Predicting Runoff, Sediment and Management Scenarios for Reducing Soil Erosion in Data Scarce Regions, Blue Nile Basin

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Abstract. This study presents modeling runoff and sediment with management scenarios for watershed management and resource erosion in Koga watershed using AnnAGNPS model. Calibration of the model was carried from 1988–2001 and validation from 2002–2007. The result of sensitivity analysis indicated that the CN was the most sensitive parameter to runoff and peak runoff rate whereas LS and K-factor were for sediment yield following RF, and these parameters were subjected to calibration. For model calibration, R^2 of 0.69, 0.35, 0.55; NSE of 0.69, −0.38, 0.55; RSR of 0.54, 1.14, 0.67; and PBIAS of 0.07%, −80.56% and 4.09% were obtained for surface runoff, peak runoff rate, and sediment load, respectively. Similarly validation results indicated an R^2 of 0.76, 0.54, 0.62; NSE of 0.76, 0.38, 0.62; RSR of 0.43, 0.71, 0.56, and PBIAS of 2.31%, −36.58% and 5.68% for surface runoff, peak runoff rate, and sediment load, respectively. Where the model efficiency was rated at the range of fair to excellent for three of the outputs of the model for both calibration and validation period. Only 21.5% of the area was able to generate the 78.8% of total soil erosion, with higher than tolerable limit. Hence converting of 21.5% of highest eroding cropland cells either to forest or grassland would reduce soil erosion, sediment yield and load significantly. Ultimately it would help to reduce the sedimentation in Koga dam which could result in reduction of storage capacity.

Keywords: Blue Nile basin · Koga watershed · Runoff · Sediment yield · AnnAGNPS

1 Introduction

1.1 Background

Soil erosion, which accelerated by anthropogenic effects which is resulting soil degradation and becoming a severe ecological challenge worldwide [1]. Mainly it is aggravated by rapid population growth, deforestation, unsuitable land cultivation, uncontrolled and overgrazing [2]. It results the non-point source (NPS) pollutants is inflow in to surface water system from agricultural watersheds. Intensive agriculture has been long

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recognized as a major source of NPS pollutants such as sediment, nutrients and pesticides which are the major cause of water-quality degradation [3]. This results eutrophication on reservoirs and loss of valuable essential nutrients and fertile topsoil [4] and reduces productivity. Across the globe soil erosion causes the largest contaminant of surface water which the leading pollution problem in rivers and streams [5].

In Ethiopia soil erosion is considered as the main challenge for agriculture due to its capability to reduce productivity [6]. Particularly in the highland areas and which with 43% of the total area of the country [7] soil erosion is at high rate and threatening productivity. In the Blue Nile basin, specifically in In Koga Watershed there was continuous soil erosion challenges in Koga watershed [8] and it decreases farm income [9]. In order to rescue the soil erosion best management practices has to be identified and targeted for watershed management. To accomplish this watershed models could play key role for evaluating the runoff, sediment and source areas in the watersheds to reduce soil erosion.

Watershed models were developed to describe help to understand the watersheds management dynamics [10]. For example it helps to understand the land degradation related to soil erosion [11], and help to identify recommendable solutions through best management practices [12]. In addition models also could help for planning effective landscape interventions to reduce land degradation and requires knowledge on spatial distribution of runoff [13]. Hence models for predicting sediment yield based on different management scenario are very important for reducing threats of the soil erosion.

There have been different watershed models for predicting runoff, sediment load and other hydrological variables including Areal Non-point Source Watershed Environment Response Simulation-2000, ANSWERS-2000 [14], Soil and Water Assessment Tool, SWAT [15], Annualized Agricultural Non-Point Source, AnnAGNPS [16]. The AnnAGNPS model has been applied worldwide and proved as very effective tool for identifying erosion source areas. It helps in decision-making processes for adopting BMPs and/or conservation programs. Where NPS pollution control can be achieved in the most efficient way [17, 18]. Some of the models have been developed and tested in different part of the world such as in the United States [17], Norway [19], China [18], Island [20], Canada [21], Spain [22], Belgium [23], and Portugal [24]. In Ethiopia, AnnAGNPS model has been used in some parts of the country by [25–28]. Among these models AnnAGNPS was widely applicable in the range of watershed to predict flow, sediment, and nutrients [29].

Predicting the sediment load from rivers is important for estimating the siltation of artificial and natural reservoirs [30]. Modeling of runoff and sediment would help evaluation of soil erosion and loss of nutrient [31] from watersheds. Hence looking for the model which will mainly predict the runoff and sediment in identifying the source areas for simulating the management scenario for reducing erosion is paramount. In this regard this study chooses the AnnAGNPS model for predicting runoff, peak runoff rate and sediment yield in the study area. Simulation and investigation of sources soil erosion in the agricultural watersheds such as in the Koga watershed was vital. Because in less than 2 km upstream of the watershed was existing dam with an irrigation potential of 7000 ha which has been started since 2007. Hence effective watershed management and planning is critically needed reduce the soil erosion. This will help to minimize the inflow of sediment in to the reservoir. Therefore the objectives of this study were trifold (1) to evaluate capability of the AnnAGNPS model to predict the runoff and sediment yield, (2) to assess the sediment yield and runoff generation with respect to different land use practice and (3) to identify the source areas (hot spots) of erosion and evaluate the effectiveness of alternative BMPs scenarios with its impact on soil erosion, sediment yield and sediment load of Koga watershed.

2 Research Methodology

2.1 Description of the Study Area

Koga watershed with 293 km^2 in lies in the head water of the Blue Nile basin. Geographically it is located at 37°2′0″ to 37°19′0″E longitude and 11°10′0″ to 11°25′0″N latitude with altitude range 1883 to 3084 a.m.s.l. (Fig. 1). The upland of the watershed is narrow and mountainous while the downstream flat and gentle slope [32]. The climate in the watershed is categorized under subtropical climate zone (Yeshaneh et al. 2013). Where the weather condition is characterized by distinct dry and wet seasons and cold locally known as "*woina dega*". The rainfall is mono-modal which lasts from end of May to end of September. The mean annual rainfall in the watershed was 1403 mm from 1988 to 2007. The annual average minimum and maximum temperature in the watershed was 11.5 °C and 27 °C, respectively. The major crops grown in the watershed were teff, millet, maize, barley, wheat, rice, pulses, oilseed and potatoes. The soil type constitutes 32.2% Nitosols, 24.7% Vertisols, 16.4% Alisols, 15.4% Luvisols, 9.7% Leptosols and 1.6% Regosols. The land use in the watershed was characterized as 71.32% cropland, 12.76% forest, 10.29% pasture and 5.62% built up.

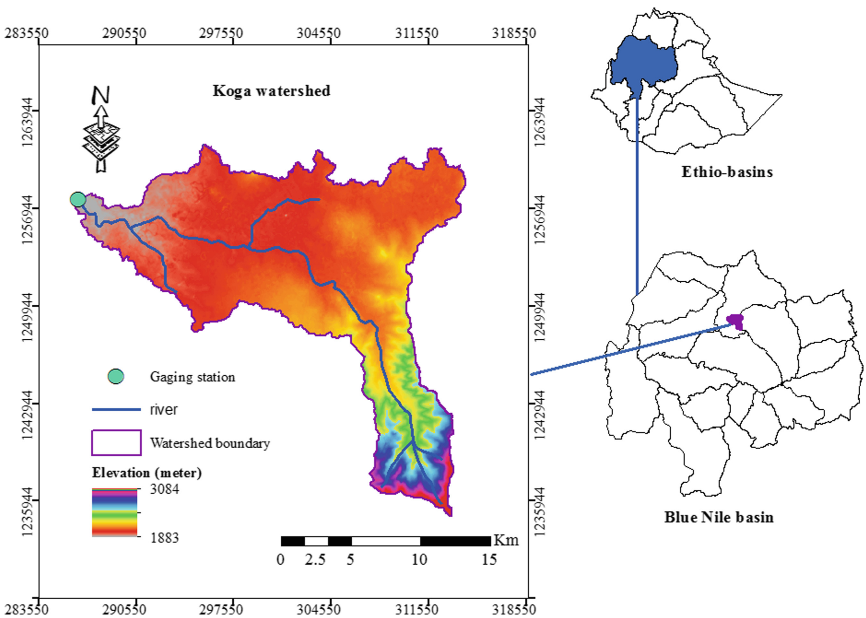

Fig. 1. Relative and geographical positioning of the study area

2.2 Data

Primary data such as observation of operation and management in the watershed, hydro-geological features, visiting detail investigation for specific sites for a confidential conceptual model and confirmation of the secondary data collected at the deskwork were performed. Main data type used for this study was presented in Table 1 with the source availability and duration. Details on description of data input types used were presented in the following sub sections.

Climate Data
Daily climate variables such as precipitation, maximum and minimum temperature, dew-point temperature, solar radiation and wind speed were required by AnnAGNPS model. This helps for the model simulation to consider the temporal and spatial climate variability. The nearest weather stations for Koga watershed were Meshanti, Adet, Dangila and Bahir Dar. Precipitation was obtained from Meshanti, Adet and Dangila. Temperature data was used from stations of Adet, Dangila and Bahir Dar stations. Similarly from Adet and Bahir Dar stations relative humidity for calculating of dew point temperature Sunshine for computation of solar radiation and wind speed. Thiessen polygon method was used for estimating the areal climate data from the selected stations. Climatic data quality has also been be carried out. The consistency of the data was tested by a double mass curve whereas homogeneity and trend analysis of the data were tested using RAINBO software version 2.2 [33]. The data quality tests indicated that the time series of climatic data was found consistent and homogenous. Station-average method (for missing data less 10%) and normal ratio method (for stations with missing data greater than 10%) was used to fill the missed data [34].

Topography Data
DEM processing (Watershed delineation) was based on an outlet location and two user-defined network parameters, (i) the high source area (CSA) and (ii) the minimum source channel length (MSCL). The watershed discretization was to form homogeneous drainage areas (cells). The hydrographic network segmentation into channels (reaches) was performed using TopAGNPS and AgFlow programs integrated with AnnAGNPS and MapWinGIS interface. The geometry and the density of the drainage network in the watershed were set by fixing the CSA to 20 ha and the MSCL to 140 m.

Hydrological Data
The runoff and sediment data was necessary for performing calibration and validation of the AnnAGNPS. The data was collected from Ministry of Water Irrigation and Electricity (MoWIE). Twenty years daily flow data were collected (1988 to 2007) from Koga watershed gaging station near Merawi. Where the data collected was the stream which includes direct runoff and base flow. AnnAGNPS model does not simulate base flow contribution to stream flow. However in order to evaluate the observed and simulated runoff the base flow was separated from the observed stream flow records to get the observed runoff. This was carried out using the Water Engineering Time Series.

Land Use/Land Cover Data
The land use map for Koga watershed obtained from Ministry of Water and Irrigation Electricity (MoWIE). The watershed was classified in to four major types of land use

(Table 2). The major crops grown in the watershed were teff, millet, maize, barley, wheat, rice, pulses, oilseed, and potatoes. The dominant land use was assigned to each AnnAGNPS cell. There were five types of land use identifier (cropland, pasture, forest, rangeland, and urban) in the AnnAGNPS model. Crop management operation in the watershed was vital to estimate the sediment yield [18]. It was prepared based on field observation in the watershed and RUSLE as recommended by [35].

Soil Data
Soil physical properties such as particle size fraction, depth, texture, field capacity and wilting point were required by the AnnAGNPS model. Organic matter content, PH, bulk density, saturated hydraulic conductivity, soil hydrologic group and soil erodibility factor were also required as the model input. Soil layer particle size fraction, depth, texture, PH and organic matter content were extracted from the soil data obtained from the Amhara Design and Supervision Works Enterprise [36]. Soil Plant Air Water, SPAW [37] was used to estimate the soil hydraulic parameters such as saturated hydraulic conductivity, field capacity, bulk density and wilting point of the soil. The soil erodibility (K) was computed based on [38].

Sediment Data
The sediment data collected at the gaging station of the Koga watershed was used for was used for calibration and validation of the runoff from 1988 to 2007. Nevertheless, for sediment data is not enough to carry out the calibration and validation as measured values obtained from the Ministry of Water and Electricity were scarce where the 63 event sediment data in the years of 1990–2011 were used to generate the observed data for calibration using the rating curve.

2.3 AnnAGNPS Model Description

The AnnAGNPS [16] model is a distributed physically based, continuous simulation, daily time step model. It was developed through a project between the USDA Agricultural Research Service (ARS) and the Natural Resources Conservation Service (NRCS). AnnAGNPS model was planned to be used as a decision support tool to evaluate the NPS pollution from the agricultural watersheds ranging in size up to 300,000 ha [39]. The AnnAGNPS hydrologic sub-model the SCS curve number technique [40] was used to determine the surface runoff on the basis of a continuous soil moisture balance. The model only needs an initial values of curve number (CN) for antecedent moisture condition (AMC) II. Despite the model updates the hydrologic soil conditions based on the soil moisture balance and crop cycle [41].

The model requires physical parameters of the watershed, soil data, climate data, and land use and management data. Topographic Parameterization, TOPAGNPS [42] used to extract the physical parameters including the cell and stream network information from DEM. The output from TOPAGNPS was used by Agricultural Watershed Flownet generation (AGFLOW) convert the output in to the format required by AnnAGNPS [41]. Climate data can be either simulated by using t Generation of Weather Elements for Multiple Applications (GEM) program or manually using historical data [43]. Spatial data such as DEM, soils, and land use for AnnAGNPS model was prepared by using MAPWinGIS. It also makes an intersection of each generated cell with land use and soil spatial to assign each cell with specific land use and soil type. The AnnAGNPS Input editor has a spreadsheet with all the data collected from the cell and the reaches. After importing the parameters in the cell it will automatically sort and check all the information within each cell. At the end the model simulation was taken place.

2.4 Sensitivity Analysis

Sensitivity analysis is a measure of the response of selected output variables to variations in input parameters and/or driving variables [44]. It helps to look for the most sensitive parameters which can significantly play role in the simulation of runoff, peak runoff, and sediment. According to [25, 26, 44] parameters such as CN, RF, RUSLE LS-factor, SRR, 10 Year Energy Intensity factor (EI10), soil erodibility factor (K), sheet flow manning's (SFM), concentrated flow manning's (CFM) were selected for sensitivity analysis. Likewise this study has also used this parameter for sensitivity analysis. The relative parameter importance was evaluated by using [45]. Accordingly, each selected parameter was changed with an increment of ±10%, ±20, ±30 and ±50 and by fixing the values of the remaining parameters.

2.5 Model Performance

The model performance during calibration and validation periods was evaluated on the monthly time scale by using both qualitative and quantitative approaches. The qualitative procedure consisted of visually comparing in data-display graphics of the observed and predicted values. Quantitative evaluation was based on the range of statistical summary. Mainly the model performance efficiency of the AnnAGNPS model was evaluated by using statistical criteria's. Which include the Coefficient of determination (R^2), Nash-Sutcliff efficiency, NSE [46], percentage bias (PBIAS), Root Mean Square Error (RMSE) and RMSE-observation standard deviation ratio (RSR) as presented Table 4. Where each statistical output of the model efficiencies were evaluated by using the class category based on [29].

3 Result and Discussion

3.1 Sensitivity Analysis of AnnAGNPS Model

CN was found the most sensitive parameter to surface runoff and peak runoff rate with high output variations. For instance, the percent deviation of runoff and peak runoff rate were −35.04 to +129.52%, and 17.05 to +17.34% respectively due to changes in CN from −10% to +10% (Fig. 2). Similarly changes in precipitation had a great impact on the output variations of runoff and peak runoff rate. LS-factor, soil erodibility factor (K), concentrated flow manning's (CFM) and surface random roughness (SRR) did not significantly resulted variation in the hydrological outputs. Sediment yield was highly sensitive to RF. Following RF, change in LS, K, CN, CFM, and SRR had an impact on sediment yield in decreasing order. Unlike these parameters EI10 was less sensitive and did not have significant effect variation of the model output.

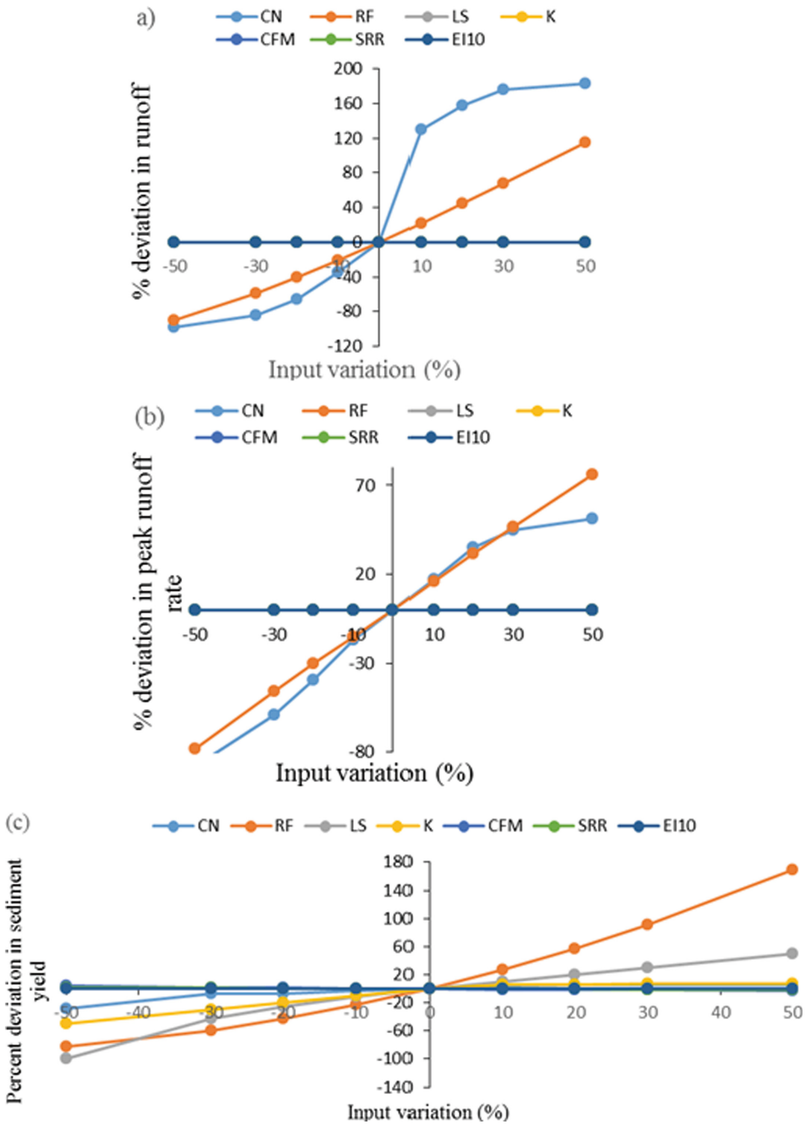

Fig. 2. Sensitivity of (a) runoff, (b) peak runoff rate, (c) sediment yield by ±10, ±20, ±30 and ±50 input variation

The same trend with outputs was observed to ±20%, ±30% and ±50% change in input parameters as the response to ±10% input changes but with a higher magnitude. In Ethiopia sensitivity of CN by using the AnnAGNPS model has been observed from studies by [25, 28]. In addition, CN higher sensitivity was reported in studies carried out worldwide on as indicated by [20, 29, 44, 47, 48].

Calibration of AnnAGNPS Model

The curve numbers for each cell were proportionally adjusted, from the model default value by trial and error for calibration period. LS-factor, K-factor, CFM and SRR 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. Reducing curve number by 8.8% from its original value, increasing LS-factor, K-factor, CFM and SRR by 40%, 31.7%, 1250% and 625%, the best result was obtained for runoff, peak runoff and sediment yield calibration.

Surface Runoff

The comparisons between monthly observed and simulated surface runoff amounts were presented in Table 1 and Fig. 3. The coefficient of determination, R^2, for runoff amount was 0.69 (good correlation). This reveals that measured and predicted runoff was linearly correlated. The Nash and Sutcliff coefficient of efficiency, NSE, was 0.69 which demonstrated good agreement. The RSR value which was 0.54 indicated good agreement. On average, the model under predicted runoff only by PBIAS of 0.07% (Table 1).

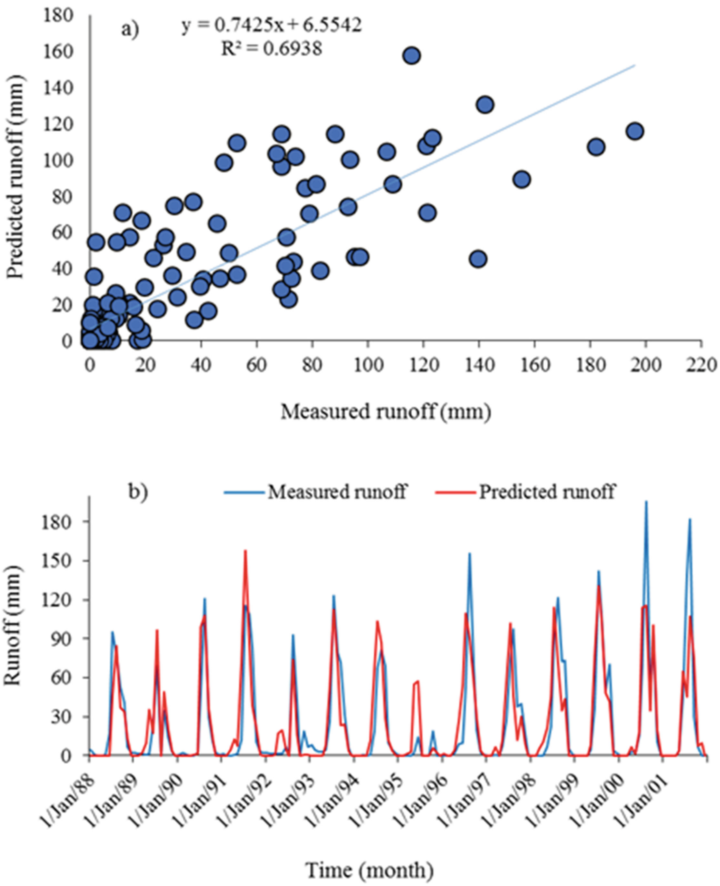

Fig. 3. Observed and predicted runoff (a) scatter plot (b) hydrograph for calibration period on monthly scale

Based on o model performance measuring criteria classification by [29] the results indicated a good to an excellent agreement of simulated runoff by the AnnAGNPS model. Closely related model prediction performance values were obtained during calibration period time for AnnAGNPS model by [28] an R^2 of 0.83 and NSE of 0.76, [27] an R^2 of 0.78 and NSE of 0.73, [24] an R^2 0.87 and NSE of 0.73. The model prediction for the runoff was relatively better than by [25] in Augucho catchment, Ethiopia with an R^2 of 0.57 and NSE of −0.69. The poor model prediction performance was attributed to the shortfalls of Soil Conservation Research Program database and inconsistencies in data collection.

Peak Runoff Rate

The model performance in predicting peak runoff rate was fair with an R^2 value of 0.35 although according to the NSE, RSR and PBIAS value unsatisfactory correlation between observed and simulated data exist (Table 1 and Fig. 4). The model over predicted peak runoff rate by PBIAS of 80.56%. The over prediction of the model for peak runoff rate was also found by [25–28] The model prediction for peak runoff rate (NSE of −0.38) was better than in the study conducted by [28] reported the NSE values of −33.

Table 1. Estimated statistical parameters of model performance for calibration and validation period

Calibration on monthly scale (1988–2001)						Validation on monthly scale (2002–2007)				
	R^2	NSE	RMSE	RSR	PBIAS	R^2	NSE	RMSE	RSR	PBIAS
Surface runoff	0.69	0.69	22.08	0.54	0.07	0.75	0.75	20.17	0.433	2.31
Peak runoff	0.35	−0.38	18.23	1.14	−80.56	0.54	0.38	13.25	0.71	−36.58
Sediment	0.54	0.54	0.20	0.67	4.09	0.62	0.62	0.19	0.56	5.68

Sediment Load

The evaluation of model performance observed and simulated sediment load provided an R^2, NSE, RSR and PBIAS were 0.55, 0.55, 0.67 and 4.09% respectively (Table 2 and Fig. 5). This indicated fair to an excellent agreement with the simulated value. Similarly the study by [26] with NSE of 0.9; [28] with NSE of 0.71; [27] with NSE of 0.47; [25] found less result of NSE value of 0.158 during calibration. Comparing the average monthly values of measured and predicted sediment load, the model under predicted sediment load by 4.09%. The result in this study indicated better statistical performance than the study conducted by [26] which reported that the model under predicted sediment yield by 15%. Similarly in terms of performance the result provided better result by [23] reported NSE values of 0.16, and [22] found NSE values of 0.2.

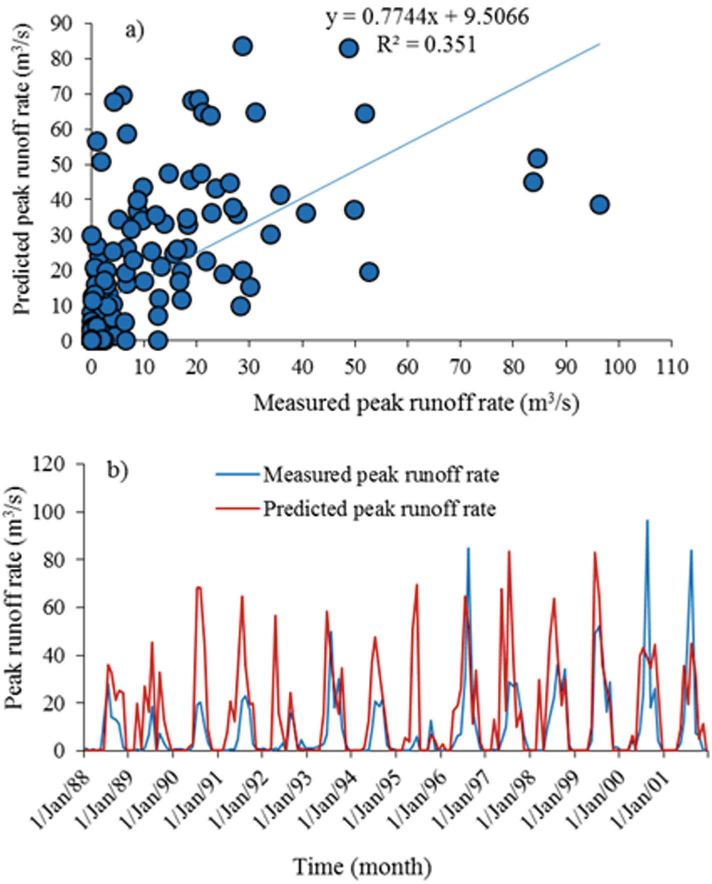

Fig. 4. Observed & predicted peak runoff rate (a) scatter plot (b) hydrograph for calibration period on monthly scale

Validation of AGNPS Model

Validation of AnnAGNPS was performed on a monthly time scale from 2002–2007. The observed and validated output results were presented in Table 3 and the statistical parameters of the model performance were summarized in Table 1. Surface runoff validation provided a very good agreement of 0.75 for both R^2 and NSE, also the value of RSR and PBIAS were 0.43 and 2.31%. This illustrated a very good to excellent agreement respectively (Table 1). The comparisons between monthly observed and simulated surface runoff amounts were improved during validation period (Fig. 6).

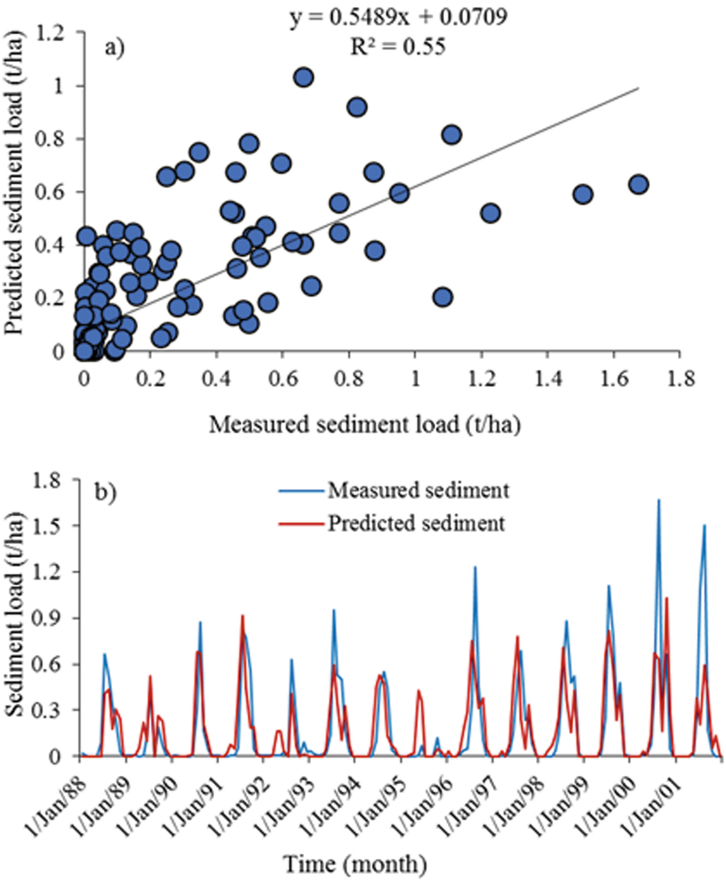

Fig. 5. Observed & predicted sediment load (a) scatter plot (b) hydrograph for calibration period on monthly scale

Peak runoff rate during validation was in a satisfactory agreement with 0.54 and 0.38 value for R^2 and NSE respectively and the model overestimated peak runoff rate by 36.58% (Table 1). This indicated improved agreement than during calibration. The comparisons between monthly observed and predicted peak runoff rate was indicated in Fig. 7.

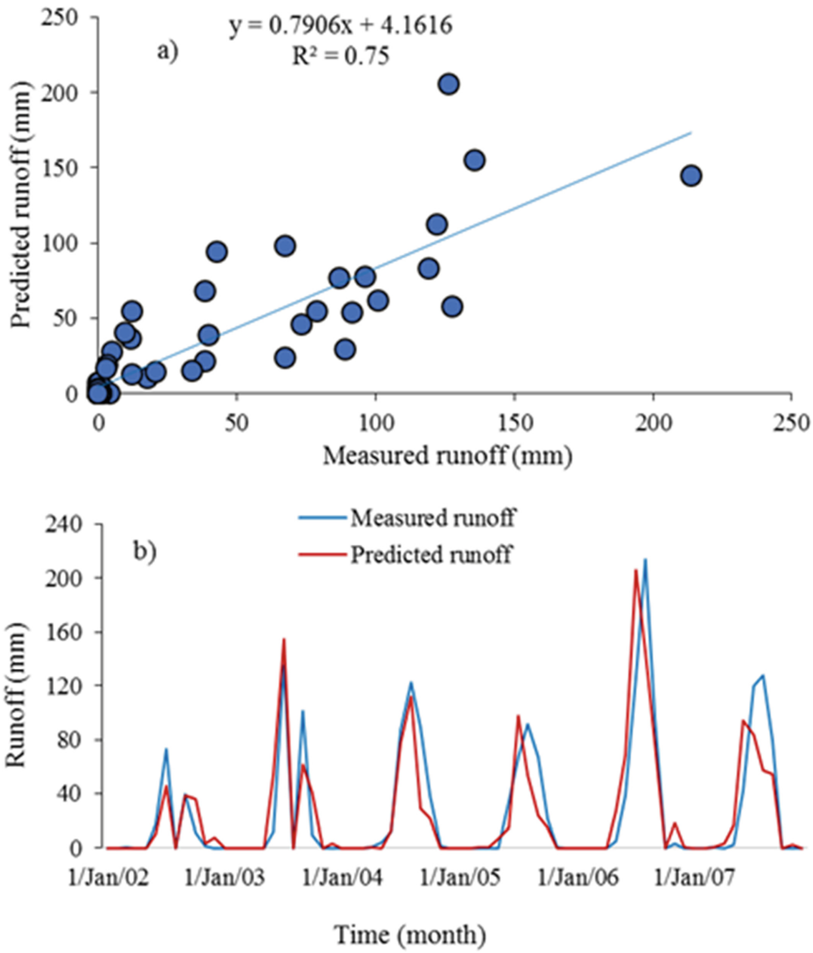

Fig. 6. Observed and predicted runoff (a) scatter plot (b) hydrograph for validation period on monthly scale

The overall efficiency for predicted peak runoff rate was a little bit improved during the validation period. The comparisons between observed and predicted sediment load were shown in Fig. 8. The attained statistical parameters value of R^2, NSE, RSR and PBIAS were 0.62, 0.62, 0.56 and 5.68% respectively (Table 1 and Fig. 8). These indicated a good to an excellent agreement. All statistical model performance measuring parameters except PBIAS were improved during validation period.

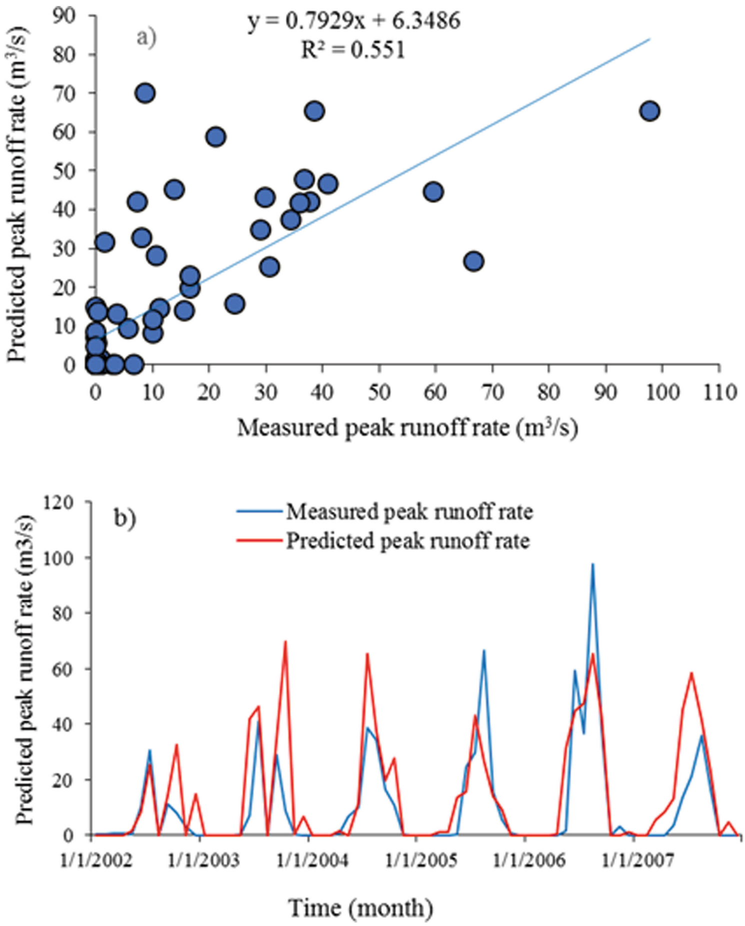

Fig. 7. Observed and predicted peak runoff rate (a) scatter plot (b) hydrograph for validation period on monthly scale

3.2 Sediment Yield and Soil Erosion

The soil erosion amount varied greatly with different land use types (Table 2). The results indicated that the highest amounts of average annual runoff and soil erosion, 405.17 mm/ha and 10.99 ton/ha respectively. It were generated from cropland (cultivated agricultural land), followed by pasture (grass land) and urban (residential area) which had contributed average annual soil erosion of 0.05 and 0.03 t/ha respectively. Forestland had contributed the least soil erosion (0.001 t/ha). The study indicated that erosion increases as the land use changed from grassland/forest land to crop land for agricultural crop production. The spatial distribution in soil loss ranges from insignificant amount (nearly zero) up to moderate in around middle of the watersheds. It also ranges from low up to severe in lower parts and very severe to extremely severe

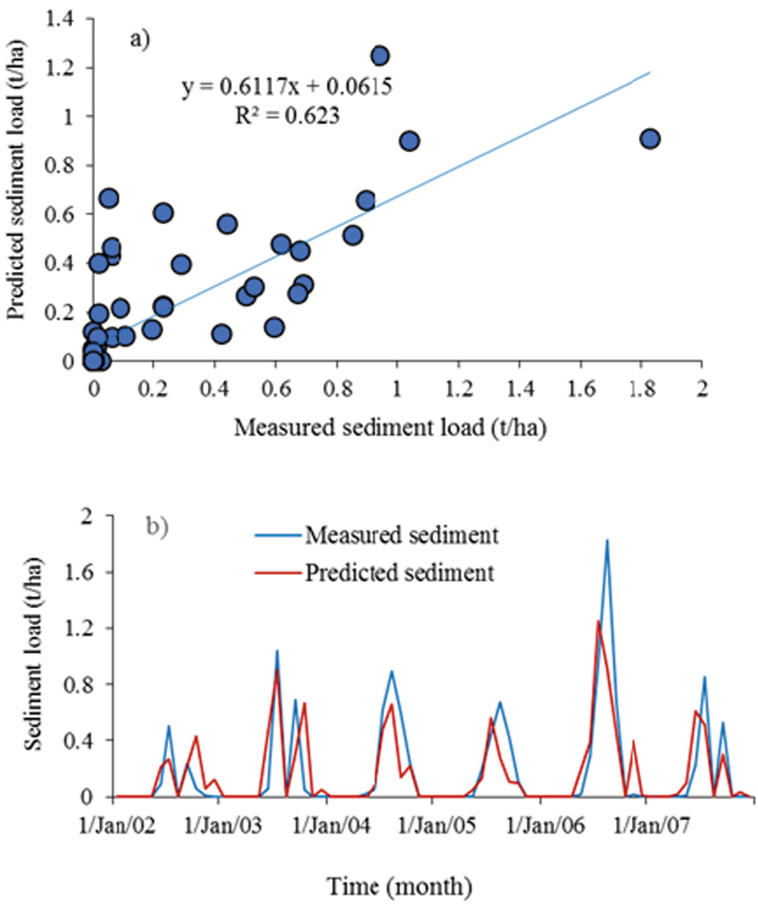

Fig. 8. Observed and predicted sediment load (a) scatter plot (b) hydrograph for validation period on monthly scale

in the upper part of the watershed. Soil erosion highly affected areas were spatially located in the narrow steep slope which is the mid upper part of the watershed. In addition to the steep slope (>30%) mainly the cultivated agricultural land was more highly susceptible to erosion.

Table 2. Average soil erosion of different land use types predicted by AnnAGNPS

Land use types	Area (ha)	Percent of area (%)	Average soil erosion (t/year)	Percent of soil erosion (%)	Average soil erosion rate t/ha/year
Cropland	21,027.4	71.70	249.91	99.37	10.99
Forest	3,738.4	12.75	0.02	0.01	0.001
Pasture	3,061.8	10.44	1.00	0.40	0.05
Urban	1,501.1	5.12	0.56	0.22	0.03
Total	29,328.7	100	251.49	100	11.07

Soil erosion rates/soil loss predicted was spatially variable and reached up 82 t/ha/year (Fig. 9). The total soil erosion from the study watershed was estimated to be 276.37×10^3 t/year (Table 3). The overall average soil erosion estimation was 9.4 t/ha/year. This result was in line with the range of the average annual soil erosion estimated for Ethiopian highlands with an average soil erosion of 9.7 t/ha/year by [49].

Soil loss tolerance was the maximum amount of soil erosion that can occur without any reduction in crop productivity [50]. Worldwide accepted maximum limit of soil loss tolerance was 11.2 t/ha/year [51]. Whereas for Ethiopia maximum tolerable soil

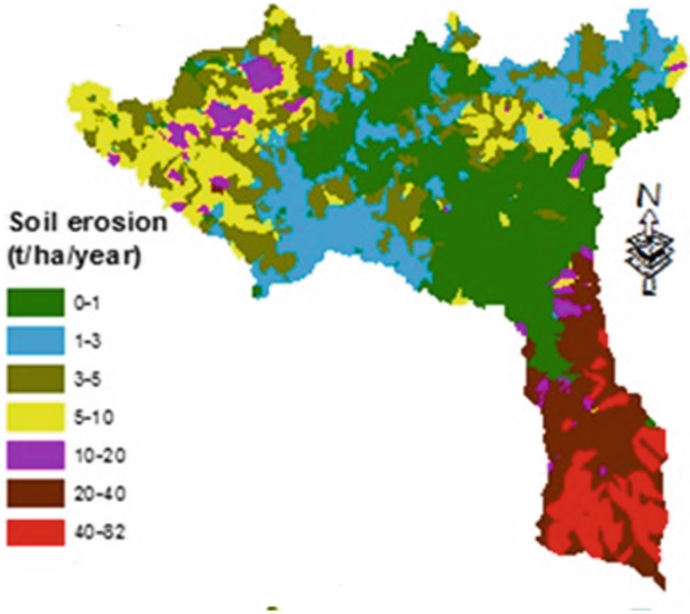

Fig. 9. Spatial distribution of soil erosion rates in Koga watershed

loss of 18 t/ha/year was recommended by [52]. Similarly [53] recommended 10 t/ha/year as the tolerable limit of soil loss. Therefore, by considering the recommended value of 10 t/ha/year, a soil loss less than 10 t/ha was on 78.53% of the watershed area of land and accounts only 21.2% of the total soil erosion. The remaining area of land with 21.47% accounts 78.8% of total soil erosion indicating above the recommended tolerable limit of soil loss. Out of the area that was above the tolerable limit of soil loss 4.99% belongs to severe, 39.71% to very severe and 34.10% to the extremely severe erosion classes (Table 3). Thus priority watershed management should be carried out on those areas considered and found as highly affected area. Where the best management practices recommended would reduce the soil erosion in the watershed.

Table 3. Soil erosion rates numeric classification according to [11]

Soil erosion rate (t/ha/year)	Soil erosion risk class	Area (ha)	Percent of total area (%)	Soil erosion (t/year)	Percent of total soil loss (%)	Average annual soil erosion rate (t/ha/year)
0–1	Very low	8750.0	29.83	449.4	0.16	9.4
1–3	Low	4778.8	16.29	10352.7	3.75	
3–5	Moderate	5332.4	18.18	20740.7	7.50	
5–10	High	4173.2	14.23	27053.1	9.79	
10–20	Severe	1020.8	3.48	13788.6	4.99	
20–40	Very severe	3422.9	11.67	109734.0	39.71	
40–82	Extremely severe	1850.7	6.31	94251.2	34.10	
Total		29328.7	100.00	276369.9	100.00	

3.3 Sediment Delivery Ratio (SDR)

Sediment yield is usually not available as a direct measurement, but it can be estimated by using a sediment delivery ratio, SDR [54]. The SDR estimated in the Koga watershed outlet by the AnnAGNPS model was about 25.5%. This indicated that soil materials that carry non-point source pollutant loadings (soil material and nutrients such as nitrogen and phosphorus) could be delivered to Koga watershed dam. Where this dam is located 1 km upstream of the gaging station and commenced started in 2007. While 74.5% of the eroded soil materials were re-deposited in the catchment of the watershed. The SDR information is helpful in planning future the watershed management for effective reduction soil erosion [18] because it helps to estimate the amount of sediment load from the soil loss estimation. To reduce soil erosion/sediment loss it is important to have more soil deposited in the cells. Hence Best Management Strategies has to focus on cells or sub basins which have more soil loss rate to reduce further siltation of Koga reservoir.

3.4 Best Management Practices

Best Management Practices (BMPs) are treatment alternatives. Such as conversion from cropland cells having erosion risk class of severe and above to forest or grassland. It was demonstrated and simulated run in the AnnAGNPS model as a means to reduce soil erosion within the watershed. Similarly to minimize and sediment load from the watershed i.e. the cells that produce erosion above tolerance limit should be converted to forest or grassland. Average annual values of soil erosion, sediment yield and sediment load over twenty years of simulations (1988–2007) were presented in Table 4. It was summarized based on reference to the different management practices that were implemented. By implementing scenario III or V, the maximum soil erosion in the watershed was reduced to less than 10 t/ha/year. This indicates that the landscape soil loss became within the tolerable limit of soil loss. Converting croplands cells having severe and above soil erosion risk classes to grassland have the same trend as converting to a forest (Table 4). Therefore converting the traditional agriculture in to conservation agriculture with and afforestation in degraded areas could bring tolerable soil loss in the watershed. The systems (scenarios) considered in this study have a reasonable chance of being implemented with appropriate rural policy of development including with some incentive for encouragement programs.

Table 4. Summary (1988–2007) of management scenario analysis and results of reduction for sediment load & yield

Scenario		Average				Reduction (%)			Maximum landscape erosion (t/ha/year
No	Description	Runoff amount (mm)	Landscape erosion (t/ha/yr)	Sed. yield (t/ha/yr)	Sed. loading (t/ha/yr)	Soil erosion	Sed. yield	Sed. load	
I	Baseline condition (no change of original land use)	354.25	9.42	3.08	2.41	0	0	0	81.34
II	Cropland cell having soil erosion risk classes of extremely severe (40–82 t/ha/year) changed to forest	338.73	6.21	1.89	1.53	34.10	38.53	36.51	39.90
III	Cropland cell having soil erosion risk classes of sever and above (10–82 t/ha/year) changed to forest	301.26	2.00	0.45	0.39	78.79	85.41	83.63	9.91
IV	Cropland cell having soil erosion risk classes of extremely severe (40–82 t/ha/year) changed to grassland	345.02	6.25	1.91	1.55	33.65	38.01	35.75	39.90
V	Cropland cell having soil erosion risk classes of very sever and above (10–81.34 t/ha/year) changed to grassland	322.82	2.10	0.48	0.42	77.75	84.28	82.42	9.91

4 Conclusion

The total annual erosion of the Koga watershed was 0.3 million metric tons, and of which about 74.5% of the eroded soil materials was re-deposited in the catchment of the watershed, with the rest (25.5%) delivered to the watershed outlet. The simulations result of alternative management practices showed that converting 21.47% of highest eroding cropland cells, to either forest or grassland would reduce soil erosion, sediment yield and sediment load by 78.79%, 85.41% and 83.63% respectively, indicating that the maximum soil erosion in the watershed was reduced to less than 10 t/ha/year which means that the landscape soil loss was became within the tolerable limit of soil loss. Above all the results obtained from applying AnnAGNPS on Koga watershed demonstrate that the model has significant potential as a management tool for evaluation of the effectiveness of alternative BMPs scenarios and their impact on soil erosion, sediment yield and sediment load, long term monthly estimation of runoff, peak runoff rate and sediment load, identification of hot spot area of erosion, and investigation of sediment delivery characteristics. Hence, the method could be replicated in other parts of Lake Tana sub-basin in general in the country for similar watersheds to predict of runoff and sediment, assessment of conservation prioritization, to evaluate the effectiveness management practices to reduce soil erosion.

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