Streamflow and sediment yield prediction using *AnnAGNPS* model in upper ebonyi river watershed, south-eastern Nigeria

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Abstract: Sediments resulting from soil erosion are the major non-point source pollutant of surface waters in agricultural watersheds. Annualized Agricultural Non-Point Source Pollution Model (AnnAGNPS) is a computer-based watershed model that predicts non-point source pollutants and runoff loadings within agricultural watersheds. AnnAGNPS v5.2 was used in conjunction with ArcView 3.2 GIS to predict streamflow and sediment discharges from a 1700 ha or 17 km^2 Upper Ebonyi River watershed located at Obollo-Etiti in Udenu Local Government Area in Enugu State, South-eastern Nigeria. AnnAGNPS predictions were compared with two months (September and October) of streamflow and sediment discharge field measurements from the study watershed. The September data were used to calibrate the model to a reasonable agreement with predicted data (R^2 = 0.9341 for streamflow and R^2 = 0.7066 for sediment yield). Statistical performance evaluation of the model was carried out on the validation results. The model performed very well in following the trends, peaks and volumes of the measured hydrograph and sediment graph, with R^2 = 0.9908 for hydrograph and R^2 = 0.9675 for sediment graph. The results show that the model performed better in predicting runoff than predicting sediment yield.

Keywords: AnnAGNPS, non-point source pollution, sediment, streamflow, model

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1 Introduction

Agricultural activities are among the main factors causing soil and water degradation in agricultural areas, and excessive loads of nutrients and sediments from agricultural non-point source pollution (NPS) and erosion in runoff water result in the degradation of drinking water quality, siltation of reservoirs, and pollution of aquatic ecosystems (Chahor et al., 2014; Li et al., 2015). Pease et al. (2010) attributed the primary cause of soil and water degradations in agricultural areas to NPS pollution. NPS pollution is a global environmental degradation issue (Carpenter et al., 1998) that leads to surface water degradation due to intensification of agricultural production in recent years (Ma et al., 2001). Schaffner et al. (2011) reported that excessive loads of nutrients (e.g. nitrate, phosphorus) and sediments from non-point source pollution and soil erosion were being recorded at the outlet of agricultural watersheds. As a result of excessive nutrients in a water body, eutrophication is a very serious threat to water resource quality. NPS pollution is often caused by poor management practices that include soil erosion, agricultural runoff, pathogens from feedlots urban runoff and sewage discharge (Tim and Jolly, 1994).

Presently, soil erosion constitutes a great threat to the environment (Casali et al., 2008), causing soil degradation that severely affects soil and water resources which would lead to a long term agricultural sustainability issues. Therefore, effective land management strategies depend upon an improved assessment and understanding of soil loss rates from agricultural land (Casali et al., 2009). In

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addition, excessive sediment loadings from the non-point sources needs to be addressed through the watershed approach (Shrestha et al., 2006). However, due to the spatial uncertainty nature of NPS pollution and limitations of experiments and field measurements, spatial simulation modeling is usually an important technique commonly used in the management of NPS pollution (Arnold et al., 1998; Li et al, 2015; Shamshad et al., 2008). Licciardello et al. (2007) reported that among the different structural and non-structural measures to control negative impact of erosion processes, reliable prediction models can help in solving erosion problems.

It is widely reported that watershed models are cost-effective and time-efficient measures for the assessment of pollutant loads and simulation of watershed processes and management practices in an effort to address non-point source pollution (Baginska et al., 2003; Shrestha et al., 2006; Li et al., 2015). Several watershed-scale hydrological and water quality models reviewed in Borah and Bera (2003), such as AnnAGNPS (Annualized Agricultural Non-Point Source) and SWAT (Soil and Water Assessment Tool) have been developed to evaluate the hydrologic and water quality responses of a watershed to alternative management practices and to understand hydrologic systems and pollutant loadings in recent years (Bingner et al., 2014; Arnold and Allen, 1999; Hua et al., 2012; Yuan et al., 2003). Also, these models can be used to predict the amount and effect of NPS as well as erosion from watersheds. These pollutants have a major impact on water quality especially in rural environments. In fact, watershed models can help to select suitable land uses and the best management practices to reduce the damaging effects of agricultural practices on the environment (Chahor et al., 2014). In general, there is no single best model for all applications but the most appropriate model will depend on the intended use and the characteristics of the watershed under study (Shamshad et al., 2008).

The AnnAGNPS model was developed as an expansion of the capabilities of the single-event AGNPS with improved technology and significantly advanced features to evaluate NPS pollution from agricultural watersheds (Young et al, 1989; Bingner et al., 2014). The model was designed to simulate water, sediment, and chemical movement from agricultural watersheds on a daily basis (Yuan et al., 2011). Various studies worldwide have evaluated the ability of AnnAGNPS model to predict runoff and sediment loads under different climate conditions and land uses as well as various watershed sizes ranging from 0.1 to 130 km^2 (Baginska et al., 2003; Chahor et al., 2014; Das et al., 2008; Hua et al., 2012; Li et al., 2015; Licciardello et al., 2007; Shamshad et al., 2008; Shrestha et al., 2006; Taguas et al., 2009; Yuan et al., 2001). In South Eastern Nigeria, Mbajiorgu (2004) evaluated the applicability and predictive capacity of the single event AGNPS to estimate runoff and sediment yield. This paper examined the applicability and predictive capacity of the AnnAGNPS model embeded in ArcView 3.2 GIS environment in upper Ebonyi river watershed in Enugu, Nigeria. The objective of this study included: to prepare the database for the simulation of streamflow and sediment yield using AnnAGNPS model. Secondly, to calibrate and validate the model for upper Ebonyi river watershed in Enugu, Nigeria.

2 Methods

2.1 Watershed description

The study area is Upper Ebonyi River watershed located between latitude 6°52′N to 6°56′N and longitude 7°33′E to 7°37′E in Obollo-Etiti community in Enugu State, Nigeria (Figure 1). Upper Ebonyi River watershed of about 1700 ha or 17 km^2 in area is a subwatershed of River Ebonyi headwater catchment (37900 ha or 379 km^2) which is located on the western border of the Cross River plains, headed by the Udi-Nsukka escarpment and situated in the transition zone between the Guinea–Congolian wetter-type forest and Guinea savannah eco-climatological zones (Campling et al, 2002). The catchment has a rural setting and is used extensively for agriculture. The watershed varies in slope from 0 to about 45%, which is derived from 1:50,000 topographic maps, with the elevation ranges between 200 and 500 m above Sea level (Figure 2). The mean temperature of the area is between 27°C and 28°C, and the prominent climatic seasons in the area includes rainy season, lasting from April to October and the dry season lasting from November to March (Ofomatta, 1976). The mean annual rainfall is 1577 mm (Campling et al, 2002). The dominant soil in the watershed is red in colour and well drained which could be classified as sandy loam. The major soil types were derived from dominant soil map of Nigeria as acrisol and solonetz (Figure 4(a)). The land use map was developed from Landsat spectral satellite image of December 17, 2013. Water body, riparian vegetation, settlement, cultivated area and forest/upland vegetation were identified and classified as the major land use types in the watershed, accounting for 1.13%, 9.68%, 11.64%, 29.73% and 47.82% of the study area covered respectively (Figure (4b)).

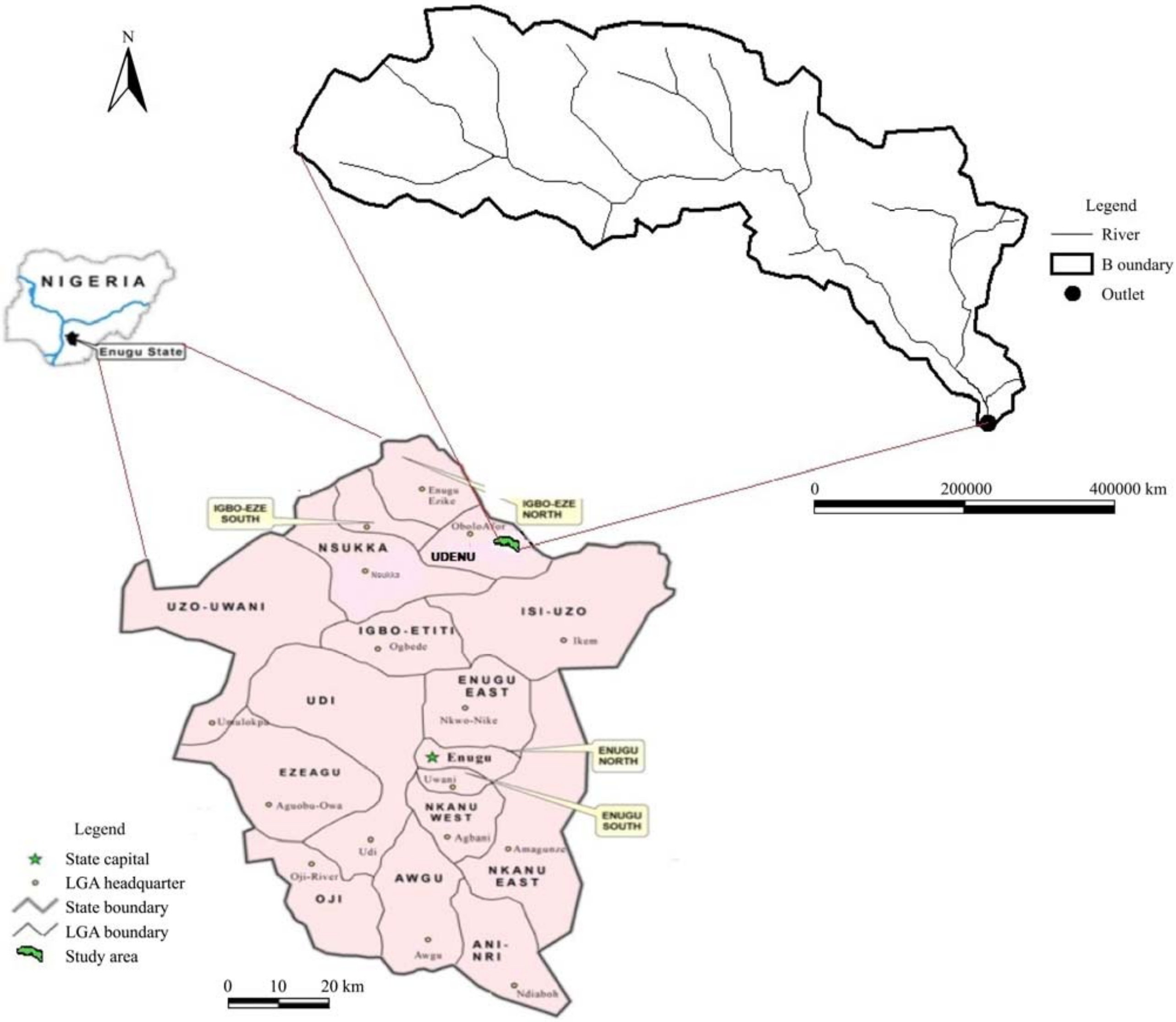


Figure 1 Study area location map -Upper Ebonyi River watershed

2.2 Model description

The AnnAGNPS model is an advanced technological watershed evaluation tool developed by a joint effort of USDA Agricultural Research Service and USDA Natural Resources Conservation Service for continuous simulation of sediment and chemical transport from ungauged agricultural watersheds (Bingner et al., 2014). In fact, AnnAGNPS is an update of the single event AGNPS model, which was developed in the early 1980's for evaluation of watershed response to agricultural management practices (Young et al., 1989). AnnAGNPS designed as a distributed parameter, continuous simulation, and physically-based surface runoff model assist with determining Best Management Practices (BMPs), the setting of Total Maximum Daily Loads (TMDLs), and for risk and cost-benefit analyses. As an enhancement of the single event AGNPS, AnnAGNPS consists of a system of modules, such as an input data preparation model (AnnAGNPS editor), flownet generators (Topographic Parameterization for AGNPS (TOPAGNPS) and Agricultural watershed Flownet generation (AGFLOW)), a synthetic weather generator (Generation of weather Elements for Multiple applications (GEM)), a pollutant loading model (AnnAGNPS PL) and an output processor model (Summarization Tool to Evaluate AnnAGNPS Data (STEAD)). This system of modules improves the capability of the model as well automating many of the input data preparation steps for large watershed analysis (Bingner et al., 2014).

The basic components of AnnAGNPS models include hydrology, sediment, nutrient and pesticide transport. The watershed is subdivided into homogenous land areas or cells with respect to soil type, land use, and land management with the cells providing spatial variability of the landscape. The physical or chemical constituents are routed from their origin within the land area and are either deposited within the stream channel system or transported out of the watershed. Pollutant loadings (PLs) can then be identified at their source and tracked as they move through the watershed system. AnnAGNPS incorporates the Soil Conservation Service Curve Number (SCS-CN) technique (USDA, 1972) to generate daily runoff from the field using Equation (1):

$$Q = \frac{(WI - 0.2S)^2}{WI + 0.8S} \tag{1}$$

where, Q = runoff (mm); WI = water input to soil (mm); S = retention parameter (mm); and

$$S = 254(\frac{100}{CN} - 1) \tag{2}$$

where, CN = curve number.

The peak discharge of the runoff hydrograph is easily calculated using extended TR-55 method (Theurer and Cronshey, 1998) incorporated within AnnAGNPS as:

$$q_p = 2.77777778 \times 10^{-3} \times P_{24} \times D_a \times [\frac{a + (c \times T_c) + (e \times T_c^2)}{1 + (b \times T_c) + (d \times T_c^2) + (f \times T_c^2)}] \tag{3}$$

where, q_p = peak discharge, $m^3\ s^{-1}$; D_a = total drainage area, ha; P_{24} = 24-hr effective rainfall over the total drainage area, mm^2; a, b, c, d, e and f are the unit peak discharge regression coefficients for a given Ia/24 rainfall distribution type and T_c = time of concentration, hr which is the time required for water to flow from the hydraulically most distant point in the watershed (in this case, the cell) to the outlet. The model estimated T_c as the sum of overland flow, shallow concentrated flow and concentrated flow by treating the first 50 m of flow from the determined hydraulically most distant point in the cell as overland flow, the next 50 m as shallow concentrated flow, and the remainder of the length as concentrated flow (Bingner et al., 2014).

Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) is embedded in AnnAGNPS for calculation of erosion in individual cells as:

$$A = RKLSCP \tag{4}$$

where, A = average annual soil loss (Mg ha^{-1}); R = rainfall-runoff erosivity factor; K = soil erodibility factor; LS = slope length and steepness factor; C = cover management factor and P = support practices factor.

Since RUSLE is used only to predict erosion of the area whenever there is runoff event, the Hydro-geomorphic Universal Soil Loss Equation (HUSLE) (Theurer and Clarke, 1991) is used to estimate the total sediment delivered to the stream reach after deposition by considering the particle size and fall velocity for each of the five classes of eroded particles (clay, silt, sand, small aggregate and large aggregate). The Sediment reach routing of the model based on a modified Einstein deposition equation (Einstein and Chien, 1954) used the Bagnold suspended sediment equation for sediment transport capacity of the flow determination (Theurer and Cronshey, 1998; Hua et al., 2012).

Thus, the sediment yield received at the stream reach is calculated by AnnAGNPS as:

$$S_Y = 0.22 \times Q^{0.68} \times q_p^{0.95} \times KLSCP \tag{5}$$

where, S_Y = sediment yield (Mg ha^{-1}); Q = surface runoff volume (mm); q_p = peak rate of surface runoff (mm s^{-1}); and, K, L, S, C, P are as defined in Equation (4) above. AnnAGNPS model combines the latest technology of geographic information systems (GISs) data manipulation and physical characterization of the watershed to provide modeling opportunities for ungauged areas and areas with limited data in order to solve the problems of handling massive data with the single event AGNPS model (León et al., 2000). However, the input data required by the AnnAGNPS model are of two major types: (1) the first category is the daily climatic records including minimum and maximum temperatures, rainfall, dew point, sky cover or solar radiation and wind speed; and (2) the second category comprises a description of the physical characteristics and management practices of a watershed such as morphological parameters, soil, crops and agricultural practices. Moreover, the output parameters are available at daily, monthly and annual scales.

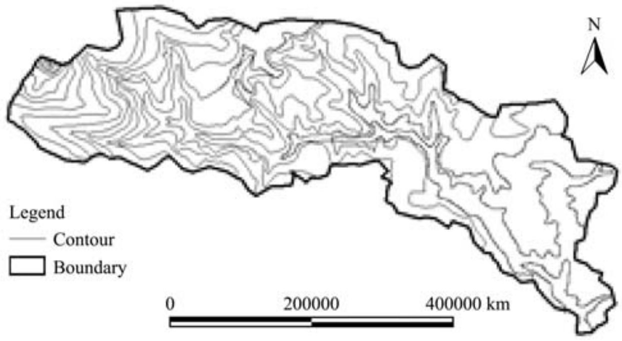
2.3 AnnAGNPS input requirements and preparation

2.3.1 Climate data

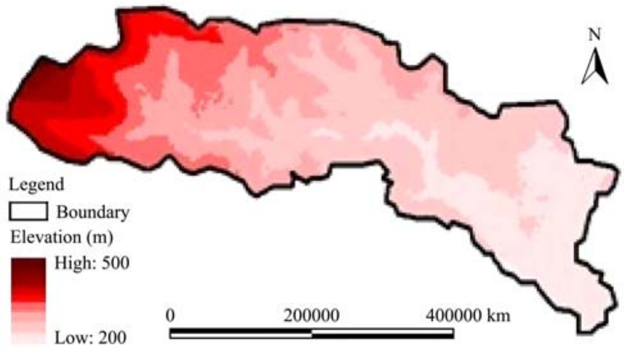
The weather input file for AnnAGNPS simulation can be created through a combination of measured historical and generated synthetic weather data using the climate generator program (Yuan et al., 2006). This file was created using recorded data from Centre for Basic Space Sciences (CBSS), University of Nigeria, Nsukka. Maximum and minimum daily temperatures, daily precipitation, average daily dew point, sky cover and wind speed are the weather elements required for the weather input file. The time span of the data acquisition was 10 years from January 2004 to the end of 2013. The synthetic weather generator, GEM (Johnson et al., 2000), was used to generate the daily 10 year weather input file from the 10 year historical weather data from CBSS, UNN. The global storm type was assumed as type "II" based on the rainfall distribution patterns included in AnnAGNPS that most closely resembled the annual rainfall distribution pattern of the locality.

2.3.2 Topography data

The contour map of the watershed (Figure 2(a)) which was created from 1:50,000 Igumale NW topographic sheets was used to construct a 30-m raster Digital Elevation Model (DEM) of the watershed (Figure 2(b)). The DEM was used to obtain the necessary input files for running TOPAGNPS program to define surface drainage channels and reaches, to subdivide watersheds into hydrologically defined subwatersheds or cells and to identify and measure topographic feature parameters of the cells for the simulation of AnnAGNPS model. Thereafter, the AGFLOW program was run to determine the topographic-related input parameters for AnnAGNPS and formatting the TOPAGNPS output into the AnnAGNPS format. The size of the cell depends on the values of Critical Source Area (CSA) which is the threshold (minimum) upstream drainage area above which a source channel is initiated and maintained, and Minimum Source Channel Length (MSCL) which is the minimum acceptable length of the cell for the source channel to exist. A CSA value of 3 ha and MSCL value of 70 m combination was selected after series of testing different combinations of CSA and MSCL values to represent the existing stream network of the watershed when compared with the real stream network map of the watershed. The study area was discretized into 447 cells and 206 reaches (Figure 3) by these selected values of CSA and MSCL during the processing of the DEM data. Also, cell area, slope, perimeter, RUSLE LS-factor, channel segment length and slopes, and the topology of the cell network values were all calculated during the process.



(a) Contour map



(b) DEM

Figure 2 Contour map and DEM of the watershed

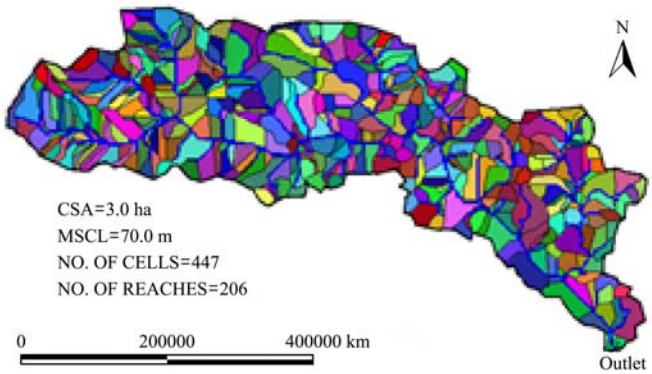
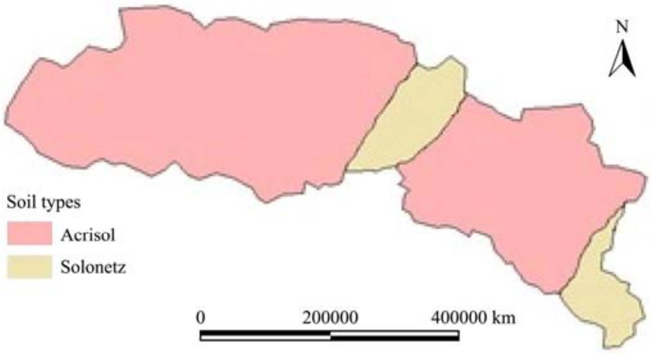


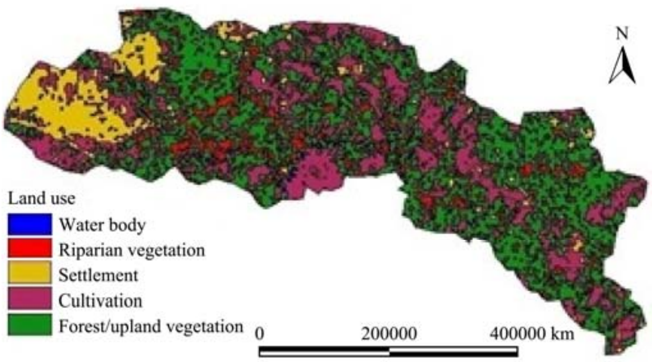
Figure 3 Generated subwatersheds (AnnAGNPS Cells) and reaches of the watershed

2.3.3 Soils data

Particle size fraction, bulk density, albedo, saturated hydraulic conductivity, field capacity, and wilting point are some of the required soil data inputs into the model. The dominant soil type was determined for each AnnAGNPS cell from the dominant soil map of the watershed (Figure (4a)) prepared from the dominant soils map of Nigeria at scale of 1:1,300,000 and associated characteristics for that soil type were organized through the Input Editor. However, some necessary soil information for AnnAGNPS simulation was not available. Using the Harmonized World Soil Database (HWSD v1.2) viewer software (FAO, 2012) at the scale of 1:5000000, the required Soil parameters at two layers of 0-30 cm (upper horizon soil) and 30-100 cm (lower horizon soil) were derived.



(a) Soil use maps



(b) Land use maps

Figure 4 Soil and Land use maps of the study area

2.3.4 Crops and cultivation practices

Crop management operation information reflecting the effect of human activities on the watershed is important for determining the sediment yield accurately (Hua et al., 2012). Crop operation and field management data in the watershed were obtained through field investigation in consultation with the local farmers, and also based on RUSLE guidelines and databases. The common grown crops in the area are Maize, Cocoa yam, and Cassava. Therefore, the operation management were developed with as much detail as possible, especially concerning soil disturbances and land cover changes. The major cropping pattern and typical operations for each grown crop are summarized in Table 1.

Table 1 Major crops grown, management schedules and management operations identified in the watershed in 2011

Management Schedule	Event		Management Operation	Crops	Fertilizer
	No	Date			
Maize Crop	1	2/1/2012	Bush Clearing	Maize	
	2	3/28/2012	Burning		
	3	3/30/2012	Manual Tilling		
	4	4/5/2012	Manual Planting		
	5	4/30/2012	Thinning		
	6	5/25/2012	Hoe Weeding		
	7	6/10/2012	Fertilizing		N, P, K
	8	7/15/2012	Hoe Weeding		
	9	8/20/2012	Harvesting		
Coco-Yam Crop	10	4/5/2012	Manual Planting	Coco-Yam	N, P, K
	11	5/25/2012	Hoe Weeding		
	12	6/10/2012	Fertilizing		
	13	7/15/2012	Weeding_Hoe		
	14	12/10/2012	Harvesting		
Cassava Crop	15	4/5/2012	Manual Planting	Cassava	N, P, K
	16	5/25/2012	Hoe Weeding		
	17	6/10/2012	Fertilize		
	18	2/25/2013	Hoe Weeding		
	19	5/30/2013	Harvesting		

2.3.5 Land use data

The land use map (Figure (4b)) was developed from Landsat spectral satellite image of December 17, 2013. Five major types of land use: settlement, waterbody, riparian vegetation, cultivated area and upland vegetation were identified in the watershed and classified using ENVI 4.7 software. ENVI is the ideal software for the visualization, analysis, and presentation of all types of digital imagery. The dominant land use was assigned to each AnnAGNPS cell that represents more than 30% of the total cell area, and all associated properties such as curve number of that land use were assigned to the cell.

2.3.6 Selection of runoff curve numbers (CN)

Curve Number is a key factor to obtain accurate prediction of runoff and sediment yields (Grunwald and Norton, 2000; Hua et al., 2012). Initial Runoff Curve Numbers were selected based on the land use, treatment practices and soil data with some adjustment to incorporate local conditions for each AnnAGNPS cells. Therefore, selection of an accurate CN is essential for better model performance. The estimated CN values for different land uses of the watershed and the major crops were listed in Table 2.

Table 2 Selection of CN values for each AnnAGNPS cell

Cover Describtions	Initial curve numbers (CN) (AMC II) Hydrologic soil groups A	B	C	D
Bare soil	77	86	91	94
Seed broadcast (Poor)	66	77	85	89
Row crops straight (Good)	67	78	85	89
Crop residue (Good)	74	83	88	90
Rangeland (Fair)	49	69	79	84
Woodland (Fair)	36	60	73	79
Forestland (Good)	30	55	70	77
Corn Straight row (Poor)	65	76	84	88
Urban	89	92	94	95
Cassava	55	62	74	85
Coco-Yam	50	71	81	89
Vegetable	72	81	88	91

2.4 Estimation of RUSLE parameters

Rainfall-runoff erosivity (R-factor) and 10-year frequency storm EI-value (EI_{10}) were calculated by using Equations (6) and (7) respectively as recommended by Renard and Freimund (1994).

$$R = 587.8 - 1.219P + 0.00410P^2,\ P > 850\ (\text{mm}) \quad (6)$$

$$EI_{10} = R^{0.6987} \quad (7)$$

where, R = Rainfall-runoff erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}); P = Mean annual precipitation (mm); EI_{10} = 10-year frequency storm EI-value. The R-factor accounts for the effect of raindrop impact and also shows the amount and rate of runoff associated with precipitation events. Therefore, the estimated R-factor and its corresponding EI_{10}-value were 5,524.634 MJ mm ha^{-1} h^{-1} year^{-1} and 411.856 MJ mm ha^{-1} h^{-1} year^{-1} respectively for annual precipitation of 1,256 mm. RUSLE technology within AnnAGNPS calculates the K factor for each soil in the watershed and topography (LS) factor, crop management (C) factor, and support practice (P) factor for each cell in the watershed during the data preparation pre-processing step. The K-factor was determined by the Equation (8) that uses the soil physical properties and organic matter content (Lal, 1994). The estimated erodiliblity factors of the upper and lower layers of the predominant soils of the watershed are shown in Table 3.

$$K = 2.8\times10^{-7}\times M^{1.14}\times(12-a)+4.3\times10^{-3}\times(b-2)+ 3.3\times10^{-3}\times(c-3) \quad (8)$$

where, K = Soil erodibility factor (t ha h ha^{-1} MJ mm); M = particle size parameter; a = organic matter (%); b = soil structure code (very fine granular = 1; fine granular = 2; medium or coarse granular = 3; blocky, platy or massive = 4); c = profile permeability class (rapid = 1; moderate to rapid = 2; moderate = 3; slow to moderate = 4; slow = 5 and very slow = 6); VFS = Very fine sand.

Table 3 Basic properties of the predominant soils of the watershed and their estimated erodibility factors

Soil type	Soil layers	Sand (%)	Silt (%)	Clay (%)	OM [a] (%)	b [b]	c [c]	VFS [d] (%)	M [e]	BD [f] (g cm^{-3})	K [g]
Acrisol	Upper	76	13	11	0.61	3	2	10	2047	1.53	0.0200
	Lower	62	13	25	0.27	3	2	8	1575	1.55	0.0155
Solonetz	Upper	49	27	24	1.00	3	2	13	3040	1.40	0.0298
	Lower	40	24	36	0.42	3	2	10	2176	1.40	0.0217

Note: [a] Organic matter; [b] Soil structure code (3 was assigned for medium or coarse granular (USDA, 1983)); [c] Permeability class (2 was assigned for the sandy loam texture (USDA, 1983)); [d] Very fine sand (calculated as the product of sand and silt divided by 100 (Mitchell et al., 1997)); [e] Particle size parameter ((% silt + % VFS) × (100 - % clay)); [f] Bulk density; [g] Soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}).

The topography factor for each AnnAGNPS cell was calculated for each raster as an individual slope-length profile segment from DEM by TOPAGNPS. Each raster's flow vector slope was used to calculate the raster's LS-factor prior to determining its respective cell's average LS-factor. The average LS-factor for the segment was determined for the raster area assuming that the slope-length for the segment is equal to the raster length for all rasters. Each raster and its respective cell's hydraulically most distant path used the raster's flow vector slope to calculate the cell's time of concentration (T_c) profile segment slope and lengths. In this procedure, the average RUSLE topographic factor (LS-factor) for each AnnAGNPS cell was calculated. The RUSLE LS calculation includes calculating slope steepness and slope length sub-factors and combining them into a single LS value. The slope length value is modified based upon the susceptibility of the soil to rill and interrill erosion. From a geomorphological perspective, slope length and steepness partly determine the erosive energy of surface runoff and the depth and velocity of flow, which also influence the transport capacity of runoff and its ability to transport the eroded sediment (Toy et al., 2002). Crop management (C) factor was determined within AnnAGNPS based on prior land use, canopy cover, surface cover, surface roughness, soil moisture condition and their corresponding percentages of annual energy intensities values. The C-factor reflects the effect of cropping and management practices on erosion rates. It compares the relative impacts of management options on conservation plans. The C-factor is an indication of how conservation plan affects the average annual soil loss potential and its distribution in time.

The support practice (P) factor was determined by AnnAGNPS model based on the conservation measures and the cover code assigned for specified land use. AnnAGNPS calculates a P factor based upon the type of conservation - terraces, strip-cropping or contours (Renard et al., 1997). A P-factor value is calculated once per growing year and is based upon how the placement or configuration of the practice relative to the hill slope affects the hydraulics of the hill slope, which in turn impacts the sediment transport capacity of runoff. The impact of previous cropping practices on surface roughness is also included when determining P values for strip - cropping. The range of cover codes assigned for various land uses is showed in Table 4.

Table 4 Assigned cover code for various land uses (Bingner et al., 2014)

Scenario	Land Use	RUSLE Predefined Cover Code
1	Fallow	7- Clean Tilled, Smooth, Fallow
2	Cropland	5- Light cover and/or moderately rough
3	Forest	3- Heavy cover and/or very rough
4	Pasture	1- Established sod- forming grass
5	Rangeland	4- Moderate cover and/or rough
6	Tillage	6- Clean row crop tillage, no cover or minimum roughness

2.5 Hydrology and sediment load data

The watershed outlet was manually gauged. Current meter was used to determine the total discharge calculated from flow velocity measured with current meter. Sediment yield was determined from water samples collected daily with an improvised water sampler. Water samples were analyzed for sediment concentration following the standard methods in (WMO, 2008) at Soil and Water Laboratory in the Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka.

2.6 AGNPS input preparation

The development of input parameters used to characterize the watershed conditions involved collection of elevation maps of the area, soil data, Landsat spectral satellite image of the area, in field operation management practices and climate information. These available sources of information were used to obtain DEM, soil map, land use map, management schedule and climate file respectfully. The use of a GIS is, therefore, critical in gathering the needed data for AnnAGNPS simulations of the watershed. The GIS data provide the vital link between the characteristics of the watershed and the parameters needed by the model. Therefore, the compilation of the data into the form needed by AnnAGNPS was performed using the AnnAGNPS/ArcView GIS interface. GIS data layers of the watershed include the digital elevation models (DEMs) to characterize the topography; the land-use GIS layer to characterize the vegetative cover; and soils GIS layer for soil spatial layer, which altogether provide the spatial variation of the important characteristics of the watershed. Further steps included developing the soil layer attributes to supplement the soil spatial layer, the different crop operation and management data, channel hydraulic characteristics, and preparation of climate data file.

GIS has an important role to play in data processing. Therefore, watershed area, average slope, average elevation, distance to watershed outlet, aspect, flow length and RUSLE LS factor for each AnnAGNPS cell were easily determined using ArcView GIS and AnnAGNPS 5.20 interface.

2.7 AnnAGNPS model performance evaluation

Performance evaluation of AnnAGNPS model was based on qualitative (graphical displays) and quantitative (statistical measure) assessments during calibration and validation processes of the model. The qualitative procedures consisted of visually comparing the observed and simulated values. Quantitative evaluations of the model were based on the following statistical parameters: coefficient of determination R^2 (Equation (9)), root mean square error *RMSE* (Equation (10)), index of agreement *d* (Equation (11)) and mean error *ME* (Equation (12)).

$$R^2 = \frac{[\sum_{i=1}^{n}(Q_i - O_{avg})(P_i - P_{avg})]^2}{\sum_{i=1}^{n}(Q_i - O_{avg})^2 \sum_{i=1}^{n}(P_i - P_{avg})^2} \qquad (9)$$

$$RMSE = \frac{\sqrt{\sum_{i=1}^{n}(O_i - P_i)^2 / n}}{O_{avg}} \quad (10)$$

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(|P_i - P_{avg}| + |O_i - O_{avg}|)^2} \right] \quad (11)$$

$$ME = \frac{\sum_{i=1}^{n}(P_i - O_i) / n}{O_{avg}} \quad (12)$$

where, Q_i and P_i are the observed and predicted data respectively; O_{avg} and P_{avg} are the mean of the observed and predicted data respectively; and n is the total number of events.

The R^2 values indicate the strength of the linear relationship between the observed and predicted values and the value of 1 means that the dispersion of the predicted data equals that of the observed data (Fernandez et al., 2006). The *RMSE* with values range from 0 to ∞ describe the difference between the model predicted and field observed values in the unit of the variable, and 0 indicates there is no difference between them (Hua et al., 2012). The *d* varies between 0 and 1 measures the degree of model prediction error (Yuan et al., 2008). A value of 1 is an indication of a perfect agreement between the observed and predicted values, while 0 is an indication of no agreement at all (Willmott, 1984). *ME* indicates the degree of bias that is whether the model has over- or under-estimated the values, while mean absolute error (MAE) is a measure of how far the predicted values can be in error.

3 Results and discussion

3.1 AnnAGNPS model calibration

Calibration is a process of comparing predicted results with observed data and thereafter adjustments are made to the most sensitive parameters in the model (Pullar and Springer, 2000). Calibration is one of the most important steps in model application especially for process based models (Ndiritu and Daniell, 2001). Therefore, model calibrations for stream flow and sediment yield were necessary to optimize the model inputs so that the differences between predicted and measured data could be minimized for the model to yield more accurate predictions by adjusting the sensitive parameters using measured daily data collected in the month of September, 2011.

In their studies (Chahor et al., 2014; Li et al., 2015; Licciardello et al., 2007; Parajuli et al., 2009; Shamshad et al., 2008; Shrestha et al., 2006), SCS-CN has been shown to be the most sensitive input parameter for accurate runoff prediction. The calibration steps were performed by initially running the model without any change in the SCS-CN parameter, and then adjustments were made to the SCS-CN values for all land-use categories independently by trial and error until the graphical comparison (Figure 5) as well as the comparison of statistical parameter of measured and predicted of the model performance was best at a certain values of CN.

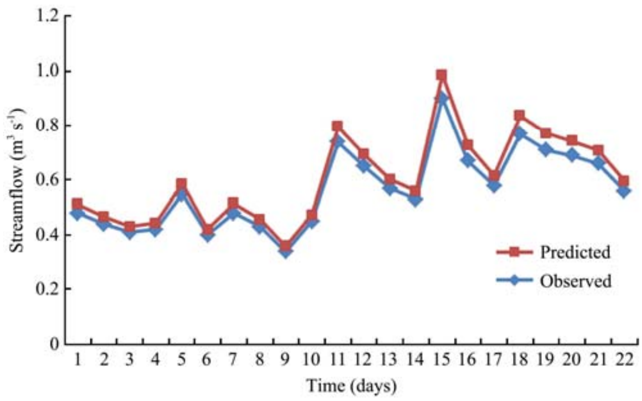


Figure 5 Comparison of daily average predicted and measured streamflow during calibration

Some studies have been done on calibration of sediment yield prediction by AnnAGNPS model by modifying different input parameters (Chahor et al., 2014; Parajuli et al., 2009; Das et al., 2008; Licciardello et al., 2007; Shrestha et al., 2006). Based on these studies, RUSLE-P factor and surface roughness (n) parameters were selected for calibration due to their high sensitivity in sediment yield prediction. Surface roughness is one of the factors that accounts for better prediction of sediment because it affects soil erosion directly as well as indirectly through the impact on residue effectiveness (Shrestha et al., 2006; Cogo et al., 1984). Based on the sensitivity analysis by Chahor et al. (2014), RUSLE-P factor being the most sensitive parameter was adjusted first with the range of values between 0.4 and 0.6. Therefore, manning's roughness coefficient (n) in the model was then adjusted by trial and error until the model performance was best.

The daily data collected in September, 2011 were used to calibrate the model to a reasonable agreement with predicted data with $R^2 = 0.9341$ for streamflow (Figure 5 and Figure 6) and $R^2=0.7066$ for sediment yield (Figure 7 and Figure 8).

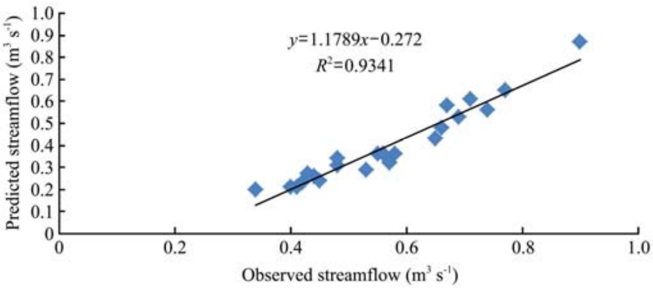


Figure 6 Regression analysis for measured and predicted streamflow during calibration

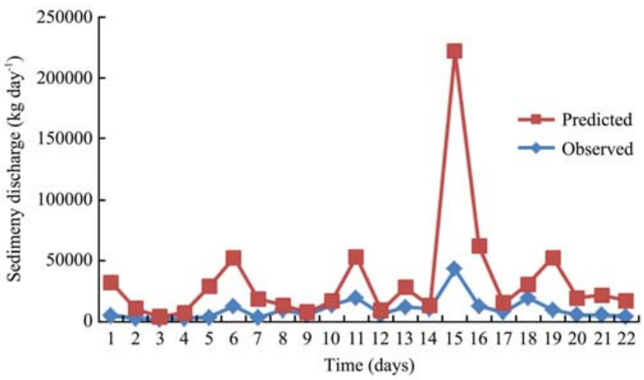


Figure 7 Comparison of daily average predicted and measured sediment discharge during calibration

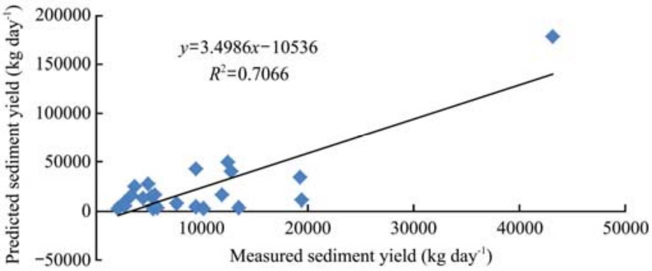


Figure 8 Regression analysis for measured and predicted sediment yield during calibration

3.2 AnnAGNPS model validations

Model validation is done to determine the quality of model predictions for time periods not considered during the process of calibration (Shrestha et al., 2006). The validation of AnnAGNPS model was performed for Streamflow and sediment yield by comparing daily data measured in October, 2011 with daily average predicted streamflow and sediment discharge for 10 years as shown in Figure 9 and Figure 11.

Statistical performance evaluation of the model was carried out on the validation results. The model performed very well in following the trends, peaks and volumes of the measured hydrograph and sediment graph, with $R^2 = 0.9908$ for hydrograph (Figure 10) and $R^2 = 0.9675$ for sediment graph (Figure 12) as shown in Table 4.

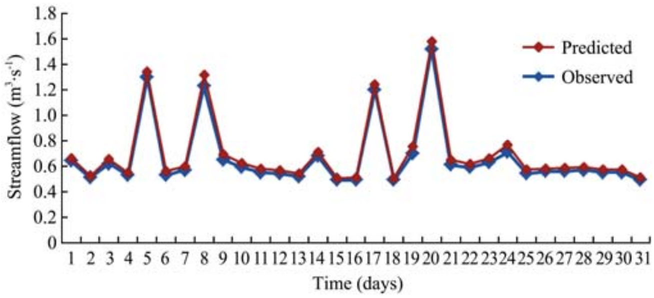


Figure 9 Comparison of daily average predicted and measured streamflow during validation

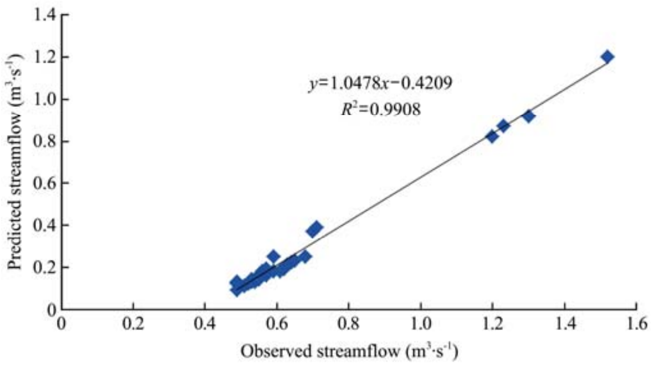


Figure 10 Regression analysis for measured and predicted streamflow during validation

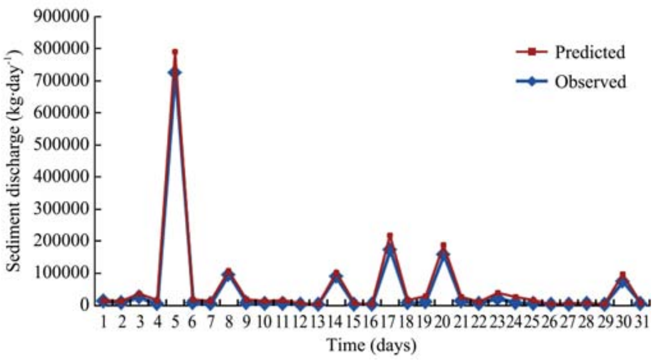


Figure 11 Comparison of daily average predicted and measured sediment discharge during validation

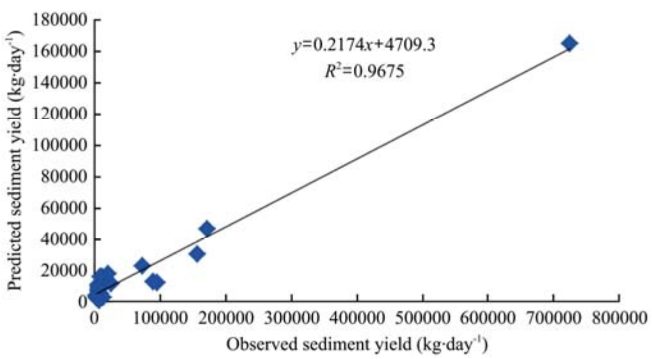


Figure 12 Regression analysis for measured and predicted sediment yield during validation

Table 4 Model quantitative (statistical measures) evaluation

Value	ME	MAE	RMSE	d	R^2
Streamflow	–0.1	0.1	0.28	0.87	0.9908
Sediment Discharge	0.15	0.15	0.54	0.79	0.9675

4 Conclusion

Watershed models are cost-effective and time-efficient methods for the assessment of NPS pollutants and for prediction of watershed responses to hydrological processes for watershed management planning. The AnnAGNPS model was implemented in Upper Ebonyi River watershed, experimental watershed located at Obollo-Etiti in Udenu Local Government Area in Enugu State, South-eastern Nigeria, in order to evaluate model prediction capability with special reference to streamflow and sediment yield.

The data collected in the month of September, 2011 were used to calibrate the model to a reasonable agreement with predicted data (R^2 = 0.9341 for streamflow and R^2=0.7066 for sediment yield). Statistical performance evaluation of the model was carried out on the validation results. The model performed very well in following the trends, peaks and volumes of the measured hydrograph and sediment graph, with R^2=0.9908, RMSE =0.28 for hydrograph and R^2=0.9675, RMSE=0.54 for sediment graph. The implementation of the AnnAGNPS model in the experimental watershed provided better performance in simulating streamflow than sediment yield.

The AnnAGNPS model is a valuable tool to analyze non-point source pollution in agricultural watersheds. The model may be considered suitable to simulate significant runoff events which are mostly responsible for soil erosion. The application of AnnAGNPS on this experimental watershed demonstrated that the model as a research tool has a great potential for estimation of runoff and sediment yields on a daily, monthly and yearly scales. Therefore, the model could be recommended to serve as a management tool for comparative assessment on erosion studies for identification of erosion hot spots in the experimental watershed.

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