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Prediction of Runoff and Sediment Yield Using AnnAGNPS Model: Case of Erer-Guda Catchment, East Hararghe, Ethiopia

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ABSTRACT

Land and water resources degradation are the major problems in Ethiopia. Poor land use practices and improper management systems have been playing a significant role in causing high soil erosion rates, sediment transport and loss of soil nutrients. In this study a physically based watershed model, AnnAGNPS model was applied to the Erer-Guda river catchment for prediction of runoff and sediment yield. The objectives were to evaluate the AnnAGNPS model capability to predict the runoff and sediment yield with respect to different land use practice factors and to identify the most erodible sub-catchment of Erer-Guda gauged catchment of East Hararghe zone. Sensitivity analysis, model calibration and validation were also performed to assess the model performance. Four sensitive parameters were identified of which curve number (CN) was the most sensitive one. For model calibration, model efficiencies of 0.758, -331.068 and 0.710 were observed for surface runoff, peak runoff rate, and sediment yield, respectively. Corresponding coefficient of determination were founded to be 0.825, 0.110 and 0.763, respectively. Runoff and sediment yield were well predicted but, peak runoff rate was over predicted. Validation results produced model efficiencies (NSE) as 0.778, -77.999 and 0.779 for surface runoff, peak runoff rate and sediment yield, respectively. The coefficient of determination (R2) as 0.923, 0.235 and 0.857 for runoff, peak runoff rate and sediment yield, respectively. Surface runoff and sediment yield simulation were found better in validation stage as well as the peak runoff rate showed almost the same as for calibration. Erer-Guda catchment was simulated with respect to land use practices for runoff and sediment yield generation. Cultivated agricultural land was contributed large amount of runoff and sediment yield. Runoff and sediment yield from the contributing land use was 486mm/yr and 10.50t/ha/yr, respectively. Erer-Guda catchment was divided in seven sub-catchments. Runoff and sediment yield for each sub-catchment were quantified. The result of simulation of runoff and sediment yield after calibration for the most erodible sub-catchment (SWT-5) was 498.41mm/yr. and 17.30tons/ha/yr. respectively. In conclusion, the AnnAGNPS model can effectively be used to predict runoff and sediment yield in order to effectively design soil and water related development in absence of gauged information.

Keywords: *Runoff, Sediment Yield, Estimation, and Model*

1. INTRODUCTION

Rainfall-runoff-sediment yield is the most complex hydrological phenomenon to comprehend due to tremendous spatial variability of watershed characteristics and precipitation patterns, making the physical modeling quite complex and involved. The quantity of runoff and sediment yield resulting from a given rainfall depends mainly on rainfall intensity, duration, and distribution besides others, such as initial soil moisture, land use, slope, etc. The runoff is critical to many water resources activities, for example, design of flood protection works, protection of agricultural lands, planning of water storage, etc. The erosion in the watershed may be occurred due to rainfall and runoff, and degrades its land. The sediment transport caused the reduction of storage capacity of rivers and reservoirs [2].

In Ethiopia, soil and water are the most critical natural resources. Nearly 85% of the population depends on subsistence agriculture. One process that threatens the resource base is soil erosion. Studies have shown that billions of tons of soil are lost annually [48]. Due to greater population pressure and consequently more intensive cultivation, erosion losses have been increasing to an annual areal average of 7 ton/ha equivalent to depth 0.5 mm [22]. Local erosion rates are highly spatially variable ranging from less than 1 to over 400 tons/ha/year [26, 28, 31 and 45]. The high variation in soil loss might be due to variations in slope, rainfall, soil type, land use, plot size and method of estimations. Beside soil losses, rainwater loss in the form of runoff is an important production constraint.

The poor land use practices, improper management systems and lack of appropriate soil conservation measures have been major causes of soil erosion and land degradation problems in Ethiopia. Because of the rugged terrain, the rates of soil erosion and land degradation in Ethiopia are high. In addition to this, the combined effects of deforestation, overgrazing, expansion of cropland and unsustainable use of natural resources have contributed to land degradation [14].

Soil erosion has a serious ecological impact that costs a nation due to both on-site and offsite damages. Three major universal impacts of erosion are reduction in productivity of crops, flood hazards, and the decrease of the life expectancy of water storage structures [15]. Sediment degrades water quality, and carries soil adsorbed polluting chemicals. Sediment deposition in irrigation canals, stream channels, reservoirs, water conveyance structures, reduces their capacity and would require costly operation for removal [21].

In order to formulate management options, soil erosion must be considered. Soil loss from a watershed can be estimated based on an understanding of the underlying hydrological process in a watershed, climatic conditions, landforms and soil factors. One option for formulating management options is to use models to elucidate processes controlling the hydrologic and sediment fluxes.

Assessing and mitigating soil erosion at the watershed level is complex both spatially and temporally. Soil type, depth, and location, land cover type and management, topology and other factors make the watershed a complex system where hydrologic and erosive process may differ greatly over a small spatial scale. Knowledge of rainfall, runoff, and soil loss, and their relationships as well as variation in time and space are very important for soil and water management such as designing soil and water conservation and water harvesting structures [42].There are many event based that continuously simulate stream flow, erosion/sedimentation, or nutrient loss from a watershed. However, few models have been developed or tested in the monsoonal climates of Ethiopia.

To estimate soil erosion and develop optimal soil erosion management plans, many erosion models such as: Universal Soil Loss Equation (USLE) [49], Water Erosion Prediction Project (WEPP) [20], Soil and Water Assessment Tool (SWAT) [3]. European Soil Erosion Model (EUROSEM) [33] and AnnAGNPS [5] have been developed and used over many years. Among these models, the USLE has remained the most practical method of estimating soil erosion potential and to estimate the effects of different erosion factors on soil erosion. USLE has been used for more than 40 years [12; 29] whereas other process-based erosion models developed afterward have limitations in applicability due to intensive data and computation requirements. However, studies using the USLE do not consider the sediment delivery ratio to estimate the sediment delivered to the downstream point of interest [30]. As a result, more recent physical-models for soil erosion estimation have been developed that consider the sediment delivery process.

Therefore, physical-based hydrologic models are required for studying hydrological process and hydrological responses to land use and climatic changes.

AnnAGNPS is a continuous-simulation, physical-based, watershed-scale model intended to be used as a tool to evaluate non-point source pollution from agricultural watersheds ranging in size up to 300,000 ha [5]. The physically based distributed watershed models have higher accuracy in analyzing the impact of land management practices on water and sediment yields in large complex watersheds. The selection of AGNPS for the project was based on the capability of the watershed approach to assess the impact of conservation planning, including BMPs, to reduce sediment loadings to Erer-Guda catchment. It incorporates the most current methodologies used by NRCS such as the Revised Universal Soil Loss Equation (RUSLE) [38] and Soil Conservation Service (SCS, now NRCS) hydrologic procedures [44]. In addition, AnnAGNPS provides the ability to aid in the identification and evaluation of sources of water and sediment production within the watershed.

There is a knowledge gap with respect to the interdependence between the runoff and sediment yield and watershed on different temporal and spatial scale in Erer-Guda river catchment. The magnitude of sediment transported by the upper Erer-Guda catchment has become a serious concern for planning, design and implementation of numerous national development projects in the area. Furthermore natural vegetation has been almost cleared for agricultural crop production. Shrubs covers small area in the catchment and classified as deciduous and dry forest with medium and small trees including bushes, and some scattered trees showing evidence of former natural forest. Reduction in the soil production capacity, change in river bank and flooding due to sediment deposition are problems calling for estimation of annual runoff and sediment yield in upper Erer-Guda river catchment. Although a number of researchers have conducted erosion studies in Ethiopia, the lack of compelling tool or method has hindered adoption and implementation of their findings [36; 46]. Both mathematical and parametric methods require a lot of information, which is a major constraint in many developing countries [46]. These countries have no appropriate and accurate soil erosion prediction models although universal soil lose equation (USLE) is used in different tropical countries [34]. Assessment of Annualized Agricultural Nonpoint Source (AnnAGNPS) Pollution model for predicting runoff and sediment yield in Upper Erer-Guda river catchment is imperative.

The general objective of this study is to provide a basis for future scenario analysis of water resource management of Erer-Guda River.

The specific objectives of this study were: to evaluate the AnnAGNPS model capability to predict the runoff and sediment yield in Erer-Guda river catchment, and to assess the sediment yield and runoff generation with respect to different land use practice and to identify the most erodible sub-catchment of Erer-Guda river catchment.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

2.1.1 Location and description of area

Erer-Guda catchment is located in Babile district, Oromia National Regional State, Eastern part of Ethiopia. It is located at a distance of 525 km from Addis Ababa (14km from Harar town). The watershed covers an area of 45,703 hectares and lies at 42˚ 05′ 20″ to 42˚ 21′ 52″ E and 09˚ 14′ 33″ to 09˚ 31′ 55″ N (Figure1) with elevation ranging from 1314m a.s.l. around gauging station to almost in the upper ridge 3000m a.s.l.. The watershed drains to the Wabishebele River Basin. Mean annual rainfall is 795.855mm and mean maximum and minimum

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annual temperatures are about 25.10˚C and 12.40˚C respectively.

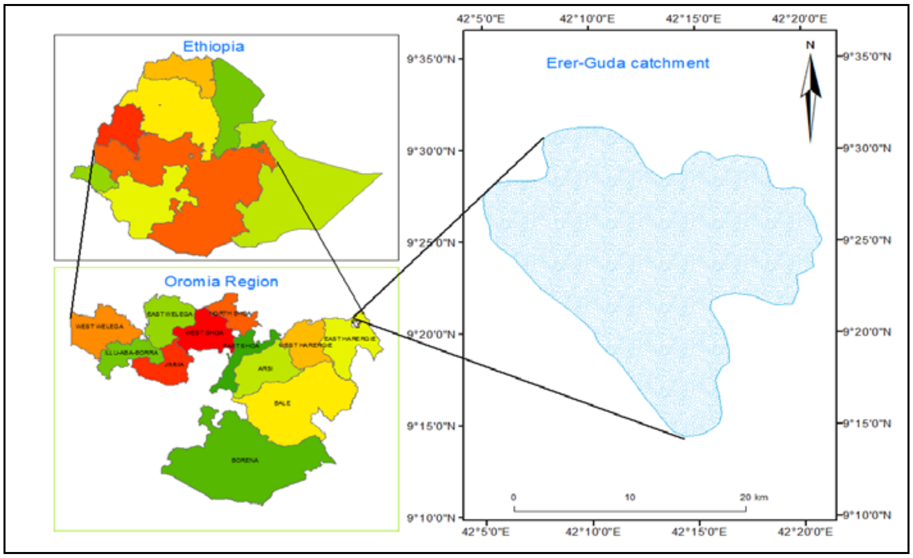

Fig 1: Location map of Erer-Guda catchment

Table 1: Slope class of Erer-Guda catchment

Slope (%)	Area Coverage (ha)	Area Coverage (%)
0-2	6938	15
2-10	14734	33
10-15	16163	35
15-30	2829	6
>30	5039	11

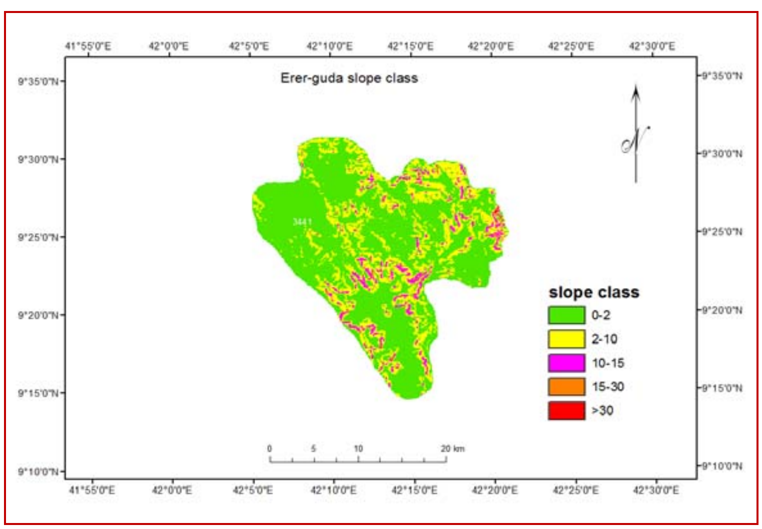

Fig 2: Slope map of Erer-Guda catchment

2.1.2 Soil Data

The AnnAGNPS model requires different physico-chemical properties of soil such as: soil texture, hydraulic conductivity, bulk density and organic carbon content for different layers of soil. These data were obtained mainly from the following sources: Wabishebele river basin soil database and digital soil map from the Ministry of Water Resource. Soil water characterization software was used to calculate the available soil moisture content, bulk density and saturated hydraulic conductivity

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[41]. The soil erodibility (K) factor was calculated according to [49] by using equation 3.1

$$K_{USLE} = f_{csand} \cdot f_{cl-si} \cdot f_{orgc} \cdot f_{hisand} \quad (3.1)$$

Where f_{csand} is a factor that gives low soil erodibility factors for soils with high coarse-sand contents and high values for soils with little sand, f_{cl-si} is a factor that gives low soil erodibility factors for soils with high clay to silt ratios, f_{orgc} is a factor that reduces soil erodibility for soils with high organic carbon content, and f_{hisand} is a factor that reduces soil erodibility for soils with extremely high sand contents. The factors are calculated by using equation 3.2 to 3.5

$$f_{csand} = \left[0.2 + 0.3 \exp\left[-0.256\, m_s \left(1 - \frac{m_{silt}}{100}\right)\right]\right] \quad (3.2)$$

$$f_{cl-si} = \left[\frac{m_{silt}}{m_c + m_{silt}}\right]^{0.3} \quad (3.3)$$

$$f_{orgc} = \left[1 - \frac{[0.25\, orgC]}{[orgC + \exp[3.72 - 2.95\, orgC]]}\right] \quad (3.4)$$

$$f_{hisand} = \left[1 - \frac{\left[0.7\left(1 - \frac{m_s}{100}\right)\right]}{\left[\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9\left(1 - \frac{m_s}{100}\right)\right]\right]}\right] \quad (3.5)$$

Where m_s is the percent sand content (0.05-2.00mm diameter particles), m_{sitl} is the percent silt content (0.002-0.05mm diameter particles), m_c is the percent clay content (< 0.002 mm diameter particles), and orgC is the percent organic carbon content of the layer (%).

There are five types of soils in Erer-Guda river catchment. The dominant soil type in the catchment is Cambisols which cover an area of 74.23%. Leptosols, Glyesols, Luvisols and Nitisols cover 19.40%, 4.35% 1.70%, and 0.32% of the catchment respectively. The soil type of the catchment is presented in Table 3 and Figure 3.

Table 3: Soil distribution of Erer-Guda catchment

Soil Type	Areal Coverage (ha)	Areal Coverage (%)
Cambisols	33,923	74.23
Leptosols	8,867	19.40
Glyesols	1,989	4.35
Luvisol	778	1.70
Nitisols	146	0.32
Total	45,703	100

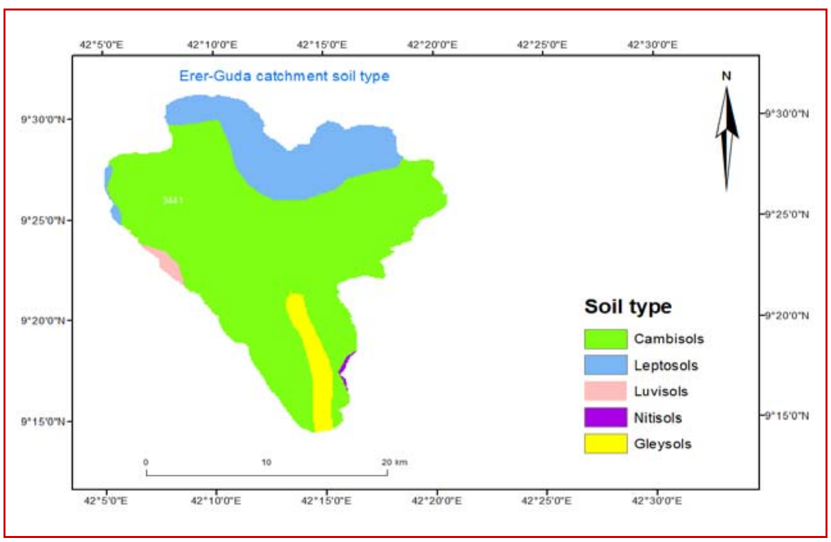

Fig 3: Soil map of Erer-Guda catchment

2.1.3 Land use/ Land Cover

Land use is one of the most important factor that affect runoff, evapotranspiration and surface erosion in a watershed. The land use map of the study area was obtained from Ministry of Water and Energy (MoWE) from the study of Wabisheble river basin and field observation. The GIS output of land use/cover shows that intensively and moderately cultivated agricultural land

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(covered with maize and sorghum) covers 92.83% of the entire catchment followed by open and dense shrubs land that takes 6.91% and the least is 0.26% covered by open grass land. The area coverage by each land use type is presented in Table 4 and Figure 4. The current situation in the site was observed as cultivated land is encroaching the shrubs and grazing land due to mainly agricultural land use. The reclassification of the land use map was done to represent the land use according to the specific land cover types. AnnAGNPS model calculated the area covered by each land use for each cell area. The different land use/cover types are presented in Table 4 and Figure4.

Table 4: Land use/cover of Erer-Guda catchment

Land use	Areal coverage (ha)	Areal coverage (%)
Cultivated land	42424.99	92.83
Shrubs land	3159.45	6.91
Grass land	119.18	0.26
Total	45703	100

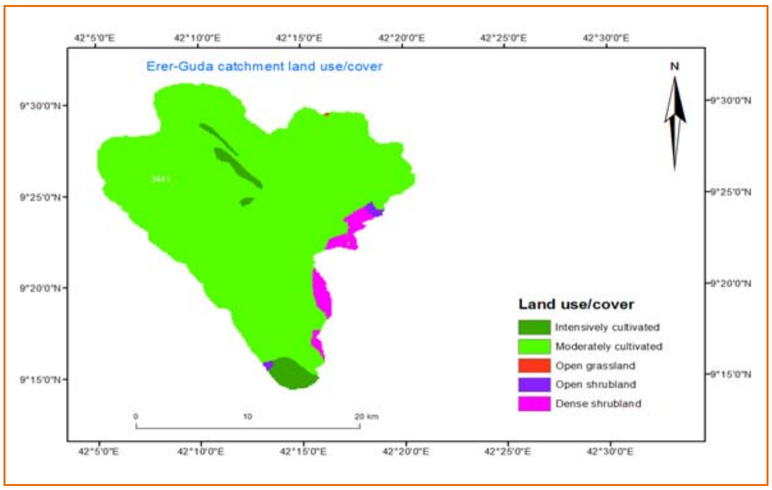

Fig 4: Land use/cover map of Erer-Guda catchment

2.1.4 Meteorological Data

Meteorological data is needed by the model to simulate the hydrological conditions of the catchment. The meteorological data required for this study were collected from the Ethiopian National Meteorological Services Agency (NMSA) and MoWE. The meteorological data collected were precipitation, maximum and minimum temperature, wind speed and sunshine hours. Data from four stations, which had been within and around the study area, were collected. For Haramaya, Gursum and Babile stations records between 1981 and 2000 were obtained. However for the Harar station, climatic records during the years 1991 to 2000 were obtained. But most of them have missing data especially during 1991 and 1993. The other problem in the weather data was inconsistency in the data record, in some periods there is a record for precipitation but temperature data are missing, and vice versa.

For this study the selected weather generator stations (station used for infilling of missing data by normal ratio method of equation 3.9) were Harar and Haramaya stations due to the availability of data, closeness to the project and quality of data. They are class A meteorological stations. Moreover, the arithmetic mean method was used to estimate the representative rainfall stations. The arithmetic mean method is the simplest method of determining areal average rainfall. It involves averaging the rainfall depths recorded at a number of gauges. This method is satisfactory if the individual gauge measurements do not vary greater than 10% about the mean [9]. Gursum and Babile arithmetic mean value was used as an input for rainfall and Haramaya and Harar for temperature. The rainfall and temperature data of at least 20 years were collected from the Ethiopian Meteorology Agency and wind speed from MoWE and the dew point temperature was computed by equation 3.8.

The saturation vapor pressure e_s was derived from the daily air temperature values T (equation 3.6). After that, the actual average daily vapor pressure ea was calculated using saturation vapor pressure at minimum air temperature e_s (Tmin).

$$e_s = 0.6108 \exp\left(\frac{17.27T}{T+237.3}\right) \quad (3.6)$$

$$e_a = e_s(T_{min}) = 0.6108 \exp\left(\frac{17.27T_{min}}{T_{min}+237.3}\right) \quad (3.7)$$

According to FAO, [27], where humidity data are lacking or are of questionable quality, an estimate of

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actual vapour pressure ea (equation 3.7) can be obtained by assuming that dew point temperature T_{dew} is near the daily minimum temperature (T_{min}). This statement implicitly assumes that at sunrise, when the air temperature is close to T_{min}, that the air is nearly saturated with water vapour and the relative humidity is nearly 100%. For arid regions, the air might not be saturated when its temperature is at its minimum. Hence, T_{min} might be greater than T_{dew} and a further calibration may be required to estimate dew point temperatures. In these situations, "T_{min}" in the above equation may be better approximated by subtracting 2-3 °C from T_{min}.

The daily dew point temperature was calculated using equation 3.8.

$$Dew = \frac{(116.91 + 237.3\ln(e_a))}{16.78 - \ln(e_a)} \qquad (3.8)$$

Where, Dew = dew point temperature [°C], e_s = saturation vapour pressure [mbar], e_a = actual vapor pressure [mbar], exp = 2.7183 (base of natural logarithm) and T = air temperature [°C] .

Using daily minimum and maximum temperature data, the saturation vapor pressure were derived twice (e_{smin} and e_{smax}) according to equation 3.6. In this case the saturation vapor pressure used by equation 3.6 was the mean value of e_{smax} and e_{smin}.

2.1.5 Hydrological Data

The runoff and sediment data required for performing calibration and validation of the model were collected from the Ethiopian MoWE hydrology section. The data collected were daily flow and sediment from 1984 to 1995 for the Erer-Guda hydrology gauging station which flows into Wabishebele River. The homogeneity of average annual daily flow data was tested using RAINBO software version 2.2. In a frequency analysis estimates of the probability of occurrence of future rainfall (or flows) events are based on the analysis of historical rainfall (or flows) records. Frequency analysis of data requires that the data be homogeneous and independent. The restriction of homogeneity assures that the observations are from the same population. By assuming that the past and future data sets are stationary and have no apparent trend one may expect that future time series will reveal frequency distributions similar to the observed one. RAINBO software package was used as tools for the historic event record of the data to be tested.

2.1.6 Digital Elevation Model

The digital elevation model (DEM) is any digital representation of a topographic surface made available in the form of raster or regular grid. It is the basic input of AnnAGNPS hydrological model. The Erer-Guda river watershed was delineated and river networks (Figure 5) were generated from DEM. It had a horizontal resolution of 30m. A grid size of 100 m x 100 m was selected based on the recommendation of Young et al. [53]. It was considered to be a good representation of a homogenous land unit for hydrological soil cover complex which determine the Curve Number and other input parameters as finer as possible.

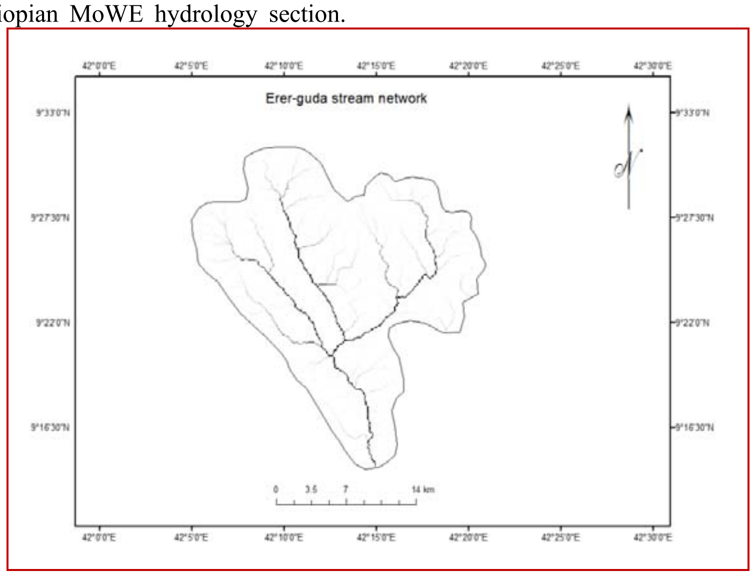

Fig 5: Land use/cover map of Erer-Guda catchment

2.1.7 Data Screening

Engineering studies of water resources development and management depend heavily on hydrological data. These data should be stationary, consistent, and homogeneous when they are used for frequency analyses or to simulate a hydrological system. To determine whether the data meet these criteria, one needs a simple but efficient screening procedure. A time series of hydrological data may exhibit jumps and trends owing to what call inconsistency and non-homogeneity [51]. Inconsistency is a change in the amount of systematic error associated with the recording of data. It

VOL. 4, NO. 10, October 2014 ISSN 2225-7217
ARPN Journal of Science and Technology

can arise from the use of different instruments and methods of observation.

2.1.8 Identification and Estimation of Missed Data

Missing values in the series is a real handicap to the hydrologic data users; the estimation of these missing values is often desirable prior to the use of the data. In this study, the years, that had inadequate daily records for selecting the annual, were identified and considered to be missed. Hence, they were needed for reconstruction to make them at least relatively complete for the estimation of missed data. The missed data were estimated and reconstructed by normal ratio method given as:

$$P_x = \frac{A_x}{3}\left(\frac{P_1}{A_1} + \frac{P_2}{A_2} + \frac{P_3}{A_3}\right) \quad (3.9)$$

Where the ratio (Pi/Ai) is the proportion of rain gauge station (i) of the mean annual catch that occurs in specific storm.

This average proportion is used as the proportion at gauge x where amount Px was not recorded. The estimate of Px is found by multiplying the average proportion (P) by the average annual catch at gauge x (Ax). The value of P is considered the best estimate of the true proportion (P) of the catch during the storm for which the recorded value is missing [9].

2.1.9 Test for Consistency, Homogeneity and Trend Analysis

The consistency of the data set of the given stations was cheeked by the double mass-curve method with in-reference to their neighborhood stations. The double mass curve was plotted by using the annual cumulative total rainfall of the station under study as ordinate and the average annual cumulative total of neighboring stations (base stations) as abscissa. Homogeneity and trend analysis of annual rain fall and flow data used for calibration and validation were tested using RAINBO software version 2.2.

2.1.10 AnnAGNPS Model Input Data File

Watershed identification, cell area, number of cell, average land slope, slope shape, average field slope length and aspect were generated using ARCGIS 10 software of ARCINFO and Topographic Parameterization (TOPAZ) software of AnnAGNPS model. Data for the Revised Universal Soil Loss Equation (RUSLE) adapted to the study area, meteorological data, hydro-sedimentological data, digitized land use/land cover maps and slope map were obtained from MoWE Wabishebele River basin database. Finally these data were organized, and processed to build AnnAGNPS input file

2.2 AnnAGNPS Model Description and Setup

2.2.1 AnnAGNPS Input Parameters Generation and Editing Programs

The input generation process consists of data acquisition, data reformatting and data conversion. The programs used for input generation include software utilities; an integrated GIS assisted computer program, and the TopAGNPS (Topographic AGNPS) and Input Editor executable files. The GIS and TopAGNPS programs were used to generate topographically related data required to compute hydrologic, hydraulic, and watershed parameters. These parameters were initialized, revised and finalized via the Input Editor Programs specific GUI (Graphical User Interface) window for each of the model input categories. In addition to input data, watershed climate data was generated using the Generation of weather Elements for Multiple applications (GEM) program. The GEM generator was used to generate AnnAGNPS required climate data input file.

Input parameters that were used by the model to predict runoff, peak runoff rate and sediment yield are discussed in this section. Methods of evaluation of these parameters and procedures followed during their evaluation are explained. The evaluation of parameters was based on the AnnAGNPS model manuals, which were prepared by Robert Darden and Vance Justice [40].

2.2.2 Watershed Parameters

a. Watershed name: This is the name given to the watershed under study. Erer-Guda catchment is the name of the study site. This name identifies the input and output data files for the watershed.
b. Watershed description line: It is where the user can input short account of the watershed, storm, and/or parameters set. It is an optional parameter and is useful to describe any special scenarios being implemented.
c. Watershed Location: The location of the watershed where it is found. Babile district is the location of the study site
d. Number of cells: It is the total number of base cells in the watershed. For Erer-Guda catchment 2434 cells were used.
e. Precipitation: It is the amount of arithmetic mean rainfall of the stations for the daily basis. Since AnnAGNPS is continuous based model, it was run for each separate rainfall day. For this study 1981-2000 daily rainfall data were used.
f. 10 year frequency storm EI-value (EI10): It is the rainfall erosion index for the 10 year frequency storm EI-value (EI10) (equation 3.10) which was calculated by using R-factor from the equation 3.11 recommended by Renard and Freimund [39].

$$EI_{10} = 2.68(R - factor)^{[illegible]} \quad (3.10)$$

Rainfall-runoff erosivity factors were estimated by using mean annual precipitation [39] methods. The equation which uses the mean annual precipitation is:

$$R - factor = 587.8 - 1.219P + 0.004105P^2, \; P > 850mm$$

(3.11)

Where R = rainfall-runoff erosivity factor (MJ mm ha-1h-1yr-1); P = mean annual precipitation (mm).

2.2.3 Cell Parameters

a. Cell ID: It is the main identifier for each cell in the watershed. The cells were numbered consecutively.

b. Soil ID: Alphanumeric string used to identify the soil type for the cell.

c. Reach ID: It is the number of the cell into which the most significant portion of the runoff from the cell drains. The receiving cell numbers were determined by cell topography of the drainage map using ARCGIS software.

d. Cell area: It is a numeric value representing the base cell size of all the cells in the watershed. Cells are uniformly square areas subdividing the watershed, allowing analysis at any point within the watershed. The model recommends that the initial area must be in the range from 0.001 to 1000 hectares. For this study, base cell automatically generated by TOPAZ was used. This grid size was considered to represent a homogeneous land characteristic of Erer-Guda catchment.

e. Management Field ID: An alphanumeric string used to identify the field or land use type.

f. Reach location ID: An alphanumeric string used to identify the channel reach.

g. Reach length: The length of the channel reaches which was generated by TOPAZ.

h. Reach slope: The average channel slope for the reach which was generated by TOPAZ.

i. Reach elevation: The elevation of the downstream end of the reach which was generated by TOPAZ.

j. Cell average elevation: Representative average elevation for the cell.

k. Curve Number (CN): It is the hydrologic soil cover complex number used in Soil Conservation Service (SCS) equation for estimating direct runoff from the storm. This parameter was determined based on the actual land use/cover, land treatment, hydrologic condition, hydrological soil group, and antecedent soil moisture condition of the study watershed. The land use/cover, land treatment, hydrologic condition and hydrologic soil group were determined from digitized land use/cover map of Wabishebele river basin. The maps were digitized so that the weighted average Curve Number was calculated for each grid cell for antecedent moisture condition II (AMC II). Later on, AMC II was converted to AMC III and I based on AnnAGNPS users' manual according to the moisture condition preceding the selected rainfall day. Since CN is a dynamic parameter sensitive to land use/land cover changes, the respective AMC values were taken as the first approximation. The final Curve Number values then were determined during the calibration of the model and used later for validation of the model.

l. Cell average land slope: It is the average slope of the cell. It was generated from the DEM of the watershed using TOPAZ.

m. RUSLE LS factor: RUSLE erosion equation factor for normal erosion conditions, which was generated from DEM using TOPAZ.

n. Sheet flow slope: Slope of the sheet flow path within the cell, which was generated from DEM using TOPAZ.

o. Sheet flow length: Length of the sheet flow path within the cell, which was generated from DEM using TOPAZ.

p. Shallow concentrated flow slope: Slope of the shallow concentrated flow path within the cell, which was generated from DEM using TOPAZ.

q. Shallow concentrated flow length: Length of the shallow concentrated flow path within the cell, which was generated from DEM using TOPAZ.

r. Concentrated flow slope: Slope of the concentrated flow path within the cell, which was generated from DEM using TOPAZ.

s. Concentrated flow length: Length of the concentrated flow path within the cell, which was generated from DEM using TOPAZ.

t. Manning's roughness coefficient: It is the roughness coefficient for the predominant surface condition within the cell at the time of the rainfall. There were two roughness values, one for overland conditions which was derived from a look up table given in the AnnAGNPS users' manual according to land use and cover density, and the other for the channel that was determined from other look up table based on the cover condition of the channel bank.

u. Soil erodibility factor (K): It is the factor used in the sub-model of RUSLE. The erodibility values were determined by equation 3.1.

v. The cropping management factor (C): The model was internally calculated during TOPAZ execution.

w. Conservation practice factor (P): The model was internally calculated P factor from land use land cover data during TOPAZ execution.

x. Surface condition constant: It is a value based on land use at the time of the rainfall to make adjustments for overland flow velocity. This parameter was determined for land use/cover conditions of the cell at the time of the rainfall from the table given in the users' manual.

y. Soil texture: It is the major soil texture classification for the cell. Soil texture of the Erer-guda watershed was taken from MoWE. Major soil texture was determined for each cell from the digitized soil map.

z. Cell aspect: Representative land slope orientation for cell measured from north in a clockwise direction.

2.2.4 AnnAGNPS Model Output Options

AnnAGNPS model gives an output both at the outlet of the watershed and for any cell in the watershed. Calculations for all cells in the watershed were made in the first loop. These calculations include estimates for upland erosion, overland runoff volume, and the time until overland flow becomes concentrated.

The second loop calculated runoff volume leaving cells containing sediment yields from primary cells (a cell that no other cell drains in to). Sediment from these and other cells was broken into five particle size classes: clay, silt, sand, small aggregates (sagg) and large aggregates (lagg) Table 14. Sediment was routed through the watershed by surface runoff in loop three. Calculations were made to establish the concentrated flow rate, to derive the channel transport capacity, and to calculate the actual sediment flow rates. Using the graphical output utility or ARCGIS, spatial data were depicted (Figures 21) to show the capability of AnnAGNPS pinpointing zones of the various degrees of soil erosion processes within the watershed.

Since the model was developed in both International System (IS) and British Unit System, the outputs were displayed in user selected system, for this study they were expressed in International System. The output options requested for this study of AnnAGNPS model at the watershed outlet or for any cell were hydrology output (Runoff volume in mm and Peak runoff rate in m^3/s) and Sediment output (Sediment yield and Sediment generated within the cell in tones).

2.2.5 Execution of AnnAGNPS Model

The organized AnnAGNPS initial data and cell parameters were entered for the watershed and each cell using AnnAGNPS input editor version 5.30 to create and edit an AnnAGNPS input file. The edited values had undergone a check through check data utility programme to scan AnnAGNPS input in order to make sure whether proper values and ranges of values were entered. The model was then run to obtain three outputs: runoff volume, which the model calculated using equation (2.2), peak runoff rate computed using equation (2.5), of section 2.3.4.1.and sediment yield, using equation (2.7) of section 2.3.4.2.Finally formatted numeric outputs of AnnAGNPS model were depicted as watershed summary and for each cell by utilizing tabular output utility.

2.2.6 Sensitivity Analysis

Sensitivity analysis is a methodical study of the response of selected output variables to variations in input parameters and/or driving variables [19]. Model users refer to sensitivity analysis results to guide their parameterization efforts and to recommend best management practices using those parameters to which the model is most sensitive.

The sediment outflow from each cell and sub-catchment is primarily governed by soil, hydrologic and hydraulic parameters such as soil erodibility, surface runoff, stream discharge and stream flow velocity. AnnAGNPS model considers many parameters, but it is mandatory to identify which of the watershed parameters are most important to govern runoff, peak runoff and sediment yield. Before calibration and validation of runoff, peak runoff and sediment yield, governing parameters should be prioritized according to their order of influence. Prioritization of the parameters had been done by variation in ±10 and ±20 from base value using equation 3.12 and 3.13. Parameters that might have significant impact on model outputs were selected based on information from model structure.

a. Percent deviation [10]

$$D = \left(\frac{Px - B}{B}\right) 100 \qquad (3.12)$$

where,

D = per cent deviation of output from base value simulate

Px = increment or decrement of output due to % increase or decrease of input

B = reference model output

b. Sensitivity index [11] cited in Gete, 2000

$$SI = \left(\frac{Px - Mx}{B}\right) 100 \qquad (3.13)$$

Where, SI= sensitivity index

Px = model output with x% increase of the variable

Mx = model output with x% decrease of the variable

B = reference model output

2.2.7 Calibration of AnnAGNPS

The most sensitive parameters, which resulted in high output variation were selected for the calibration of AnnAGNPS model. The model was separately calibrated for measured data of runoff, peak runoff and sediment yield of Erer-Guda gauging station. Eight years (1988-1995) data records of flow and sediment were used for model calibration. The simulated versus observed values for each adjustment were evaluated with coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE) up to the values of R^2 and NSE reach maximum calibration.

2.2.8 Validation of AnnAGNPS

In order to utilize the calibrated model for estimating the effectiveness of future potential management practices, model validation against an independent set of measured data from 1984-1987 was employed for runoff, peak runoff rate and sediment yield to adjust uncertain parameters based on the information obtained from model calibration. The model predictive capability demonstrated in validation phases were used for prediction of runoff, peak runoff rate and sediment yield of Erer-Guda catchment and for each sub-catchments of Erer-Guda watershed.

VOL. 4, NO. 10, October 2014 ISSN 2225-7217
ARPN Journal of Science and Technology

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2.2.9 Statistical Tools

The accuracy of the model predictions were tested by comparing predicted with observed values of runoff, peak runoff rate and sediment yield by using model simulation efficiency (NSE) equation 3.14 of Nash and Sutcliffe [59] and Coefficient of determination (R^2) equation 3.15. It is given by:

$$NSE = \frac{\sum_{i=1}^{n}(m_i - \bar{m})^2 - \sum_{i=1}^{n}(p_i - m_i)^2}{\sum_{i=1}^{n}(m_i - \bar{m})^2} \qquad (3.14)$$

Where, NSE = Nash and Sutcliffe model efficiency, m_i = measured variable, p_i = predicted variable, $\bar{m}$ = arithmetic mean of m_i , $\bar{p}$ = arithmetic mean of p_i for all events i = 1 to n

Nash and Sutcliffe Model efficiency (NSE) is essentially the sum of the deviations of the observations from a linear regression line with a slope of 1. If the measured variable is predicted exactly for all observations, NSE is 1. Low values of NSE represent high deviations between measured and predicted values. If NSE is negative, predictions are very poor, and an average value for the measured output is a better estimate than the model prediction.

The R^2 value is an indicator of strength of relationship between the observed and simulated values.

$$R^2 = \frac{\left(\sum_{i=1}^{n}(m_i - \bar{m})(p_i - \bar{p})\right)^2}{\left(\sum_{i=1}^{n}(m_i - \bar{m})^2\right)\left(\sum_{i=1}^{n}(p_i - \bar{p})^2\right)} \qquad (3.15)$$

2.2.10 Annual Runoff and Sediment Yield of Erer-Guda Catchment

After the model calibration and validation were employed, runoff and sediment yield were simulated with respect to different land use practice factor. The entire catchment was divided in seven sub-catchments based on their stream courses. The model was run to generate annual average runoff and sediment outflow for each sub-catchment. The runoff and sediment yield generated from each sub-catchment was quantified and the most erodible sub-catchment was identified.

3. RESULTS AND DISCUSSION

3.1 Hydro-Meteorological Data Analysis

3.1.1 Estimation of Missed Data

Stations having inadequate daily records were identified and considered to be missed. Out of the 4 stations, Haramaya and Babile for the year 1993 had missed information and the missed values were manipulated by using normal ratio method (equation 2.9).

3.1.2 Consistency and Homogeneity Tests

The double mass curve which is the plot of the annual cumulative total rainfall data of the base station with the average annual cumulative total rainfall data of neighborhood stations (Haramaya, Harar, Gursum and Babile accordingly for each. There was a little slope change of Babile rainfall data that was not persistence significant change in the double mass curves. The little change in slope might have occurred by chance or due to micro-meteorological and climatic properties. Therefore, the changes were not significant for the existence of inconsistency of records. Hence, relative homogeneity of records was observed for the precipitation. In flow data no slope change was observed.

Rainfall and hydrological data used for the study area were from 1981-2000 and 1984-1995, respectively. The homogeneity of the annual rainfall and runoff were tested by using RAINBO software. The result of homogeneity test for the observed rainfall and gauging stations data shows that the collected data was homogeneous except rain fall data for Haramaya and Babile which were rejected at 90% (Figure 6). This was due to the maximum cumulative deviation crossed the 90% probability line. The estimated change point were the record of annual rainfall in 1990 (996.78 mm) and 1986 (1146.94mm), Haramaya and Babile station respectively. The test results for Haramaya are presented in Figures 6, 7 and 8.

Homogeneity test graph of annual rainfall was used to determine the position of change points where the cumulative deviation sum plot showed a clear change of slope in, 1990 (Figure 6).

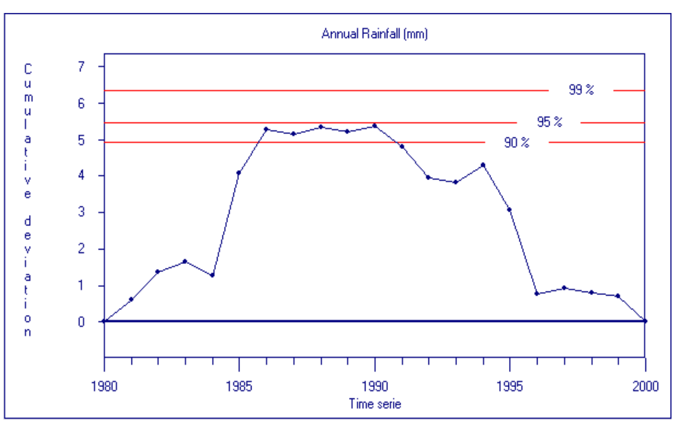


Fig 6: Rescaled cumulative deviation of Haramaya annual rainfall

The probability plot of annual rainfall is given in Figure 7. Closeness of linear relationship (CDF) $R^2 = 0.90$

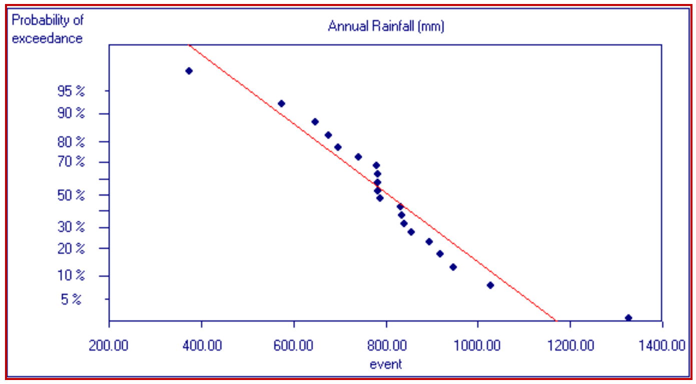
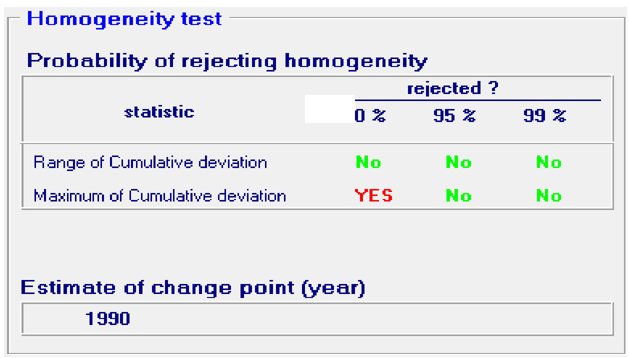


Fig 7: Probability plot of Haramaya annual rainfall



Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ? 0 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	YES	No	No

Estimate of change point (year)

1990

Fig 8: Probability of rejecting homogeneity of Haramaya annual rainfall

Homogeneity test graph of average annual flow at gauging site of Erer River used to determine the position of change points. At points where the cumulative deviation sum plot showed a clear change of slope, indicating that a change in trend estimates of change point was none (Figure 9).

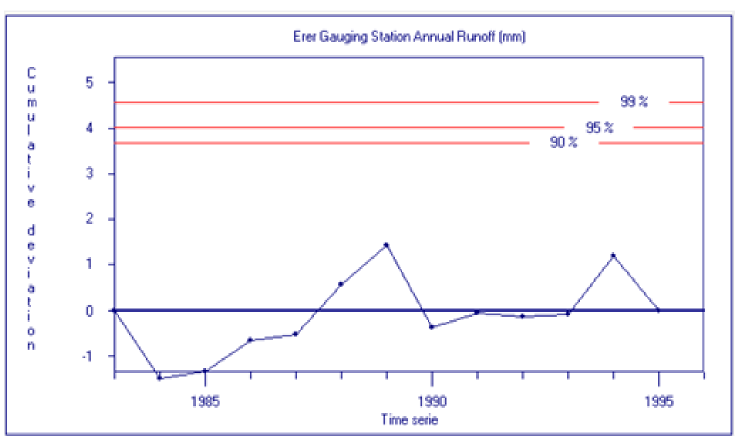


Fig 9: Rescaled cumulative deviation of annual runoff of Erer gauging station

VOL. 4, NO. 10, October 2014 ISSN 2225-7217
ARPN Journal of Science and Technology

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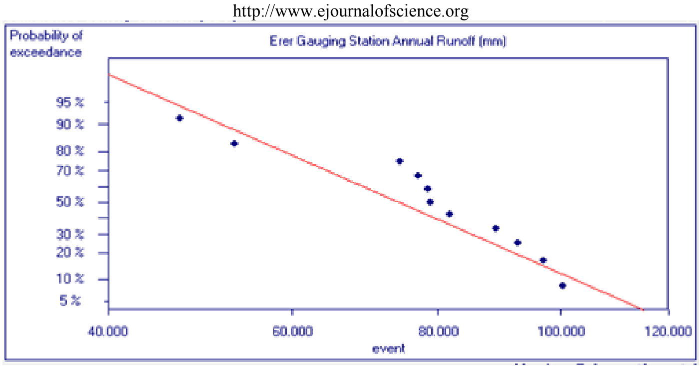

Fig 10: Probability plot of annual runoff at Erer gauging station

The probability plot of annual average flow is given in Figure 10 and shows a close linear relationship (CDF) with R^2 value as 0.90

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -

Fig 11: Probability of rejecting homogeneity at annual flow (Erer station)

3.1.3 AnnAGNPS Model Setup

3.1.3.1 Sensitivity Analysis of AnnAGNPS Model

Ten input parameters: precipitation (RF), RUSLE 10 Year Energy Intensity Factor (EI30), Curve Number (CN), Land slope (S), RUSLE length slope factor (LSF), Manning's roughness coefficient (n), soil erodibility factor (K), surface condition constant (SCC), concentrated flow length (CFL) and concentrated flow slope (CFS) were selected for sensitivity analysis. Each of the input parameters were varied ±10% and ±20% about the simulated base values of runoff, peak runoff rate and sediment yield, while other parameters were kept constant to their standard value.

The effect of input parameters on outputs of runoff, peak runoff rate, and sediment yield was examined (Figures 13, 14 and 15). Curve Number was the most sensitive parameter, which resulted in high output variations. For instance, the percent deviation of runoff, peak runoff rate and sediment yield were -52.56 to +453.80%, -52.95 to +243.84% and -81 to +233.83%, respectively due to changes in Curve Number from -10% to +20% from its base value (runoff = 56.69mm ,Peak runoff rate = 62.72m3/s, sediment yield = 9.14tons). The corresponding sensitivity indices were 5.06, 2.97 and 3.15, respectively. Next to curve number, changes in precipitation had a great impact on the three outputs. All other input parameters, except land slope and RUSLE length slope factor had brought about a very little change on sediment yield. Manning's roughness coefficient, soil erodibility factor, concentrated flow length, concentrated flow slope, energy intensity factor and surface condition constant do not substantially influence the hydrological outputs. Surface condition constant was the least sensitive parameter, which could not affect all output values of the model.

For ± 10% input changes, the outputs showed the same trend as the response to ± 20% input changes but with lower magnitude. The only exception was the land slope, which brought about a mild change in runoff.

Teshome [47] had reported during application of AGNPS model in Tikurso watershed, North Shoa, that Land slope was the most sensitive parameter, followed by practice factor. Surface condition constant was the least too. The sensitivity analysis results of this study confirmed the findings of Yoon [52] in the study of Sand Hill River sub basin in Minnesota, and Hassen [24] in the Validation of AGNPS in Kori Watershed, South Wollo zone when CN was the most sensitive parameter

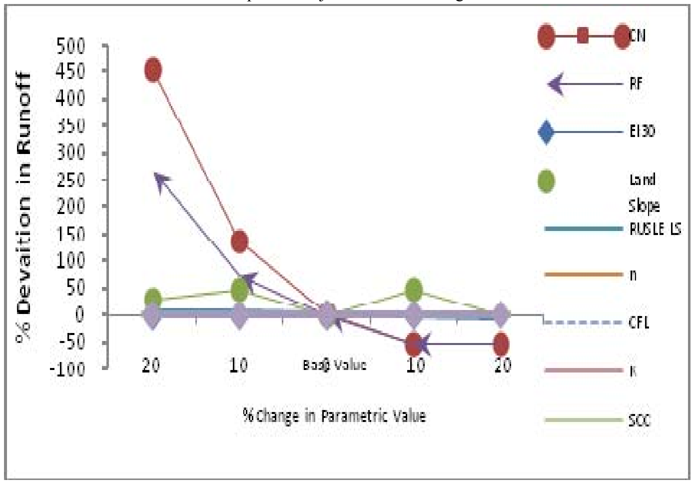

Fig 12: Comparison of model runoff sensitivity to selected input parameters

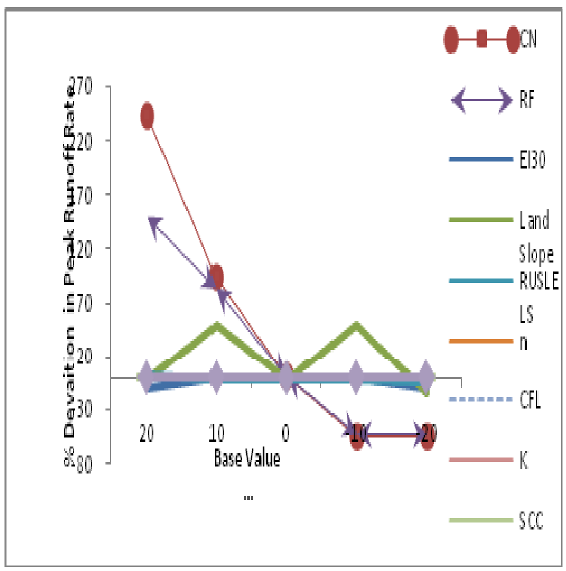

Fig 13: Comparison of model peak runoff rate sensitivity to selected input parameters

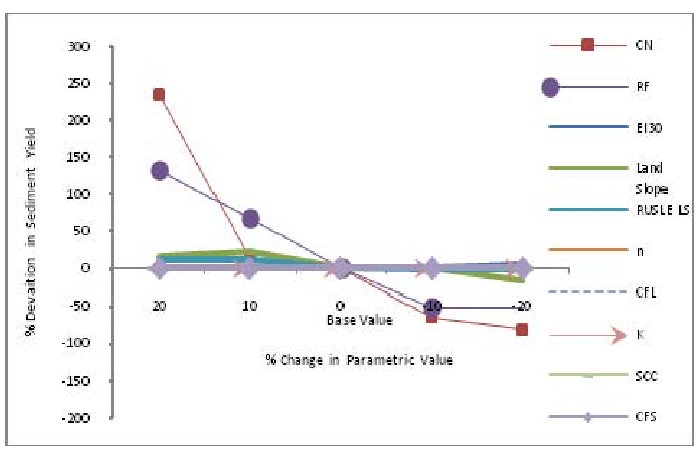

Fig 14: Comparison of model sediment yield sensitivity to selected input parameters

3.1.4 Calibration of AnnAGNPS Model

AnnAGNPS model was calibrated for runoff, peak runoff rate and sediment yield to adjust uncertain parameters for the next validation stage. Of the parameters reported in this study, most of them were known or measured values obtained from ARCGIS and TOPAGNPS application, measured data records and direct field measurements. Rainfall and energy, land slope, channel flow length, channel flow slope and RUSLE LS factor were derived from DEM by using TOPAGNPS. K value was calculated by using equation 3.1. RUSLE practice and cover factors were internally calculated by model. Manning's roughness coefficient and surface condition constant were insensitive and their values were taken from look up tables in the AnnAGNPS manual.

From sensitivity analysis of AnnAGNPS mode CN, land slope and RUSLE LS factor were the sensitive parameters. CN had been found uncertain and subjected for calibration because its value would be dynamic as land cover changes through the rainy period. Slope length and steepness were also other dominant factors that would have been integrated with factors of CN.

To begin a calibration, curve number values for each cell were determined by the SCS Curve Number Method [84] for AMC II (Table 7) that was later converted to AMC I and III according to the moisture condition preceding the selected rainfall. Curve number for AMCII conditions were taken from AnnAGNPS user manual.

Table 7: Curve number and hydrologic soil group value

Soil type	Soil texture	Land use	Curve number ID	Curve number II	Hydrologic soil group
Leptosols	Loam	Open Grass	Pasture_(Poor)	79	B
		Intensively Cultivated	Row_Crop_(C& T-poor)		
Cambisols	Sandy clay loam			79	C
Nitisols	Sandy loam	Shrubs	Brush_(fair)	35	A
Cambisols	Sandy clay loam				
		Moderately Cultivated	Row_Crop_(SR-poor)	88	C
Glyesols	Sandy loam			74	A
Luvisols	Sandy clay loam			88	C

Observed hydrologic data of 1988-1995 were selected for calibration. The SCS curve numbers for each cell were proportionally adjusted, about the initial value by trial and error for calibration period. Land slope and RUSLE LS factors were varied, increased or decreased, while curve numbers were decreased or increased in the contrary until the predicted runoff and sediment yield came closer to the observed outputs. To adjust higher records of runoff, curve numbers were increased. But the increases in curve numbers also boost up both peak runoff rate and sediment. Decreasing the land slope and RUSLE LS factor value in turn a little bit reduced the increased sediment yield, because CN affected all the three outputs, but land slope and RUSLE LS factor affected only the sediment yield.

Several attempts were tried to obtain the best fit. About 22 different calibration trials were conducted for each output. Increasing from original value CN by 5% for Runoff, decreasing CN, land slope and RUSLE LS factors by 10%, 39% and 41 %, respectively for sediment yield were the best results for calibration. The best calibrated R^2 and NSE results of the trials for each year with the observed output values are listed in Table 8.

Table 8: Observed and predicted annual runoff, peak runoff rate and sediment yield data for calibration

Calibration years	Observed runoff (mm)	Observed peak runoff rate (m3/s)	Observed sediment yield (tons/ha)	Calibrated runoff (mm)	Calibrated peak runoff rate (m3/s)	Calibrated sediment yield (tons/ha)
1988	97.01	22.88	7.23	90.82	62.71	8.46
1989	92.68	19.84	13.66	85.14	66.70	8.80
1990	41.16	15.02	6.01	40.73	21.05	4.93
1991	81.94	11.42	3.08	77.37	94.23	3.65
1992	74.52	13.78	1.51	72.68	93.71	2.00
1993	77.06	21.34	3.02	80.57	60.90	4.80
1994	100.25	24.16	2.38	123.99	191.94	4.05
1995	53.18	18.26	2.44	59.99	57.05	1.94

3.1.5 Runoff

Calibration of the model was done for an independent data set of eight years from 1988 to 1995. It was found that the model had well predictive capability with NSE and R^2 value of 0.758 (Table 9) and 0.825 (Figure 15), respectively. It can be seen from Figure 16 that the model simulates the observed runoff quite well. It was a satisfactory result attributed to the maximum possible calibration. This result confirmed both the report of Hassen, et al. [24] and Admasu [1], which indicated

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ARPN Journal of Science and Technology

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that the runoff component of the model was predicted in a better fashion with the efficiency of 0.73. Mitchell et al. [31] and Perrone and Madramooto [37], also reported that runoff in Illinois and Quebec watersheds resulted with reasonable accuracy.

Nigussie and Fekadu [37] reported that model efficiency and test of significance for both runoff calibration and validation on Agucho catchment was less than zero and insignificant, respectively. Eshetu [16] tested and evaluated the model on the treated and untreated sub-catchment of Gununo and reported that the model performed better for predicting peak runoff rate and sediment yield where as the model was not capable enough to predict volume of runoff.

3.1.6 Peak Runoff Rate

Peak runoff rate produced a coefficient of efficiency of -331.068 (Table 9) and 0.110 (Figure 16), NSE and R^2, respectively. This indicated that the predicted and measured peak runoff rate had no relationship and, in generally the model over predicted peak runoff rate. Perrone and Madramooto [38] and Admasu [1] also came across with over prediction of the model for peak runoff rate. The negative value of model efficiency showed that the model prediction was very poor.

3.1.7 Sediment Yield

The model efficiency for sediment yield was 0.710 (Table 9) and 0.763 (Figure 17) for NSE and R^2, respectively. It shows that sediment yield was well calibrated. This was a satisfactory result attributed to the maximum possible calibration. This result confirmed both the report of Hassen, et al. [24] and Admasu [1].

Table 9: Paired samples model efficiency for calibration

Paired samples model efficiency		
Pair	N	NSE
Observed runoff and calibrated runoff	8	0.76
Observed peak runoff rate and calibrated peak runoff rate	8	-331.07
Observed sediment yield and calibrated sediment yield	8	0.71

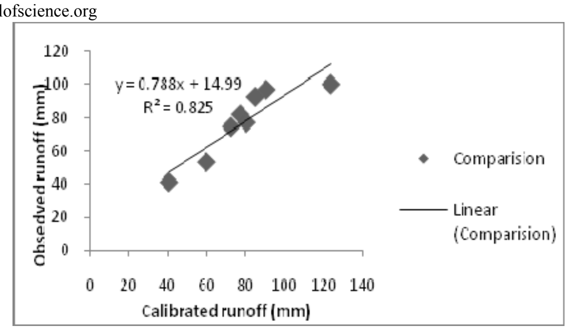

Fig 15: Observed versus predicted runoff for calibration

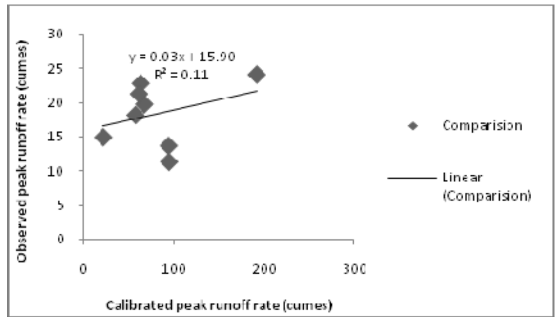

Fig 16: Observed versus predicted peak runoff rate for calibration

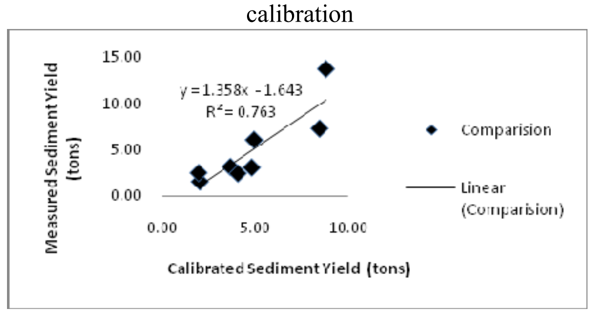

Fig 17: Observed versus predicted sediment yield for calibration

3.1.8 Validation of AnnAGNPS Model

Once the model calibration process was used to estimate the best values for the model parameters, the outcomes were evaluated whether they represent the observed values. The AnnAGNPS model was validated for runoff, peak runoff rate and sediment yield from the observed data of 1984 to 1987. The CN, and land slope values determined during the calibration runs were substituted for similar periods of occurrence of runoff volume, peak runoff rate and sediment yields. Observed and validated output results are presented in Table 10.

Table 10: Observed and predicted runoff, peak runoff rate and sediment yield data for validation

Validation years	Observed runoff (mm)	Observed peak runoff rate (m3/s)	Observed sediment yield (tons/ha/yr)	Validated runoff (mm)	Validated peak runoff rate (m3/s)	Validated sediment yield (tons/ha/yr)
1984	47.20	3.84	5.64	46.35	9.09	4.56
1985	78.93	8.93	7.26	93.37	20.83	7.01
1986	89.18	2.57	8.01	92.12	58.69	7.93
1987	78.51	7.65	4.93	80.19	22.64	5.25

3.1.9 Runoff

The model efficiency (NSE) and coefficient of determination (R^2) for runoff were estimated at 0.778 (Table 11) and 0.923 (Figure 18), respectively which outperformed to that calculated in model calibration. The model overall efficiency for surface runoff was improved during validation and.

3.1.10 Peak Runoff Rate

The model efficiency for peak runoff rate was less than zero (Table 11), which was the same result to that obtained in model calibration. In this study, poor relationship (0.235) was observed between observed and validated peak runoff rate (Figure 19).

3.1.11 Sediment yield

The model efficiency for sediment yield was found more than satisfactory (0.779) (Table 11), which was the same result to that obtained in model calibration (Figure 20). It was found that the model had well predictive capability with NSE and R^2 value of 0.779 (Table 11) and 0.857 (Figure 20), respectively.

Table 11: Paired samples model efficiency for validation

Paired samples model efficiency		
Pair	N	Efficiency
Measured Runoff and Validated Runoff	4	0.778
Measured Peak Runoff Rate and Validated Peak Runoff Rate	4	-77.999
Measured Sediment Yield and Validated Sediment Yield	4	0.779

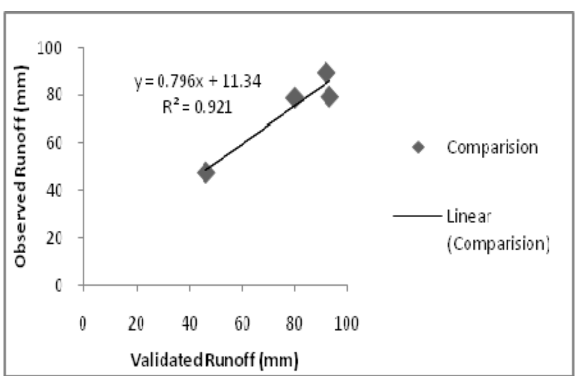

Fig 18: Observed versus validated runoff

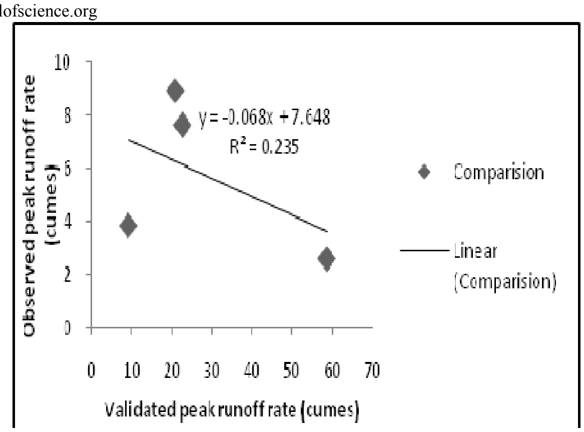

Fig 19: Observed versus validated peak runoff rate

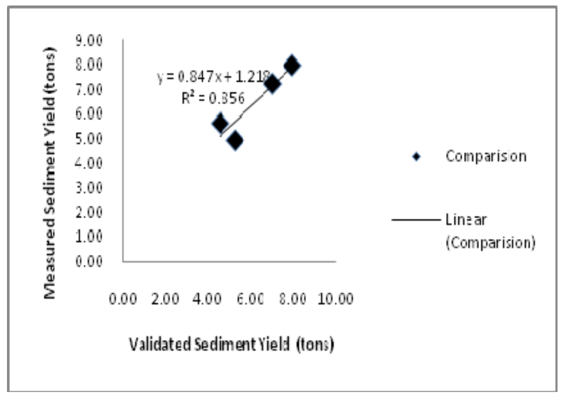

Fig 20: Observed versus validated sediment yield

3.1.12 Annual Runoff and Sediment Yield of Erer-guda catchment

The predicted annual runoff and sediment from Erer-Guda catchment based on land use/cover indicated that, the highest amounts of annual runoff and sediment yield 486 mm and 10.50 t/ha (Table 12 and Figure 4) were generated from cultivated agricultural land, respectively, followed by open grass land which had contributed 447mm and 2.11 t/ha annual runoff and sediment yield, respectively. The least 287.5 mm and 0.24 t/ha annual runoff and sediment yield were from dense shrubs land, respectively. This indicates that the erosion increases as the land use changed from forest/shrubs land to crop land for agricultural crop production. Reduction in forest cover increases water yield [6; 8]. Vegetation also retards the surface flow and giving more time to infiltrate and to evaporate [19].

However, the arithmetic average rate illustrated the highest amount of runoff and sediment yield was generated from cultivated agricultural land. This indicates that the soil erosion rate increases in cultivated agricultural land use due to soil manipulation for crop production and the soil exposed to rain drop energy and erosivity of runoff water.

Deforestation may increase erosion. In Malaysia, streams from logged areas carry 8-17 times more sediment load than before logging [17]. The actual soil loss, however, depends largely on the use to which the land is put after the trees have been cleared. Surface erosion from well-kept grassland, moderately grazed forests and soil-conserving agriculture are low to moderate [7].

Table 12: Runoff and sediment yield of Erer-Guda catchment from different land use/cover

Land use practice	Sediment yield (t/ha/yr)	Runoff (mm/yr)	Areal coverage (ha)	Areal coverage (%)
Cultivated land	10.50	486	42424.9	92.83
Open grass land	2.11	447	119.18	0.26
Shrubs land	0.24	287.50	3159.45	6.91

3.1.13 Annual runoff of Erer-guda catchment

The Erer-Guda catchment area delineation and sub-catchment definition done by TOPAGNPS and ARCGIS software's was gave an area of 45,703ha which resulted in seven sub-catchments (Table 13 and 15 and Figure 21) for the identification of the most erodible sub-catchment.

The predicted annual average runoff from Erer-guda catchment was 407.61mm. The total annual runoff outflow to the gauging station was 2853.28 mm (Table 13). The first 498.41 and second 496.03mm maximum runoff was generated from East central and Northern part of the catchment, respectively.

Spatial differences in runoff were apparent in the watershed (Table 13 Figure 21). Sub-catchment SWT_5, SWT_4 and SWT_2 were the first, second and third contributed large amount of the annual runoff, respectively and the lowest was from sub-catchment SWT_7. The land use of sub-catchment SWT_5, SWT_4 and SWT_2 were cultivated agricultural croplands which contributed larger amount of runoff and the lowest is from sub-catchment SWT_7 which have shrubs land (Figure 21).

Area weighted average runoff from each sub-catchment indicated that the rate of runoff range from 209.40mm to 498.41mm from shrubs land (SWT_7) and cultivated agricultural land (SWT_5), respectively. However, the arithmetic average rate illustrated the highest amount of runoff was generated from cultivated agricultural land (SWT_5). This indicates that the erosion increases as the land use changed from shrubs land to cultivated agricultural land.

Table 13: Average annual catchment runoff

Sub- catchment	Water Yield (ha-m)	Runoff (mm)	Area (ha)	Areal cov. (%)	Land use practice
SWT_1	2607	260.67	4634	10	Cultivated land
SWT_2	4754	475.44	6866	15	Cultivated land
SWT_3	4529	452.94	6729	15	Cultivated land
SWT_4	4960	496.03	8100	18	Cultivated land
SWT_5	4984	498.41	5618	12	Cultivated land
SWT_6	4604	460.38	7710	17	Cultivated land
SWT_7	2094	209.40	6046	13	Grass, shrubs, and cultivated land
Mean	4076	407.61			
Total	28532	2853.28	45703	100	

3.1.14 Annual sediment yield of Erer-guda catchment

The predicted annual average soil loss from Erer-guda catchment was 21 tons ha-1 year-1 (Table 14) while an average soil formation rate of the nation is 1 ton ha^{-1} $year^{-1}$ [30]. This estimated average annual soil loss of the watershed is 50% of the national average annual soil loss of (42 tons ha-1year-1) from crop lands [25].

The total annual sediment outflow from the catchment to the gauging station was 415,150 tons (Table 15) which is smaller than the amount indicated by erosion from contributing catchment (Table 14). The average annual rate of sediment yield was estimated 9.26 ton ha-1year-1. The first 17.30 ton ha-1year-1 and second 11.38 ton ha-1year-1 maximum sediment were generated from East central and West central part of the catchment, respectively.

Table 14: Average annual catchment soil erosion

Catchment erosion [ton/ha/yr]						
Source of erosion	Clay	Silt	Sand	Sm. Agg.	Lg. Agg.	Subtotal
Gully	2.365	0.014	0.292	4.168	12.713	19.553
Sheet & Rill	0.177	0.008	0.020	0.323	0.923	1.452
Subtotal	2.542	0.022	0.313	4.491	13.636	21.005

Table 15: Average annual catchment sediment yield

Sub- catchment	Sediment (t/yr)	Sediment (t/ha/yr)	Area (ha)	Areal cov(%)	Land use practice
SWT_1	48943	10.56	4634	10	Cultivated land
SWT_2	70795	10.31	6866	15	Cultivated land
SWT_3	76587	11.38	6729	15	Cultivated land
SWT_4	89744	11.08	8100	18	Cultivated land
SWT_5	97208	17.30	5618	12	Cultivated land
SWT_6	30563	3.96	7710	17	Grass, shrubs, and cultivated land
SWT_7	1329	0.22	6046	13	Dense shrubs and cultivated
Mean	59310	9.26			
Total	415150		45703	100	

Soil erosion in the watershed was affected by different factors such as: rainfall, soil type, vegetation cover and land use. Spatial differences in soil loss were apparent in the watershed (Table15). Sub-catchment SWT_5, SWT_3 and SWT_4 were the first, second and third contributed large amount of the annual sediment, respectively and the lowest was from sub watershed SWT_7. The land use of sub-catchment SWT_5, SWT_3 and SWT_4 were cultivated agricultural lands which contributed large amount of sediment and the lowest was found from shrubs land (Table 15 and Figure 21). These

were attributed due to the topographic slope and land use of these sub-catchments. They were an agricultural land with > 61% of which has a slope > 10%. And the minimum yield of less than 0.22 tons/ha was obtained for SWT_7, it has a slope < 10% and 50.87% of it was covered by shrubs land the rest was agricultural.

Area weighted average sediment yield from each sub-catchment indicated that the rate of erosion range from 0.22 ton ha-1year-1 to 17.30 ton ha-1year-1 from shrubs land (SWT_7) and crop/cultivated agricultural land (SWT_5), respectively.

Hurni [27] had conducted a research to estimate the rate of soil formation for Ethiopia and found that the range of tolerable soil loss level for various agro-ecological zone of Ethiopia from 2 to 18 tons/ha. The simulated sediment yield in this study area was found to be in the tolerable rate as indicated in Table 15 and Figure 21.

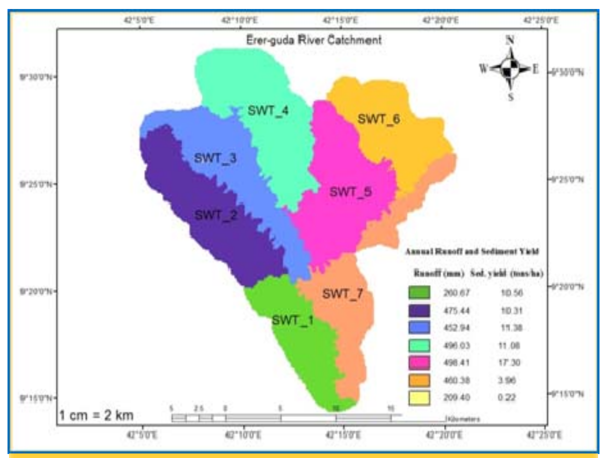

Fig 21: Annual runoff and sediment yield map of each sub-catchment of Erer-Guda

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