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Sediment Yield Assessment and Mitigation Measures in Finchaa Watershed, Ethiopia

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***Abstract* - The effects of land use land cover changes and improper management systems have played a significant role in causing high soil erosion rates, sediment transport and affects life expectancy of the reservoir and have an impact on the water balance of the catchment.This study investigates sediment yield to changes in land use, land cover and mitigation measure practices at Finchaa watershed, Ethiopia.The input data used for this study were Digital Elevation Model, land use land cover map, soil map and data, and weather data. As the measured data was not available on sediment yield, only the simulated data has been used to identify the impact of value on some measure of simulated sediment output. Model calibration and uncertainty analysis were performed with sequential uncertainty fitting (SUFI-2) that is linked with SWAT. The results of the land use and land cover change analysis identified those farmlands agricultural land use class has expanded. Performance of the model for both calibration and validation watershed were found to be reasonably good for calibration and validation respectively. Various land use mitigation measures were further evaluated based on economic analysis as adaptation options to mitigate the land use land cover change impacts and appropriate soil conservation measures based on suitable afforestation techniques can prove influential in mitigating the risk of soil erosion in this Finchaa watershed.**

Keywords: Finchaa watershed, Mitigation measures, Sediment yield, SWAT Model

1. INTRODUCTION

Land use change is the main causes for soil degradation and could significantly change the sediment yield availability. Land cover change is a primary concern in watershed management as it may also lead to increased flooding, soil degradation and decreased recharge of aquifers. The land use and land cover change occurrence is increasingly rapid, and that can have adverse impacts and implications at local, regional, and global environments [1].

Deforestation which has converse effects to afforestation, significantly affects the characteristics of stream flow [2]. Forests are thought to make rain, augment low flows, reduce floods, improve soil erosion, reduce amount of sediment in the reservoir and sterilize water. Therefore, such changes of land use and land cover may have impacts on the sediment yield to reservoirs during the wet and dry months. The major sources of sediments may be from other human activities such as road construction, poorly constructed and maintained terraces, and runoff from cultivated land or bank erosion [3]. The overland flow of watershed also affects the land use land cover, it also depends upon the rainfall runoff charecteristics like intensity, slop of watershed and duration of rainfall [23, 24]. Soil erosion is largely determined by the absence of protective land cover, whereas sediment export to rivers is determined by on site sediment production and connectivity of sediment sources and rivers [4]. All reservoirs formed by dams on natural water courses are subject to some degree of sediment inflow and deposition. The reservoir sedimentation is a complex process that varies with the watershed amount of sediment production, rate of sediment transportation and mode of deposition in watershed. Sediment is fragmental material, primarily formed by the physical and chemical breakdown of rocks from the earth’s crust. Sediment yield refers to the amount of sediment exported by a basin over a period of time and also it is the amount of eroded sediment discharged by a stream at any given point; it is the total amount of fluvial sediment exported by the watershed tributary to a measurement point and is the parameter of primary concern in reservoir studies. Sediment export is also a function of land use, since the sediment transport capacity is different for different types of land cover.

Sediment yield is dependent on factors of soil erosion (mainly rainfall, soil condition, land use, topography) and the capacity of transportation. Sediment is deposited between the source and the stream cross section whenever the transport capacity of runoff water is insufficient to sustain transport. Reservoir sedimentation is a phenomenon that also has positive impacts to water usage systems particularly to the downstream river. The Reservoir sediment deposition is a indication of watershed erosion and deposition in the watershed processes which can be controlled by different processes such as terrain form, soil type, surface cover, drainage networks and rainfall- related environmental attributes [5]. In order to increase the life expectancy of the reservoir and to best achieve the purpose for which the reservoir has been constructed, reducing sediment inflow and removing sediment from the reservoir are substantial activities. In Ethiopia accelerated sedimentation in reservoirs providing hydroelectric power and irrigation water has resulted in loss of these intended services.Therefore, the aim of this study was to evaluate the effects of sedimentation and to develop the adaptation options to mitigate the adverse impacts of sediment on the reservoir.

Finchaa sub-basin is located in the moist humid climatic zone of the Blue Nile basin. Finchaa sub-basin lies between 9°10'30" to 9°46'45" North latitude and 37°03'00" to 37°28'30" East longitude. The sub-basin is located around 280km of Addis Ababa western Ethiopia, in Blue-Nile river basin. Finchaa sub-basin is a part of Blue-Nile river basin which contains three watersheds. The sub-basin has an area of 4089km^2.Stream flow data and randomly measured suspended sediment data on the NesheRiver is available

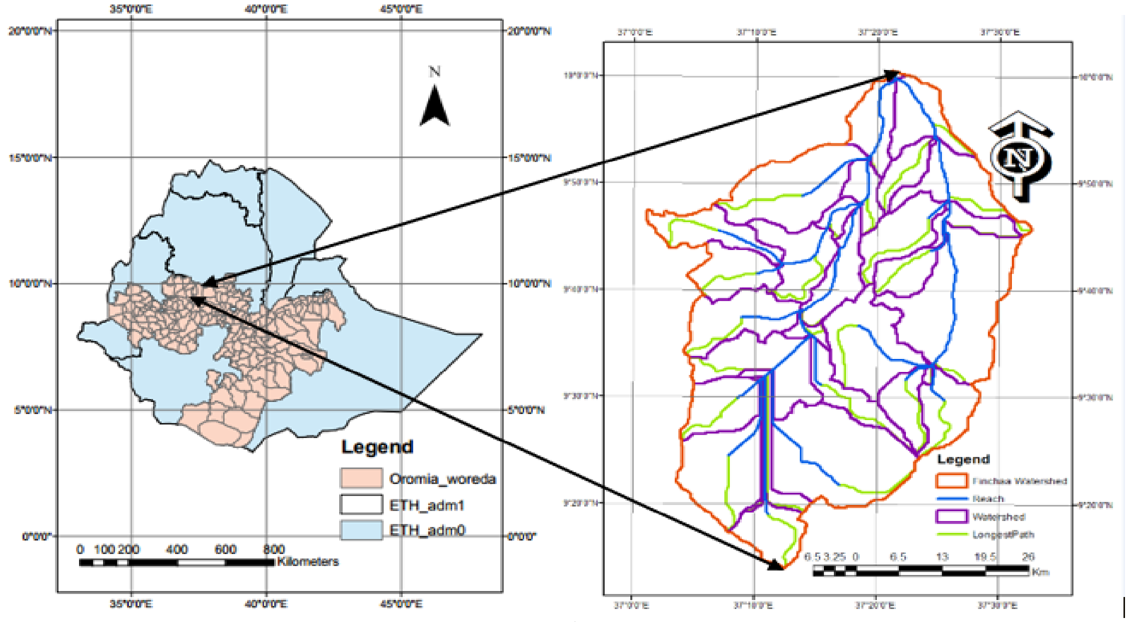

Fig.1 Study area of Finchaa sub-basin

2. MODELLING APPROACH

The Soil and Water Assessment Tool (SWAT) is a physical based hydrological model developed by USDA Agricultural Research Services (ARS) [6] will be used to analyses the impact of land use change, climate change and reservoir construction on sediment yield in river basins. The SWAT model is capable in simulating hydrological process and the magnitude of erosion and sediment yield from data poor watersheds with reasonable model performance numerical values. Hydrologic models can be further divided into event-driven models, continuous process models, or models capable of simulating both short-term and continuous events.

3.1. Hydrological component of SWAT

The land phase of the hydrologic component controls the water movement in the land and determines the water, sediment, nutrient and pesticide amount that is loaded into the main stream. Infiltration, redistribution, evapotranspiration, lateral sub-surface flow, surface runoff, ponds and tributary channel return flow are simulated in this hydrological component. The second component is the routing phase in which the water is routed in the channel network of the basin, carrying the sediment, nutrients and pesticides to the outlet.

SWAT is a model that can be used to simulate flow and sediment for large basins. The method to evaluate the hydrological impacts due to LULCCs and land use modifications can be achieved through integrating Geographical Information System based Soil and Water Assessment Tool model.

3.2. Application of SWAT model

SWAT has already been validated in the regions of the world for a variety of applications in hydrologic as well as water quality studies [7] and SWAT has been successfully applied in evaluating the best management practices in various parts of the world. The SWAT model has good standing for best use in agricultural watersheds and its uses have been successfully calibrated and validated in many areas of the USA and other continents [8]. The SWAT model application was also calibrated and validated in some parts of Ethiopia. [9] Argued that based on reasonable model results, SWAT twisted out to be sensitive to land use land cover changes and would be a good tool to assess soil erosion and the effects of best management practice in Ethiopia.

3.3. Comparisons of SWAT with other models

For this study the program SWAT was selected due to its continuous time scale, computational efficiency, its ability to simulate long-term impacts, its applicability to large-scale catchment, distributed spatial handling of parameters and integration of multiple processes such as climate, hydrology, nutrient and pesticide, erosion, land cover, management practices, channel processes, and processes in water bodies has an important tool for watershed scale studies.

The model was applied for LULCC impact assessment in different parts of the world and also in Ethiopia. [10], compared SWAT with several otherwatershed-scale models. In the study, they reported that the Dynamic Watershed Simulation Model (DWSM), Hydrologic Simulation Program-Fortran (HSPF) model. SWAT and other models have hydrology, sediment and chemical routines applicable to watershed-scale catchments and concluded that SWAT is a promising model for continuous simulations in predominantly agricultural watersheds [11]. They found that

SWAT and HSPF could predict yearly flow volumes and pollutant losses, were adequate for monthly predictions except for months having extreme storm events and hydrologic conditions and were poor in simulating daily extreme flow events. In Contrast, DWSM reasonably predicted distributed flow hydrographs and concentration or discharge graphs of sediment and chemicals at small time intervals. [12] Found that the average daily flow, sediment loads, and nutrient loads simulated by SWAT were closer than HSPF to measured values collected at five sites during both the calibration and verification periods for the upper north Bosque River watersheds in Texas.

[13], found that both SWAT and the MIKE-SHE model simulated the hydrology of Belgium's Jeker River basin in an acceptable way. However, MIKE-SHE predicted the overall variation of river flows slightly better. [14], found that SWAT estimated flow more accurately than the Soil Moisture Distribution and Routing (SMDR) model that SWAT was also more accurate on a seasonal basis.

3.4. Benefits of SWAT Model Approach

- Watersheds with no monitoring data (e.g., stream gage or water quality data) can be modeled.
  - The relative impact of alternative input data (e.g. changes in management practices, climate, vegetation, or land use) on water quality or another variable of interest can be quantified.
  - The model uses readily available inputs.
  - SWAT is computationally efficient. The Simulation of very large basins management strategies can be performed without excessive investment. The model enables users to study long-term impacts.
  - SWAT explicitly incorporates elevation or orographic effects on precipitation and temperature.
  - It is a continuous time or long term yield model able to simulate long term impacts of land use, land management practices and build-up of pollutants.
  - SWAT has daily data weather simulation model that generates for rainfall, solar radiation, relative humidity, wind speed and temperature from the average monthly variables for the data provides a useful tool to fill in gaps in daily data in the observed records.
  - SWAT is designed to use either observed meteorological data or statistically generated meteorology, facilitating the development of long term analysis.
  - SWAT was developed for and has been widely applied to simulation of watersheds in arid regions.
  - SWAT explicitly incorporates routines for agricultural diversions and irrigation.
  - The other advantage of the SWAT model is the ability to build different scenarios.
  - SWAT includes routines designed to address the impacts on flow and pollutant loading of multiple small (or large) farm ponds within a basin.

3.5. SWAT-CUP

SWAT-CUP is an interface that was developed for SWAT. SWAT-CUP is designed to integrate various sensitivity analysis, calibration, validation and uncertainty programs for SWAT using different interface. The main function of an interface is to provide a link between the input/output of a calibration program and the model.Using this generic interface; any calibration, validation/uncertainty or sensitivity program can easily be linked to SWAT.

The recently developed SWAT-CUP interfaced program for calibration and uncertainty analysis procedures [15] also made the SWAT model more attractive for this study. SWAT-CUP is linked to five different algorithms such as: Sequential Uncertainty FItting (SUFI-2)[15] Generalized Likelihood Uncertainty Estimation (GLUE) [16], Parameter Solution (ParaSol) [17], Particle swarm optimization (PSO) [18], and Markov Chain Monte Carlo (MCMC) [19], procedures to SWAT.

- SUFI2 [15]: Sequential Uncertainty Fitting Ver. 2, the parameter uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data.
- GLUE [16]: Generalized Likelihood Uncertainty Estimation is based on the estimation of the weights or probabilities associated with different parameter sets, based on the use of a subjective likelihood measure to derive a posterior probability function, which is subsequently used to derive the predictive probability of the output variables.
- Parasol [17]: Parameter Solution method aggregates objective functions into a global optimization criterion and then minimizes these objective functions or a global optimization criterion using the SCE-UA (Shuffled Complex Evolutionalgorithm, which is a global search algorism for minimization of a single function, were utilized in the calibration process.
- MCMC: Markov Chain Monte Carlo generates samples from a random walk which adapts to the posterior distribution [19]. This simple technique from this class is the Metropolis Hasting algorithm [20].

Various SWAT parameters for estimation discharge were estimated using the SUFI-2 program [15]. In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data. Uncertainty is defined as discrepancy between observed and simulated variables in SUFI-2 where it is counted by variation between them.

The SUFI-2 was the most suitable way to find the SWAT Uncertainty under the condition that the parameter range. The Goodness of fit in SUFI-2 is expressed by the 95PPU band, it cannot be compared with observation signals using the traditional indices such as R^2, Nash-Sutcliffe (NS). For this reason two measures referred to as the P-factor and the R-factor [15], the P-factor is the percentage of the measured data bracketed by the 95PPU. The R-factor, on the other hand, is a measure of the quality of calibration and indicates the thickness of the 95PPU.As all forms of uncertainties are reflected in the measurements (e.g., discharge), the parameter uncertainties generating the 95PPUaccount for all uncertainties.

3.6. *Sensitivity analysis*

Sensitivity analysis determines the sensitivity of the input parameters by comparing the output variance due to the input variability. The sensitivity analysis was carried out to identify the sensitive parameters of the SWAT model. The sensitivity analysis is done by varying parameters value and checking how the model reacts. If small change on a given parameter value results on a remarkable change on the model output, the parameter is said to be sensitive to the model.

3.7. Model calibration and validation

In hydrologic simulation there are two main exercises that must be successfully achieved before using a model. These are calibration and validation of the models.

3.7.1. Calibration

Calibration is an intensive exercise used to establish the most suitable parameter in modeling studies and an iterative process that compares simulated and observed data of interest (typically streamflow data) through parameter evaluation. The exercise is vital because reliable values for some parameters can only be found by calibration [21].

3.7.2. Validation

Model validation is the process of representing that a given site specific model is capable of making sufficiently accurate simulation. The degree of accuracy of parameter estimates was assessed by applying the model to different data set that was not used for calibration. This implies the application of the model without changing the parameter values that were set during calibration [22].The model is validated if its accuracy and predictive capability in the validation period have been proven to lie within acceptable limits [22].

3.8. Assessment of model performance

The performance of SWAT is evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values.During calibration and validation of a hydrological model it is necessary to assess the performance of the model. This is done by statistically comparing the model output and observed values using various statistical measures. These measures include the coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NS). The range of values for R^2 is 1.0 (best) to 0.0(poor). The R^2 coefficient measures the fraction of the variation in the measured data that is replicated in the simulated model results. Nash-Sutcliffe simulation efficiency (NS) indicates the degree of fitness of the observed and simulated plots with the 1:1 line. The statistical index of modelling Nash-Sutcliffe Efficiency (NS) values range from 1.0(best) to negative infinity. NS is a strictertest of performance than R^2 and is never larger than R^2.

4. RESULTS AND DISCUSSIONS

4.1. Evaluation of sediment yield due to land use/ land cover changes to hydropower reservoir

Evaluation of the impacts of LULCC on sediment yield was one of the most significant parts of this study. The major land use changes that affect stream flow and sediment yield in this study catchments were changes to farmland, grassland and other Agriculture land use types. One of the most important things of the study was to evaluate the impacts of LULCCs on sediment yield to hydropower reservoir. The evaluation was done in terms of the impacts of LULCCs on the variation of LULC types and the variations caused depending on the LULC types on the major components of sediment yield including surface runoff and groundwater flow.

To assess the changes in the contribution of the components of the stream flow due to the LULCC, analysis were made on the surface runoff and sediment yield, ground water flow. The surface runoff and sediment yield has increased and the ground water flow has decreased during the expansion of agricultural land over the forest, the surface runoff and sediment yield decreased and the ground water flow has increased during the expansion of forests. Conversion to Agriculture has the largest impact on the yearly surface run off and sediment yield while has the smallest. The expansion of agricultural land use type results the increasing of sediment yield and reduction of water infiltrating in to the ground. Generally, the Hydrological investigation with respect to the LULCCs within Finchaa watershed showed that the flow characteristics/ water balance components have changed through different LULCCs of the study.

4.2. Sediment yield calibration and validation

Initially one year data was taken as the warming period and the rest of the period was used for the model calibration.The coefficient of determination R^2 and the Nash- Sutcliffe equation has been applied for model testing between simulated and observed flows and calculated on monthly basis was 0.74 and 0.70 respectively. The amount to which all uncertainties are accounted for is quantified by a measure of the P-factor, which is known as the percentage of measured data bracketed by the 95% prediction uncertainty. Validation proves the performance of the model for simulated flows in periods different from the calibration periods, but without any further adjustment in the calibrated parameters.The correlation coefficient ($R^2 = 0.76$) and the Nash-Sutcliffe (NS=0.74) shows a good agreement between the observed and simulated values.

Table 1. Percent changes in annual average water balance components for the Finchaa watershed land use/ land cover change scenarios.

	Conversion to agriculture	Conversion to forest
Sur_Q (mm)	0.664	-15.979
Lat_Q (mm)	-26.265	-25.369
Gw (shalAq)_Q (mm)	0.973	5.412
Gw (Deep Aq)_Q (mm)	0.976	5.418
Total WYLD (mm)	-0.036	-0.160
Perc (mm)	0.977	5.389
Total SEDYLD (T/Ha)	0.949	-16.207

4.3.Adaptation options to mitigate the adverse impacts of the land use/ land cover changes on the reservoir

The adaptation of LULC patterns are an essential aspect of minimizing the expected impact of LULCCs at the regional and local scales. LULCC can play an important role in reducing the amount of sediment yield to the reservoir through LULC and forestry activities that can occur through avoiding deforestation. Improved management of grassland over the agricultural land use type was also one type of mitigation measure to improve the LULCC. The adaptation of watershed land use patterns used to mitigate the impact of LULCC on the region's hydrology.

The LULC based mitigation measures include afforestation of the areas. The afforestation/ reforestation has a function to reduce over land flow and rainfall erosivity. Appropriate soil conservation measures based on suitable afforestation techniques can be highly influential in risk mitigation of soil erosion. Therefore, the adaptation options to be taken to mitigate the adverse impacts of the LULCCs on reservoir would be, if possible to cover the land use type byforest or increase the forest type or grass land type of the watershed area in order to decrease the amount of sediment yield to the reservoir. figure 2 and 3 shows the afforestation areas have reduced the intensity of soil loss rate in the Finchaa watershed by reducing the amount of sediment yield generated and the annual surface runoff to the reservoir.

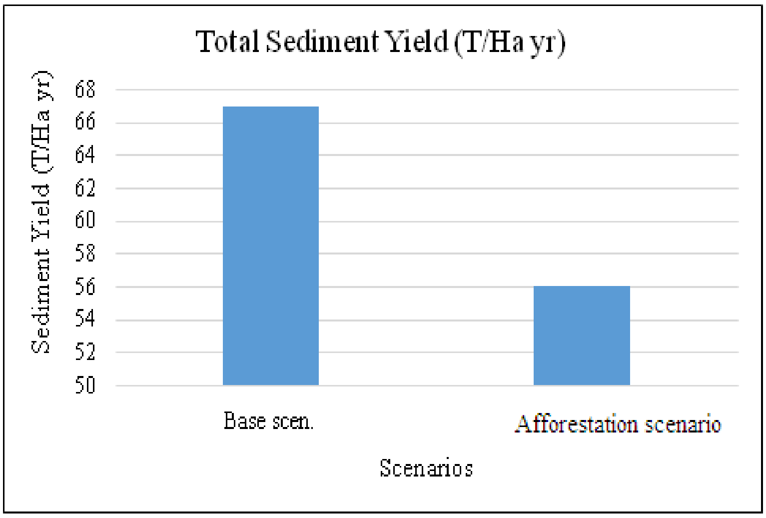

Figure 2.Sediment yield of the watershed before and after applying the mitigation measures.

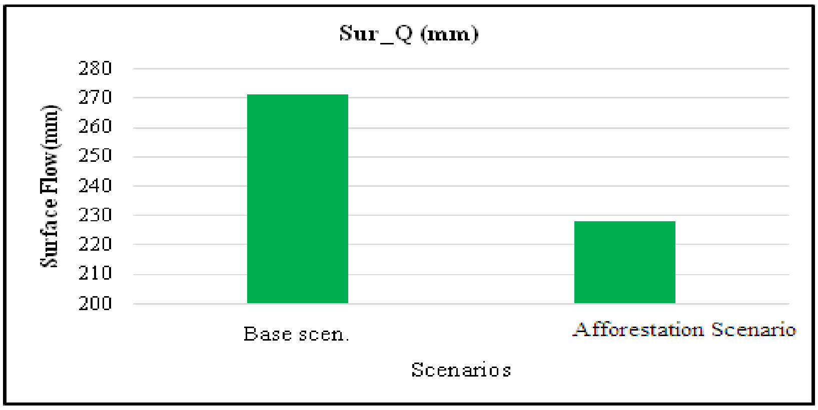

Figure 3. Surface flow of the watershed before and after applying the mitigation measures.

5. CONCLUSIONS

Land use/ land cover change in Finchaa watershed should be controlled to reduce deforestation, which increases the frequencies and concentrations of sediment in the reservoir. Re- afforestation must be introduced within the catchment area of Finchaa watershed which tends to increase filtration of rainfall water and reduce surface runoff which subsequently reduces erosion within the catchment. In addition, solutions to the problems of LULCC should include improving the productivity of the agricultural sector through technical intervention.Reservoir sediment management, especially in sediment rich areas of Ethiopia and other countries around the world is becoming more and more a major problem for the hydro projects.

In this study SUFI-2 was used for model calibration and validation, it could perform uncertainty analysis and calibrate the model for more number of parameters. The model simulations considered only LULCC scenarios assuming one variable at a time and keeping other values unchanged. To analyze the impacts of LULCC on sediment yield to hydropower reservoir sedimentation some changes of land use land cover/options were developed. The options were developed simply to show the potential change of stream flow and sediment yield from the corresponding land use/ land cover change to the hydropower reservoir. The LULCC scenarios developed shows in LULC variables are likely to have significant impacts on the flow volume into reservoirs and the hydrological components were changed. Therefore, decision makers and all concerned stakeholders should plan and implement an integrated watershed development program in advance to alleviate the problem.

REFERENCES

[1] Brandon, R. (1998). Mapping Ruaral Land Use and Land Cover Change in Carroll Country, Arkansas: Utilizing Multi- Tempora Landsat Thematic Mapper Satellite Imagery. UniversitynOf Arkansas.
[2] Calder, I. R. (1992). Hydrologic effects of land use change, Ed. in Chief D. R. Maidment. Handbook of Hydrology. 13.1-13.50.
[3] Sidle, R. C., Ziegler, A. D., and Negishi, J. N. (2006). Erosion processes in steep terrain- truths, myths and uncertainties related to forest management in southeast Asia. Forest Ecology and Management 224(1-2). 199 - 225.
[4] Bakker, M., Govers, G., Van Doorn, A., Quetier, F., Chouvardas, D., and Rounsevell, M. (2008). The response of soil erosion and sediment export to land-use change in four areas of a Europe: the importance of landscape pattern. Geomorphology 98. 213 - 226.
[5] Tamene, L., Park, S., Dikau, R., and Vlek, P. (2005). Analysis of factors determining sediment yield variability in the highlands of Northern Ethiopia. Geomorphology, 76. 76-91.
[6] Arnold, J. G., Allen, P. M., and Bernhardt, G. (1993). A comprehensive surface - groundwater flow model. Journal of Hydrology 142, 47 - 69.
[7] Jha, M. K., Gassman, P. W., and Arnold, J. G. (2007). Water quality modelling for the raccoon river watershed using SWAT. American Society of Agricultural and Biological Engineers, 50. 479 - 493.
[8] Tripathi, M. P., Panda, R. K., and S., R. N. (2003). Identification and prioritization of critical sub-watersheds for soil conservation management using SWAT model. Bio systems Engineering, Vol.85.
[9] Tibebe, D., and Bewket, W. (2010). Surface rRunoff and Soil Erosin Estimation Using the SWAT Model in the Keeta Watershed, Ethiopia. Land Degradation and Developement.
[10] Borah, D. K., and Bera., M. (2003). Watershed-scale hydrologic and nonpoint-source pollution models: Review of mathematical bases. Trans. ASAE 46(6). 1553-1566.
[11] Bicknell, B. R., Imhoff, J. C., Donigian, A. S., and Johanson., R. C. (1997). Hydrological simulation program - FORTRAN (HSPF): User's manual for release 11. EPA-600/R-97/080. Athens, Ga.: U.S. Environmental Protection Agency.
[12] Saleh, A., and Du., B. (2004). Evaluation of SWAT and HSPF within BASINS program for the upper North Bosque River watershed in central Texas. Trans. ASAE 47(4). 1039-1049.
[13] El-Nasr, Arnold, A. J., Feyen, J., and Berlamont., J. (2005). Modelling the hydrology of a catchment using a distributed and a semi-distributed model. Hydrol. Process. 19(3), 573-587.
[14] Srinivasan, M. S., Gerard-Marchant, P., Veith, T. L., Gburek, W. J., and Steenhuis., T. S. (2005). Watershed scale modeling of critical source areas of runoff generation and phosphorus transport. J. Am. Water Resour. Assoc. 41, 361-375.
[15] Abbaspour, K., M.Vejdani, and Haghighat, S. (2007). SWAT-CUP calibration and uncertainty programs for SWAT. In proc. Int. Congress on Modelling and Simulation (MODSIM'07). 1603 -1609.
[16] Beven, K., and Binley, A. (1992). The Future of Distributed Model-Model Calibration and Uncertainty Prediction. Hydrological Processes, 6(3), 279 - 298.
[17] Van Griensven, A., and Meixner, T. (2006). Methods to quantify and identify the sources of uncertainty for river basin water quality models. Water science and Technology, 53(1), 51 - 59.
[18] Eberhart, R., and Kennedy, J. (1995). A new optimizer using particle swarm theory. Proceedings of the sixth International symposium on Micro Machine and Human Science, Nagoya, Japan, 39 - 43. Piscataway, NJ: IEEE Service Center.
[19] Kuczera, G., and Parent, E. (1998). Monte Carlo assessment of parameter uncertainty in conceptual catchment models: the Metropolis algorithm. Journal of Hydrology 211(1-4), 69 - 85.
[20] Gelman, S., Carlin, J. B., Stren, H. S., and Rubin, D. B. (1995). Bayesian Data Analysis, Chapman and Hall, New York, USA.

[21] Beven, K. J. (1989). Changing ideas in Hydrology. The Case of Physically - Based Models. Journal of Hydrology 105: 157 - 172. Catchments, Tanzania. Proceedings of the 3rd International SWAT conference, Zurich, 2005.

[22] Refsgaard, K., and Storm, B. (1996). Construction, calibration and validation of hydrological models, Distributed Hydrological Modelling(eds. M. B. Abott and J. C. Refsgaard), Kluwer Academic Publishers.

[23] Ankit Chakravarti, Nitin Joshi and Himanshu Panjiar (2015) Rainfall runoff modeling using artificial neural networks. Indian Journal of Science and Technology, Vol. 8(14), pp 1-7, ISSN – 0974-5645.

[24] Ankit Chakravarti and M. K. Jain (2014) Experimental investigation and modeling of rainfall runoff process. Indian Journal of Science and Technology,Vol. 7(12), pp 2096-2106, ISSN – 0974-5645.