edition. Longman Group UK Ltd., Essex, England. 198p.

Morgan R., 2005. Soil erosion and conservation, 3rd edition.

Nash J., Sutcliffe J., 1971. River flow forecasting through conceptual models. Journal of Hydrology 13: 297-324.

NRCS,1986. Urban Hydrology for Small Watersheds. TR-55

Nyssen J., Clyman W., Descheemaeker K., Poesen J., Vandecasteele I., Vanmaercke M., Zenebe A., Camp M., Mitiku H., Nigussie H., Moeyersons J., Martens K., Tesfamichael G., Deckers J., Walraevens K., 2010. Impact of soil and water conservation measures on catchment hydrological response a case in north

Ethiopia, Hydrological Proccsses, 1880-1895.

Poertner, 1974. Practices in Detention of Urban Stormwater Runoff: An Investigation of Concepts, Techniques, Applications, Costs, Problems, Legislation, Legal Aspects, and Opinions. Issue 43 of American Public Works Association. Special report.

Schwab G., Fangmeier D., Elliot W., Frevert R., 1993. Soil and Water Conservation Engineering (4th ed.), John Wiley and Sons, Inc., New York.

Saleh A., Arnold G., Gassman P., Hauck L., Rosenthal D., Williams R., McFarland S., 2000. Application of SWAT for the upper North Bosque River watershed. Transactions of the ASAE, 43(5), 1077.

Shahin M., 1993. An overview of reservoir sedimentation in some African river basins, in: Sediment Problems: Strategies for Monitoring, Prediction and Control (Proceedings of the Yokohama Symposium, July 1993).

Tamene L., Park S., Dikau R., 2006. Analysis of factors determining sediment yield variability in the highlands of northern Ethiopia. Gemorphology 76: 76-91.

Tesemma Z., Mohamed Y., Steenhuis T., 2010. Trends in rainfall and runoff in the Blue Nile Basin: 1964-2003, Hydrol. Process., 24(25), 3747–3758.

Thodore G., David B., Xing F., 2011. Use of the rational and modified rational method for hydraulic design. Texas department of transportation.

Theresa B., Erwin Z. and Axel B., 2007. Rainfall-runoff response, event-based runoff coefficients and hydrograph separation, Hydrological Sciences Journal, 52:5, 843-862.

Tilahun S., Guzman C., Zegeye A., Engda T., Collick A., Rimmer A., Steenhuis T., 2013. An efficient semi-distributed hillslope erosion model for the sub-humid Ethiopian Highlands. Hydrol. Earth Syst. Sci., 17, 1051–1063.

Tilahun S., Guzman C., Zegeye A., Ayana E., Collick A., Yitaferu B., Steenhuis T., 2014. Distributed discharge and sediment concentration predictionsin the sub-humid Ethiopian highlands: The Debre Mawi watershed Hydrol. Process.

Vanmaercke M., Poesen J., Maetens W., Vente J., Verstraeten G., 2010. Sediment yield as a desertification risk indicator. Science of the total Environment, 409, 1715-1725.

Viessman and Lewis, 2003. Introduction to Hydrology, 5th Edition

Water and Land Resource Centre (WLRC), 2015. Area Closure working paper.

Xixi W., Tingxi L., Wanhong Y., 2012. Development of a robust runoff-prediction model by fusing the Rational Equation and a modified SCS-CN method, Hydrological Sciences Journal, 57:6, 1118-1140.

Zokaib S., Naser G., 2012. A study on rainfall, runoff, and soil loss relations at different landuses-A case in Hilkot watershed in Pakistan. International Journal of Sediment Research 27 388-393.