

# Simulation of Runoff and Sediment Yield Using AnnAGNPS Model at Dawe Watershed, Eastern Hararghe, Ethiopia

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**Abstract:** The high erosion rates are mainly affecting the developing countries due to intensive cultivation, deforestation; extreme climate hazard, sediment transport and loss of agricultural nutrients were caused by unwise land use practices, intensive cultivation and improper management. Soil conservation is the only known way to protect the productive land. In this study a physically based watershed model, Annualized Agricultural Non-Point Source (AnnAGNPS) pollution model was applied to the Dawe River watershed for simulation of the runoff and sediment yield. The objectives were to estimate potential runoff and sediment yield and to recommend and design appropriate soil and water conservation measures on a sub watershed basis in Dawe watershed of east hararghe zone. Sensitivity analysis, model calibration and validation were also performed. Four highly sensitive parameters were identified and of which CN was the most sensitive one. For model calibration, model efficiencies of 0.742, -231.081 and 0.828 were observed for surface runoff, peak runoff rate, and sediment yield, respectively. The corresponding determination of coefficients was 0.825, 0.1669 and 0.848, respectively. Runoff and sediment yield were well predicted but, peak runoff rate was over predicted. Validation results produced model efficiencies NSE of 0.769, -73.801 and 0.718 for surface runoff, peak runoff rate and sediment yield, respectively. With coefficient of determination ( $R^2$ ) of 0.9215, 0.235 and 0.764 for runoff, peak runoff rate and sediment yield, respectively. Surface runoff and sediment yield simulation were well in the validation stage and peak runoff rate shows the same trend as calibration. Dawe watershed was divided in thirteen sub-watersheds. Runoff and sediment yield for each sub-watershed were quantified. Average annual watershed runoff, average annual soil loss and total annual sediment outflow from Dawe watershed was 194.48mm, 22.467 tons/ha/yr and 354215 tons/yr, respectively. In Dawe watershed, gully, rill and inter-rill erosions were identified as major problems. Thus, check dam and bench terrace designed and vegetative waterway are recommended for intensively cultivated crop land of Dawe watershed.

**Keywords:** Dawe Watershed, Runoff, Sediment Yield, Soil Loss, Peak Runoff

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## 1. Introduction

Nowadays, Soil erosion is a worldwide environmental problem that reduces the productivity of all-natural ecosystems and agriculture, which threatens the lives of most smallholder farmers [5]. The expansion of agriculture has accelerated soil erosion by rainfall and runoff significantly, mobilizing around 783\_243 Pg. of soil organic carbon (SOC) globally over the past 8000 years [15] it has been observed that, most of the existing structures in Dawe watershed were

demolished due to the sediment overload, vulnerability to livestock damage and inappropriate SWC practices over there. Therefore, appropriate and standardized soil and water conservation measures for different erosion-prone land uses and land forms need to be implemented. Models which give a comprehensive picture of the various hydrologic processes are called as integrated watershed models. There are a number of integrated physically based distributed models.

The high erosion rates are mainly affecting the developing countries due to intensive cultivation, deforestation, plowing of marginal lands and extreme climate hazards [3].

Most of the previous studies on soil erosion modeling in Ethiopia concentrated only on the estimation of mean annual soil loss due to rill and inter-rill erosion using the USLE. However, research shows that few extreme events are more important than annual average soil loss values. The greatest criticism of the USLE has been its ineffectiveness in applications outside the range of conditions for which it was developed. Adaptation of the USLE to a new environment requires a major investment of resources and time to develop the database required by the model.

These limitations can be overcome with the use of the agricultural non-point source pollution (AnnAGNPS) model which is process-based but maintains some empirical parameters. The model performed well in US conditions but its application in eastern Africa has been less frequent. [1] The general objective of this study was to simulate runoff and sediment yield using AnnAGNPS model at Dawe watershed.

The Soil Conservation Research Project (SCRIP) has estimated soil loss of which 1.5 billion tons of soil has been eroded every year from Ethiopia [8] several practices in agriculture today have resulted in misuse and degradation of previously fertile land. Bad cropping patterns, unsuitable cultivation techniques, misuse of tractor power, improper choice of implements and machines, the abuse of natural pastures and forests, the extension of cultivation to marginal and sub-marginal lands, and faulty irrigation and drainage systems are mostly responsible for the present situation. In an attempt to solve some of these problems, many mistakes have been made resulting in failures and worsening of the situation in many developing countries.

The basic concept of a multi-disciplinary approach to the solution of the problems has unfortunately been overlooked in most cases. Quantifying the effects of the soil loss helps to substantiate investment in sustainable land management for the benefits to land users. Appropriate soil conservation measures bring economic advantages to the land users, but farmers resist adopting improved erosion control measures due to lack of awareness on the immediate impacts of soil loss for livelihood, and low skills for construction of soil conservation structures [13] In order to address the above-mentioned development strategies, a proper investigation of the runoff yield of the watershed is essential for management and utilization of water resource. If these are not investigated, there will be loss of productive soil which leads to decrease in agricultural productivity as well, the life of the water harvesting structures is shortened by sedimentation on the farm land and, it makes difficult to design the appropriate and economical conservation measures and structures in Dawe watershed. Moreover, it makes difficult to select the appropriate crop type scheduling with respect to available runoff. Increased soil erosion and sedimentation rates can also jeopardize the array of ecosystem services provided by the watersheds. Erosion can reduce soil nutrient contents, degrade soil structure, and reduce the effective rooting depth, thereby reducing soil productivity [14].

Nash, J. E. et al. [12] Recognized that a “planetary boundary” limited the first constraint, the expansion of crop lands or the surface area of land used. Then, the second constraint, water use is limited: while rainfall or green water availability is relatively constant, additional use of blue water, or freshwater derived from surface or groundwater sources, was calculated by [7] to be limited to 20% of the global annual runoff.

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## 2. Materials and Methods

### 2.1. Description of the Study Area

The Dawe watershed falls into three Administrative woredas, Kersa, Kurfa Chele and Metta districts of East Harerge Zone, Oromia Regional States. It is located about 46km North West of Harar town. Kersa and Kulibi are the nearest towns located within 5 km and 7km distance respectively. Geographically, the Dawe watershed area is situated at 9°17'00"- 9°26'22" North latitudes and 41°42'00"- 41°52'00" East longitudes, with an elevation range of 1730-3232 meter above sea level. The area covers 256.9km<sup>2</sup> of land. There is high elevation difference between the upstream and downstream of the watershed.

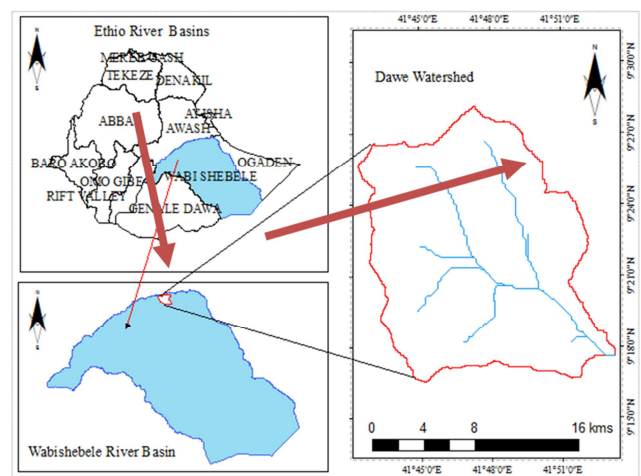


Figure 1. Location map of Dawe watershed.

## 2.2. Digital Elevation Model (DEM) of the Study Area

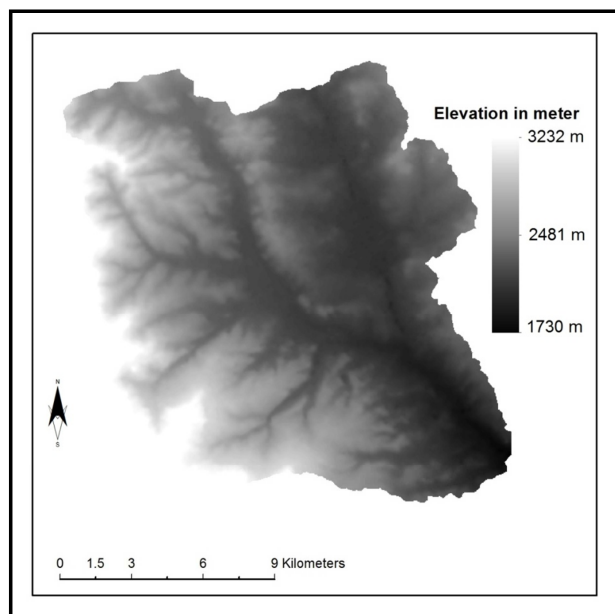


Figure 2. DEM of Dawe watershed.

TOPAGNPS, a Geographic Information System (GIS)-based land-escape analysis component of AnnAGNPS, uses DEM data to determine the spatial characteristics of the watershed. It divides the watershed into homogeneous sub-watersheds called 'cells' and routes flow through reaches, which are a required model input for simulation [2] The

30m by 30m RASTER derived elevation grid DEM used in this study was obtained from <https://earthexplorer.USGS.gov>. (2019). before the DEM data were loaded into Arc SWAT interface, it was projected into projected coordinate system.

The projection of the DEM data was done using the Arc tool box operation in Arc GIS. The projected coordinate system parameters of study area are: UTM— other GCS— Adindan UTM zone 38N. As the DEM covered a larger area in which part of it was not required for the modeling work but reduced the processing time of the GIS functions, a mask was created for the study area. Hence, only the portion of the DEM covered by the mask was processed by the interface.

## 2.3. Land Use/Land Cover

The land use is one of the most important inputs for the model. The land use map of the study area was obtained as shape file from MWIE from the study of Wabisheble river basin and field observation has been carried out. The reclassification of the land use map was done to represent the land use according to the specific land cover types and the respective crop parameter was selected from AnnAGNPS database. A look up table that identifies the 4-letter AnnAGNPS code for the different categories of land cover/land use were prepared so as to relate the grid values to AnnAGNPS land cover/land use classes.

Table 1. Land use/land cover redefinition and areal classification.

Original Land Use	AnnAGNPS Redefined Land use	Area (km <sup>2</sup> )	Areal coverage %
Maize	Corn	121.41	47.26
Sorghum	Grain Sorghum	83.00	32.31
Dense Shrub Land	Dense Shrub Land	8.31	3.23
Wheat	Durum Wheat	28.25	11.00
Open Shrub Land	Range Brush	15.92	6.20

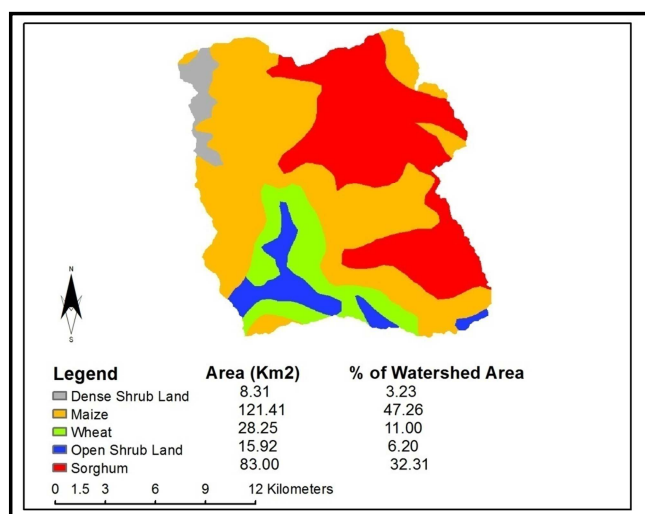


Figure 3. Land use/land cover map of Dawe watershed.

AnnAGNPS calculated the area covered by each land use.

Furthermore, recent studies show that change in land use in cultivated areas are increasing land degradation and as a consequence, soil erosion [11] The land use and soil maps were classified and then overlaid in order to make combinations and distributions of types of soil and their corresponding land use for each sub-basin in the watershed. Thus, most portion of Dawe watershed was covered with Maize, which accounted for 47.26%.

## 2.4. Soil Data

The AnnAGNPS model requires soil data. The required soil data and digital soil map of the study area were collected from MWIE. The major soil types in the area include; Chromic Luvisols, Rendzic Leptosols, Eutric Cambisols and Humic Nitisols. The soil types were also identified in watershed. The Chromic Luvisols and Eutric Cambisol were the major soil types covering 37.15% and 32.94% of the watershed area, respectively. The smallest portion of the area was covered by Humic Nitisols (1.3%).

## 2.5. Meteorological Data

Meteorological data are needed by the AnnAGNPS model to simulate the hydrological conditions. For this study the required meteorological data were collected from the Ethiopian National Meteorological Services Agency (NMSA). The meteorological data collected were precipitation, maximum and minimum temperature, relative humidity, wind speed and sunshine hours. Data from four stations, which are around the study area, were collected. However, most of the stations have short length of record periods. Two of the stations (Kulubi and Girawa) have records from 1996 to 2016 but some of them have missing data.

For this study Kulubi station was selected for weather generator station (station used for infilling of missing data), due to the availability and quality of data. Moreover, to identify the representative rainfall stations, which contribute for the watershed, Thiessen polygon method was used. The nearest meteorological stations such as Kersa, Kulubi and Girawa were identified and used as an input for rainfall where as Haramaya and Girawa stations were used for temperature.

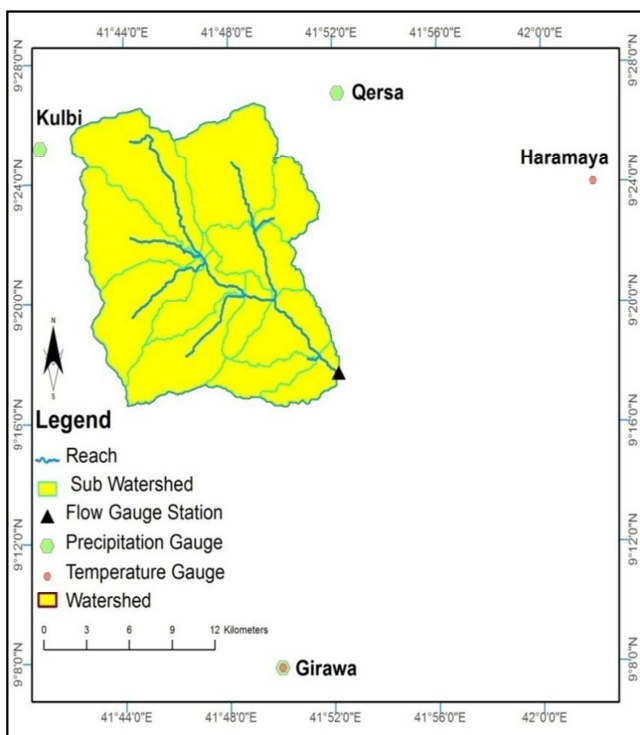


Figure 4. Location map of weather stations.

## 2.6. Hydrological Data

The daily recorded river flow data was required for performing sensitivity analysis, calibration and validation of the model. These data were collected from the Ethiopian MWIE. The hydrological data collected was daily flow for the Dawe gauge station feeding into Wabishebele River. Using RAINBOW software, the homogeneity of average annual daily flow data was tested.

## 2.7. 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 rainfall, 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 (equation 1).

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

Where the ratio ( $P_i/A_i$ ) 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  $P_x$  was not recorded. The estimate of  $P_x$  is found by multiplying the average proportion (P) by the average annual catch at gauge x ( $A_x$ ). 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 [1].

## 2.8. AnnAGNPS Model Setup and Description

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 MWIE Wabishebele River basin database. Finally, these data were organized, and processed to build AnnAGNPS input file. 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 generators were used to generate AnnAGNPS required climate data. 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 [1].

### 2.9. Watershed Parameters

**Watershed name:** This is the name given to the watershed under study. Dawe watershed is the name of the study site. This name identifies the input and output data files for the watershed.

**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.

**Watershed Location:** The location of the watershed where it is found. Thus, the study area falls in Kersa, Kurfa Chele and Metta districts of East Hararghe.

**Number of cells:** It is the total number of base cells in the watershed. For Dawe watershed, 2434 cells were used.

**Precipitation:** It is the amount of rainfall for the daily basis. Since AnnAGNPS is continuous based model, it was run for each separate rainfall day. For this study (1996-2016) daily rainfall data were used.

**The energy intensity value:** It is the rainfall erosion index.

### 2.10. Cell Parameters

1. **Cell ID:** It is the main identifier for each cell in the watershed. The cells were numbered consecutively.
2. **Soil ID:** Alphanumeric string used to identify the soil type for the cell.
3. **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.
4. **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 Dawe watershed.
5. **Management field ID:** An alphanumeric string used to identify the field or land use type.
6. **Reach location ID:** An alphanumeric string used to identify the channel reach.
7. **Reach length:** The length of the channel reaches which was generated by TOPAZ.
8. **Reach slope:** The average channel slope for the reach which was generated by TOPAZ.
9. **Reach elevation:** The elevation of the downstream end of the reach which was generated by TOPAZ.
10. **Cell average elevation:** Representative average elevation for the cell.
11. **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.

## 3. 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 program 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 peak runoff rate and sediment yield and finally formatted numeric outputs of AnnAGNPS model were depicted as watershed summary.

### 3.1. Sensitivity Analysis

In this study, sensitivity analysis was demonstrated by employing the AnnAGNPS model to see how much it was sensitive with respect to input changes and thereby to decide which parameter should be subjected for calibration. All of watershed and cell parameters do not equally affect the output of the model. Parameters that might have significant impact on model outputs were selected based on information from model structure. Ten input parameters: precipitation (RF), RUSLE 10 Year Energy Intensity Factor ( $EI_{30}$ ), 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  $\pm 10\%$  and  $\pm 20\%$  about the simulated base values of runoff, peak runoff rate and sediment yield, while other parameters were kept constant to their standard value. Totally 40 different files, 4 files for each parameter, were prepared.

SCS curve number is the most important parameter in the model for predicting runoff, and it is the parameter utilized in many studies to calibrate runoff [4] Therefore, the SCS curve number was also used to calibrate runoff in this study.

### 3.2. Model Calibration

Calibration is a process of standardizing predicted values, using deviations from observed values for a particular area to derive correction factors that can be applied to generate predicted values that are consistent with the observed values. In order to improve model predictability, the hydrologic component of the model was calibrated with respect to local observational data of Dawe gauging station for calibration period of 2009-2016. Model assessment and evaluation was performed by comparing observed and AnnAGNPS-predicted data at the watershed outlet where the auto sampler was located.

The model was assessed for runoff on a daily and monthly time scale. Sediment prediction was compared for storm events, while nutrient data were compared on a monthly time scale. Assessment of model performance for runoff, sediment, and nutrients included both qualitative and quantitative methods. Qualitative methods included comparing graphs of observed and predicted data, while coefficient of determination ( $R^2$ ) and Nash Sutcliffe Efficiency (E) were the statistical methods used for quantitative evaluations.  $R^2$  represents the variation in measured data explained by the model [10].

Values can range from 0 to 1, with 1 indicating that all variation in the measured data is explained by the model. Values greater than 0.5 are normally considered acceptable [10]. E is a normalized statistic that determines the relative magnitude of the residual variance ('noise') when compared to the variance in the measured data ('information') [12]. The statistic denotes how well the observed data fit the predicted data in the 1:1 line. The E value ranges from  $-\infty$  to 1 with 1 representing a perfect fit. Values between 0 and 1 are considered an acceptable performance level for the model [10].

When model results match, observed values from stream-flow measurement, users have greater confidence in the reliability of the model. Before calibration, the base flow and surface runoff were separated using base-flow filter program. Calibration was achieved in two steps, first surface runoff calibrated then the sensitive parameters affecting the base flow were calibrated. At each manual calibration processes, the coefficient of determination ( $R^2$ ), and the Nash and Sutcliffe simulation efficiency (NSE) statistical tests were applied and evaluated in accordance to recommendation ( $R^2 > 0.5$  and  $NSE > 0.5$ ). The final acceptable parameter values that were manually calibrated were used as the initial values for the auto-calibration procedure. Maximum and minimum parameter value limits were used to keep the output values within a reasonable value range. Finally, the auto calibration tool was run to provide the best fit between the measured and simulated data. For calibration of the model, the measured value recorded for eight years (2009-2016) were used.

### 3.3. Model Validation

Once the model parameters were calibrated, the model was validated. Validation of the model was conducted to see how the model would respond to the data set beyond the calibration data set. In this study, data for a period of five years (2005-2009) which is not used for calibration was used at Dawe gauged station to validate and evaluate the model accuracy. The statistical measures criteria used during the calibration procedure were also used for model validation. To determine the quality and reliability of prediction compared to the observed values, the following methods for goodness-of-fit measures of model predictions were used during the calibration and validation periods.

These numerical model performance measures are coefficient of determination ( $R^2$  coefficient), Percent difference between simulated and observed data (D) and the Nash-Sutcliffe simulation efficiency (ENS) [12]. The

regression coefficient ( $R^2$ ) is the square of the Pearson product-moment correlation coefficient and describes the proportion of the total variance in the observed data that can be explained by the model. The closer the value of  $R^2$  to 1, the higher is the agreement between the simulated and the measured flows and calculated as;

$$R^2 = \frac{\sum [(X_i - X_{av})][Y_i - Y_{av})]^2}{\sum [X_i - X_{av}]^2 \sum [Y_i - Y_{av}]^2}$$

where:

$X_i$  is measured value and  $X_{av}$  is average measured value.

$Y_i$  is simulated value and  $Y_{av}$  is average simulated value.

The percent difference measures the average difference between the simulated and measured values for a given quantity over a specified period (usually the entire calibration or validation period) were calculated as follows:

$$D = 100 = \frac{\sum Y_i - \sum X_i}{\sum X_i}$$

Where:

$X_i$  is measured value and  $Y_i$  is simulated value.

A value close to 0% is best for D.

However, higher values for D are acceptable if the accuracy in which the observed data gathered is relatively poor. Nash and Sutcliffe simulation efficiency (ENS) indicates the degree of fitness of observed and simulated data and calculated by the following formula:

$$ENS = 1 - \frac{\sum (X_i - y_i)^2}{\sum (X_i - X_{av})^2}$$

## 4. Results and Discussions

### 4.1. Watershed and Channel Delineation

Before the watershed delineation was processed, the threshold area for the sub-watershed was defined. Based on this area threshold approach, 13 sub-watersheds were identified and delineated.

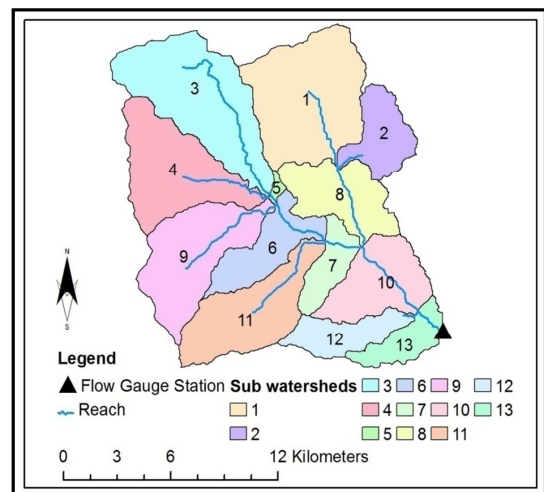
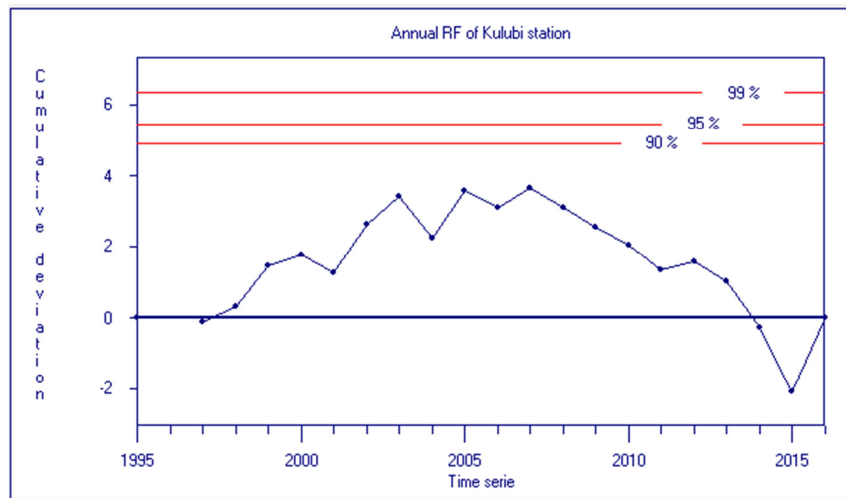


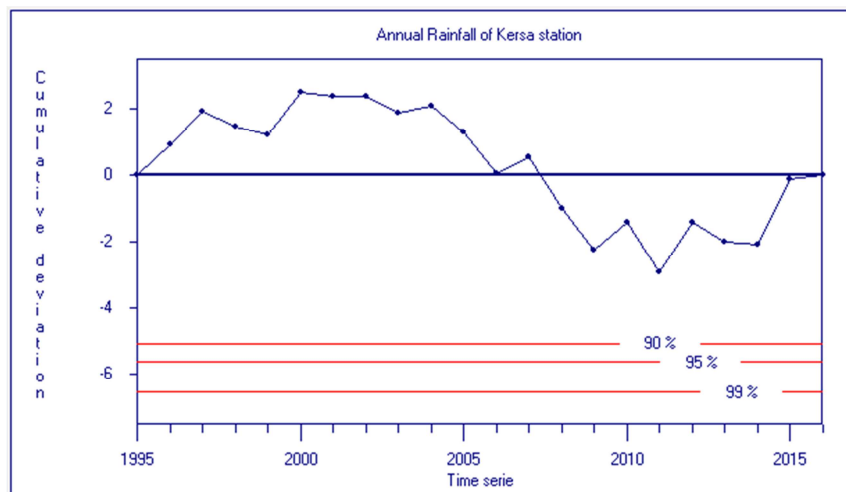
Figure 5. Dawe sub-watershed map.

The homogeneity of the annual rainfall data from 1996 to 2016 was tested for all stations using RAINBOW software and the result of the homogeneity test for the rainfall data showed that the collected data were homogeneous since no

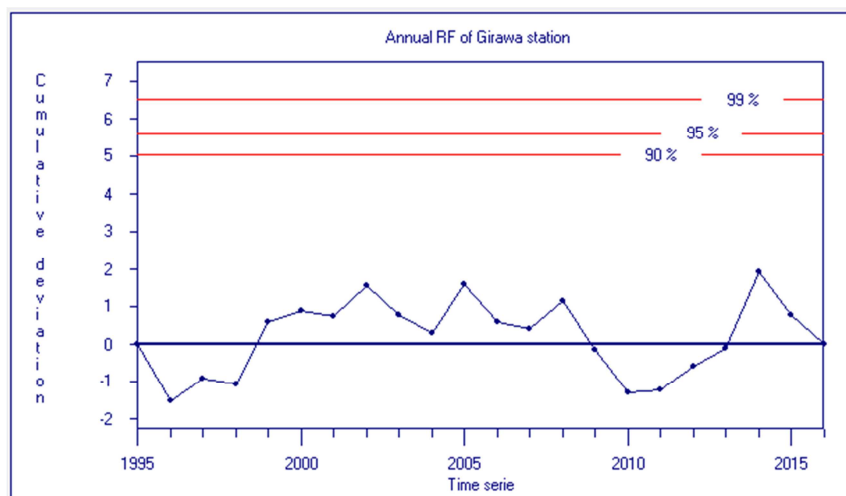
cumulative deviation crossed horizontal lines of 90%, 95% and 99% probability levels. Therefore, the restriction of homogeneity assured that, the observation of all stations (i.e. Kulubi, Kersa and Girawa), were from the same population.



**Figure 6.** Homogeneity graph of annual rainfall at (Kulubi station).



**Figure 7.** Homogeneity graph of annual Rainfall at Kersa station.



**Figure 8.** Homogeneity graph of annual rainfall at (Girawa station).

#### 4.2. Sensitivity Analysis

The model was run for all 40 files. The summary of output values for one file at the watershed outlet was depicted. The effect of input parameters on outputs of runoff, peak runoff rate, and sediment yield was examined (Table 2 and Table 3). 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 -52.77 to +462.70%, -51.77 to +251.81% and -79.30 to +323.74%, respectively due to changes in Curve Number from -10% to +20% from its base value (runoff = 54.73mm, Peak runoff rate = 59.72m<sup>3</sup>/s, sediment yield = 9.72 tons). The corresponding sensitivity indices were 5.31, 3.01 and 2.72, respectively. Next to Curve Number, changes in precipitation have a great impact on the three outputs. All other input parameters, except Land slope and RUSLE Length Slope Factor have brought about a very little change on sediment yield. Manning's roughness coefficient, soil erodibility factor, concentrated flow length; slope, energy intensity factor and surface Condition Constant do not substantially influence the hydrological outputs, it was the least sensitive parameter, which could not affect all output values of the model. For  $\pm 10\%$  input changes, the outputs showed the same trend as the response to  $\pm 20\%$  input changes but with lower magnitude.

The only exception was the land slope, which brought about a mild change in runoff. The result showed that SCS-CN, Precipitation, Land slope, RUSLE Length Slope Factor were sensitive in descending order of significance. Manning's roughness coefficient, soil erodibility factor, concentrated flow length; slope, energy intensity factor and surface condition constant were not sensitive parameters. [16] 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 [17] in the study of sand hill river sub basin in Minnesota, in the validation of AGNPS in Kori watershed, South Wollo zone that CN was the most sensitive parameter.

Note: As a modification, the absolute value of sensitivity index was used and not expressed as a percentage

##### 4.2.1. Calibration of AnnAGNPS Model

The runoff, peak runoff rate and sediment yield were calibrated to prepare and adjust uncertain parameters for validation 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. Using TOPAGNPS, rainfall, energy land slope, channel flow length, channel flow slope and RUSLE LS factor were derived from DEM. RUSLE practice and cover factors were internally calculated by the model. Manning's roughness coefficient and surface condition constant were insensitive and their values were taken from tables in the AnnAGNPS manual.

From sensitivity analysis of AnnAGNPS model (Table 1 and Table 2), CN, Land slope and RUSLE LS factor were the sensitive parameters. CN had been found uncertain and subjected for calibration because its value is dynamics as land cover changes through the rainy period. Slope length and steepness were also another dominant factor that would have been integrated with factors of CN. To begin a calibration, it was necessary to assign first approximation of parameter values. Curve Numbers for each cell were determined by the SCS Curve Number Method for AMC II (Table 2) that was later converted to AMC I and III according to the moisture condition preceding the selected rainfall.

**Table 2.** Curve number and hydrologic soil group values.

Soil Type	Soil Texture	Land Use	Curve Number ID	Curve Number II	Hydrologic Soil Group
Rendzic Leptosols	Loam	Open Grass	Pasture_(Poor)	79	B
Eutric Cambisols	Sandy clay loam	Intensively cultivated	Row_Crop_(poor)	79	C
Luvisols	Sandy clay loam	Cultivated		88	C
Humic Nitisols.	Sandy loam	Shrubs	Brush_(fair)	35	A

Measured hydrologic data of 2009-2016 were selected for calibration. The SCS Curve Numbers for each cell were proportionally adjusted. 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 measured 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 the sediment yield was only affected by Land slope and RUSLE LS factor. Thus, the measured and calibrated surface runoff, peak runoff rate, and sediment yield data were presented as follows:

**Table 3.** Measured and predicted annual runoff, peak runoff rate and sediment yield data for AnnAGNPS calibration.

Calibration Years	Measured Runoff (mm)	Measured Peak Runoff Rate (m <sup>3</sup> /s)	Measured Sediment Yield (tons/ha)	Calibrated Runoff (mm)	Calibrated Peak Runoff Rate (m <sup>3</sup> /s)	Calibrated Sediment Yield (tons/ha)
2009	97.01	22.88	2.409	90.82	62.71	2.4579
2010	92.68	19.84	3.415	85.14	66.70	3.7983



Calibration Years	Measured Runoff (mm)	Measured Peak Runoff Rate (m <sup>3</sup> /s)	Measured Sediment Yield (tons/ha)	Calibrated Runoff (mm)	Calibrated Peak Runoff Rate (m <sup>3</sup> /s)	Calibrated Sediment Yield (tons/ha)
2011	41.16	15.02	3.003	40.73	21.05	2.9272
2012	81.94	11.42	1.285	77.37	94.23	1.6550
2013	74.52	13.78	0.880	72.68	93.71	1.0038
2014	77.06	21.34	1.509	80.57	60.90	1.7998
2015	100.25	24.16	1.782	123.99	191.94	1.0543
2016	53.18	18.26	1.629	59.99	57.05	1.9422

#### 4.2.2. Runoff Volume

Calibration of the model was done for an independent data set of eight years from 2009 to 2016. It was found that the model has well predictive capability with NSE and  $R^2$  values of 0.742 and 0.825, respectively, that the model simulates the observed runoff well. It was a satisfactory result attributed to the maximum possible calibration. This result confirmed both the report of [1] which indicated that the runoff component of the model was predicted in a better fashion with the efficiency of 0.73. [9], also reported that runoff in Illinois and Quebec watersheds with reasonable accuracy. [6] reported that model efficiency and test of significance for both runoff calibration and validation on was less than zero and insignificant, respectively.

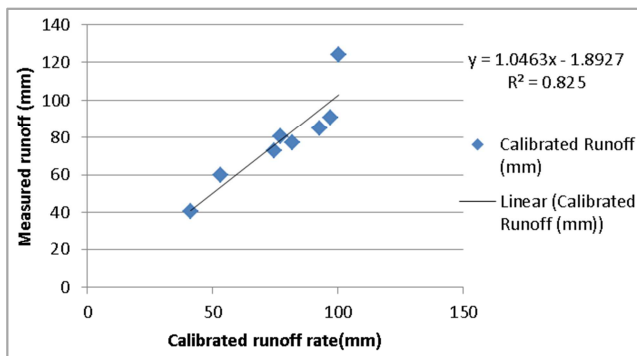


Figure 9. Scatter plot of measured versus simulated runoff rate for calibration.

#### 4.2.3. Peak Runoff Rate

Peak runoff rate produced a coefficient of efficiency of -231.081 and 0.1669, NSE and  $R^2$ , respectively. This indicated that the predicted and measured peak runoff rate have no relationship and, in generally the model over predicted peak runoff rate. The negative value of model efficiency showed that the model prediction was very poor.

#### 4.2.4. Sediment Yield

The model efficiency for sediment yield was 0.828 and 0.848 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

the report of [2].

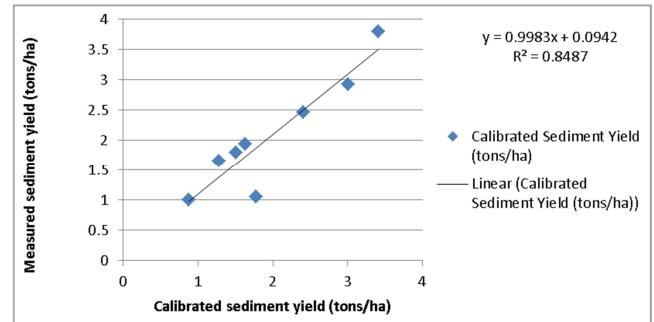


Figure 10. Validation of AnnAGNPS Model.

Once the model calibration process has used to estimate the best values for the model parameters, the outcomes were evaluated whether they represent the real values. The AnnAGNPS model was validated for runoff, peak runoff rate and sediment yield from 2005 to 2009. The CN and land slope value determined during the calibration runs were substituted for similar periods of occurrence of validation precipitation. Measured and validated output results were presented in Table 4.

#### 4.2.5. Runoff Rate

The model efficiency (NSE) and Coefficient of determination ( $R^2$ ) for runoff was 0.769 and 0.9215, respectively which outperformed to that calculated in model calibration. The model overall efficiency for surface runoff was improved during validation (Figure 11).

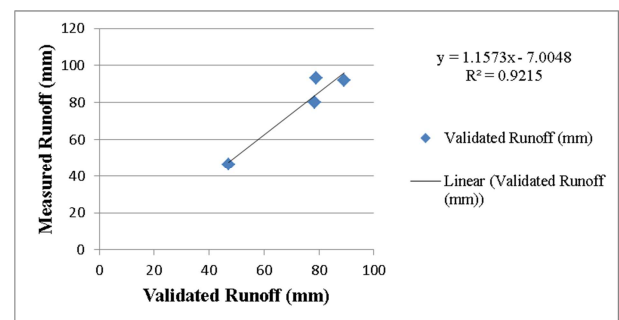


Figure 11. Scatter plot of measured runoff versus simulated runoff for validation.

Table 4. Measured and simulated runoff, peak runoff rate and sediment yield data for validation.

Validation Years	Measured Runoff (mm)	Measured Peak Runoff Rate (m <sup>3</sup> /s)	Measured Sediment Yield (tons/ha/yr)	Validated Runoff (mm)	Validated Peak Runoff Rate (m <sup>3</sup> /s)	Validated Sediment Yield (tons/ha/yr)
2005	47.20	3.84	1.409	46.35	9.09	1.5579
2006	78.93	8.93	1.815	93.37	20.83	2.0083
2007	89.18	2.57	2.003	92.12	58.69	1.9272
2008	78.51	7.65	2.056	80.19	22.64	1.9550

#### 4.2.6. Peak Runoff Rate

The model efficiency and ( $R^2$ ) for peak runoff rate was less than zero and 0.235 respectively, which was the same result to that obtained in model calibration. In this study, poor relationship was observed between measured and validated peak runoff rate (Figure 12).

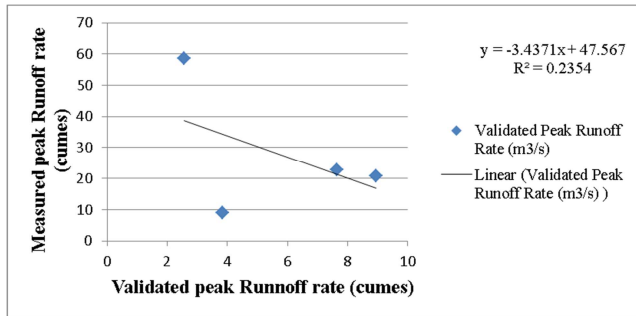


Figure 12. Scatter plot of measured peak runoff versus simulated peak runoff rate for validation.

#### 4.2.7. Sediment Yield

The model efficiency for sediment yield was well, which was the same result to that obtained in model calibration (Figure 13). It was found that the model has well predictive capability with NSE and  $R^2$  value of 0.718 and 0.764,

respectively.

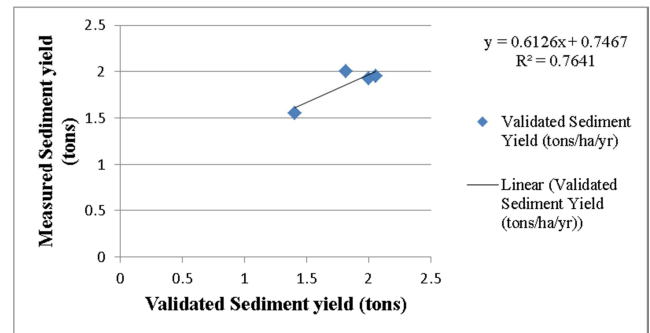


Figure 13. Scatter plot of measured sediment yield versus simulated sediment yield for validation.

#### 4.3. Annual Runoff and Sediment Yield Simulation

After calibration of sensitive parameters for flow obtained during the auto-calibration of Dawe gauging station, the AnnAGNPS was run to simulate the water yield for the years 1996 to 2016 on monthly time step. The monthly water yield ( $Mm^3$ ) simulated for the watershed is summarized below.

Table 5. Simulated monthly water yield ( $Mm^3$ ).

Year	Month												Total
	Jan.	Feb.	Mar	Apr	May.	Jun.	Jul.	Aug.	Sep	Oct.	Nov	Dec	
1996	0.18	0.53	1.03	2.34	0.21	0.12	0.02	0.93	7.30	1.33	0.19	0.19	14.37
1997	2.37	0.15	2.04	3.91	0.67	0.05	0.20	3.44	0.29	0.32	0.08	0.04	13.55
1998	0.03	0.05	0.12	0.69	2.40	0.15	0.49	3.08	0.48	0.46	0.06	0.15	8.16
1999	0.35	0.16	0.28	3.20	3.59	0.82	1.19	1.20	1.07	0.86	0.36	0.21	13.28
2000	0.66	0.30	0.04	0.86	1.79	0.11	3.95	7.89	0.91	0.75	0.29	0.19	17.73
2001	0.06	0.03	0.05	0.62	1.49	1.37	0.27	8.33	0.69	0.27	0.36	0.27	13.82
2002	0.17	0.10	1.68	2.80	14.62	2.28	2.59	6.81	1.29	1.22	0.41	0.08	34.07
2003	0.09	0.03	0.27	1.60	1.83	0.99	1.97	5.94	1.55	0.42	0.42	0.27	15.37
2004	0.34	0.13	0.04	0.06	2.30	0.07	1.97	4.00	1.41	0.92	0.23	0.09	11.56
2005	0.14	0.06	1.85	0.67	0.12	2.47	0.66	8.69	9.03	10.38	0.71	0.11	34.88
2006	0.08	0.04	0.06	2.73	2.49	0.08	0.12	2.26	5.23	4.16	0.60	0.07	17.92
2007	0.04	0.03	0.10	6.63	3.16	0.12	2.67	13.09	2.54	0.23	0.05	0.06	28.72
2008	1.62	0.04	0.08	0.35	0.14	0.22	0.18	4.00	2.10	0.72	0.04	1.97	11.45
2009	0.29	0.04	0.04	6.04	0.62	0.17	1.46	2.71	2.18	0.41	0.04	1.22	15.20
2010	0.10	0.05	0.13	7.07	0.52	0.04	0.19	2.30	1.14	0.99	0.06	0.04	12.63
2011	0.03	0.03	0.92	0.79	2.11	0.19	0.35	1.71	1.51	2.45	0.25	0.13	10.47
2012	0.18	0.03	0.13	4.28	1.33	0.17	0.44	2.21	1.65	1.38	0.53	0.19	12.52
2013	1.24	0.11	0.16	3.00	0.44	0.06	0.35	2.52	1.39	0.49	0.04	2.13	11.94
2014	0.39	0.18	0.07	1.22	0.50	0.65	0.19	5.11	0.59	0.56	0.17	0.37	10.00
2015	0.27	0.14	0.03	0.03	0.11	0.08	0.37	1.72	1.37	1.81	0.18	0.10	6.20
2016	0.04	2.15	2.82	3.61	2.43	0.20	0.53	5.72	6.02	1.15	0.08	0.36	25.09
Mean	0.41	0.21	0.57	2.50	2.04	0.49	0.96	4.46	2.37	1.49	0.25	0.39	16.24
STD	0.61	0.46	0.83	2.15	3.07	0.72	1.08	3.10	2.40	2.23	0.20	0.60	7.94

In this case, relatively small amount of average annual water yield generated from the Eastern part of the watershed, this was attributed due to Eastern part of the watershed were receiving small amount of precipitation, also the topography of the land was flat to gentle flat slopes.

## 5. Conclusion

In order to overcome the food security and related problem, Sub-watershed based development and

management strategy is widely used and becoming important topic in our country. However, lacks of systematic and proper investigation of hydrological process in the watershed the general achievement was not satisfactory. As a result, shown in this study, a properly calibrated and validated AnnAGNPS model is promising model for strategic decision-making on water resource and watershed as well as sub-watershed related development projects. However, a careful calibration and uncertainty analysis and proper application of modeling results should be exercised.

The hydrological investigation of AnnAGNPS model indicates that the rates and amounts of runoff generated from the watershed are dominantly influenced by topographical condition and land use of the watershed. SWC structures require regular maintenance and repairs if they get damaged. Replanting vegetative materials and lining out of construction and channels should be done at least every season. Therefore, the agricultural sectors of Kersa, Kulubi and Girawa have to collaborate with FARC and Haramaya University, so that, it is the best way to prevent gully erosion from occurring, and is linked closely to connecting people to conservation and sustainable use of the natural resources in the watershed.

Despite the fact that, AnnAGNPS is a great modeling tool due to its temporal and spatial capabilities, in this study, in addition to its good performance, it was limited only to a one-year simulation period on a 256 km<sup>2</sup> watershed due to the paucity of time and budget resources. It is therefore, recommended that, further studies be conducted in the future in order to find out how the model responds when applied at a wider scale both temporally and spatially. Beside this, being a continuous modeling tool, AnnAGNPS can serve as an alternative to the USLE to predict annual average runoff and sediment yield at landscape as well as watershed scale.

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