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Research Article

Runoff and Sediment Yield Prediction Using Agriculture Non-Point Source (AGNPS) Model in Ata-Gad Watershed, Uttarakhand, India

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Abstract The present study was undertaken to predict the runoff and sediment loss from Ata-gad watershed, Chamoli district, Uttarakhand, India. The land use/land cover (LULC) map was prepared using IRS-P6 LISS-III data. Digital Elevation Model (DEM) from ASTER and soil information from Soil and Land Use Survey of India (SLUSI) was used for runoff and sediment yield prediction. It was observed that large part of the watershed is forested (71.9%) and agricultural activity is ongoing in lower reaches of the valley (18%). The watershed area is mostly under moderately steep (15-35%) to very steep slope (50-75%). LULC, Soil, DEM and other inputs were fed into Agriculture Non-point Source (AGNPS) model through AGNPS Data Generator (ADGen) interface of image processing software. The AGNPS model helps to visualize the effect of slope, rainfall, LULC, etc. on runoff and sedimentation characteristics of a watershed. It was observed that nearly fifty percent area of the watershed produced 2.54 cm of runoff corresponding to 17.8 cm of rainfall. As large part of the watershed is under forest and consequently 64.24% of its area produced less than 1.42 cumec and only 0.11% of the area showed more than 49.55 cumec of peak runoff. Twenty-one percent area of the watershed is having steep slope (slope>75%) and showed the maximum rate of erosion as 48.67 tons/ha. Erosional characteristics vis-à-vis other properties of the landscape were also analyzed. It was also observed that with the increase in slope, though the soil erosion has increased but the slope factor solely does not affect erosional characteristics.
Keywords *AGNPS; GIS; Remote sensing; Runoff; Soil erosion*

1. Introduction

The hydrological behaviour of a catchment is a complex phenomenon, which is controlled by large number of climatic and physiographic factors that vary in time and space. The models are required not only to predict water yield and subsequently to build design parameters of hydraulic structures, but also for understanding and to evaluate the anthropogenic and disaster-induced effects on the hydrological regime of a river basin.

The Himalayan regions are adversely affected with erosional processes due to high elevation differences, denuding forest cover, varying climatic conditions, agriculture practices and inhabitation, etc. in comparison to other mountainous regions. The hilly region is also inhabited by livestock population which results in overgrazing and that induces soil erosion. The rainfall is a major triggering factor which enhances the chances of water erosion. By adopting appropriate soil conservation practice and proper water management, this problem could be tackled to a great extent.

The hydrological models help to identify the cause and sink areas of sediment transport, runoff and nutrients that leave its original place. The Agricultural Non-point Source Pollution Model is a event based distributed computer simulation model developed by Agriculture Research Service, United States Dept. of Agriculture with the assistance of National Resource Conservation Service and the Minnesota Pollution Control Agency (Bosch et al., 1998)

Many GIS based AGNPS interfaces are available for the preparation of input parameters and to run the model. Among them, the AGNPS Data Generator (ADGen) and ERDAS Interface and Map Window Interface (MWAGNPS) are most popular and widely used. Grunwald and Norton (1999) compared surface runoff and sediment yield using AGNPS water quality simulation model for 52 rainfall-runoff events, 22 for calibration and 30 for validation for two small watersheds in Bavaria, Germany. Ma and Bartholic (2003) used AGNPS model used in combination with GIS tools to assess the feasibility of water quality effluent trading for phosphorus in Morrow Lake sub-watershed, Kalamazoo, Michigan, USA. Chowdary et al. (2001) have studied AGNPS for quantitative assessment of nonpoint source pollution within the Karso watershed, Damodar river valley, Hazaribagh district of Bihar state, India. Zema et al. (2012) used AnnAGNPS model to assess runoff water amount and quality as well as sediment yield in small to large monitored watersheds in different climatic and geomorphologic conditions. Jianchang and Luoping (2008) used AGNPS model for Wuchuan catchment in Fujian Province, China for ten storms. Haregeweyn et al. (2003) evaluated the AGNPS model on Augucho catchment in western Hararghe region of Ethiopia using observed data of 8–10 years. AnnAGNPS did not simulate base-flow, hence to compare the model predicted runoff to observed runoff; base-flow was separated from the observed runoff using the straight-line method (Sarangi et al., 2007). Najim et al. (2006) tested the suitability of AGNPS pollution model for a mixed forested watershed. The simulated runoff volume reasonably matched with the observed runoff volume, with coefficient of performance of 0.09. Rainis (2004) compared the effects of slope information derived from three sources on sediment yield estimated using AGNPS model.

1.1. Study Area

The present study has been carried out for the Simli watershed which is also known as Ata-Gad watershed and falls within Pindar Catchment in Bageshwar district of Uttarakhand province in India. The geo-bounds of the study are 30º05' N to 30º16' N longitude and from 79º10' E to 79º17' E latitude. Agriculture is the prime occupation of watershed inhabitants. Paddy and Millets are the major *Kharif* crops, which are practiced during rainy season whereas Wheat and Mustard are grown as winter or *Rabi* crops. The river at its initial course flows through sedimentary rock and further to the south meanders through quartz, schist and granite found in abundance in the study area. The drainage pattern is dominantly dendritic. The nature and type of soil found in the study area varies from place to place and along with it changes the vegetation it supports. There is rich humus present in the thin soil layers.

2. Data Used and Methodology

There are four important parameters which are required to run the AGNPS model. These are DEM, hydrological soil group, watershed boundary and land use/land cover (LULC). These maps should have same spatial resolution (30 m in the present study). The hydrological soil group map has been prepared using soil map and later, attributes were added to determine soil erodibility factor (K factor) using nomograph method. LULC map was prepared using supervised classification method and later contextual refinement was conducted to improve the results. Some attributes have also been attached to LULC map like SCS CN for Antecedent Moisture Condition-II (AMC), Manning's roughness factor (N), cropping factor, and surface condition constant. Figure 2 explains the methodology followed in the present study.

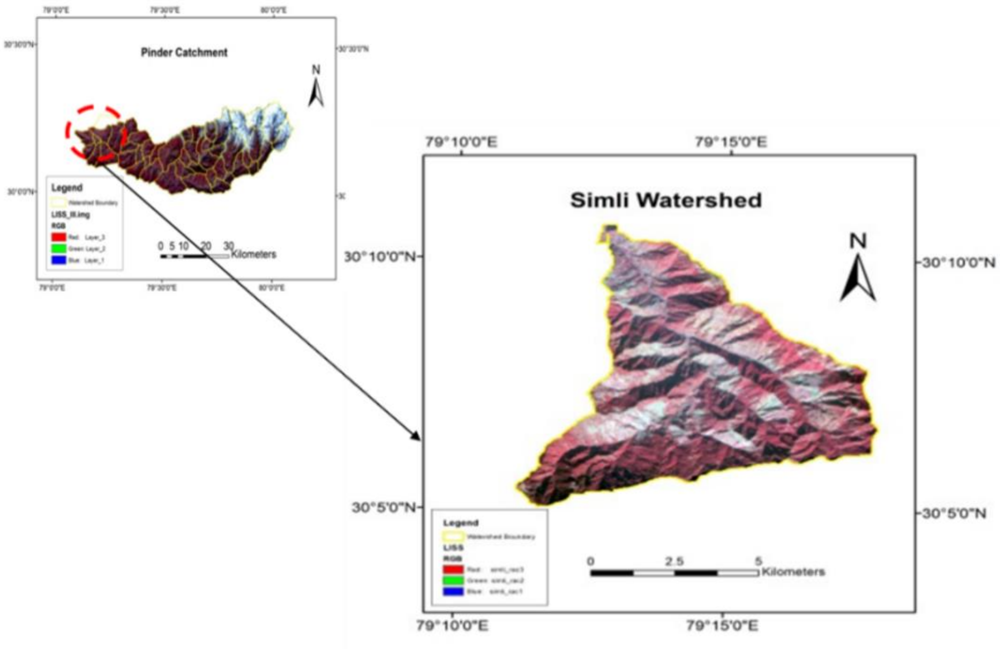

Figure 1: *Location map of Simli watershed within catchment of Pinder river*

In the present study, IRS-P6 LISS-III acquired on 26 December 2007 and ASTER Digital Elevation Model (DEM) has been used. The Survey of India (SOI) topographical map at 1:50,000 scale has been used for preparing the base map for the study area. The existing soil map, rainfall data (event-specific), SCS CN table has been used for running the model. The ADGen (AGNPS data generator) interface has been used for estimating runoff and soil loss. The Arc Hydro tool has been used to derive several data sets that collectively describe the drainage and topographic properties of a watershed. The raster analysis is performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation and watershed delineation. These data are later used to develop a vector representation of catchments and drainage lines. Using these information, the geometric network was constructed. Later, the Arc Hydro data model has been used for micro-watershed delineation.

2.1. Model Description

The model uses Natural Resources Conservation Service (NRCS) Soil Conservation Service (SCS) Curve Number (CN) method to estimate runoff which uses the following equation:

$$Q = (P-0.2S)^2/(P+0.8S) \text{ ...... } (1)$$

Where, Q is runoff depth (mm), P is rainfall (mm), and S is retention parameter (mm) which is defined as:

$$S = (1000/CN) - 10 \text{ ...... } (2)$$

The erosion is estimated using a modified version of Universal Soil Loss Equation (Wischmeier and Smith, 1978)

$$SL = (EI)\ K\ LS\ C\ P \ \ldots\ldots (3)$$

Where, SL is soil loss, EI is product of storm kinetic energy and maximum 30 minute Intensity, K is soil erodibility factor, LS is topographic factor, C is cover management factor and P is conservation practice factor. The peak flow is estimated using empirical relationship developed for CREAM model by Smith and Williams (1980) as given below:

$$Q_p = 3.79\ (A)^{0.7}\ (CS)^{0.16}\ (R/25.4)^{0.9A\wedge 0.02}\ (L^2/A)^{-0.19} \ \ldots\ldots (4)$$

Where, Q_p is peak runoff rate (m^3/s), A is watershed area (km^2), CS is channel slope (m/km), R is runoff volume (mm), L is the watershed length (km).

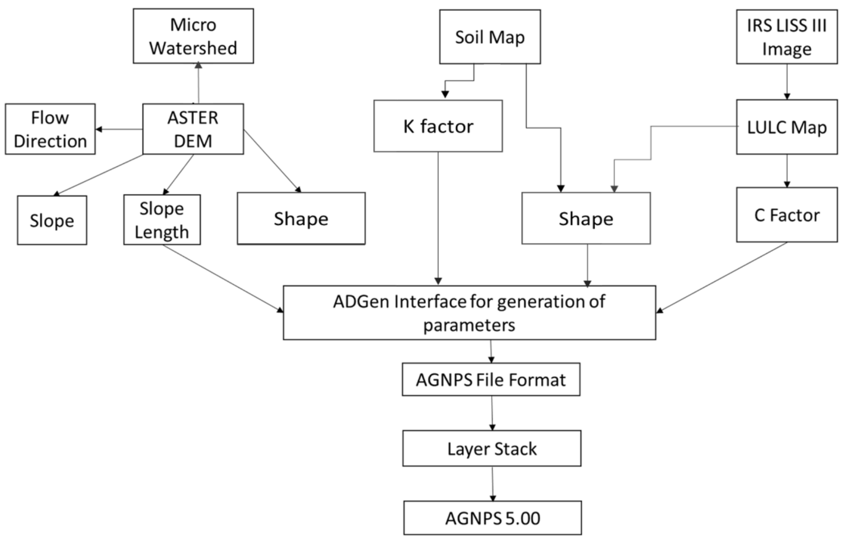

Figure 2: *Methodology flow chart*

The AGNPS model has following limitations: a) all runoff and associated sediment, nutrient, and pesticide loads for a single day are routed to the watershed outlet before the next day simulation begins (regardless of how many days this may actually take), b) there are no mass balance calculations tracking inflow and outflow of water, c) there is no tracking of nutrients and pesticides attached to sediment deposited in stream reaches from one day to the next, and d) point sources are limited to constant loading rates (water and nutrients) for entire simulation period, and there is no allowance for spatially variable rainfall.

Rainfall at antecedent periods of 5-30 or more days prior to the storm are commonly used as indices of watershed wetness. These are only rough approximations, as they do not include the effect of evapotranspiration and infiltration on watershed wetness. The ADGen is a 22 parameter driven interface that facilitates compatible database generation for AGNPS model. Table 1 shows the utility of the parameters and the sources from where these are derived. The AGNPS Model generates a *.nps file after successful execution of the input data. The ADGen interface provides a useful tool to convert the *.nps files to ERDAS Imagine *.img format such that user can visualise the output results.

3. Results and Discussion

The AGNPS model estimates runoff, soil loss and nutrients on a cell-to-cell basis for entire watershed. It generates the runoff map for various hydrologic-soil-land use/land cover complexes and estimates runoff and soil loss corresponding to various rainfall events. As the area is mountainous and receives high amount of rainfall, the AMC of soil is important as it gets saturated easily and immediately produces surface runoff. The major LULC units in the Ata-Gad watershed are classified as forest, agriculture, barren land, scrub, settlement, snow cover and water body. It was observed that large part of the watershed is forested (61.9%) and agricultural activity is ongoing in lower reaches of the valley (18%). The watershed area is mostly under moderately steep (15-35%) to very steep slope (50-75%) (Table 2). During the peak runoff analysis, it was observed that 64.24% of watershed area produced less than 1.42 cumec and only 0.11% of the area showed more than 49.55 cumec of peak runoff (Table 3). Other parts of the watershed showed the runoff in the range of 1.42-49.55 cumec. One of the important parameter that affects runoff and soil erosion is slope. 1196 ha area of the watershed is having moderate to steep slope (slope>75%) and showed the maximum rate of erosion as 48.67 tons/ha. The surface runoff for Ata-Gad watershed has been assessed using AGNPS model. Figure 3a shows the runoff contributing area on cell-to-cell basis. Figure 3b shows the overland runoff from the cell. It is observed that maximum runoff is observed from agricultural region and it involves the transport of agricultural chemical via surface runoff which could be a threat to downstream ecosystems. The runoff from scrub, open forest and dense forest areas are comparatively lesser. The figure 3c shows upstream concentrated flow. As AGNPS gives information on cell-to-cell basis, thereby it shows the upstream concentrated flow that is received by each pixel from upstream. Figure 3d shows the upstream accumulated runoff computed on a cell to cell basis. Figure 3e shows downstream accumulated runoff i.e. runoff emanating from each pixel. Figure 3f shows the downstream concentrated flow. All these figures help to understand hydrological processes, human influence activities related to land use and natural impacts related to climate. Figure 3g depicts upstream and downstream sediment yield generated at various parts of watershed. The agriculture fields are contributing higher soil erosion followed by the scrub and then forest land due to poor vegetation characteristics and over grazing practices.

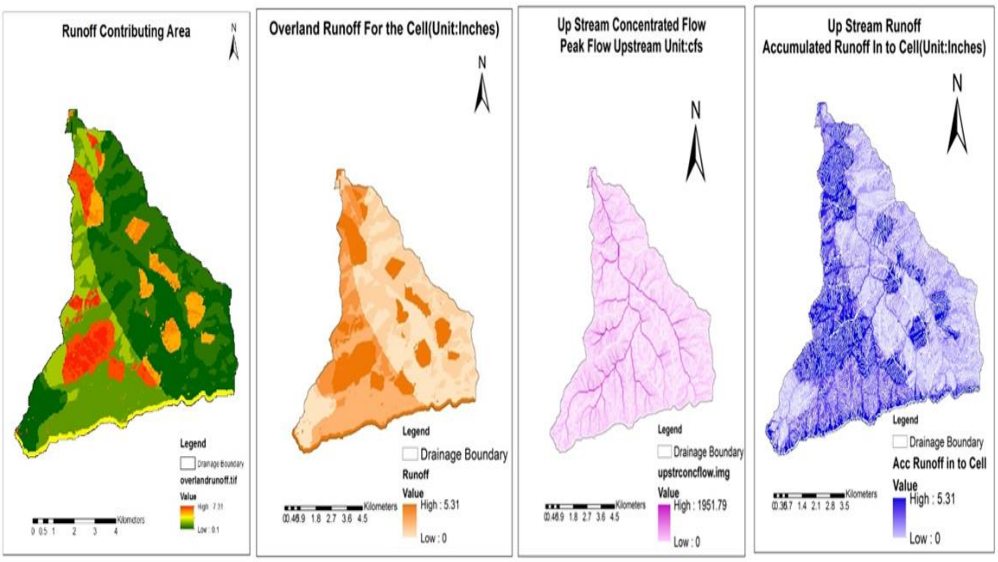

Figure 3: a. *Runoff contributing area, b. Overland runoff from the cell, c. Stream contributing area, d. Upstream accumulated runoff*

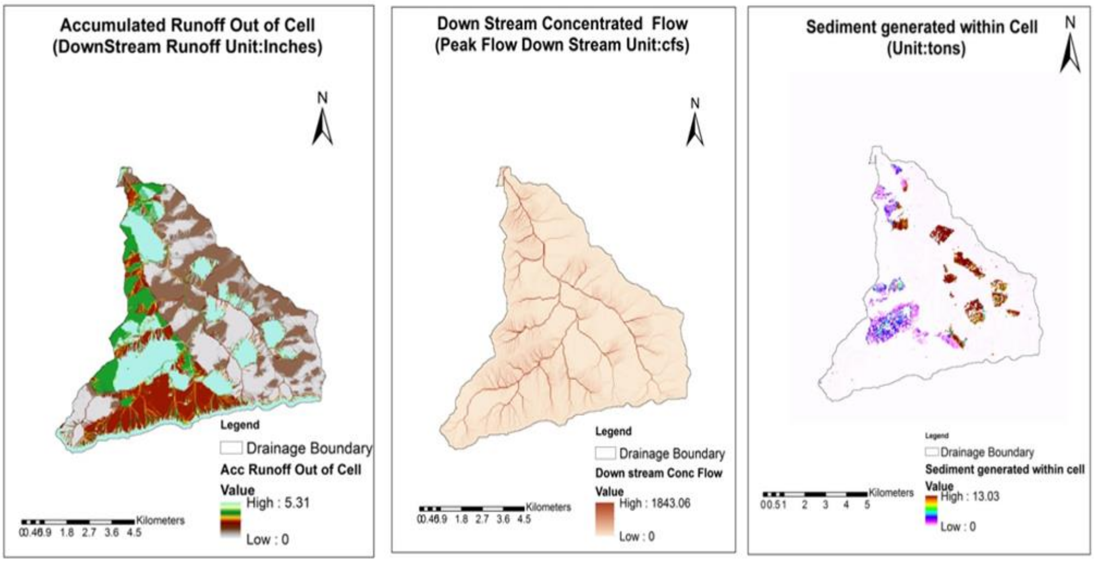

Figure 3: *e. Downstream accumulated runoff, f. Downstream concentrated flow, g. Sediment generated within cell*

The runoff parameter has been studied using SCS CN method incorporated within AGNPS model. It was observed that 50% area of the watershed produced 2.54 cm of runoff corresponding to 17.8 cm of rainfall. Similarly, the peak runoff characteristics of the watershed depicts that 64% of the Ata-Gad watershed produced peak runoff of 1.42 cumec corresponding to 17.78 cm of rainfall (Table 3).

Table 1: *Input parameters used in AGNPS model*

S. No	Parameter	How To Derive	Utility In the Model
1	Cell Number	Divide watershed into small cells of convenient size and number them as 1 for top left cell and proceed by each row, till the end	Identification
2	Receiving Cell	Based on drainage direction	To compute drainage direction for any cell
3	SCS Curve Number	Using standard curve number table based on land use map, hydrologic soil group map and antecedent moisture condition.	To compute retention factor and surface runoff
4	Land Slope	Using DEM	To determine velocity of overland flow
5	Filed Slope Length	Based on field observation of overland flow areas.	To calculate peak discharge
6	Channel Slope	Based on drainage map, topographic data and field observation	To calculate width of channel (for peak discharges)
7	Channel Side Slope	To calculate width of channel (for peak discharge)	Based on field observation and land use
8	Manning Roughness Coefficient	To calculate velocity in channel	Based on land use and field observation
9	Surface Condition Constant	To calculate time of overland flow	Based on topographic contour information
10	Flow Direction	To determine length of channel	Based on topographic contour information

11	Channel Length	Based on drainage	To determine length of channel
12	Soil Erodibility Factor (K)	To identify erodibility of soil	Based on soil type using USLE
13	Surface Condition	To identify soil surface condition	Based on land use
14	Aspect	Indicates drainage direction	Based on DEM
15	Soil Texture	Identification of clay, silt, sand	Based on soil map
16	Fertilization level	Based on field data	To identify fertilizer requirement
17	Fertilizer availability Factor	Based on field data	This estimates percentage availability of fertilizer left in top 1 cm of soil
18	Point source indicator	Based on field data	Indicates existence of a point source input within a cell
19	Gully source level	Based on field data	To estimate Gully Erosion In Cell (Tons)
20	Chemical oxygen level	Based on land use	Based on land use type
21	Impoundment indicator	Based on present terraces in the cell	Indicating presence of an impoundment terrace system within cell
22	Channel indicator	To determine the presence of channel	Based on Drainage

Table 2: *Erosional characteristics of Ata-Gad watershed under various slope categories*

S. No.	Slope category (%)	Area (ha)	Max. soil erosion (Tons/ha)	Mean soil erosion (Tons/ha)
1	0-5%	16.56	17.55	0.74
2	5-10%	48.53	14.97	0.63
3	10-15%	92.70	23.40	0.72
4	15-35%	955.86	29.39	0.99
5	35-50%	1396.57	31.14	1.26
6	50-75%	1980.65	36.43	1.21
7	> 75%	1196.33	48.67	0.99
	Total	5687.19		

Table 3: *Peak runoff characteristics of Ata-gad*

Peak Runoff (cumec)	Area (ha)	% of Area
<1.42	3653.28	64.24
1.42 - 7.08	738.81	12.99
7.08 - 14.16	382.77	6.73
14.16 - 21.24	381.60	6.71
21.24 - 28.32	326.16	5.73
28.32 – 35.40	164.34	2.89
35.40 – 42.48	26.73	0.47
42.48 – 49.56	7.02	0.12
>49.56	6.48	0.11
	5687.19	100.00

4. Conclusion

Soil is an important element essential for the sustenance of biotic systems and therefore, it is utmost necessary to preserve soil and its contents. The productivity of soil is determined by the nutrients and these nutrients and other soil sediments are removed by different agents like water and wind, etc. The AGNPS model was used in the present study to assess the runoff and sediment loss from Ata gad watershed of Pinder River in Uttarakhand hills. It was observed that large part of the watershed is forested (61.9%) and agricultural activity is ongoing in lower reaches of the valley (18%). The watershed area is mostly under moderately steep (15-35%) to very steep slope (50-75%).

The erosional and runoff characteristics vis-à-vis other properties of the watershed have been analyzed. During the peak runoff analysis, it was observed that 64.24% of watershed area produced less than 1.42 cumec and only 0.11% of the area showed more than 49.55 cumec of peak runoff. Other parts of the watershed showed the runoff in the range of 1.42-49.55 cumec. One of the important parameter that affects runoff and soil erosion is slope. 1196 ha area of the watershed is having moderate to steep slope (slope>75%) and showed the maximum rate of erosion as 48.67 tons/ha. It is seen that slope factor solely does not affect the erosion characteristics. Such kind of studies will be helpful to manage resource utilization practices. The anthropogenic effects have impact on upstream-downstream interaction and water transport processes. The good catchment management practices at upstream can provide better opportunities for downstream communities and a clean and sustainable water supply for irrigation. The poor catchment management practices may not only degrade upstream environmental conditions, but will also limit the opportunities downstream.

References

Bisantino, T., Bingner, R., Chouaib, W., Gentile, F. and Trisorio Liuzzi, G. 2015. Estimation of runoff, peak discharge and sediment load at the event scale in a medium-size mediterranean watershed using the AnnAGNPS model. *Land Degradation & Development*, 26(4), pp.340-355.

Bosch, D., Theurer, F., Bingner, R., Felton, G. and Chaubey, I. 1998. *Evaluation of the AnnAGNPS water quality model*. Annual International Meeting, Orlando, Florida.

Choi, K.S. and Blood, E. 1999. Modeling developed coastal watersheds with the agricultural non-point source model. *Journal of the American Water Resources Association*, 35(2), pp.233-244.

Chowdary, V.M., Kar, S. and Adiga, S. 2004. Modelling of non-point source pollution in a watershed using remote sensing and GIS. *Journal of the Indian Society of Remote Sensing*, 32(1), pp.59-73.

Grunwald, S. and Norton, L.D. 1999. An AGNPS-based runoff and sediment yield model for two small watersheds in Germany. *Transactions of the ASAE*, 42(6), pp.1723-1731.

Haregeweyn, N. and Yohannes, F. 2003. Testing and evaluation of the agricultural non-point source pollution model (AGNPS) on Augucho catchment, western Hararghe, Ethiopia. *Agriculture, Ecosystems & Environment*, 99(1-3), pp.201-212.

Jena, S.K. and Tiwari, K.N. 2016. *Hydrologic modeling of watersheds using remote sensing, GIS and AGNPS*. Modeling Methods and Practices in Soil and Water Engineering. Apple Academic Press, pp.131-165.

Jianchang, L., Zhang, L., Zhang, Y., Huasheng, H.O.N.G. and Hongbing, D.E.N.G. 2008. Validation of an agricultural non-point source (AGNPS) pollution model for a catchment in the Jiulong River watershed, China. *Journal of Environmental Sciences*, 20(5), pp.599-606.

Ma, Y. and Bartholic, J. 2003. GIS based AGNPS assessment model in a small watershed. *Nat. Sci*, 1(1), pp.50-56.

Mishra, S.K., Chaudhary, A., Shrestha, R.K., Pandey, A. and Lal, M. 2014. Experimental verification of the effect of slope and land use on SCS runoff curve number. *Water Resources Management*, 28(11), pp.3407-3416.

Mostaghimi, S., Park, S.W., Cooke, R.A. and Wang, S.Y. 1997. Assessment of management alternatives on a small agricultural watershed. *Water Research*, 31(8), pp.1867-1878.

Najim, M.M.M., Babel, M.S. and Loof, R. 2006. AGNPS model assessment for a mixed forested watershed in Thailand. *Science Asia*, 32, pp.53-61.

Perrone, J. and Madramootoo, C.A. 1997. Use of AGNPS for watershed modeling in Quebec. *Transactions of the ASAE*, 40(5), pp.1349-1354.

Rainis, R. 2004. Estimating sediment yield using Agricultural Non-Point Sources (AGNPS) model: The effects of slope information from different GIS softwares. *Journal of Spatial Hydrology*, 4(2).

Sarangi, A., Cox, C.A. and Madramootoo, C.A. 2007. Evaluation of the AnnAGNPS model for prediction of runoff and sediment yields in St Lucia watersheds. *Biosystems Engineering*, 97(2), pp.241-256.

Smith, R.E. and Williams, J.R. 1980. Simulation of surface water hydrology. In: CREAMS, A field scale model for chemicals, runoff, and erosion from agricultural management systems. *USDA Conservation Resources Report*, 26(1), p.15.

Young, R.A. and Shepherd, R.G. 1995. *AGNPS-Agricultural Nonpoint Source Model*. Workshop on Computer Applications in Water Management, 33.

Yuan, Y., Bingner, R L. and Rebich, R.A. 2001. Evaluation of AnnAGNPS on Mississippi Delta MSEA watersheds. *Transactions of the ASAE*, 44(5), p.1183.

Zema, D.A., Bombino, G., Denisi, P., Licciardello, F. and Zimbone, S.M. 2012. *Prediction of Surface Runoff and Soil Erosion at Watershed Scale: Analysis of the AnnAGNPS Model in Different Environmental Conditions*. Research on Soil Erosion, 2012.