JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

ASSESSMENT OF PHOSPHORUS TRANSPORT PATHWAYS AND LOADING IN GILGEL GIBE-I CATCHMENT USING SWAT MODEL

A THESIS SUBMITTED TO ENVIRONMENTAL ENGINEERING CHAIR, CIVIL AND ENVIRONMENTAL ENGINEERING SCHOOL,JIMMA INSTITUTE OF TECHNOLOGY, JIMMA UNIVERSITY FOR PARTIAL FULFILLMENT OF MASTERS DEGREE IN ENVIRONMENTAL ENGINEERING (MSc)

BY

BELACHEW HIRPA LEMMA (BSc)

MARCH,2016
JIMMA, ETHIOPIA

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ABSTRACT

Eutrophication is a trouble that alter the ecological integrity of any water resources at global, regional and local scale including Ethiopia resulted by P that exported and loaded from agricultural-based catchment. Gilgel Gibe I watershed is agriculture –based catchment found in the south-western part of Ethiopia, in Oromia Regional State. This catchment is exhibited to this problem as a result of agricultural intensification with P concentration beyond the limit (0.86 mg/l).Therefore, the objectives of this study were to assess the transport pathways, quantify the amount of P load and to identify the prone sub-basins that were responsible for a significant P load utilizing SWAT model on this study area. To achieve this, a longitudinal desk study design was followed after all necessary input data was collected, analyzed and prepared.

The GIS- Arc SWAT interface was applied to distinguish and classify the land use, soil and slope of the area and found the LU as Generic (AGLI) (Agriculture, Agro-silvi-cultural, Agro-pastoral) 91.46%,Forest Evergreen (FRSE) (Silvi-culture) 2.69%,Forest Mixed (FRST) (Forest with coffee under and coffee under tree),2.89%,Pasture (PAST) (Grass land), 2.75%,Urban (URBN) (Residential) 0.21% and dominant soil as Eutric Nitosols (Ne13-3b) 65%, Eutric Vertisols (Ne12-2c) 35%.Further the model performance was evaluated and found the model was satisfactory to be applied over the area for water resources management for sustainable social and economic development. Following this, the pathways of P was assessed and found that the organic form of (Org P) was the dominant exportation mechanism and accounts around 77.2% of paths. Similarly, the maximum total P load was also investigated and found as 4.4×10^{5}tons/year on 2009 and corresponding minimum total load was around 5.7×10^{4} tons /year and holds 4.4% load on 2007.The prone sub-basins which were significantly responsible for high P load wereidentified.Lastly, conclusions and recommendations would be offered based on study findings.

Key Word:*Watershed;SWAT model; Non-point source pollutant; Phosphorus transport*

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ACRONOMY

Sed P:	Sediment attached Phosphorus
Org P:	Organic form of Phosphorus
Sol P:	Soluble form of phosphorus
HYPE:	Hydrological Predictions for the Environment
Hec-HMS:	The Hydrologic Modeling System
PRMS:	Precipitation Runoff Modeling System
Wet Spa:	Water and Energy Transfer between Soil, Plants and Atmosphere
SUFI2:	Sequential Uncertainty Fitting
PSO:	Particle Swarm Optimizations
GLUE:	Generalized Likely hood Uncertainty Estimation
PARASOL:	Parameters Solutions
LH-OAT:	Latin Hypercube
GLEAMS:	Groundwater Loading Effects of Agricultural Management Systems
SPARROW:	Spatially-Referenced Regression on Watershed
EFDC:	Environmental Fluid Dynamics Code
SWMM:	Storm Water Management Model
WISE:	Watershed Information System
WMS:	Watershed Modeling System
WEPP:	Water Erosion Prediction Project

CHAPTER 1: INTRODUCTION

1.1. Background

Flooding, upland soil and stream bed and bank erosion, sedimentation and contamination of water from agricultural chemicals are critical water resources, environmental, social and economic problems throughout the world. Understanding and evaluating the natural processing a watershedlevel leads to impairment and problems are continued challenges for scientist and engineers.Watershed models simulating hydrology, upland soil and stream erosion, transport and deposition of a sediment and mixing and transport of chemicals with water and sediment process are comprehensive analytical to understand some of water resources and environmental problems and to find solution through land use changes and best management practices (BMPs)(Borah et al., 2006; Vijay and Singh, 2006).

These models are also called a non-point sources pollution models because they simulate surface water pollutants, including sediment,nutrient, pesticides and other chemicals originating from the non-point.Also they can assist in development of Total Maximum Daily Load (TMDL) estimations required by Clean Water Act of U.S in evaluation and selection of alternative land use and BMPs scenarios, the implementation of which can help to meet the water quality standard and reducing damaging effect of storm water runoff on water bodies and land scape.The TMDL is the maximum amount of pollutant from point and non-point sources that a water bodies can receive and still meet specific water quality standards. Computer model scan simulate multiple watershed management scenarios that can help environmental policy managers make decisions that could ultimately reduce P and N loss from agricultural lands. In addition, they are inexpensive tools that can identify optimum watershed management practice scenarios for pollutant transport reduction (Singh and Woolhiser, 2002).

Modeling of NPS pollutant provide the diagnostic and predictive outputs that can be combined with socio-economic data for assessing local, regional, and global environmental risk or natural resource management issues. Therefore, modeling is increasingly being used to support decisions about alternative water management policies in the areas of land use change, climate change, water re-arrangement, and pollution control so that here SWAT was considered from existing hydrological models to assess the P load to the water resource of the study area (Vijay and Singh, 2006).

The Soil and Water Assessment Tool (SWAT) model was developed by the U.S Department of Agriculture Agricultural Research Service (USDA-ARS). It is a theoretical model that functions on a continuous time step. Model components include weather, hydrology, erosion and sedimentation, plant growth, nutrients, pesticides, agricultural management; channel routing,pond and reservoir routing. Agricultural components in the model include crop cycles from planting to harvesting, fertilization, tillage options, and animal production and have the capability to include point source loads.All model calculations are performed on a daily time step. The SWAT model predicts the influence of land-management practices on constituent yields from a watershed. It is the continuation of over 30 years of model development within the USDA-ARS (Liu and Weller, 2008; Neitsch et al., 2000).

Soil phosphorus (P) is simulated in the SWAT model and is partitioned into six P pools, Three of the pools are characterized as mineral P, and three are characterized as organic P, Crop residue and microbial biomass contribute to the fresh organic P pool, and humic substances contribute to the active and stable organic P pools. Soil inorganic P is divided into solution, active, and stable pools. The SWAT model simulates movement between P pools, such as mineralization, decomposition and immobilization. All soil P processes are simulated in the SWAT model using relationships described in the model's theoretical documentation (Liu and Weller, 2008).

1.2. Problem Statement

Gilgel Gibe-I watershed is situated in the south-western part of Ethiopia, in State of Oromia. The catchment area is about 5,125 km^2 at its confluence with the great Gibe River and about 4149.5 km^2 at the dam site. It is the major sources of water inflow for main Gibe River that recharges Gilgel Gibe-I dam reservoir project which has a live storage capacity of 657 Mm$^{3.}$ But the water quality of this reservoir is threatened by the nutrient export and subsequent enrichment from the upstream of the Gilgel Gibe basin, which leads the reservoir to be eutrophied.

Hence, Eutrophication results, increases in phytoplankton, rapid growth of primary production species, total depletion of dissolved oxygen and alteration of the ecological integrity of water resources. Previous studies indicate that there is a rapid loss of reservoir water quality due to excessive nutrient export and subsequent enrichment in Gilgel Gibe-1 dam reservoir (Beyene et al., 2015; Oberholster and Ashton, 2008).

From water samples analysis done for Gilgel Gibe-I dam reservoir, the concentrations of ammonia, chlorophyll a, total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), pH and temperature were found within the permissible limits as prescribed by WHO standards, but other parameters like phosphate, nitrate, sulphate, total solids (TS), total suspended solids (TSS) and visibility were much higher than the permissible limits.From the study, they found that nutrient enrichment were the major problems in this reservoir, as a cross sectional study and assessment of the nutrient enrichment level done for the reservoir by (Rani Devi and Dahiya, 2008).

In addition to Gilgel Gibe-I hydropower plant, the power generation of the Cascade hydropower plant to Gilgel Gibe-I, namely Gilgel Gibe-II which has an installed capacity of 420 MW and uses the water released from the same reservoir, will significantly be affected.Currently, the government of Ethiopia is constructing a huge hydropower plant, Gilgel Gibe-III, downstream of Gilgel Gibe-I and II. The Gilgel Gibe-III dam and powerhouse are being built approximately 155 km downstream of the Gilgel Gibe-II plant. Up on its completion Gilgel Gibe-III will have an installed capacity of 1,870 MW. There is also a plan to construct Gilgel Gibe-IV which will be the farthest downstream in the cascade. Although the Government of Ethiopia is putting an effort to construct large hydropower plants to supply the energy demand of the country, the rapid loss of water quality due to nutrient enrichment later on results is major problem of Eutrophication in all reservoirs.

1.3. Main Objective

- To assess the phosphorus transport pathways and loadings in the Gilgel Gibe-I catchment using SWAT model.

1.4. Specific Objectives

- To test the performance efficiency of the model.
- To discover the dominant P transport pathways.
- To quantify the amount P load to the nearby water resources.
- To identify the prone sub-basins for high P load.

1.5. Study Questions

The main study questions that were centered to be answered were the following:

1. What is the forecasting efficiency of the model?
2. Through which route P was dominantly transported?
3. How much P was loaded to the water resources in the study period?
4. Which areas were significantly responsible for higher P load?

1.6. Justifications of the Study

As the world population continues to grow, mankind faced with the onerous task of meeting the world's food demand. This only can be accomplished with sustainable agriculture. A sustainable agriculture requires a delicate balance between crop production, natural resources uses, environmental impacts, and economics. The goal of sustainable agriculture is to optimize food production while maintaining economic stability, minimizing the use of finite natural resources, and minimizing impacts upon environment. Still an agricultural activity remains as a single greatest contributor of NPS pollutants to soil and water resources (Humenik et al., 1987; Kavlock et al., 1994).

Assessing the environmental impact of non-point source pollutant at a global, regional and localized scale is a key component to achieving sustainable agriculture. Assessment involves determination of changes of some constituents over time.This change can be measured in real time or predicted with a model. Real time Measurement reflect the activities of the past, whereas, model prediction are glimpses into the feature based upon the simplified set of assumptions.

However, the advantage of prediction is that it can be used to alter the occurrences of detrimental conditions before they develop. Predictive models provide the ability to get answers to what if questions. Due to expense and intensiveness of long-term field study to quantify NPS pollutants, computer model simulations are increasingly more appealing. Forecasting information from model simulation is used in decision making strategies designed to sustain agriculture. This information permits an alteration in management strategy prior to development of conditions which is detrimentally impact either the agricultural productivity of the soil or quality of ground water. This ability optimizes the use of environment by sustaining its utility without detrimental consequences while preserving the esthetic qualities.

1.7. Scope of the Study

Geographically, the study was bounded to Gilgel Gibe I Catchment situated in the south-western part of Ethiopia, in Oromia Regional State. Objectively, the principal focus of the study was limited to assessing the P transport pathways and loading under the pre-defined time frames, budgetary and study design.

1.8. Significance of the study

Assessing the environmental impact of NPS pollutant at a global, regional and localized scale is a key component to achieving sustainable agriculture. Assessment involves determination of changes of some constituents over time.This change can be measured in real time or predicted with a model. Real time Measurement reflect the activities of the past, whereas, model prediction are glimpses into the feature based upon the simplified set of assumptions. Therefore, the key importance of this study is to recommend the applicability of the model for prediction of P load after testing the model forecasting efficiency over the study area. Additionally, to propose possible mitigation measures that should have to apply to control P load that loaded via major paths after the main route identification. Finally, to hypothesize the appropriate means of watershed management for all stakeholders to monitor the corresponding water resources effectively.

1.9. Limitation of the Study

The main challenges encountered in this study were lack of full, free, consistent, appropriate, up-to-date gauged and recorded both spatial, temporal discharge data within scheduled study period. This makes the study time to be lost on finding those data, to limit number of gauging stations, leaving P calibration which had its own impact on model prediction efficiency. Furthermore, lack of previous research and software experience put its own restriction on the study.

1.10. Structureof Thesis

This dissertation was categorized into 5 chapters. Chapter 1 focuses on the background of the study problem from global to local scenarios, statement of the problem, objectives of the study, study questions, justifications of the study, significance of the study, scope of the study and corresponding limitations. Chapter 2 was deal with a theoretical review, conceptual framework, and previous investigations, in line with pre-stated problems. Chapter 3 would address the methods followed and the materials used to finalize the paper. Chapter 4covers the findings of the study and corresponding interpretations. The last chapter, Chapter 5 points out the main conclusion that would be drawn from the study findings and corresponding recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction to P Modeling

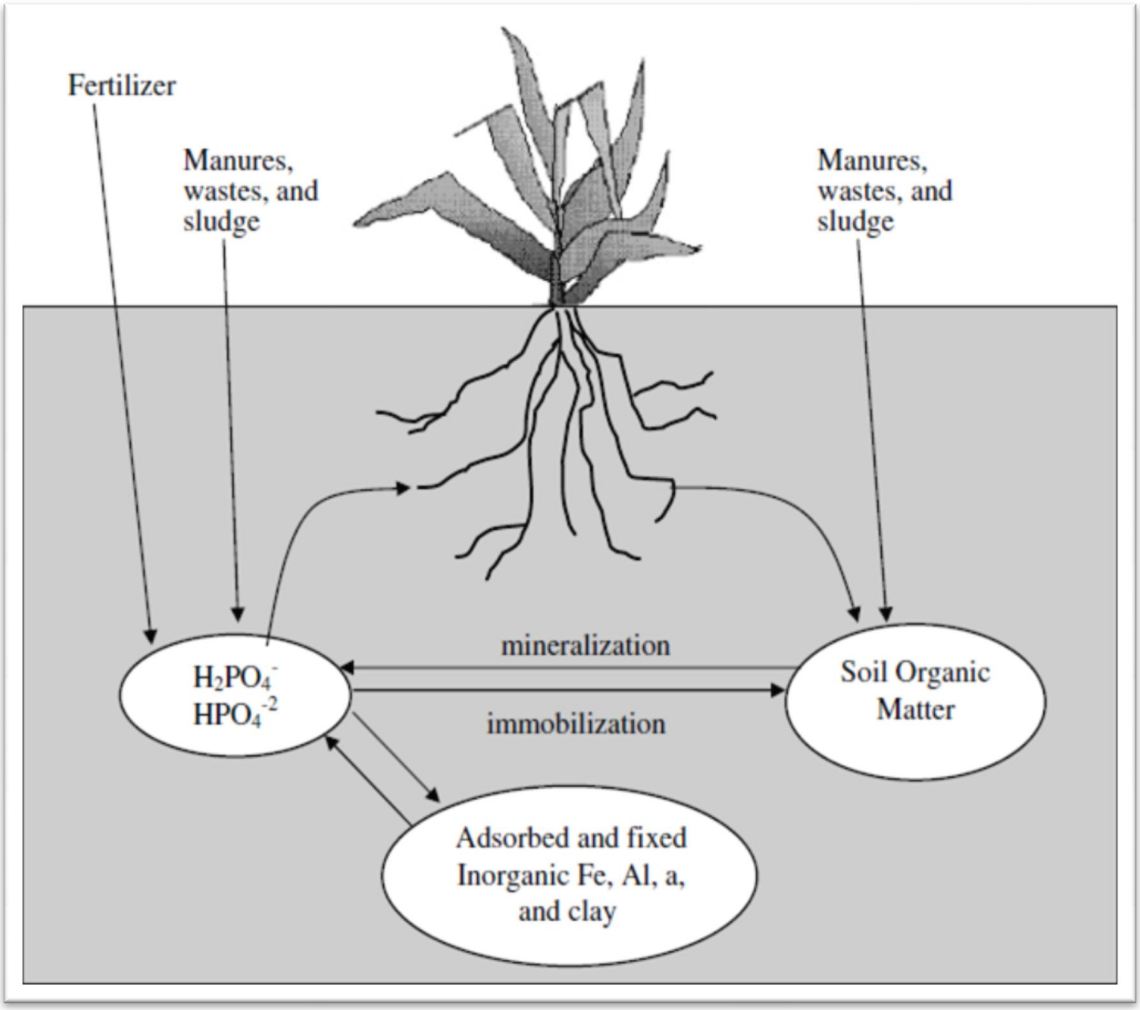
Global advances in economies and standards of living have resulted in a growing dependency on water resources. Many societies have experienced water shortage and quality degradation as a result of population growth, increased urbanization and industrialization, increased energy use, increased irrigation, desertification, global warming lead to Eutrophication of the water resources (Singh and Woolhiser, 2002).

Eutrophication is the excessive amount of nutrients mainly nitrogen (N) and phosphorus, (P) in a water body. Phosphorus and nitrogen in water resources are the determining nutrient for Eutrophication. According to the Redfield ratio it is in certain occasions defined as the ratio of the (N) to the (P) in the water body (N:P) and consequently, if it is greater than (16:1) the P would be the limiting factor, while a lower value implies that N is of great importance. However, in fresh water ecosystems, phosphorus is important because of shortest supply and often manages the rate of Eutrophication and so that modeling P in environment is necessary to assess the long time impacts on water resources.

2.2. Phosphorus Modeling Using SWAT

2.2.1. Soil Phosphorus Interactions

Phosphorus can be added to the soil matrix in the form of inorganic P fertilizer, organic P fertilizer, and as plant residue. Soil P is divided into six pools. Three of the pools are characterized as mineral P, and three are characterized as organic P as indicated in the Figure (2). Crop residue and microbial biomass contribute to the fresh organic P pool, and humic substances contribute to the active and stable organic P pools. Soil inorganic P is divided into solution, active, and stable pools. It is clear that solution P is actually labile P in conformance with the original EPIC version. Labile P is the P extracted by an anion exchange resin and therefore represents solution P plus weakly sorbed P. Transformations of soil P among these six pools are regulated by algorithms that represent mineralization, decomposition, and immobilization. The solution (labile) pool is considered to be in rapid equilibrium (days to weeks) with active pools that subsequently are considered to be in slow equilibrium with stable pools (Shapley et al., 1984; Jones et al., 1984; Neitsch et al., 2009).

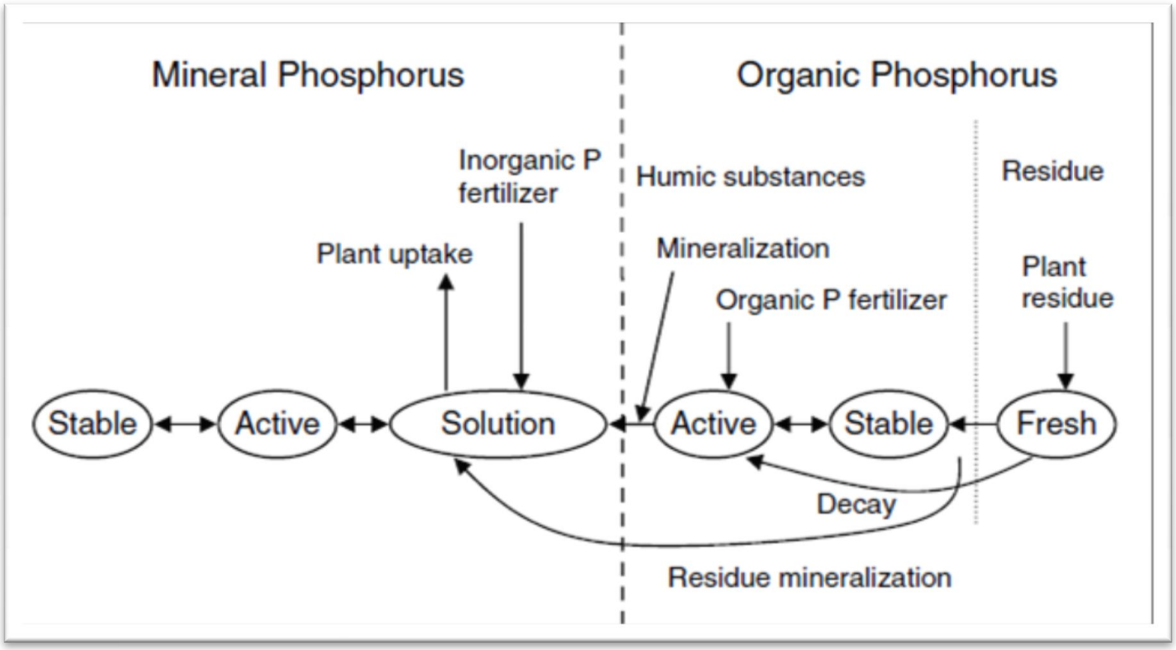


(Neitsch et al., 2009)

Figure 1: Phosphorus cycle process using SWAT model

2.2.2. Phosphorus Initiation in Soil

Initial amounts of soluble (labile) and organic P contained in humic substances forall soil layers can be either specified by the model user or designated with SWATmodel default values. The model initially sets concentration of solution (labile) P inall layers to 5 mg P kgsoil for unmanaged land under native vegetation and 25 mgP kgsoil for cropland conditions (Neitsch et al., 2009).



(Neitsch et al. 2009)

Figure 2: Various pools of and their interactions in soil

The active mineral pool concentration (mg kg^{-1}) is initialized as depicted in Eq. (1):

$$P_{act,\min eral,pool} == Psolution\left(\frac{1-PAI}{PAI}\right) \quad (1)$$

Where $P_{solution,\min eral,pool}$: is the amount of labile P (mg P kg^{-1}) PAI: the P availability index PAI is estimated using the method outlined by Shapley et al., (1984).The stable mineral pool P concentration (mg P kg $^{-1}$) is initialized as described in Eq. (2):

$$P_{stable,\min eral,pool} = 4P_{Aactive,\min eral,pool} \quad (2)$$

Organic P concentration ($P_{\text{humic\_organic}}$) is calculated assuming an N to P ratio in humic substance of 8 to 1 and is calculated using Eq. (3):

$$\mathrm{P}_{\text{humic,organic}} = 0.125 * \mathrm{N}_{\text{humic,organic}} \quad (3)$$

Where, $\mathrm{P}_{\text{humic,organic}}$ is the concentration of humic organic nitrogen in the soil layer(mg kg) of soil . Phosphorus in the fresh organic pool is set to 0.03% of the initial amount of residue on the soil surface (kg ha^{-1}). The SWAT model makes all nutrient calculations on a mass basis even though all nutrient levels are input in the model as concentrations. The nutrient concentration (mg kg $^{-1}$ or ppm) is converted to mass (kg P ha^{-1}) by multiplying it by the depth of the soil layer and soil bulk density and performing appropriate unit conversions.

2.2.3. Mineralization, Decomposition and Immobilization

The P mineralization calculations also include immobilization as described by Jones et al., (1984). The fresh organic P associated with crop residue and microbial biomass and active organic P pool associated with soil humus are two P reservoirs considered by the model for mineralization. Temperature factor (γ_{temp}) and water factor (γ_{water}) are two parameters regulating the impact of temperature and water availability on P mineralization and decomposition. These factors are calculated using Eqs. (4) and (5):

$$\gamma_{\text{temp}} = 0.9\left(\frac{\text{T}_{\text{soil}}}{\text{T}_{\text{soil}} + \exp\,[9.93 - 0.312 * \text{T}_{\text{soil}}}\right) \qquad (4)$$

$$\gamma_{water} = \frac{SW}{FC} \qquad (5)$$

WhereT_{soil} the temperature of the soil layer (°C),SW water content of the soil layer (mm) and FC water content of the soil layer at field capacity (mm).Temperature of the soil layers should be above 0°C for mineralization and decomposition to occur. The minimum value of γ_{water} water allowed by the model is 0.05. The model converts P from one form to another in the way given by the Eqs. (6) and (7).

$$\text{Organic P}_{\text{active}} = \text{Organic P}_{\text{humus}}\left(\frac{\text{Organic N active}}{\text{Organic N active + Organic N stable}}\right) \qquad (6)$$

$$\text{Organic P}_{\text{stable}} = \text{Organic P}_{\text{Humus}}\left(\frac{\text{Organic N stable}}{\text{Organic N stable + Organic N active}}\right) \qquad (7)$$

Where Organic P_{active} is the amount of P in the active organic pool (kg P ha^{-1}),Organic P_{stable}stable is the amount of P in the stable organic pool (kg P ha^{-1}),Organic P $_{\text{humus}}$ is the concentration of Humic organic P in the soil layer (kg P ha^{-1}), Organic N active is the amount of nitrogen in the active organic pool (kg N ha^{-1}) andOrganic N active is the amount of nitrogen in the stable organic pool (kg N ha^{-1}). The amount of P mineralized from the humus active organic pool is calculated as Eqs (8) and added to the solution P pool in the soil layer.

$$P_{\min eral,act} = 1.4(\beta_{\min eral})(\gamma t_{emp}\gamma_{water})^{0.5}(OrganicP_{act}) \qquad (8)$$

Where $P_{mineral\_active}$ is the P mineralized from the humus active organic P pool (kg P ha $^{-1}$), and $\beta_{mineral}$ is the rate coefficient for mineralization of the humus active organic nutrients. Mineralization and decomposition from the residue fresh organic P pool is calculated employing Eqs. (9) and (10):

$$P_{\min eral} = 0.8(\delta_{ntr})\left(organicP_{fresh}\right) \tag{9}$$

$$P_{decay} = 0.2(\delta_{ntr})\left(organicP_{fresh}\right) \tag{10}$$

Where $P_{mineral}$ is the amount of P mineralized from the fresh organic P pool (kg P ha^{-1}) and added to the solution P pool, P_{decay} is the amount of P decomposed from the fresh organic pool (kg P ha^{-1}) and added to the humus organic pool, and δ_{ntr} is the residue decay rate constant δ_{ntr} is calculated using Eq. (11):

$$\delta_{ntr} = \beta_{residue}\,\gamma_{ntr}\,\sqrt{\gamma_{temp}}\,\sqrt{\gamma_{water}} \tag{11}$$

Where, $\beta_{residue}$ is the rate coefficient for mineralization of the residue fresh organic nutrients and $\gamma_{ntr}$the nutrient cycling residue composition factor for the soil layer is calculated as Eqs (12):

$$\gamma_{ntr} = \min\left\{\exp\left(-0.693\left(\frac{\varepsilon_{C:N}-25}{25}\right)\right)\text{and}\min\left\{\exp\left(-0.693\left(\frac{\varepsilon_{C:P}-200}{200}\right)\right)\text{or } 1 \right.\right. \tag{12}$$

Where, $\varepsilon_{C:N}$is the C: N; ratio on the residue in the soil layer and $\varepsilon_{C;P}$; is the C: P ratio on the residue in the soil layer. The C: N; ratio of the residue is calculated as Eqs (13):

$$\varepsilon_{C:N} = {0.58rsd}\big/{organicNfresh + No3} \tag{13}$$

Where, rsd;is the amount of residue in the soil layer (kg ha^{-1}), 0.58 is the fraction of residue that is carbon, and NO_3;is the amount of nitrate in the soil layer (kg N ha^{-1}). The C: P; ratio is calculated as Eqs (14):

$$\varepsilon_{C:P} = \left(\frac{0.58rsd}{orgP_{fresh}+P_{sol}}\right) \tag{14}$$

2.2.4. Inorganic Phosphorus Sorption

The inorganic P pool, originating either from mineralization of organic P or P applied directly as inorganic fertilizer, is simulated considering plant uptake and conversion to active and stable forms of inorganic P. The movement of P between the solution (labile) and active mineral pools are estimated using Eqs (15-18)(Neitsch et al., 2009).

$$p_{sol/act} = P_{sol} \text{ - } \min eral\left(P_{active}\right)\frac{PAI}{1-PAI} \tag{15}$$

$$\text{IF } P_{sol} > \min eral\ P_{act}\left(\frac{PAI}{1-PAI}\right) \tag{16}$$

$$P_{sol/act} = 0.1\left(P_{sol}\right)\text{- } \min eral\left(P_{act}\right)\frac{PAI}{1-PAI} \tag{17}$$

$$\text{IF } P_{Sol} < \min eral\ \left(P_{act}\right)\left(\frac{PAI}{1-PAI}\right) \tag{18}$$

Where, P solution/active is the amount of P transferred between the soluble (labile) and active mineral pool (kg/ha), $P_{solution}$ is the amount of labile P (kg P ha^{-1}), and *PAI* is P availability index. A positive value of P solution/active indicates transfer of P from solution to the active mineral pool, and a negative value indicates that P is transferred from the active mineral pool to solution (labile) pool. Phosphorus availability index controls the equilibrium between the solution and active mineral pool and specifies what fraction of fertilizer P is in solution after the rapid reaction period.

In estimating slow sorption of P (where sorbed P is the stable pool), SWAT assumes that the stable mineral pool is four times the size of the active mineral pool. The movement of P between the active and stable pools is calculated using the Eqs (19-22)(Neitsch et al., 2009).

$$P_{act/stable} = \left(\beta_{eqp}\right)\left(4\min eral\right)\left(P_{act}\right)-\left(\min eral\right)\left(P_{stable}\right) \tag{19}$$

$$\text{IF } \min eral\left(P_{stable}\right) < \left(4\min eral\right)\left(P_{act}\right) \tag{20}$$

$$P_{act/stable} = \left(0.1\beta_{eqp}\right)\left(4\min eral\right)\left(P_{act}\right)-\left(\min eral\right)\left(P_{stable}\right) \tag{21}$$

$$\text{If } \min eral\left(P_{stable}\right) > \left(4\min eral\right)\left(P_{act}\right) \tag{22}$$

Where, $P_{active/stable}$ is the amount of P transferred between the active and stable mineral pools (kg P ha^{-1}), and β_{EQp} is the slow equilibrium rate constant (0.0006 d^{-1}). A positive value of $P_{active/stable}$ indicates transfer of P from the active mineral pool to the stable mineral pool, and a negative value indicates transfer of P from the stable mineral pool to the active mineral pool.

2.2.5. Phosphorus Leaching

When plants take up P from the root zone in the soil solution, it creates a concentration gradient in the soil-solution matrix. SWAT considers diffusion the migration of P ions over small distances (1 to 2 mm) in the soil solution in response to a concentration gradient to be the primary mechanism of P movement in the soil. Soluble P is simulated by the SWAT model to leach only from the top 10 mm of soil into the first soil layer. The mass of solution P leaching into the first soil layer is calculatedas Eqs (23):

$$P_{perc} = \frac{P_{sol,surf}\left(w_{perc,surf}\right)}{10_{\rho_b}\left(Depth_{surf}\right)\left(k_{d,perc}\right)} \tag{23}$$

Where, P_{perc} is the amount of P moving from the top 10 mm into the first soil layer (kg P ha^{-1}), $P_{Solution,surf}$ is the amount of labile P in the top 10 mm (kg P ha^{-1}),$w_{perc,surf}$ is the amount of water percolating to the first soil layer from the top 10 mm on a given day (mm),ρ_b is the soil bulk density of the top 10 mm (mg m^{-3}), $Depth_{surf}$ is the depth of the surface layer, and $k_{d,perc}$is the P percolation coefficient. The $k_{d,perc}$ is calculated as the ratio of the labile P concentration in the surface 10 mm of soil to the concentration of P in percolate.

2.2.6. Phosphorus in the Form of Fertilizer

SWAT provides the user with the option to incorporate both inorganic and organic fertilizer application to the land-management file. The amount and type of fertilizer applied, timing of application and depth distribution of application are the input information needed by the model. The model user is required to define the weight fraction of different forms of nutrients in the fertilizer. To predict the interaction of fertilizer with soil and runoff, the model assumes that the effective depth of interaction of runoff with soil is top 10 mm and runoff transports nutrients that are available only in the top 10 mm of soil. The amount of fertilizer not applied in the top 10 mm of soil is added to the first soil layer (Neitsch et al., 2000).When applied fertilizer is in the form of organic manure, the model partitions the amount of P added to fresh organic and humus organic pools as Eqs (24) and (25):

$$Organi\left(P_{fresh,fert}\right)= 0.5\left(Fert_{orgP}\right)\left(Fert\right) \tag{24}$$

$$Organic\left(P_{humus,fert}\right)=\left(0.55\left(Fert_{orgP}\right)\right)\left(Fert\right) \tag{25}$$

where *organic*$\mathrm{P}_{\mathrm{Fresh,fert}}$ is the amount of P in the fresh organic pool added to the soil as a result of fertilizer application (kg P ha^{-1}), $\mathrm{Fert}_{\mathrm{Organic\ P}}$ is the fraction of organic P in fertilizer, *fert* is the amount of fertilizer applied to the soil (kg ha^{-1}) and Organic $\mathrm{P}_{\mathrm{Humus,fert}}$ is the amount of P in the humus organic pool added to the soil as a result of fertilizer application.

2.2.7. Plants Phosphorus Demand

The model calculates plant P demand (p_{Uptake} , kg ha^{-1}) using Eqs (26):

$$P_{uptake}=\left(1.5\right)\left(Biomass_{P,optimum}\right)-\left(Biomass_{P}\right) \tag{26}$$

Where; $Biomass_{p,optimum}$; is the expected amount of P content in plant biomass at a given plant stageand $Biomass_{p}$; is the actual amount of P content in plant biomass. Because of the difference in depth distribution of root density in the soil profile uptake by plants also varies with soil depth. SWAT calculates P $_{\text{uptake}}$ from different soil depths by Eqs (27):

$$P_{Uptake,z}=\frac{P_{uptake}}{1-\exp\left(-\beta_{p}\right)}\left(1-\exp\left(-\beta_{p}\frac{z}{z_{root}}\right)\right) \tag{27}$$

Where, $P_{uptake,z}$is the potential P uptake by the plant to soil depth z (kg ha^{-1}), $P_{uptake,z}$ is the potential $P_{uptake,z}$ (kg ha^{-1}), z is soil depth from the surface (mm), and β_{p} is a distribution parameter for P uptake and can be adjusted by a model user. The P_{uptake} for a soil layer is calculated as a difference between P uptake at the lower and upper boundary of that soil layer. SWAT calculates the actual amount of P removed P_{actual} using Eqs (28):

$$P_{actual} = \min\left\lfloor P_{uptake} + P_{demand} + P_{sol} \right\rfloor \quad (28)$$

Where, P_{demand} is the P_{uptake}demand not met by overlying soil layers (kg P ha^{-1}) and $P_{solution}$ is the amount of labile P present in the soil (kg P ha^{-1}). The model assumes that plant uptake of P comes from the labile P pool. If a sufficient amount of P is not available in the soil for optimum plant growth, plants may experience P stress. The P stress in plants is calculated as Eqs (29):

$$P_{stress} = 1 - \frac{\varphi_p}{\varphi + \left(\exp\left(3.535 - 0.2597\varphi_p\right)\right)} \quad (29)$$

Where, P_{stress} ; is the P stress for a given day and φ_p is a scaling factor for P stress and is calculated as Eqs (30):

$$\varphi_p = 200\left(\frac{Biomas_p}{Biomass_{p,opt}} - 0.5\right) \quad (30)$$

Where, $Biomass_p$ is the actual P content of plant biomass and $Biomass_{p,opt}$ is the optimum P content of plant biomass (kg P ha−1) (Neitsch et al., 2009).

2.2.8. Phosphorus in stream

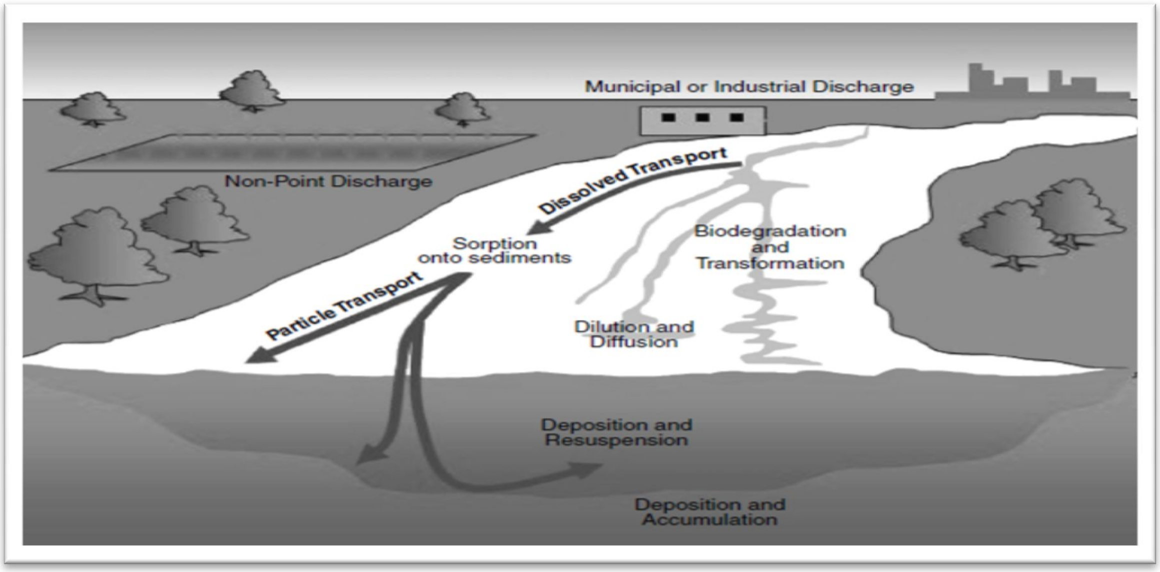
SWAT model users have an option to include or exclude in-stream processes in SWAT simulations. When the in-stream component is included, the model routes the state variables through additional algorithms that have been adapted fromQUAL2E. These QUAL2E additional algorithms are included to simulate in-stream processes otherwise not considered by SWAT. The differences between the algorithms used in SWAT and QUAL2E are predominantly related to model characteristics of being a dynamic (SWAT) or steady state model (QUAL2E). The steady-state constituent concentrations are calculated in the QUAL2E model using a mass transport equation that includes advection, dispersion, dilution, constituent reactions and interactions, and source and sink components using Eqs (31):(Brown and Barnwell, 1987).

$$\frac{dc}{dt} = d\left(\frac{A_X D_1 \frac{dc}{dt}}{dxA_x}\frac{dc}{dt}\right) + \frac{s}{v} \qquad (31)$$

Where, *C* is concentration, is the cross-sectional area, *D*L is the dispersion coefficientis mean velocity, *s* is external sources or sinks, and *v* is incremental volume. The partial derivative of *C* with respect to *t* refers to the local concentration gradient, whereas —refers to constituent changes such as growth and decay. In QUAL2E organic P is calculated using Eqs (32):

$$\frac{d}{dt}(P_1) = (\alpha)(\rho)(A) - (\beta_4 P_1 \alpha_5) \qquad (32)$$

Where, is the concentration of organic P in the water, is the P content of algae, ρ is algal respiration rate, *A* is algal biomass concentration, is the organic P decay rate, and is the organic P settling rate. The QUAL2E organic P differential equation and other QUAL2E differential equations are solved using the classical implicit backward difference method (Brown and Barnwell, 1987). These methods are appropriate for the QUAL2E steady-state model. Integration of QUAL2E equations into the SWAT model required some modification of the equations to accommodate for SWAT model daily continuous simulation.



(Neitsch et al., 2009)

Figure 3: P process in stream considered by SWAT model

The P cycle simulated in QUAL2E includes minimal sediment interactions. One sink of organic P is governed by the σ_5 parameter representing organic P settling, implying the addition of organic P to the stream bed. The additional P-sediment type of interaction in the QUAL2E model is expressed by the α_2 parameter, which describes the benthos source rate for dissolved P. These two parameters, $\alpha_2$and σ_5, are not mathematically associated with each other. No other sediment-P interactions are accounted for with the given, off-the-shelf QUAL2E model. However, there is potential for modification of the code to include sediment-P interactions such as Adsorption to sediment.

A comparison between QUAL2E and SWAT model constituent concentration equations indicated minimal differences between the two. This can be illustrated by comparing the QUAL2E model Organic P in SWAT is calculated using Eq. (33):

$$\Delta OrgP_{str} = \left(\alpha_2 \rho_a a \lg ae\right) - \beta_{p,4} orgP_{str} - \alpha_5 orgP_{str} \left(TT\right) \tag{33}$$

where $\Delta OrgP_{str}$ is the change in organic P concentration, α_2 is the fraction of algal biomass that is P, $\rho_a$is the local respiration or death rate of algae, *algae* is the algal biomass concentration at the beginning of the day, $\beta_{P,4}$is the rate constant for mineralization of organic P, $orgP_{str}$ is the organic P concentration at the beginning of the day, σ_5 is the rate coefficient for organic P settling, and *TT* is the flow travel time in the reach segment for that day (Neitsch et al., 2009). Hence, the dominant difference between the two is that the SWAT equation includes a dynamic variable *TT* for variable rates of flow travel time. The SWAT model also allows the user to adjust organic P inputs on a daily basis, which is not available in QUAL2E. This results in the $orgP_{str}$ variable being dynamic in the SWAT model instead of a steady state constraint as in QUAL2E.

2.3. Watershed Management

watershed management can be characterized as a continuous, geographically defined, integrated, collaborative process of creating and implementing plans, programs, and projects designed to sustain and enhance watershed and related eco-system functioning. Holistic watershed management should include broad stakeholder engagement to aid in defining specific watershed management goals and related actions that support attainment of those goals. Setting watershed management goals and assessing attainment of those goals must be based on the application of sound science and appropriate tools and technology (EPA, 2008).

2.3.1. Models

A watershed model simulates hydrologic processes in a more holistic approach compared to many other models which primarily focus on individual processes or multiple processes at relatively small-or field-scale without full incorporation of a watershed area. Watershed-scale modeling has emerged as an important scientific research and management tool, particularly in efforts to understand and control both point and non-point source pollutant(Golmohammadi et al., 2014; Yurekl and Kurunc, 2005).

2.3.2. Modeling Concept

Modeling approaches classified into two main types, (i) empirical (data-derived) relationships and (ii) physically-based (process-based or mechanistic) modeling. When reliable data are available covering long period of time an empirical model can be established to relate certain water quality parameters with other catchment characteristics. There is no unique empirical model that can be used absolutely to deal with problems different from the one which the model has been developed for. A variety of results can, however, be obtained from such models. The physically-based approach can be looked at as a descriptive modeling approach, which is modeling with the objective of achieving a better understanding of the physical and chemical processes involved.

2.3.3. Models Applications

Application of watershed models in hydrological studies has become an indispensible tool for understanding of the natural processes occurring at the watershed scale. Plenty of computer-based hydrologic/water quality models have been developed and available for applications in hydrologic modeling and water resources studies. They are increasingly being utilized to analyze the quantity and quality of stream flow, flood forecasting, reservoir system operations, groundwater development and protection, surface water and groundwater conjunctive use management, water distribution system, water use, climate and land use change impact study, ecology and arrangement of water management activities (Wurbs, 1998; Singh and Woolhiser, 2002).

2.3.4. Models Review

In the recent years, with the dramatic development of computational capabilities and algorithm backed with newly available distributed databases like radar rainfall, high resolution digital elevation models (DEMs), remotely sensed satellite data and space technology, mighty arsenal of available hydrological models has been reported in the published literature. These models are varied from simple empirical relationship for evaluation of flood events to simple ones containing a certain degree of physicality, to stochastic models of various kinds and finally to more recent numerically complex physically based distributed models (Gosain et al., 2009; Borah and Bera, 2003).

There is wide variability in their characteristics and potential applications, for example, spatial and temporal scale, processes modeled and the basis of relationships and algorithm used. With this increasing number of availability, wide ranging characteristics and potential applications of the models, it is becoming challenging job for the potential model users to choose a particular model best suited for the given problem. In addition, modifications are made to existing models and new models are available each year. Therefore, updated, consistent and comprehensive evaluations of hydrological models are a continuously needed.

In literatures twelve recently developed or regularly updated watershed scale hydrologic and non-point source models are found. Based on fundamental criteria such as hydrological processes that the model can simulate, Governing equations used to simulate the hydrologic processes, Minimum data required to run the model and spatial and temporal scale of the model, the appropriate model would be selected. Some of these models are: AnnAGNPS, GSSHA, HYPE, Hec-HMS, MIKE-SHE, WEPP, PRMS, SWAT, GLEAMS, EFDC, SPARROW, Wet Spa, and WinSRM.

2.3.5. Models Evaluation Techniques

To determine recommended techniques for watershed model evaluation, an extensive review was conducted in published literature related to calibration, validation, and application of watershed models. Specifically, the information compiled focused on the strengths and weaknesses of each statistical and graphical technique and on recommendations for their application. These model evaluation statistics were selected based on the following factors: robustness in terms of applicability to various constituents, models, climatic conditions, commonly used, accepted, recommended in published literature; and identified strengths in model evaluation. (CEAP-WAS, 2005; Boyle et al., 2000).

The key model evaluation statistics discussed in literatures were divided into three major categories: standard regression, dimensionless, and error index. Standard regression statistics (Slope and y-intercept, Pearson's correlation coefficient (r), and coefficient of determination (R^2) are used to determine the strength of the linear relationship between simulated and measured data. Dimensionless techniques (Index of agreement (d),Nash-Sutcliffe efficiency (NSE), Persistence model efficiency (PME), Prediction efficiency (P_e), Performance virtue statistic (PVk) and logarithmic transformation variable (e) provide a relative model evaluation assessment, lastly, error indices (MAE, MSE, RMSE, Percent bias (PBIAS, RMSE-observations standard deviation ratio (RSR), Daily root-mean square (DRMS) are commonly used in model error evaluation (Legates, 1999; Harmel et al., 2006; Liew and Garbrecht, 2003; Nash and Sutcliffe, 1970; Gupta et al., 1999; Wang and Melesse, 2005; Parker et al., 2006; Chu et al., 2004).

2.4. SWAT Model Descriptions

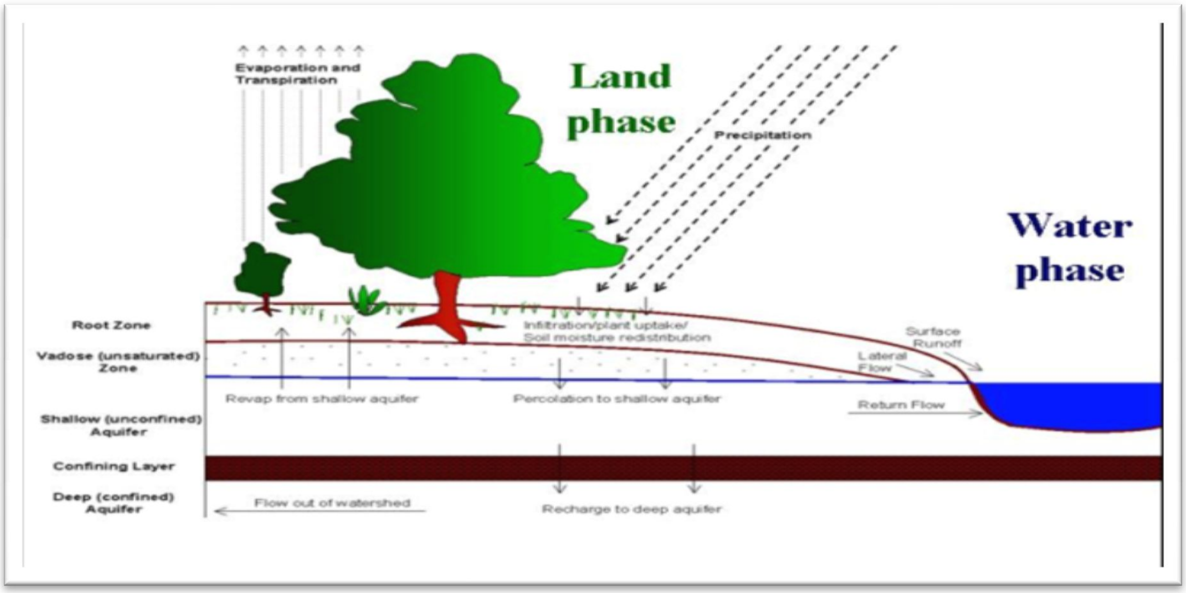
2.4.1. Overview

The Soil and Water Assessment Tool (SWAT) is a physically-based continuous-time, conceptual, long-term, distributed watershed scale hydrologic model developed by USDA' s Agricultural Research Service (ARS), designed to predict the impact of land management practices on the hydrology, sediment and contaminant transport in large, complex catchment (Arnold et al., 1998; Gassman et al., 2007).

It has capabilities of simulating surface runoff, percolation, return flow, erosion, nutrient loading, pesticide fate and transport, irrigation, groundwater flow, channel transmission losses, pond and reservoir storage, channel routing, field drainage, plant water use and other supporting processes from small, medium and large watersheds. It can be applied to a large ungagged rural watershed with more than 100 numbers of sub watersheds. For this reason, SWAT is increasingly being used to support decisions about alternative water management policies in the areas of land use change, climate change, water re-arrangement, and pollution control. There are numerous applications of SWAT model all over the world, (Dhami and Pandey, 2013).The water balance equation shown in Eqs (34) is the base of thehydrologic cycle simulation in SWAT:

$$SW_t = SW_o + \sum_{i=1}^{t}\left(R_{day} + Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \tag{34}$$

Where; WS_t : final soil water content (mm), SW_o: initial soil water content on day *i* (mm) R_{day}: amount of precipitation on day *i* (Q_{surf} : amount of surface runoff on day *i* (mm), E_a: amount of evapotranspiration on day *i* (mm), W_{seep}: amount of water entering the vadoze zone from the soil profile on day *i* (mm), Q_{gw}: amount of return flow on day *i* (mm). t: is the time (days).



(Neitsch et al., 2009)

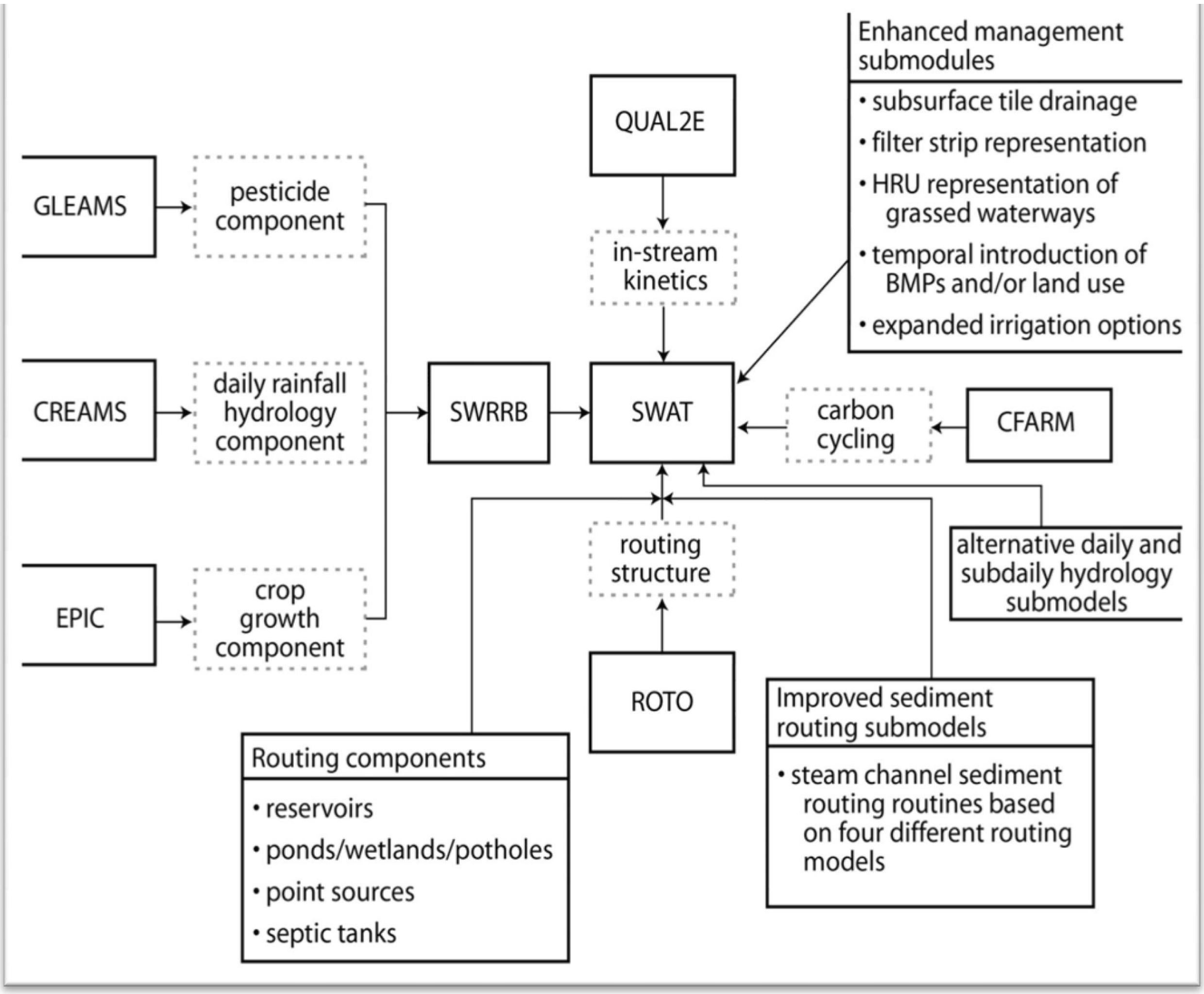
Figure 4: Hydrological cycle representation in SWAT model

2.4.2. Historical Development

The development of SWAT is a continuation of USDA Agricultural Research Service (ARS) modeling experience that spans a period of roughly 30 years. Early origins of SWAT can be traced to previously developed USDA ARS models including the Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) model (Knisel, 1980), the Groundwater Loading Effects on Agricultural Management Systems (GLEAMS) model (Leonard et al., 1987) and the Environmental Impact Policy Climate (EPIC) model (Izaurralde et al., 2006) which was originally called the Erosion Productivity Impact Calculator (Williams, 1990). The current SWAT model is a direct descendant of the Simulator for Water Resources in Rural Basins (SWRRB) model which was designed to simulate management impacts on water and sediment movement for ungagged rural basins (Arnold and and Williams, 1987).

Development of SWRRB began in the early 1980s with modification of the daily rainfall hydrology model from CREAMS. A major enhancement was the expansion of surface runoff and other computations for up to ten sub-basins, as opposed to a single field, to predict basin water yield. Others enhancement included an improved peak runoff rate method, calculation of transmission losses, and the addition of several new components such as groundwater return flow reservoir storage, the EPIC crop growth sub-model, a weather generator, and sediment transport. Further modifications of SWRRB in the late 1980s included the incorporation of the GLEAMS pesticide fate component, optional USDA-SCS technology for estimating peak runoff rates, and newly developed sediment yield equations. These modifications extended the model's capability to deal with a wide variety of watershed water quality management problems (Arnold et al., 1998).

Arnold et al., (1995b) developed the Routing Outputs to Outlet (ROTO) model in the early 1990s in order to support an assessment of the downstream impact of water management within Indian reservation lands in Arizona and New Mexico that covered several thousand square kilometers, as requested by the U.S. Bureau of Indian Affairs. The analysis was performed by linking output from multiple SWRRB runs and then routing the flows through channels and reservoirs in ROTO via a reach routing approach. This methodology overcame the SWRRB limitation of allowing only ten sub basins; however, the input and output of multiple SWRRB files was cumbersome and required considerable computer storage. To overcome the awkwardness of this arrangement, SWRRB and ROTO were merged into the single SWAT model.SWAT retained all the features that made SWRRB such a valuable simulation model, while allowing simulations of very extensive area.



(Gassman et al., 2007)

Figure 5: A schematic of SWAT development history adaptations

2.4.3. Adaptations

A key trend that is interwoven with the ongoing development of SWAT is the emergence of modified SWAT models that have been adapted to provide improved simulation of specific processes, which in some cases have been focused on specific regions. Notable examples include SWAT-Extended SWAT (ESWAT) and the Soil and Water Integrated Model (SWIM). The initial SWAT-G model was developed by modifying the SWAT99.2 which incorporate percolation, hydraulic conductivity and interflow functions to provide improved flow pre-dictions for typical conditions in low mountain ranges in (Len hart et al., 2002). Further SWAT-G enhancements include an improved method of estimating erosion loss

(Thomas Lenhart et al., 2005) and a more detailed accounting of CO_2 effects on leaf area index and stomata conductance (Eckhart and Ulbricht, 2003).

The ESWAT model features several modifications relative to the original SWAT model including: sub-hourly precipitation inputs and infiltration, runoff and erosion loss estimates based on a user-defined fraction of an hour, arriver routing module that is updated on an hourly time step and is interfaced with a water quality component that features in-stream kinetics based partially on functions used in QUAL2E as well as additional enhancements; and multi-objective (multi-site and/or multi-variable) calibration and auto calibration modules (similar components are now incorporated in SWAT2005 (Griensven and Bauwens, 2003; Griensven, 2005).

A second trend that has paralleled the historical development of SWAT is the creation of various Geographic Information Systems to support the input of topographic, land use, soil, and other digital data. Other interface tools such as the ArcView-SWAT (AVSWAT) interface tool (Luzio et al., 2004a) is designed to generate model inputs from ArcView 3.x GIS data layers and execute SWAT2000 within the same framework. Protection Agency (USEPA) Better Assessment Science Integrating point and Nonpoint Sources (BASINS) software package versions 3.0 (USEPA, 2006a), which provides GIS utilities that support automatic data input for SWAT2000 using ArcView (Luzio et al., 2002). The most recent version of the interface is denoted AVSWAT-X, which provides additional input generation functionality, including soil data input from both the USDA- NRCS State Soils Geographic (STATSGO) and Soil Survey Geographic (SSURGO) databases (USDA-NRCS, 2007a, 2007b; SWAT, 2007).

2.4.4. Versions

SWAT model simulations have provided water-resource managers with a tool to be able to plan and make decisions in evaluating water supplies and nonpoint source pollution impacts in large river basins. The model is continually evolving to increase simulation accuracy of land-use changes and agricultural management on stream flow and constituent yields.SWAT2000 was enhanced with bacterial transport routines, urban routines, the Green-Ampt infiltration equation, an improved weather generator, the ability to reading daily solar radiation, relative humidity, wind speed and potential evapotranspiration (ET), the Muskingum channel routing, and modified dormancy calculations for tropical areas. For the SWAT2000 version, theoretical documentation and a user manual are available with descriptions of the model algorithms, input and output files and variables (Neitsch et al. 2001a, 2001b).

ArcView SWAT (AVSWAT) version 1.0 (Luzio et al., 2002) is a GIS-based hydrological system that links the SWAT model and ArcView GIS software. Its main purpose is to enhance the hydrological characterization of a watershed in the assessment of nonpoint and point pollution. The AVSWAT system has user-friendly tools to assist the user in setting up and completing a model simulation (Luzio et al.2004). The main components include a preprocessor, interface, and postprocessor of the SWAT2000 model (Luzio et al. 2002). Without exiting the ArcView GIS environment, the user applies tools for the following to occur: watershed delineation, definition and editing of the hydrological and agricultural management inputs and running and calibration of the model. AVSWAT is organized accordingly: (1) watershed delineation; (2) HRU definition tool; (3) model databases editor; (4) weather stations definition; (5) input parameterization and editor; (6) model run; (7) read and map chart results; and (8) calibration tool. The pertinent GIS data that must be included to describe the watershed are the digital elevation model, the land-use and land-cover map, and the soil map ((Luzio and Arnold, 2004).

SWAT was integrated as a component of the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) version 3.0, which is a software system developed by the U.S. Environmental Protection Agency Office of Water to meet the requirements of developing total Maximum Daily Load (TMDL) programs. With over30 years of USDA modeling experience, the SWAT model has proven successful in the watershed assessments of both agricultural and urban scenario management effects on water quality, rendering it useful for the Clean Water Act’s requirement for the creation of TMDLs that appraise pollution for each listed water system. The latest version, SWAT2003, includes additional improvements

- The model contains a bacteria component that includes *E. coli* and fecal coliform. This component has been tested through a study in Walnut Creek, Iowa

- Tile flow has been improved to more adequately simulate the presence of water table and its draw down due to tile drains. Initially the lower soil levels are saturated, creating a water table. Rather than being based on soil moisture content, flow is a function of the water table above the tile.
- The presence of potholes has been added; however, additional work must be completed before it can be used.
- A curve number option based on antecedent weather (i.e., precipitation and climate) was developed rather than solely being based on soil moisture content.
- An auto calibration and sensitivity analysis option was added to SWAT2009, and progress continues to make this component more efficient and effective.
- Finally, with the enhancements added to SWAT2009, future support will focus on this version rather than maintaining SWAT2009.
- As natural resource protection, including water quality, maintains its importance, this model will continue to develop and improve according to environmental necessity while aiming to keep the model user-friendly yet adequate to efficiently simulate watershed processes. SWAT has been modified or supplemented or has formed the basis for new model developments for special requirements of various catchments throughout the world.
- (Watson et al., 2005) adapted SWAT to improve the Leaf Area Index simulation for the eucalyptus and pine forests common to Australia. The SWAT model is more suited to crops and deciduous vegetation.
- Extended SWAT (E-SWAT) is a computer program designed by (A.V.Griensven, 2002) that uses a time step of a user-defined fraction of an hour to calculate the rainfall and runoff and an hourly time step to calculate in stream river-routing processes.

2.4.5. Applications

Applications of SWAT have expanded worldwide over the past decade. many of the applications have been driven by the needs of various government agencies, particularly in the US and the European union, that require direct assessments anthropogenic, climate change, and other influences on wide range of water resources or exploratory assessments of model capabilities for potential future applications.

The wide range of specific SWAT applications that have been reported in the literature are, hydrologic assessments, applications accounting for base flow and/or for karst-influenced systems, soil ,water, recharge, tile flow, and related studies, snowmelt-related applications, irrigation and brush removal scenarios, incorporating wetlands, reservoirs, and other impoundments, Green-Ampt applications, pollutant loss studies, sediment studies, nutrient studies, pesticide and surfactant studies, scenarios of BMP and land use impacts on pollutant losses, climate change impact studies, climate change impacts on pollutant loss, Sensitivity, calibration and uncertainty analyses (Mapfumo et al., 2004; Fontaine et al., 2002; Gosain et al., 2005; Arnold et al., 2001; Saleh et al., 2000; Moriasi et al., 2007; Santhi et al., 2001a; Santhi et al., 2007).

2.4.6. Uniqueness

The following specific area of applications makes SWAT distinctive**:**

- Computationally efficient
- Consider pollutants in both dissolved and particulate phases
- Improved simulation of specific processes
- Applied to a large ungagged rural watershed with more than 100 sub-basins
- Degree of representation of various watershed processes
- Easy way of adapting to a wide variety of hydrologic conditions
- Requires readily available inputs
- Consider both point and nonpoint pollutants
- Adaptation of the model to any watershed
- Consider contributions from both surface and groundwater
- Continuous in time
- Ability to represent spatial and temporal variability throughout the watershed
- Gives reasonable results

2.4.7. Strength

The worldwide application of SWAT reveals that it is a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better-informed policy decisions. The foundational strength of SWAT is the use of the NRCS curve number method in SWAT has provided a relatively easy way of adapting the model to a wide variety of hydrologic conditions. The incorporation of non-capital HRUs in SWAT has supported adaptation of the model to virtually any watershed, ranging in size from field plots to entire river basins, A key strength of SWAT is a flexible framework that allows the simulation of a wide variety of conservation practices and other BMPs, such as fertilizer and manure application rate and timing, cover crops (perennial grasses), filter strips, conservation tillage, irrigation management, flood-prevention structures, grassed waterways and wetland, models used for watershed-scale bacteria fate and transport assessments and the ability to simulate in-stream water quality dynamics. (Lyon et al., 2006; Benham et al., 2006; Horn et al., 2004; Arabi et al., 2007b; Bryant et al., 2006).

2.4.8. Limitations

A major limitation of large-area hydrologic modeling is the spatial detail required to correctly simulate environmental processes. For example, it is difficult to capture the spatial variability associated with precipitation within a watershed. Another limitation is the accuracy of hydrologic response units simulating field variations including conservation practices. SWAT is being altered to account for landscape spatial positioning so that conservation practices such as riparian buffers and vegetative filter strips can be adequately simulated. SWAT does not simulate detailed event based flood and sediment routing.

2.4.9. Modifications

The SWAT model modifications under consideration are (1) the dynamics of P exchange between the solution and active mineral (organic) pools; (2) the desorption of From soil to runoff water; (3) the simulation of surface applied manures and the loss of P from surface manures to runoff water; (4) soil cracking; (5) the addition of best management practices that can be correctly simulated such as vegetated filter strips and buffer zones and (6) the improvement of auto calibration and sensitivity analysis components. The factors are addressed further as follow:

- SWAT assumes equilibrium between P in solution and in the active mineral pools. SWAT is being modified to slow the availability of P from the solution to the active mineral pool while transfer from the active mineral to the solution pool is instantaneous. This is potentially important when a runoff event occurs shortly after a manure application, before the solution and active mineral pools have time to reestablish equilibrium.
- In literature, it was determined that SWAT's simulation of P desorption is comparable to other hydrologic models. A model to date regard that P desorption occurs at the same rate as P adsorption. But it will expect to be proved in future.
- SWAT currently assumes that the P in manure is added directly to the P pools in the upper soil layer (1 cm). Phosphorus may remain soluble in a manure layer longer than a soil layer, and thus SWAT may underestimate movement shortly after a manure application. A conceptual model for SWAT that considers a manure layer that slowly moves the Pinto the soil has been developed. This improvement will take more time to implement and validate.
- The ability to predict runoff and storage requires understanding the processes of soil cracking (Arnold et al. 2005). Flow through each soil layer is combined with a crack flow model in conjunction with a storage routing technique for percolation to occur. Soil shrinkage cracking allows for a greater distribution of water, nutrients, and pesticides to the subsoil, rendering the solution unavailable for plant uptake and a source of groundwater pollution. Seasonal cracking also contributes to poor estimates of runoff and infiltration in areas with expansive soils. SWAT has incorporated a crack flow model. For a Texas watershed, the model was able to simulate surface runoff accurately for the winter months when the cracks were swelled closed and in the fall for recharge events when crack volume went from 70 to 10 mm. Future research is

planned to determine the impact of cracking on groundwater recharge and contaminant transport.

- The addition of best management practices such as vegetated filter strips, riparian zones, wetlands, as well as others, is known to be of importance so that SWAT can correctly simulate agricultural management in the watersheds. A component that has to be refined initially is the configuration of HRUs. This has to be done to account for more detailed variations in topography and management practices rather than each sub-basin remaining entirely independent of its adjoining sub-basins. A major concern before it will be changed is to determine the overall goal of the model. To accommodate smaller areas so that the watershed simulation will be more accurate, the model's complexity will have to increase rendering it less user-friendly. The ability to model best management practices means that the hydrology component must be redesigned to allow for more subtle topographical changes between sub-basins, thereby increasing the model's complexity. All of these adjustments are being considered while trying to maintain a less complex, more user-friendly model.
- Much work has been completed regarding the auto calibration sensitivity analysis component of SWAT through A procedure based on multi-objective calibration that incorporates the Shuffled Complex Evolution algorithm was utilized effectively for auto calibration. The optimization allows for up to 100 output variables to be considered simultaneously. The Shuffled Complex Evolution algorithm accepts as many as 30 objective functions for aggregation into a single global optimization criterion. A weighting problem is avoided due to the use of a statistical method that enables the aggregation of the objective functions for individual variables. A sensitivity analysis using the one-factor-at-a-time approach was successfully employed to identify the significant parameters for the optimization (Griensven, 2002).

2.4.10. Sensitivity

SWAT input parameters are process based and must be held within a realistic uncertainty range. The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given watershed or sub watershed. The user determines which variables to adjust based on expert judgment or on sensitivity analysis. Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters). It is necessary to identify key parameters and the parameter precision required for calibration.

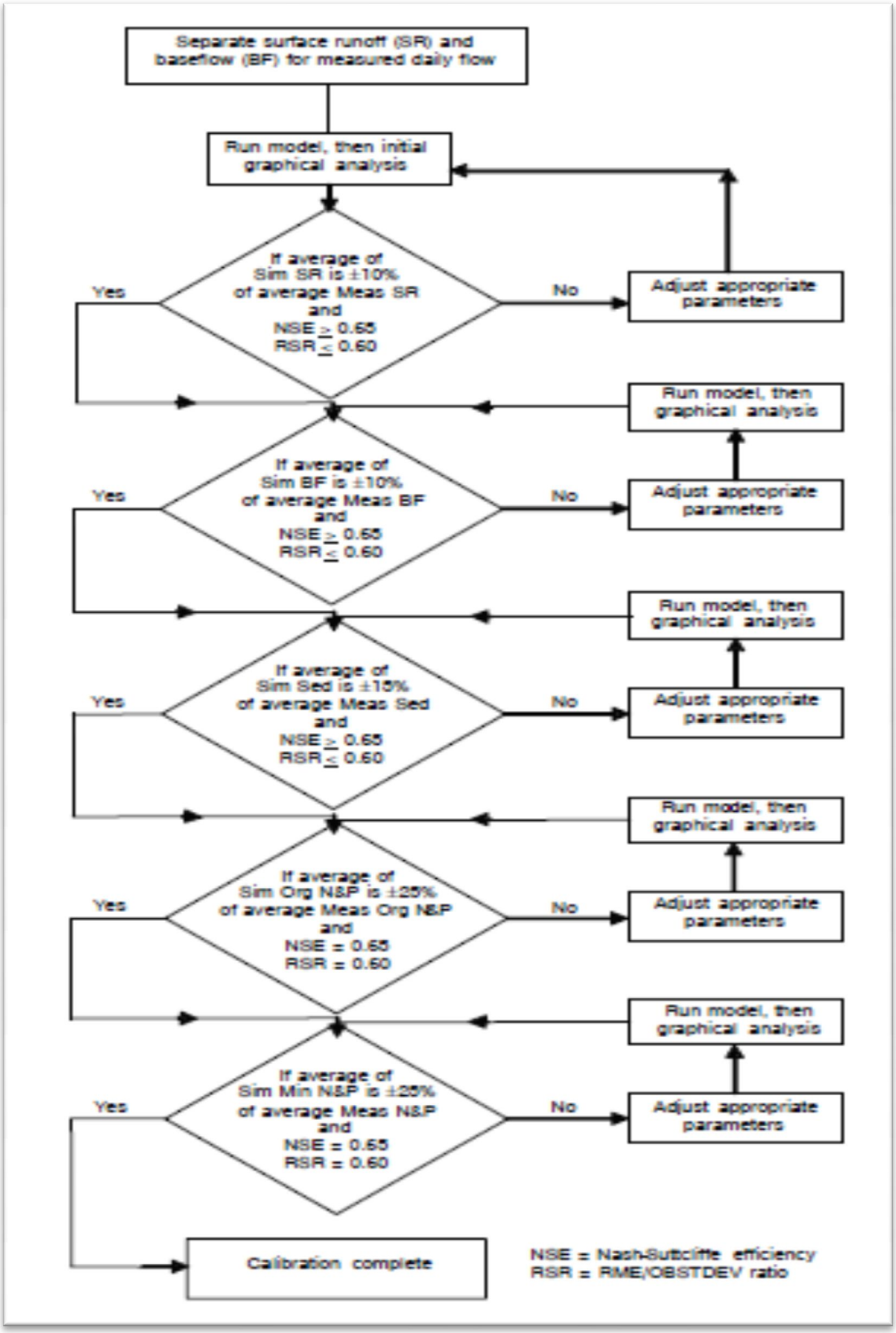
Two types of sensitivity analysis are generally performed: local, by changing values one at a time, and global, by allowing all parameter values to change. The two analyses, however, may yield different results. Sensitivity of one parameter often depends on the value of other related parameters; hence, the problem with one-at-a-time analysis is that the correct values of other parameters that are fixed are never known. The disadvantage of the global sensitivity analysis is that it needs a large number of simulations. Both procedures, however, provide insight into the sensitivity of the parameters and are necessary steps in model calibration (Ma et al., 2002).

2.4.11. Calibration

Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions. Calibration can be accomplished manually or using auto calibration tools. Calibration and validation are typically performed by splitting the available observed data into two datasets: one for calibration, and another for validation. Data are most frequently split by time periods, carefully ensuring that the climate data used for both calibration and validation are not substantially different, that is, wet, moderate, and dry years occur in both periods (Gan et al., 1997).

Ideally, calibration should be process and spatially based, while taking into account input, model, and parameter uncertainties. A good example of process-based calibration involves stream flow. Stream flow processes are comprised of the water balance in the land phase of the hydrology, including ET, lateral flow, surface runoff, return flow, tile flow (if present), channel transmission losses, and deep aquifer recharge. If data are available for each of these processes, they should be calibrated individually. For sediments, nutrients, pesticides, and bacteria, sources and sinks should be considered. If a longer time period is available for hydrology than water quality data, it is important to use all the hydrology data available for calibration to capture long-term trends. This process-based calibration should be done at the sub watershed or landscape level to ensure that variability in the predominant processes for each of the sub watersheds is captured instead of determining global (watershed-wide) processes (Hu et al., 2007; Ng et al., 2007a).

Users should check the water balance components (ET, surface/base flow ratios, tile flow proportions, plant yield, and biomass) during the calibration process to make sure the predictions are reasonable for the study region or watershed. Because plant growth and biomass production can have an effect on the water balance, erosion and nutrient yields, reasonable local/regional plant growth days and biomass production should be verified during model calibration to the extent possible. Also recommend that stream flow, sediment, and nutrient transport be calibrated sequentially (in that order) because of interdependencies between constituents due to shared transport processes. Even though a complete set of hydrologic and water quality data are rarely available, all available data should be considered. We recommend that base flow and surface runoff be separated from the observed total daily stream flow using a base flow filter (Santhi. et al., 2001;Jafet et al., 2011; Nair et al., 2011).



(Neitsch et al., 2009)

Figure 6: General calibration procedures for flow, sediment and nutrient

2.4.12. Validation

The final step is validation for the component of interest (stream flow, sediment yields, etc.).Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although "sufficiently accurate" can vary based on project goals. Validation involves running a model using parameters that were determined during the calibration process, and comparing the predictions to observed data not used in the calibration. In general, a good model calibration and validation should involve :(1) observed data that include wet, average, and dry years; (2) multiple evaluation techniques); (3) calibrating all constituents to be evaluated; and(4) verification that other important model outputs are reasonable. Ideally, as calibration, validation should be process and spatially based, while taking into account input, model, and parameter uncertainties (Refsgaard, 1997; Gan et al., 1997; ASCE, 1993; Legates , 1999;Boyle et al., 2000).

2.4.13. Uncertainty

Because models are used to develop and evaluate water resource policy, several recent pleas have been made to consider inherent uncertainties in model development and application as stated by Beven et al., 2006;Michl et al., 2011.Definition and quantification of calibration uncertainty in distributed hydrological modeling has become the subject of much research in recent years (Abbas, 2005). Three sources of uncertainty or error must be considered: (1) the uncertainty or error in the measured input data (example: rainfall and temperature), (2) the uncertainty or error in the measured data used in model calibration (example: river discharges and sediment load), and (3) the uncertainty or error in the conceptual model and model parameters (example: hydrologic processes).

(Abbas, 2005), states that there is an intimate relationship between calibration and uncertainty analysis and that they must be performed simultaneously. In other words, calibration must always be accompanied by an assessment of the goodness of the calibration, taking into account all modeling errors. The uncertainties in the conceptual model and model parameters, as well as the uncertainty in measured data used in calibration, all affect simulation quality and appropriateness; therefore (Harmel et al., 2010) developed a simple model evaluation matrix to incorporate data and simulation uncertainty in model evaluation and reporting. In addition, the modified goodness-of-fit indicator calculations of (Harmel et al., 2010), which are based on (Haan et al., 1995), are currently being incorporated into the SWAT-CUP software.

2.4.14. SWAT- CUP

SWAT-cup, a computer program used for calibration of SWAT model which is a public domain program easily used and copied. The program links SUFI2, PSO, GLUE, PARASOL and MCMC procedures to SWAT model. Likewise, sensitivity analysis, uncertainty analysis and validation can be done with it. It includes automated as well as semi-automatic procedures for model calibration (Abba sour et al., 2007; Rouholahnejad et al., 2012b).

For the second case study, an example calibration of the Danube project (Rouholahnejad et al., 2012b) was selected using SWAT-CUP (Rouholahnejad et al., 2012b) referred to the process of parameter assignment as parameterization. Correct parameterization is an important step in model calibration and must be based on the knowledge of the hydrologic processes and variability in soil, land use, slope, and location as defined by the sub-basin number. Parameterization, therefore, could be defined as "the process of imparting the analyst's knowledge of the physical processes of the watershed to the model no automatic calibration procedure can substitute for actual physical knowledge of the watershed, which can translate into correct parameter ranges for different parts of the watershed. These ranges can effectively guide the optimization routine. Hence, correct parameterization can result in faster and more accurate model calibration with smaller prediction uncertainty.

CHAPTER 3: METHODS AND MATERIALS

3.1. Methods

3.1.1. Study Area

Gilgel Gibe-I watershed is situated in the south-western part of Ethiopia, in Oromia Regional State. The reservoir is located at 49°52'0.45" N latitude and 37°19'18.79"E longitude and the whole Gilgel gibe sub catchment which sheds water to the reservoir lies between latitude of 7°21' to 7°58'N and longitude of 36°31' to 37°26'E covering an area of about 4149.5 km^2. The project is purely a hydropower scheme, with an installed capacity of 180MW. The reservoir has a live storage capacity of $657x10^6m^3$. The basin was divided into 43 sub-basins with 264 HRUs which drain in to the Gilgel Gibe 1 reservoir. The detail location of the study area was shown in Figure (7):

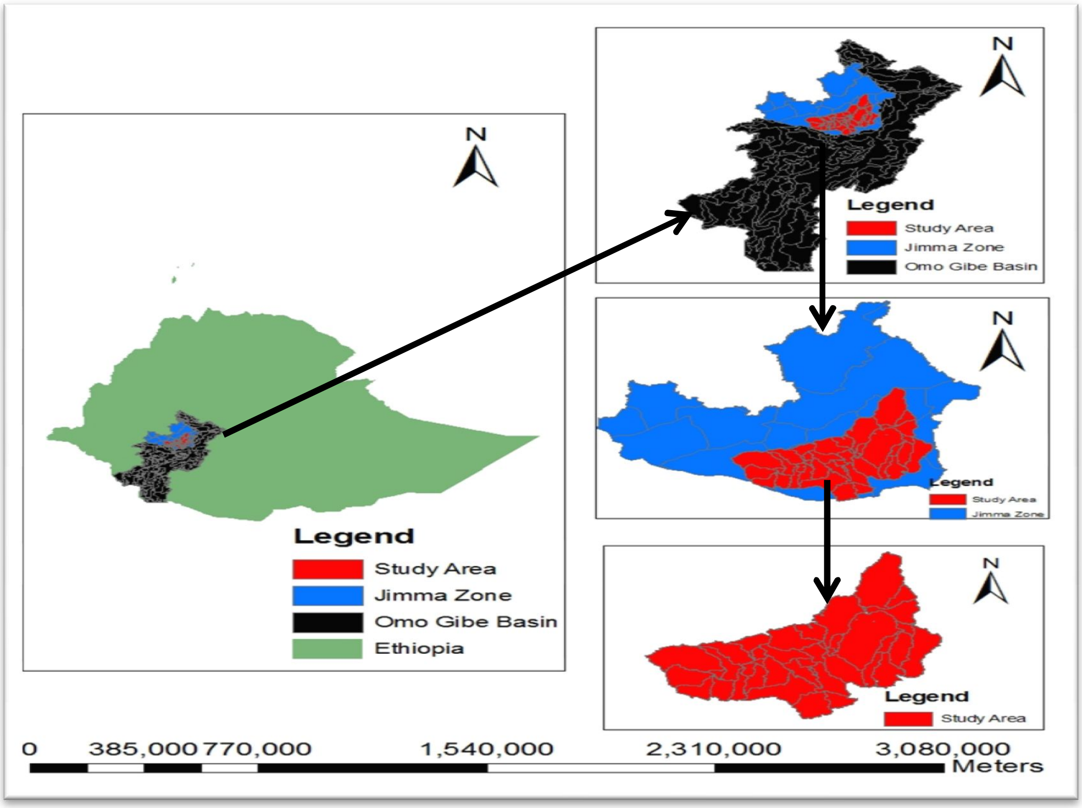


Figure 7: Location of study area

The basin is generally characterized by high relief hills and mountains with an average elevation of about 1,700 m above mean sea level. It is largely comprises of cultivated land, characterized by wet climate with an average annual rainfall of about 1,550 mm and average temperature of 19°C. The seasonal rainfall distribution takes a unimodal pattern with maximum during summer and minimum during winter, influenced by the inter-tropical convergence zone. The detail study area watershed element was detailed in the Figure (8):

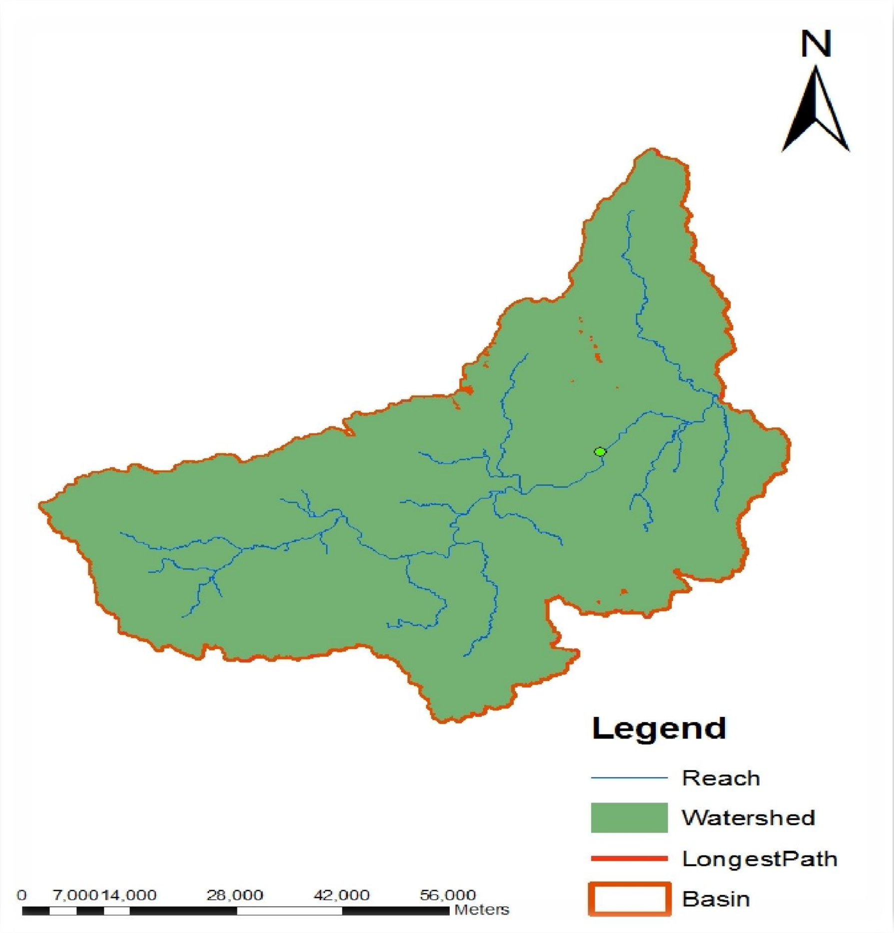


Figure 8: Reach, watershed, longest path and basin

3.1.2. Study Design

The study was following a kind desktop longitudinal research design type to answer the fundamental study questions to achieve the previously defined objectives.

3.1.3. Data Type

In order to undergo the study, a secondary types of data such as temporal data such precipitation, temperature, wind speed, relative humidity, sunshine and stream dischargeand spatial data such as digital elevation model, soil, land use, land cover was used as summarized in Table (1):

Table 1: Gauging stations relative locations and data types.

Station	UTM		ELEV	Data type				
	X_{PR}	Y_{PR}						
Jimma	260624.000	848421.000	1715.000	PCP	TMP	HMD	SLR	WND
Sekorru	323625.000	875793.000	1910.000	PCP	TMP	-	-	-
Limmu	416929.976	4089732.319	1766.000	PCP	TMP	-	-	-

PCP: Precipitation, TMP: Temperature, HMD: Humidity; SLR: Solar radiation; WND: Wind Speed; X_{PR}: Projected coordinate for longitude; Y_{PR}: Projected coordinate for latitude.

The detail location of monitoring point and hydro-meteorological data gauging stations of the study area was clearly figured in the Figure (9):

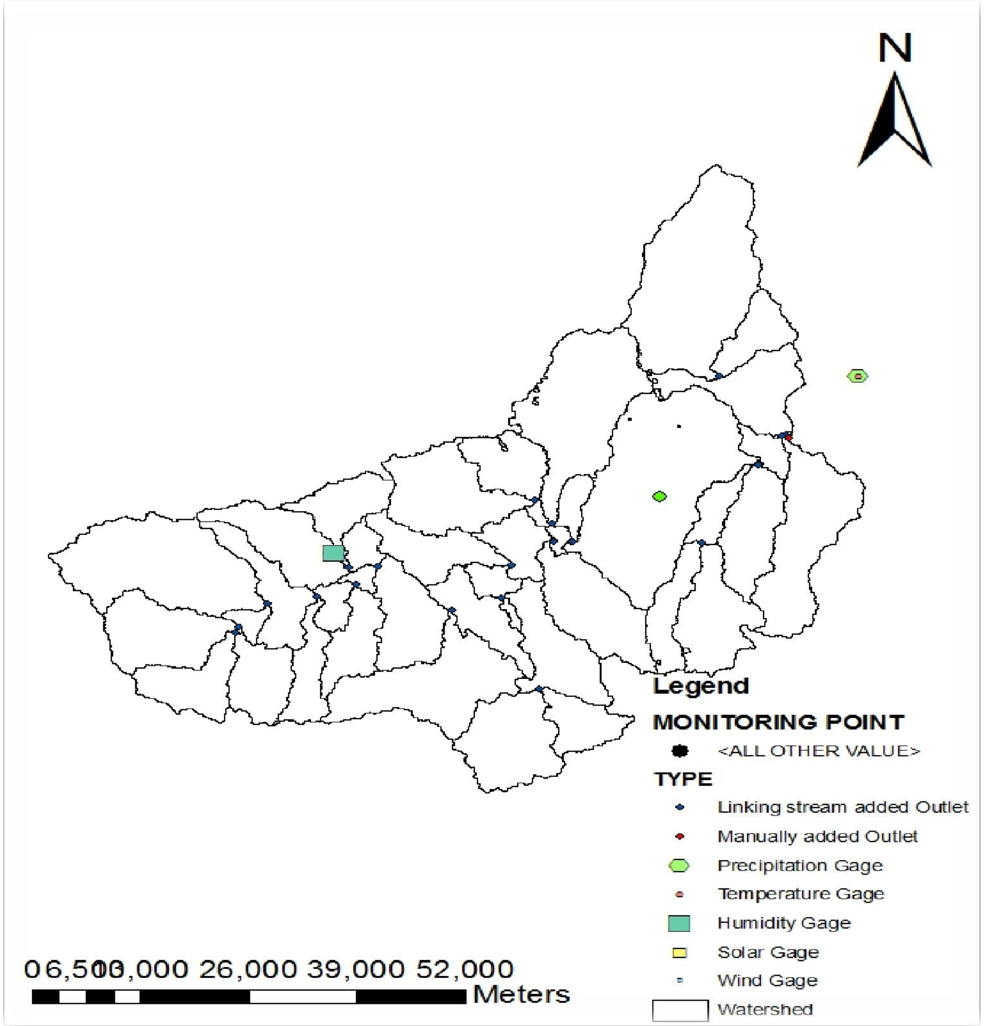


Figure 9: Relative location of monitoring point

3.1.4. Data Collection

The mentioned secondary data was collected from different sources. The temporal data (hydro-meteorological and stream discharge data was gathered from Jimma Meteorological Sub-stations and from Ministry of Water, Energy and Irrigation respectively. Whereas the spatial data (DEM, land use, land cover and soil data from various sources.DEM data gathered from a www.earthexplorer.usgs.gov using the boundary co-ordinates of the study area. The soil data of the study area was taken from a FAO-UNESCO data base address (www.fao.gov). Lastly, the land use land cover data was sourced from Ministry of Water, Energy and Irrigation.

3.1.5. Data Preparation

The data collected from various sources was prepared as follows to fit the model requirements. The DEM data downloaded from the website inform of pixels was adjusted appropriately to relevant co-ordinates and thenmosaic to cover the study area. The land use data that was picked up from the sources was clipped and projected to fit the DEM and soil data of the study area. In addition, the key land use types of the area was identified, coded to match the SWAT land use data base. Correspondingly, the lookup table both for land use and sol was prepared to define analysis and generate HRUs report. The digital soil map downloaded from the FAO website was clipped out for the study area, projected geographically and then re-projected to projected co-ordinate system to make compatible with DEM and land use data. Then after, in the same way as land use data, the dominant soil types was identified and added to SWAT user soil data base along its full parameters based on revised FAO soil legend.

Regarding the hydro-meteorological data (discharge and meteorological), which was gathered from previous source was organized, processed and arranged vertically to fit the model data requirement. Concerning the weather generator data file preparation, the dew point temperature and corresponding standard deviation of average daily maximum and minimum temperature and humidity data was prepared using dewo2 and spreadsheet pivot table. Likewise, the solar and wind speed data was prepared using Excel pivot table and the added to user weather generator database. Lastly, the statistical parameters of daily precipitation data was prepared using the pcpSTAT and then added to weather generator data bases.

3.1.6. Data Quality Control

The predictive efficiency and output of any model fundamentally depends on the level of quality of raw data feed to the model. To enhance the predictive efficiency of the model and to acquire better output, the quality of the input raw data was evaluated for each data types. A 30m * 30m resolution DEM data was used to enhance fine resolution of the study area. The soil data used was the revised and examined FAO-UNESCO Soil Map of 2007 which is high accuracy. The land use data brought from the Ministry of Water, Energy and Irrigation was used as it was. Regarding the hydro-meteorological data (discharge and meteorological data), the great care was taken during data collection, organization and arrangement to minimize the possible happening and propagation of errors that might happen during processing.

Also, to check the consistency of the data, visual observation, mean imputation (replaces missing values with arithmetic mean of available data), regression imputation, (substitutes the values using available observed data developing the corresponding regression equation to predict the missed value). Lastly, the double mass curve concept was applied to the three stations(Jimma, Sekoru and Limmu) to analysis their rainfall trend as given in the Figures (10, 11, and 12):

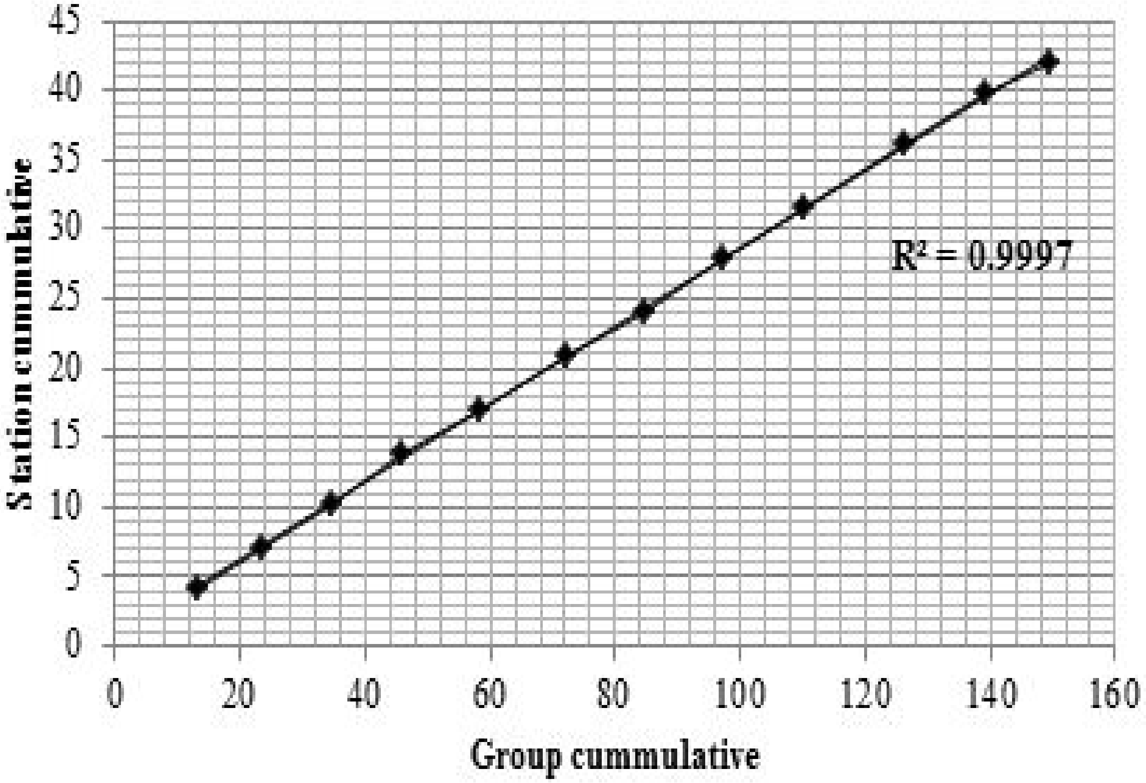


Figure 10: Consistency pattern of Jimma rainfall

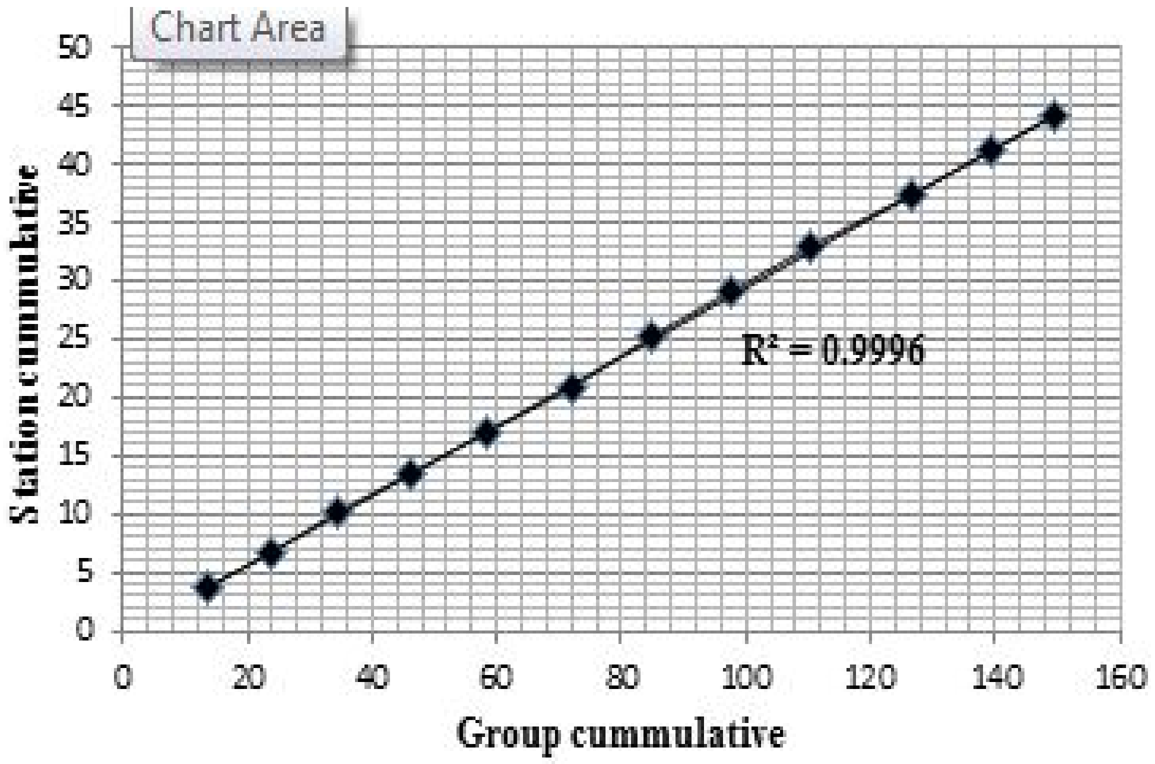


Figure 11: Consistency pattern in Sekoru rainfall

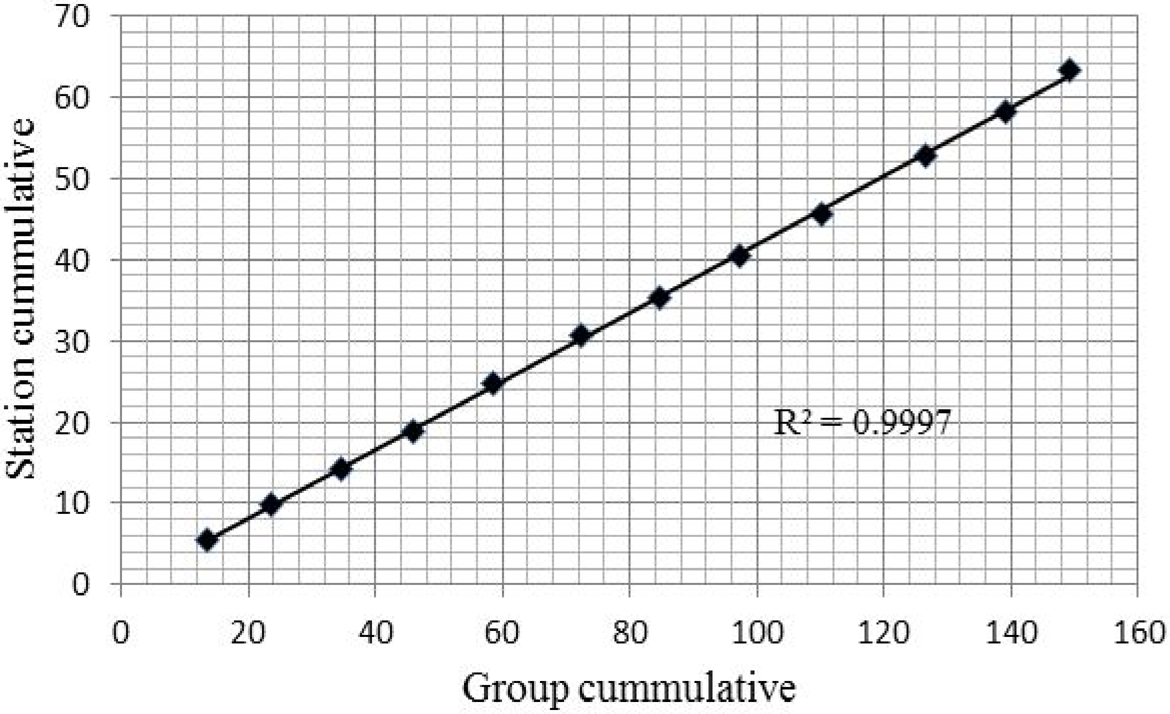


Figure 12: Consistency patterns of Limmu rainfall

3.1.7. SWAT Model Descriptions

SWAT is a hydrologic/water quality model developed by United States Department of Agriculture and Agricultural Research Service (USDA-ARS) (Anold et al., 1998).It can predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Neitsch et al., 2011).In SWAT, a watershed is divided into multiple sub-basins, which are further subdivided into hydrologic response units (HRU) that consist of homogeneous land use, management and soil characteristics. Stream-flow generation, sediment yield and nonpoint source loadings from each HRU are summed and the resulting loads are routed through channels, ponds, and/or reservoirs to the watershed outlet. Key components of SWAT include hydrology, plant growth, erosion, nutrient transport and transformation, pesticide transport and management practices. Outputs provided by SWAT include stream-flow and in-stream loading or concentration estimates of sediment, organic nitrogen, nitrate, organic phosphorus, soluble phosphorus and pesticides (Gassman et al., 2007).

3.1.8. SWAT Project Setup

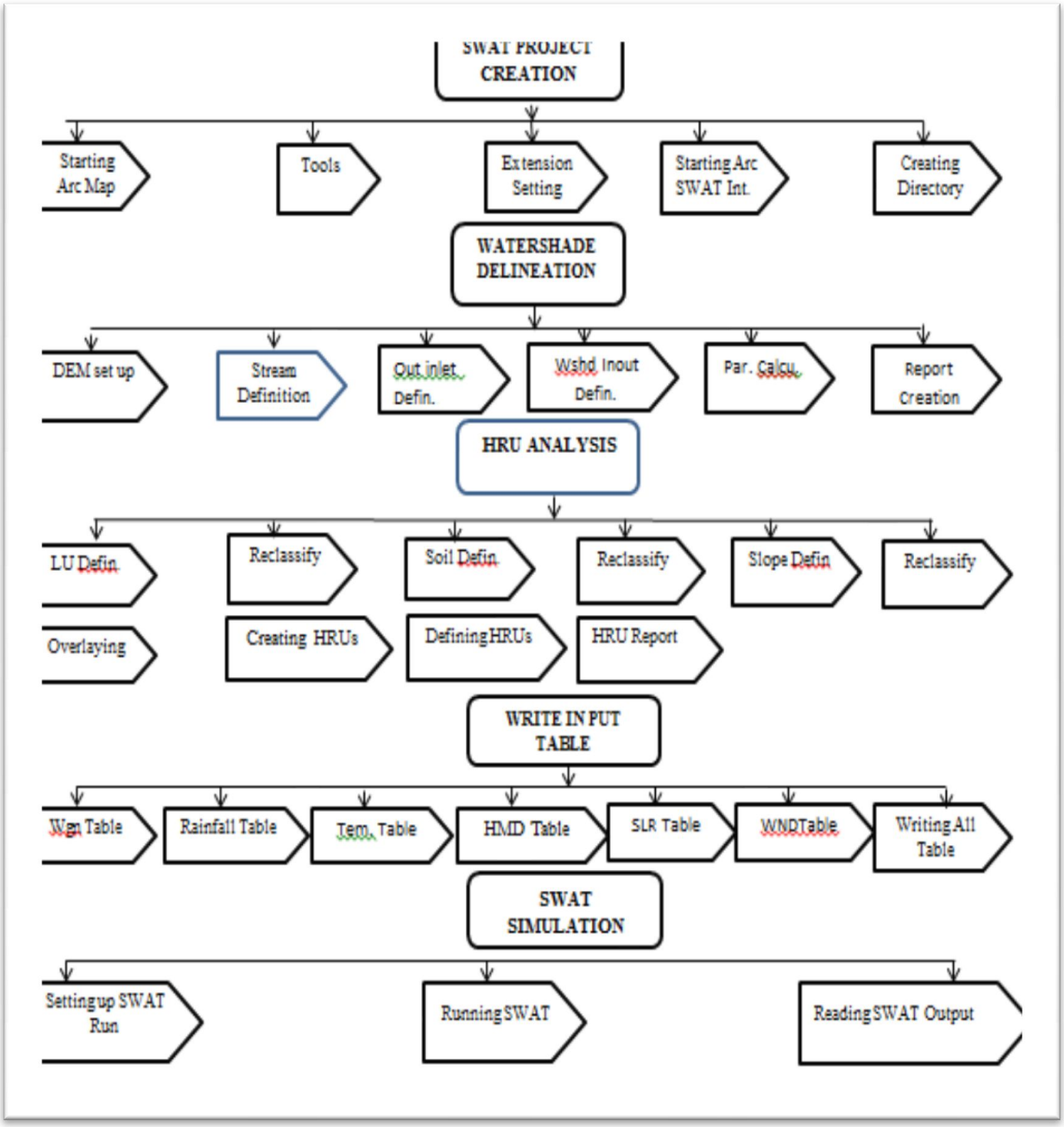
Arc SWAT extension of ArcGIS 9.1 or 9.2 creates an Arc Map project file that contains links to retrieved data and incorporates all customized GIS functions into Arc Map project file. The project file contains a customized Arc Map Graphical User Interface (GUI) including menus, buttons and tools. The major steps that were followed to create a SWAT project under Arc Map environment are conceptualized in the Figure (13): Following procedures in figure (13), the model input data, DEM (Digital Elevation Model), land use map, soil map and weather data were geo-processed step by step to set up the model for the study area. The DEM was used to delineate the catchment and provide topographic parameters such as overland slope and slope length for each sub-basin. The catchment area of the Gilgel Gibe was delineated and discretized into 43 sub-basins using a 30 m DEM.

Lastly, the land use, FAO-UNESCO soil and slope class map was overlaid to drive 264 unique HRUs.Here all of the HRUs was considered for the land use class of the area, even though the SWAT model provides an option to reduce the number of HRUs in order to enhance the computation time required for the simulation.The daily precipitation, maximum and minimum temperature, wind speed, average relative humidity data fromJimma, Sekoru and Limmu stations were used to run the model. Angstrom formula which relates solar radiation to extraterrestrial radiation and relative sunshine duration was used to estimate the daily solar radiation. Further, the weather generator file was also prepared and included in the model weather generator database required to run the model.

Daily river flow data measured at Asendabo gauging station was used for model calibration and validation. The flow observed data were available throughout the year. The model was run using daily data of 14 years. The daily meteorological data from 2001 - 2014 was used to run the model. The two years data from 2001 - 2002 was used to warm up the model. Whereas, the data from 2003 - 2008 was used to calibrate the model and the rest data from 2009 - 2012 was used to validate the model. The modeling period selection considered discharge data quality and availability.

Sensitivity analysis was carried out to identify the most sensitive parameters for model calibration using LH-OAT (One-factor-At-a-Time), an automatic sensitivity analysis tool implemented in SWAT 2009. SWAT2009 was used to perform sensitivity, auto calibration and uncertainty analysis. Based on the sensitivity analysis results, first all 27 hydrological flows related parameters and ranked by their order of sensitivity in simulating the basin hydrology, then 9 parameters, the most sensitive were identified for the basin as mentioned in Figure (14). Followed sensitivity analysis, the most sensitive parameters were calibrated by both manual calibration (expert) and automatic calibration according to the procedures in the Figures (15 and 16). Appropriate lower and upper ranges in parameter values have been assigned prior to initiating the auto calibration process.

3.1.9. Conceptual Flow



(Winchell et al., 2010)

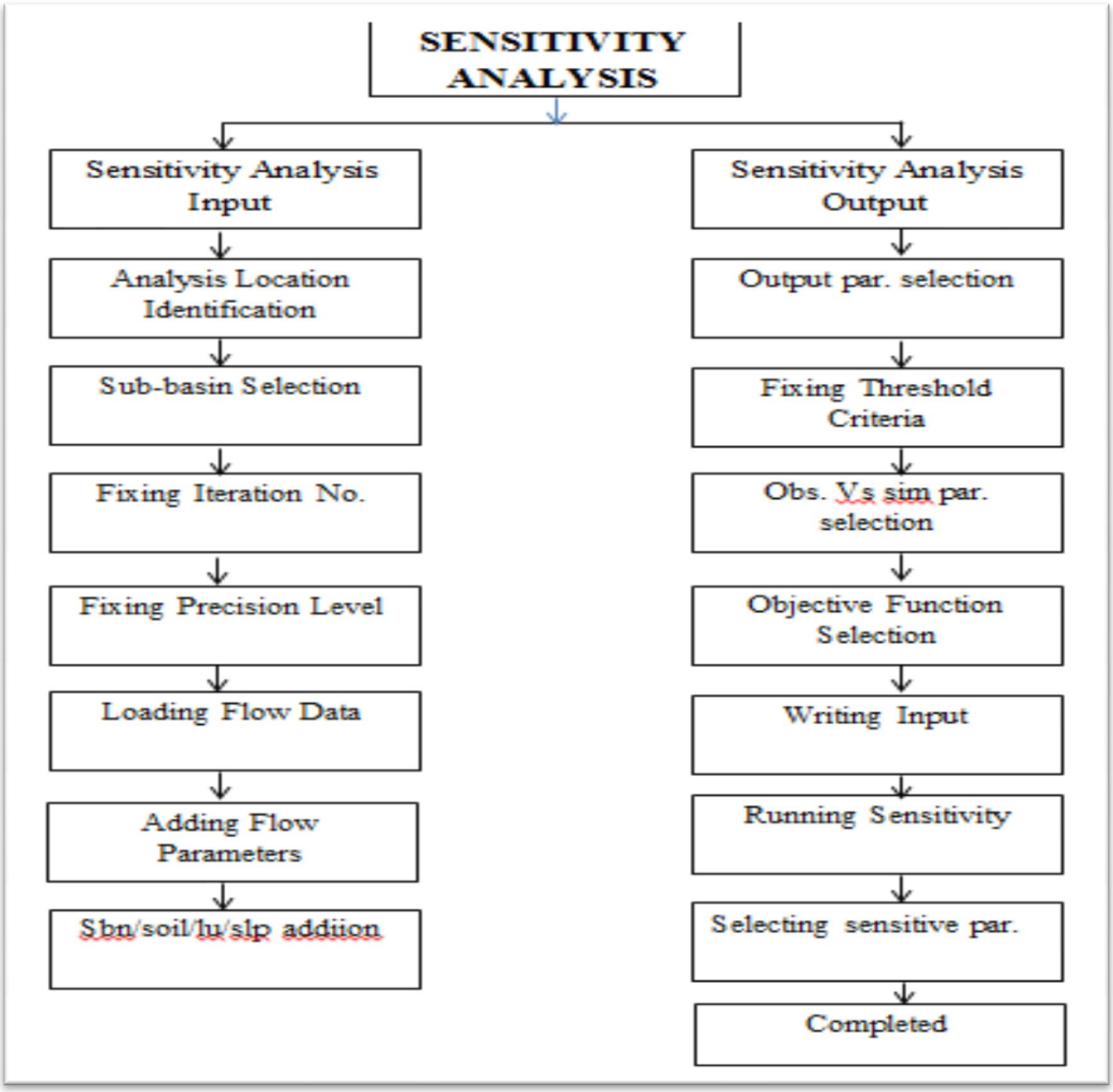
Figure 13: Sequential flow followed to run model

3.1.10. Sensitivity Analysis

SWAT input parameters are process based and must be held within a realistic uncertainty range. The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given watershed or sub watershed. The user determines which variables to adjust based on expert judgment or on sensitivity analysis. Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters). It is necessary to identify key parameters and the parameter precision required for calibration. In a practical sense, this first step helps determine the predominant processes for the component of interest.

Two types of sensitivity analysis are generally performed: local, by changing values one at a time and global, by allowing all parameter values to change. The two analyses, however, may yield different results. Sensitivity of one parameter often depends on the value of other related parameters; hence, the problem with one-at-a-time analysis is that the correct values of other parameters that are fixed are never known. The disadvantage of the global sensitivity analysis is that it needs a large number of simulations. Both procedures, however, provide insight into the sensitivity of the parameters and are necessary steps in model calibration. The general procedures followed during sensitive parameters analysis shown in Figure (14).

3.1.11. Conceptual Flow



(Winchell et al., 2010)

Figure 14: Order followed to identify sensitive parameters

3.1.12. Manual Calibration

Conventionally, calibration is performed manually andconsists of changing model input parameter values to produce simulated values that are within a certain range of the measured data. However, when the number of parameters used in the manual calibration is large, especially for complex hydrologic models, manual calibration can become labor-intensive and automated calibration methods are preferred. Both manual algorithms and automated methods have been developed for calibration of SWAT simulations.

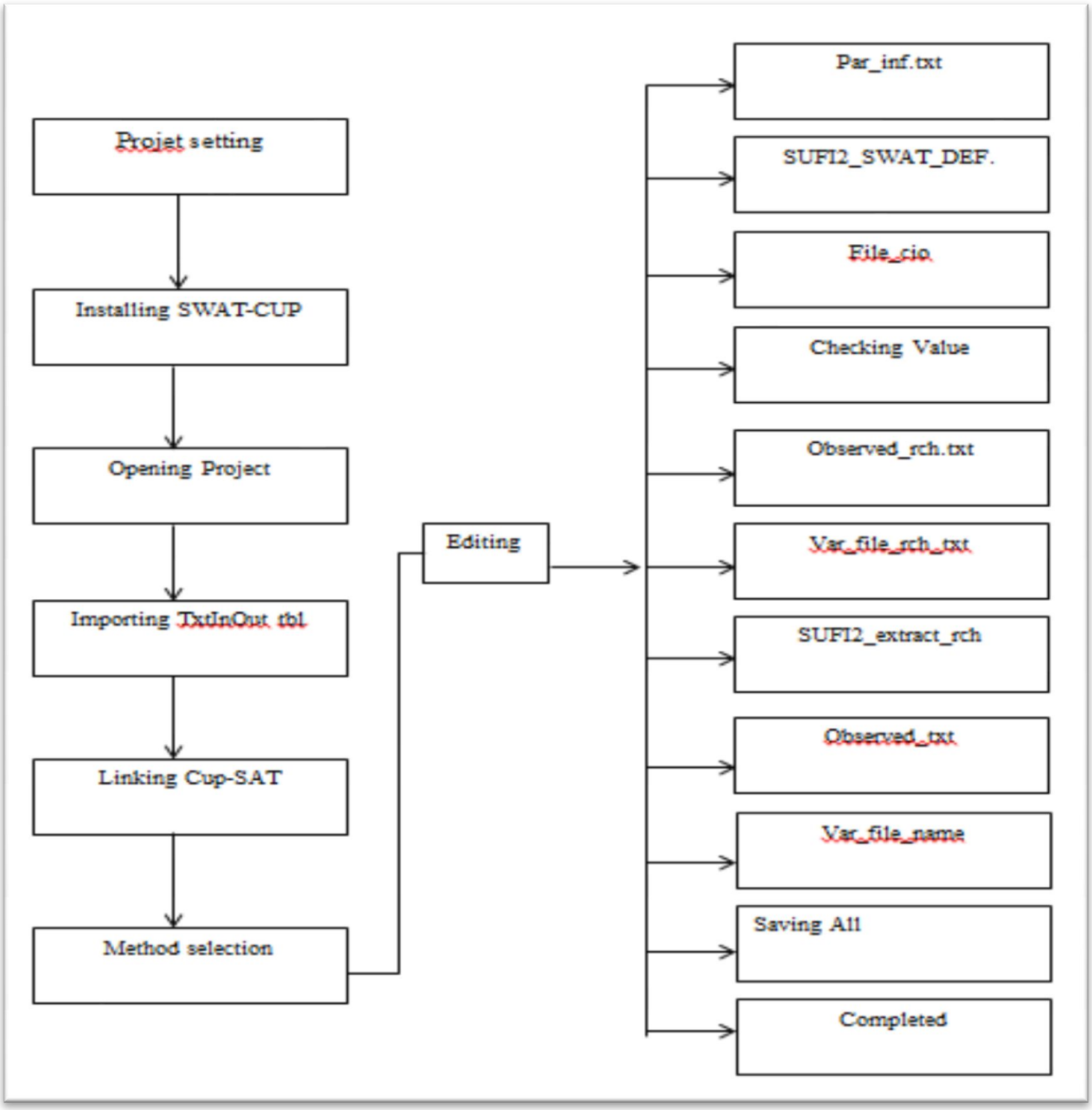
3.1.13. Conceptual Flow

Figure 15: Steps followed during manual calibrations

3.1.14. Automated Calibration

The second step of model evaluation is the calibration process. Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions.

3.1.15. Conceptual Flow



(Abbas Pour, 2005)

Figure 16: Steps followed to undergo auto calibration

3.1.16. Validation

The final step is validation for the component of interest (stream flow, sediment yields, etc.). Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although “sufficiently accurate” can vary based on project goals. Validation involves running a model using parameters that were determined during the calibration process and comparing the predictions to observed data not used in the calibration.

3.1.17. Conceptual Flow

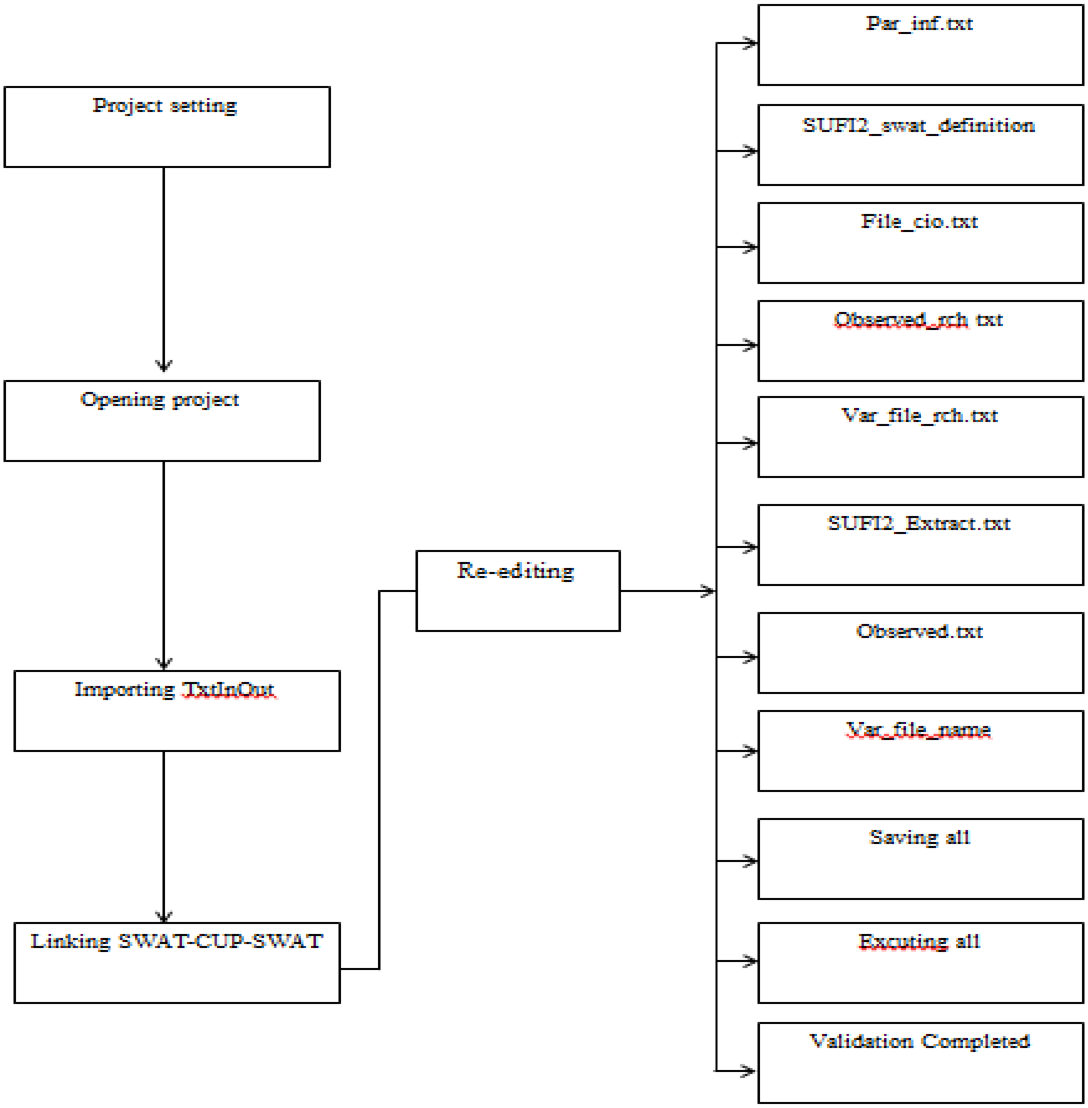


Figure 17: Series of steps followed during validation

3.1.18. Model Performance Evaluations

Model evaluation is an essential measure to verify the robustness of the model. In this study, the following methods were used; NSE (Nash-Sutcliffe efficiency) andR^2correlation coefficient) between observed and simulated flows. The NSE (Nash-Sutcliffe efficiency) is computed as the ratio of residual variance to measured data variances. The NSE simulation coefficient indicates how well the plot of observed versus simulated values fits the 1:1 line. The Nash-Sutcliffe is calculated using Eq. (35):

$$\boldsymbol{NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Q_i^{obs} - Q_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Q_i^{obs} - Q^{mean}\right)^2}\right]} \tag{35}$$

Where,Q_i^{obs} =Observed stream flow in m3/s; Q_i^{sim} = simulated stream flow in m3/s; Q^{mean} = Mean of n values; *n* = number of observations. The NSE can range from $-\infty$to +1, with 1 being a perfect agreement between the model and real (observed) data. The simulation results were considered to be good if NSE $\geq$ 0.75, and satisfactory if 0.36 $\leq$ NSE $\leq$ 0.75 (Griensven and Bauwens, 2003).

The coefficient of determination R^2value is an indicator of the strength of the linear relationship between the observed and simulated values. It ranges from 0.0 to 1, with higher values indicating better agreement. The $R^2$is calculated with Eq. (36).

$$\mathbf{R^2} = \frac{\left[\sum_{i=1}^{n}\left(Q_i^{sim} - Q_{mean}^{sim}\right)\left(Q_i^{obs} - Q_{mean}^{obs}\right)\right]^2}{\sum_{i=1}^{n}\left(Q_i^{sim} - Q_{mean}^{sim}\right)^2\left(Q_i^{obs} - Q_{mean}^{obs}\right)^2} \tag{36}$$

Where,Q_{mean}^{sim}= mean of simulated values; Q_{mean}^{obs}= mean of observed values
The PBIAS (percent bias) measure the average tendency of the simulated data to be larger or smaller than their observed counterparts. A positive value indicates a model bias toward underestimation, whereas a negative value indicates a bias toward over estimation(Hoshin Vijai Gupta et al., 1999).

3.2. MATERIALS

To finalize the paper, the following materials were used according to their requirements:

3.2.1. ArcGIS 9.3

ArcGIS was used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, managing geographic information in a database and execution of GIS processing tools (such as clipping, overlay, and spatial analysis).

3.2.2. SWAT2009

SWAT model was used for setting up the study project, delineating the study area, analyzing HRU, writing all input tables, editing inputs and simulating all inputs. Then after, it was used to simulate and predict the long-term impacts of basin scale water, sediment and nutrients load by discretizing dominant land use, soil and slope into homogeneous hydrologic response unit.

3.2.3. SWAT-CUP2012

SWAT-CUP2012 was used to calibrate the model for better parameterizing the model for a given set of local conditions, There by carefully selecting values for model input parameters within their respective uncertainty ranges by comparing the model prediction for the existing observed data under the same conditions to minimize the probable uncertainty using SUFI2 algorithm installed in the SWAT-CUP.

3.2.4. Google Earth

Google Earth was used to display satellite images of the study area in varying resolution to see things such as reservoir profile, orientation, and relative location, surrounding environment, outlets and dam axis perpendicularly or at an oblique angle in 3D dimension.

3.2.5. SPSS20

SPSS20 which is a statistical tool was used to analysis, manage and document the hydro-meteorological data, especially for filling the missed data via regression.

3.2.6. Excel

Microsoft Excel was used in this paper to organize data manipulations like arithmetic operations, display data as line graphs, histograms and charts and with a very limited three-dimensional graphical display, allows sectioning of data to view its dependencies on various factors for different perspectives (using pivot tables and the scenario manager).

3.2.7. PcpSTAT

PcpSTAT was used to calculate statistical parameters of daily precipitation data such as average total monthly precipitations, standard deviation for daily precipitation, skew coefficient for daily precipitation, probability of wet day following dry day, probability of wet day following wet day and average days of precipitation used by weather generator of SWAT models (userwgn .dbf).

3.2.8. Dew02

Similarly, the dewo2 was used to calculate average daily dew point temperature (minimum and maximum daily temperature data), humidity and dew point per month using daily data to result a more precise output.

3.2.9. Endnote

EndNote is an online search tool .It was used to search online bibliographic databases, retrieve the references,and import data files saved from a variety of online services;for storing, managing, and searching for bibliographic and for organizing figures including charts, tables, pictures, and equations. Here, it was used to insert references both in text and in main references.

3.2.10. OriginpPro

Origin Project can function as an Analysis Template for performing analysis on multiple sets of data. It combines data, notes, graphs, and analysis results in one flexibly structured document. In this paper, it was used to indicate results using graphs.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1. Land Uses

The Land use data which has been taken from Ministry of Water, Energy and Irrigation was already geo processed and so it was as it was.Based on land use data obtained,the following five land use class was derived: Agricultural Land Generic (AGLI) (Agriculture, Agro-silvi-cultural, and Agro-pastoral),Forest Evergreen (FRSE) (Silvi-culture),Forest Mixed (FRST) (Forest with coffee under and coffee under tree),2.89%,Pasture (PAST) (Grass land), Urban (URBN) (Residential) as shown in the Figure (18). According to this assessment, the large part of the area was covered with agricultural activities which account around 91.46% land use coverage which was followed by mixed forest (2.89%),pasture (2.75%),forest evergreen (2.69%) and residential (0.21%) respectively. In the catchment, although water body exists physically, it was not classifiedin the land use raw data took from the organization and hence not incorporated here.

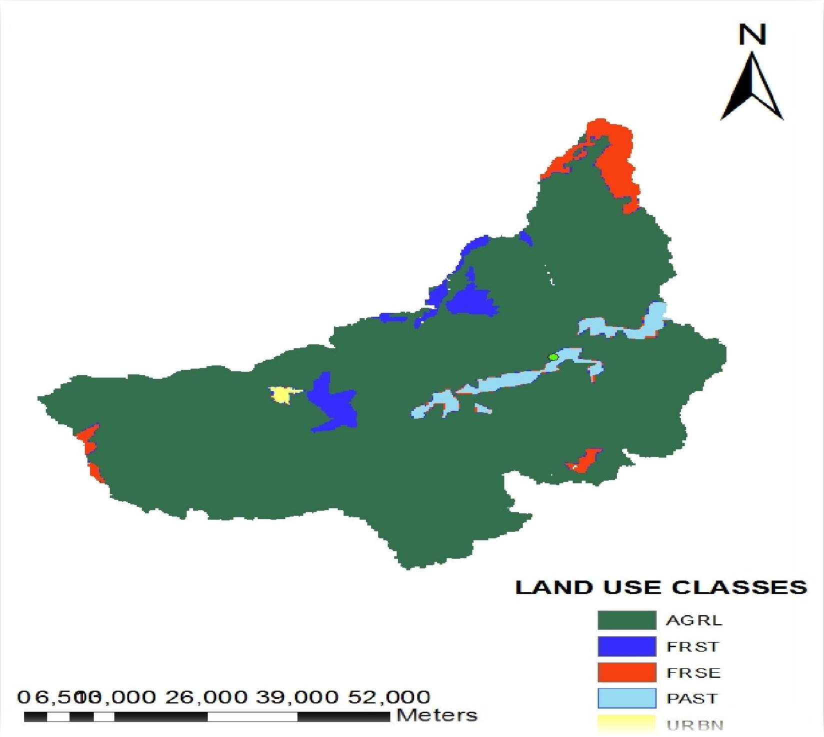


Figure 18: Land use types of the study area

4.2. Soil Types

The soil map for the study area was produced from the FAO-UNESCO Digital Soil Map of the World (DSMW) having 1km grid resolution revised and re-examined on 2007 (FAO-UNESCO, 1995).Accordingly, for the study area two dominant soil types was identified, Eutric Nitosols coded as Ne13-3b and Eutric Vertisols Ne12-2c.Large part of the catchment, like Jimma weredas named as SekaChokersa,Dedo and some part Kersa was covered with Eutric Nitosols which covers around 65% of the area and followed by Eutric Vertisols, covers TiroAfata and small part of Dedo and accounts around 35% of the respective area as clearly seen in Figure (19). The properties of these soils wereconsidered up to twosoil layers depth (0-300mm) and (300mm-1000mm). Further soil properties such as particle-size distribution, bulk density, organic carbon content, available water capacity and saturated hydraulic conductivity) were obtained from map window SWAT database(Reynolds et al., 1999).

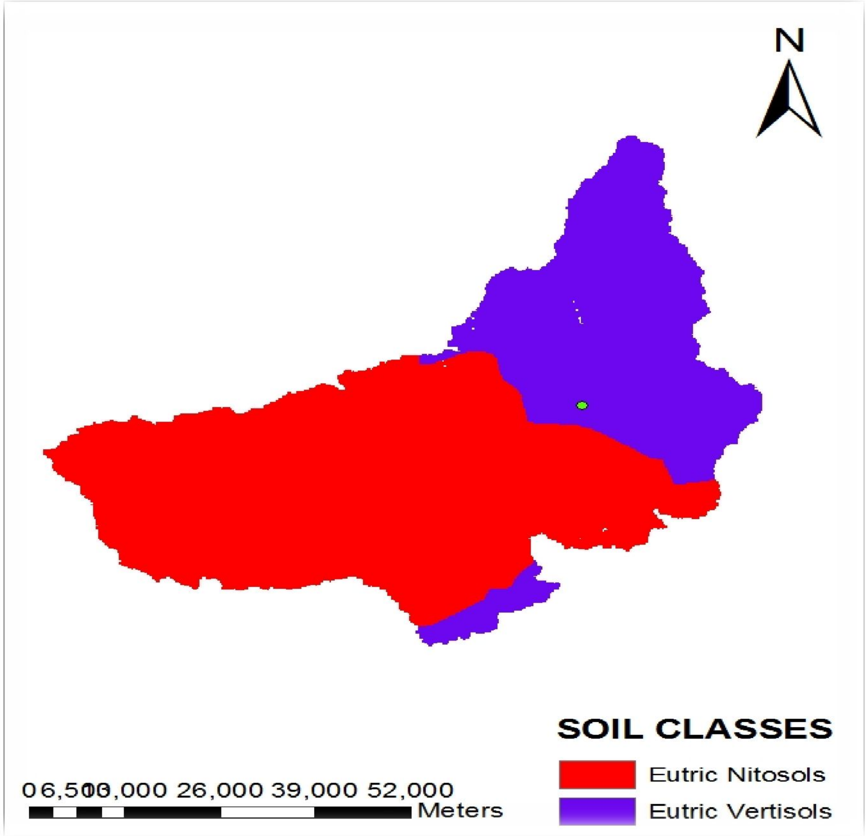


Figure 19: Dominant soil types of study area

4.3. Slope Classes

The overland slope derived from DEM was classified into three groups (0-10%), (10-20%) and above 20% for sake of assessing level impact of these slope classes on initiation of erosion responsible for sediment, nutrient and agricultural chemicals load to the nearby water resources. Accordingly, the findings of this assessment imply that high amount of P and sediments were exported via surface runoff from sub-basins found around the edge of the catchment having high elevation or slope greater than 20%. These areas incorporates boundary edge of Jimma zone weredas' such as Seka Chekorsa,Dedo,TiroAfata and Seka as figured in the Figure (20).

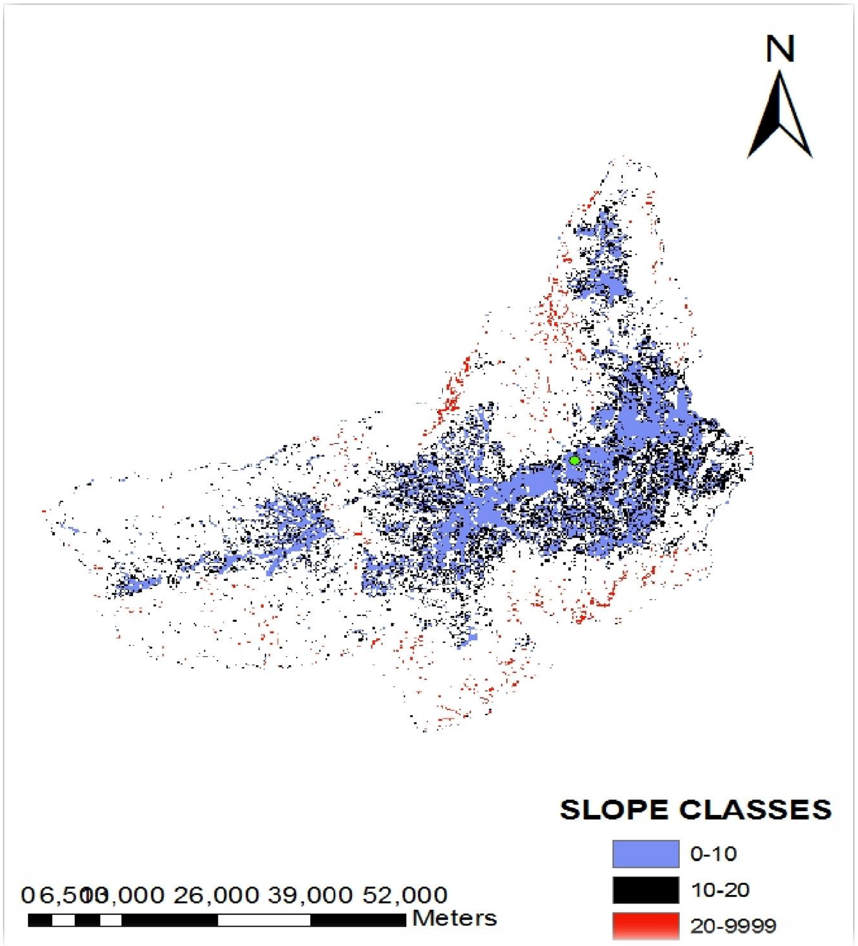


Figure 20: Slope classes of study area

4.4. Sensitivity Analysis

Sensitivity analysis was done on 27 parameters that was already incorporated into the model using SWAT2009 following the procedures figured in Figure (14). The main purpose to undergo this was separate those most influential parameters that determine the rate of change of output of the model with respect to the changes in the model input.Further, to determine parameter for which it is important to have more accurate value and understand the behavior of the system being modeled.

Accordingly, all parameters were analyzed and ranked according to(Lenhart et al.,2002)and found that 9 parameters, CN2 (curve number), ALPHA_BF (base flow alpha factor), BLAI (leaf area index),GW_REVAP (ground water "re-vap" co-efficient),REVAPMN (threshold water depth in the shallow aquifer for "revap"), ESCO (soil evaporation compensation factor), SOL_AWC (available water capacity) and CANMX (maximum canopy storage) were considered as the most sensitive parameters as shown in Table (2). Prediction of flow in is highly sensitive to curve number (CN2) and least sensitive ALPHA _BF which have direct sensitivity impact on P prediction.These flow parameters were then adjusted within the given limits to initiate auto calibration.

Table 2: Sensitive parameters along with their P-value

Parameters	File	P-value
CN2	.mgt	0.735
ESCO	.bsn	0.426
GWQMN	.gw	0.172
BLAI	.crop	0.157
SOL_AWC	.sol	0.143
CANMAX	.hru	0.142
SOL_Z*	.sol	0.109
REVAPMN	.gw	0.0505
ALPHA	.gw	0.0298

* rejected by SWAT-CUP during calibration.

4.5. Calibration

The SWAT flow predictions were calibrated against monthly average flows with those sensitive parameters ordered in the Table (2) except SOL_Z* which was unrecognized by the SWAT-CUP2012 calibration sub-model. For doing this, the flow data from 2001 to 2002 was used to initiate the model and those data from 2003 to 2008 was used for model calibration at Asendabo gauging station. Result in the Figure (21) indicates that the model under estimate the observed flow which implies model's inability to simulate the extreme storm events was inherited from the weakness of the SCS curve number method for estimating surface runoff. The model's simulation matches fairly well with measured flow with NSE and R^2 equal to0.58 and 0.85 respectivelyas shown by flow hydrograph in Figure (21) and scatter plot in the Figure (22). It may be concluded that SWATwas unable to simulate extreme hydrologic conditions (both above and below outliers). In addition, it should be noted that the subsurface contribution of water from outside the watershed into the watershed could cause significant errors in model predictions.Here, since there was no recorded P flow data at the country level, the P did not calibrated but it was assumed that since P in various forms was exported and loaded to the nearby water resources via runoff or flow, calibrated stream flow means simulatingPbut simulatedP was considered as calibrated P to generalize or talk about catchment level P impact in this study.

Table 3: Calibration parameters,range and best fitted value

Parameters	Range	Fitted value
CN2	35-98	61.15
ESCO	0-1	0.995
GWQMN	0-5000	2625
BLAI	0.5-10	8.43
SOL_AWC	0-1	0.825
CANMAX	0-100	41.5
SOL_Z*		
REVAPMN	0-500	327.5
ALPHA	0-1	0.875

*: rejected by SWAT-CUP during calibration

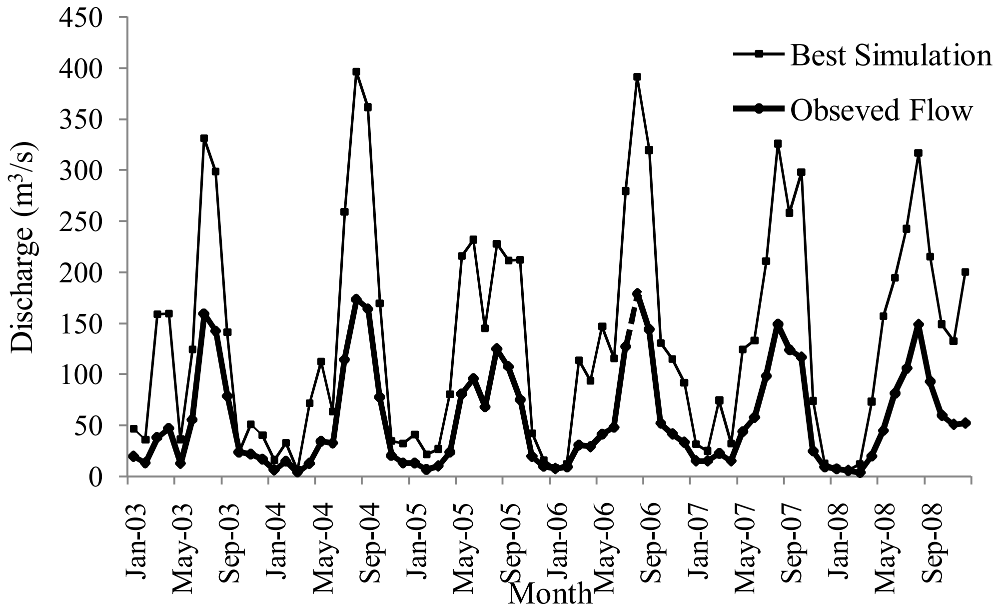


Figure 21: Relations between observed and simulated flow

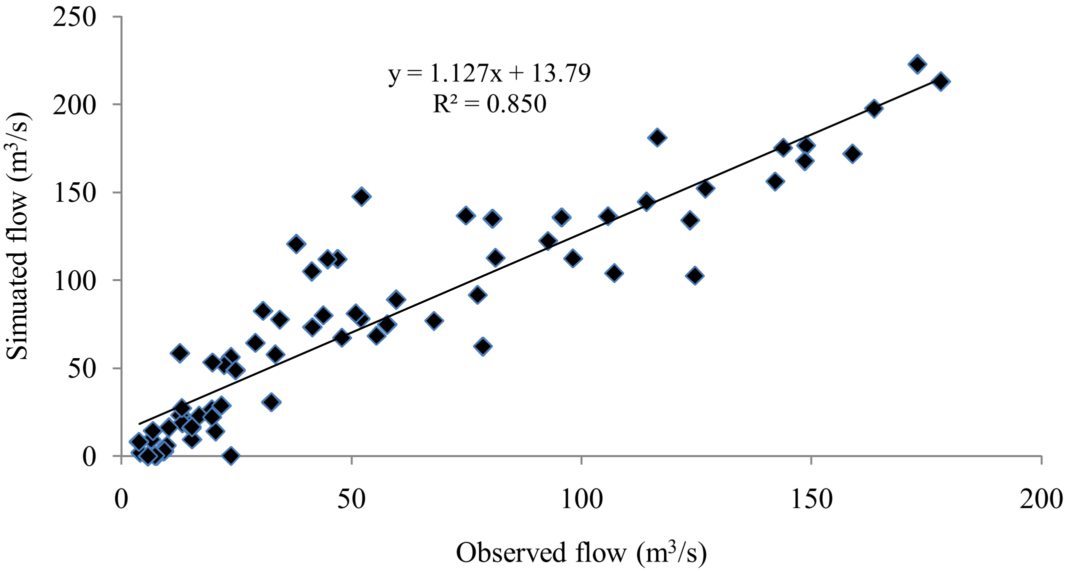


Figure 22:Co-relationship between observed and simulated flow

4.6. Validation

For the validation period 2009-2012, the observed monthly flows showed satisfactory agreement with simulated monthly flow as indicated by NSE and R^2 values which is equal to 0.52 and0.81 respectively as shown in stream flow hydrograph in Figure (23) and scatter plot in Figure (24). Similarly, in model validation, the model over validates the simulated flow and under validate observed one throughout entire validation period. This might be happened due to inability of the model to simulate extreme hydrologic events, extra subsurface flow from surrounding areaand weakness in the SCS method.

Table 4: Validation parameters, range and best fitted values

Parameters	Range	Fitted value
CN2	35-98	61.145
ESCO	0-1	0.995
GWQMN	0-5000	2625
BLAI	0.5-10	8.43
SOL_AWC	0-1	0.83
CANMAX	0-100	65.5
SOL_Z*		
REVAPMN	0-500	207.5
ALPHA	0-1	0.88

SOL_Z*: rejected during validation by model

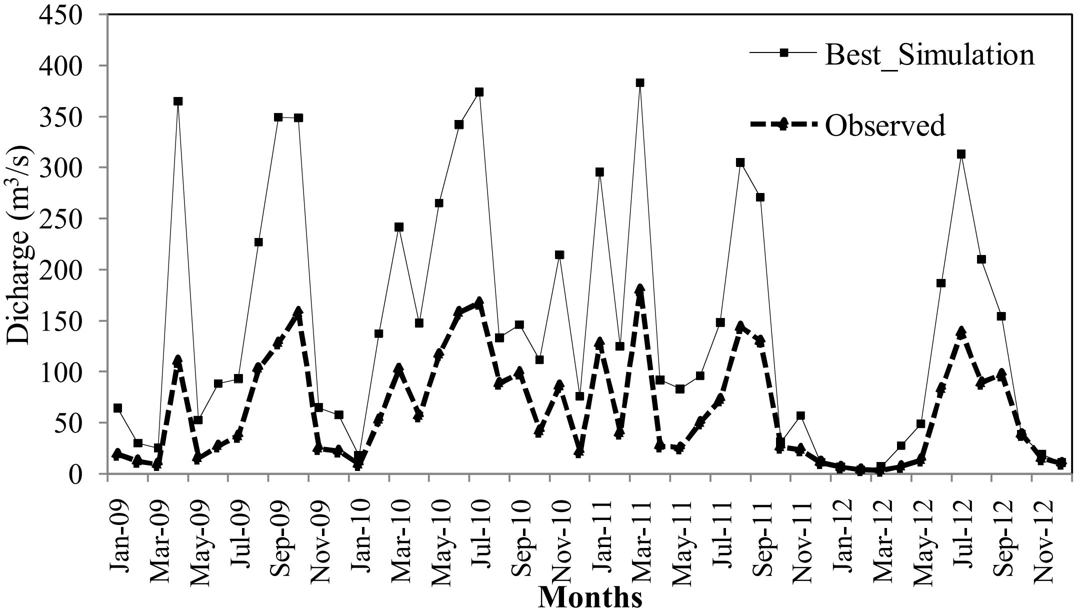


Figure 23: Relationship between observed and simulated flow

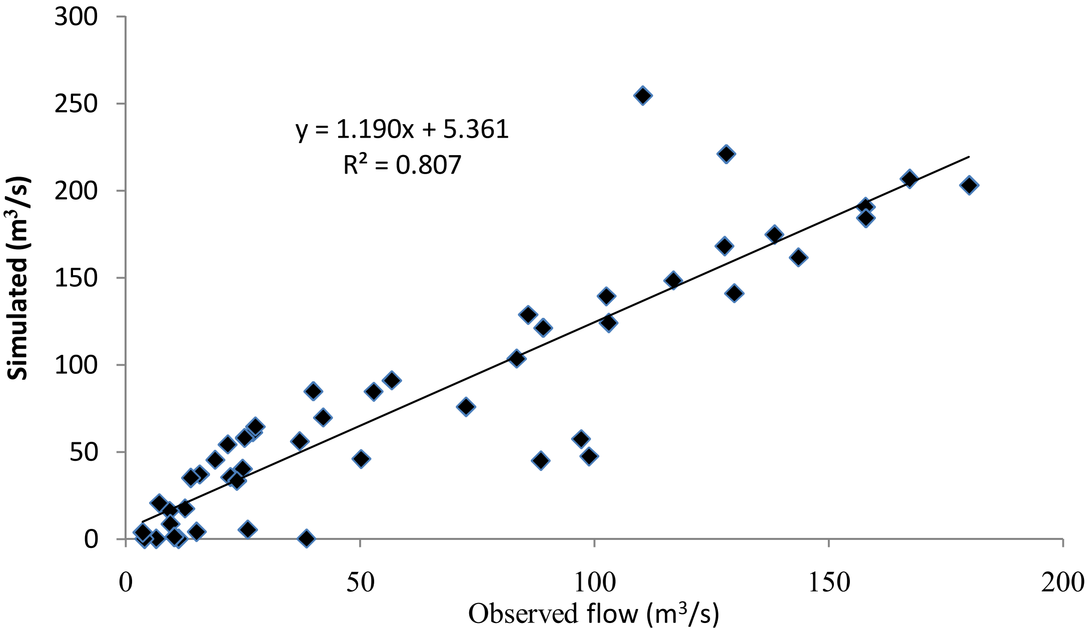


Figure 24: scatter plot between observed and simulated flow

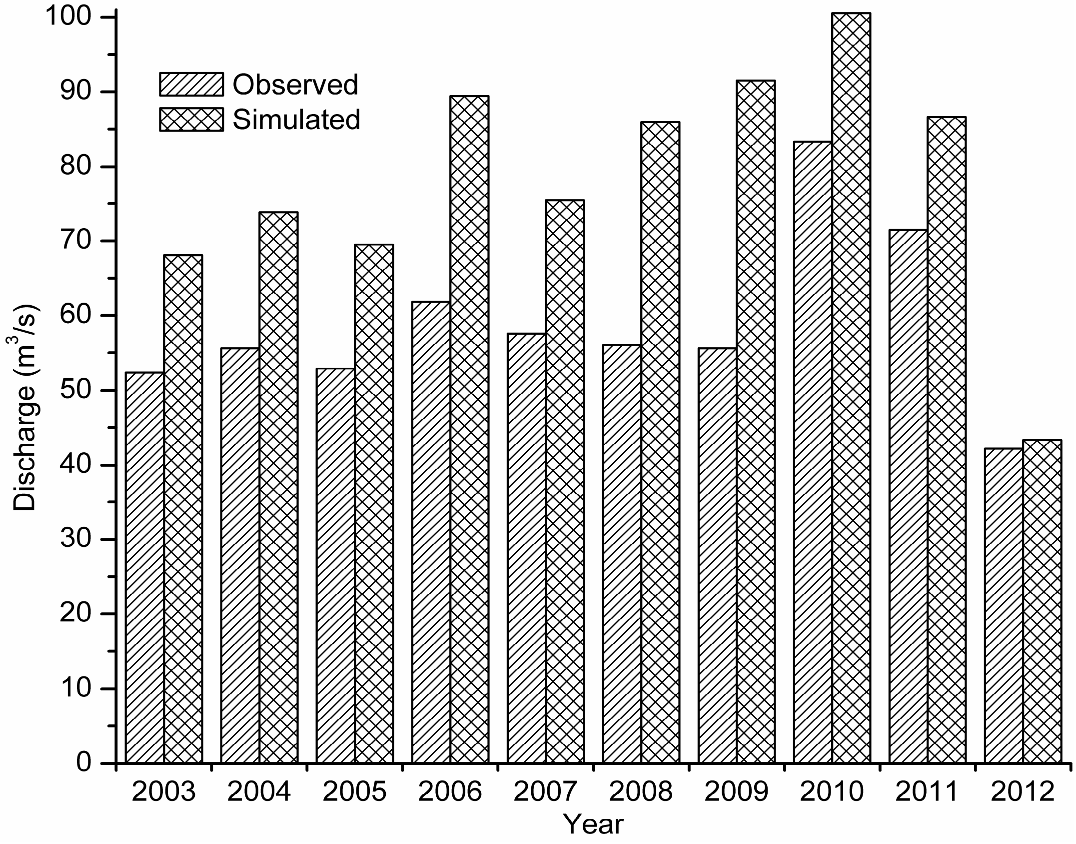


Figure 25: Hydrograph of observed and simulated stream flow

Schomberg et al., (2000)was applied a SWAT model on Minnesota watershed having drainage area of 3697km^2 to simulate stream flow with varying period and found 0.49 and 0.58 for NSE and R^2 respectively for calibration and 0.65 and 0.52 for validation period. In addition, Zhang et al., (2007) was also applied this model on Luoher river basin (China) having a drainage area of 5239km^2 to simulate stream flow from 1992-1996 for calibration and 1997-2000 for validation. He got NSE = 0.64, R^2 = 0.82 during calibration and NSE =0.75, R^2 = 0.86 during validation. Both of them concluded that the acceptance of the model for the stream flow simulation for both drainage areas based on the performance evaluation guidelines under existing hydrological conditions.

Similarly, for this assessment SWAT model was also applied on Gilgel Gibe I catchment having drainage area of 4149.5km^2(414950 ha) to simulate stream flow from 2003-2008 for calibration and from 2009-2012 for validation and got NSE = 0.58, R^2 = 0.85 during calibration,NSE = 0.52,R^2 = 0.81 during validation under existing conditions. According to the literatures reviews and model performance evaluation criteria, the model is acceptable to be applied over the study area to predict variability of environmental and hydrological conditions.

4.7. Surface Runoff

At catchment scale, surface runoff is the major agent for driving sediment, nutrients and agricultural chemicals towards the nearby surface water resources. As indicated in Figure (31), the maximum amount of surface runoff generated from the catchment was 5.3×10^{4} mm on 2009 (20.2%) and the minimum runoff generation was seen on 2003 which was about 1.3×10^{3}mm (4.9%).The possible reasons might be the slope conditions, change in hydrologic conditions, alteration of land use, land cover of the, soil physical and chemical nature and level of effective watershed management methods applied over the area. Consequently, it would be advisable to evaluate the existing management conditions and propose effective means of the catchment conservation policy.

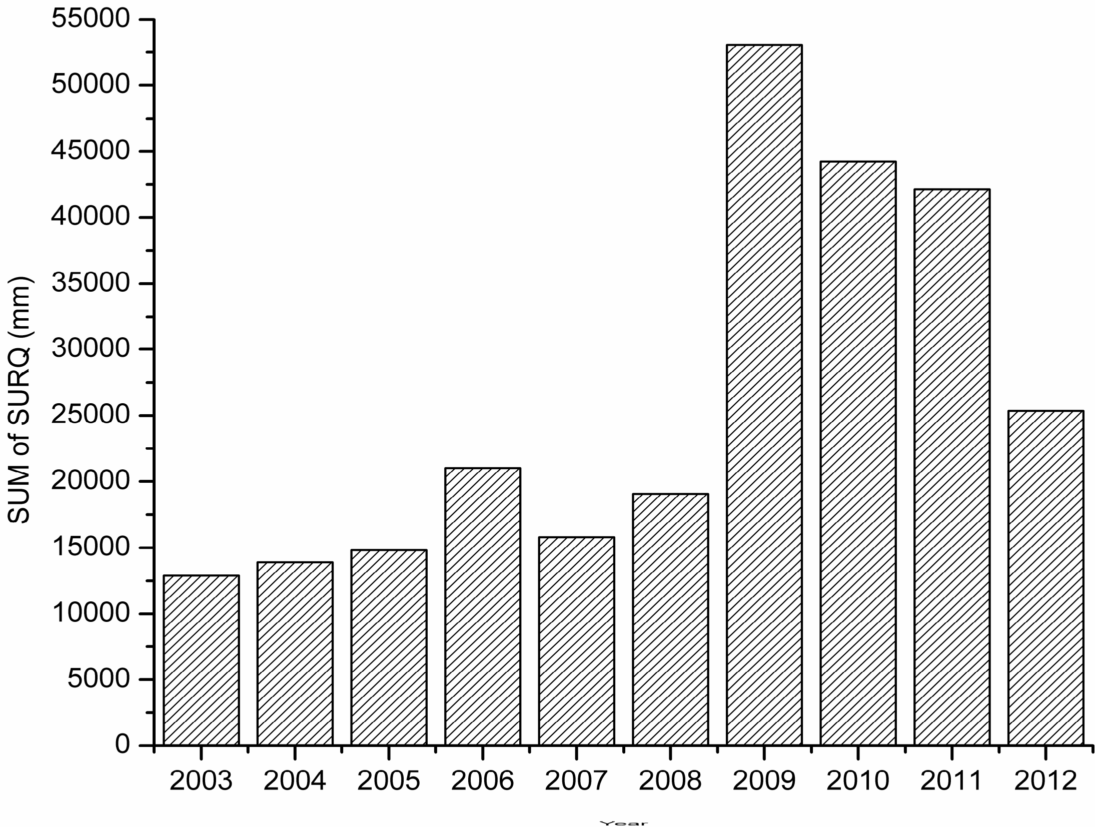


Figure 26: Yearly surface runoff

4.8. Sediment Yield

At watershed level, the sediment is the main sinks for the particulate (adsorbed) form of P which was exported to nearby reach through runoff. Based on the model simulation output, maximum amount of sediment yield was observed on 2009 which was quantified around 2.9×10^{5} metric tons per hectare (21.3%) and minimum amount was investigated on 2003 which was about 6.2×10^{3} metric tons/year (4.4%) as depicted in the Figure (32). This suggests that the high and low amount of P in the form of sediment was loaded to the nearby water resources via surface runoff on 2009 and 2003 respectively as indicated in the Figure (29). So, it would be better still to do more works on watershed conservation plan to reduce the severe impact resulted by surface runoff.

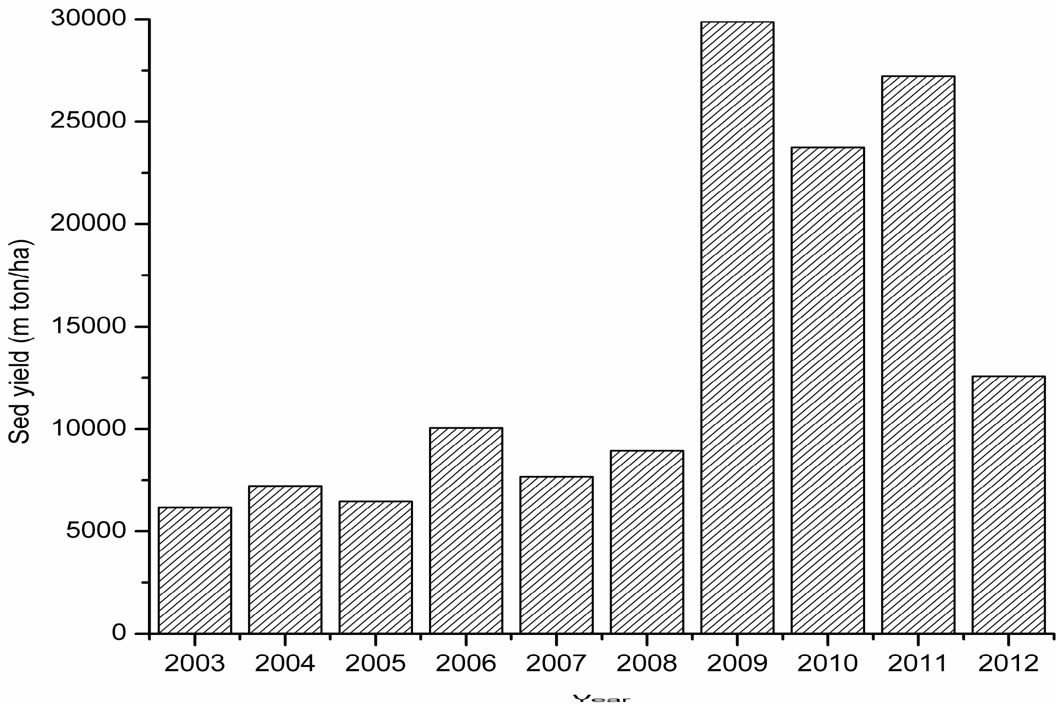


Figure 27: Yearly sediment load

4.9. P Transport Pathways

SWAT monitors six different pools of P in soils, three pools in organic forms of P while the other three pools organic pools of fresh organic P associated with crop residue and microbial biomass while active and stable organic pools related with soil humus. The organic P associated with humus is portioned into two pools to account for the variations in availability of humic substance to mineralization. Also, soil inorganic P is divided into solution, active and stable pools. Unlike, N which is highly mobile, P solubility is limited in most environment combines with other ions to form a number of insoluble compounds to that precipitate out of solutions .This characteristics contributes to build up of P near the soil surface that is readily for transport in surface runoff. Surface runoff is the major mechanism by which P is exported from most catchments (Neitsch et al., 2009).

Based on the scientific facts and considerations, this assessment investigates that P mainly exported from the area in the form of Org P attached to sediment and transportedto the nearby water resources in the form of particulate. It was quantified as 1×10^6 tons/year which holds around 77.3% transport mechanisms. The main reasons behind was that since the catchment dominantly covered with various pants and agriculturally intensive, production P in the form of Org P which resulted from crop residues, animal biomass, humic substances and some transformation was so high. Following this, Sediment attached P (adsorbed) which accommodates around 2.8×10^5 tons/year (22.1%) of the transport paths. Lastly, the soluble form of P which was around 7.8×10^3 tons/year (0.6%) was the least transport mechanism as indicated in Figure (26). For the three forms of P transport surface runoff was the dominant means of transport agent. Hence it would better to manage the area to reduce the amount of surface runoff initiation.

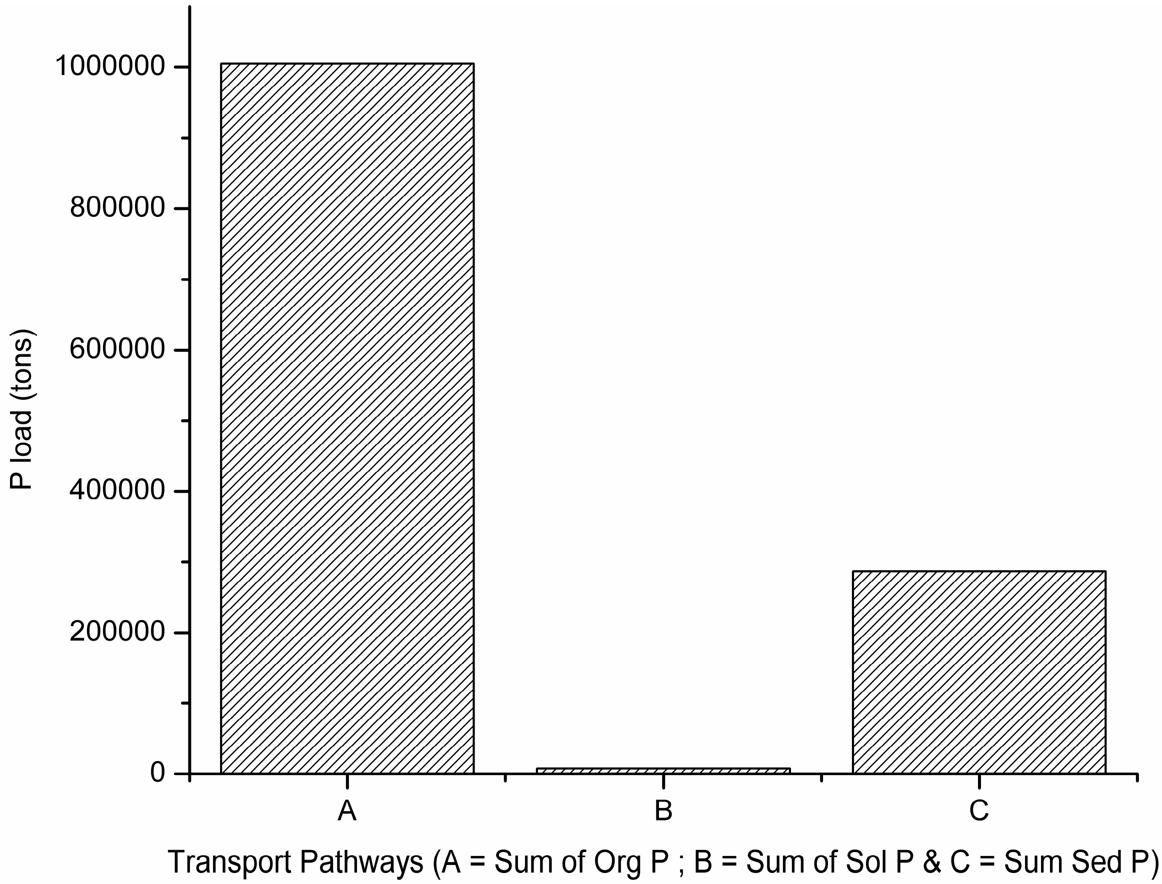


Figure 28: Different forms of P transport pathways

4.10. P Load

4.10.1. Org P

According to this assessment finding, the Org form of P loaded to the water resources was quantified around 3.5×10^{5} tons/year (35.3%) which was detected on 2009 and the least Org P load observed on 2007 which was about4.7 $\times 10^{5}$tons/year (4.7%)as shown in the Figure (27). Themajor facts behind the rise of Org P load on 2009 was generation of high amount surface runoff and sediment load resulted due to high erosion from highly elevated area around the edge the catchment boundary,dominantly near Seka Chekorsa, Dedo and some part of TiroAfataWereda.

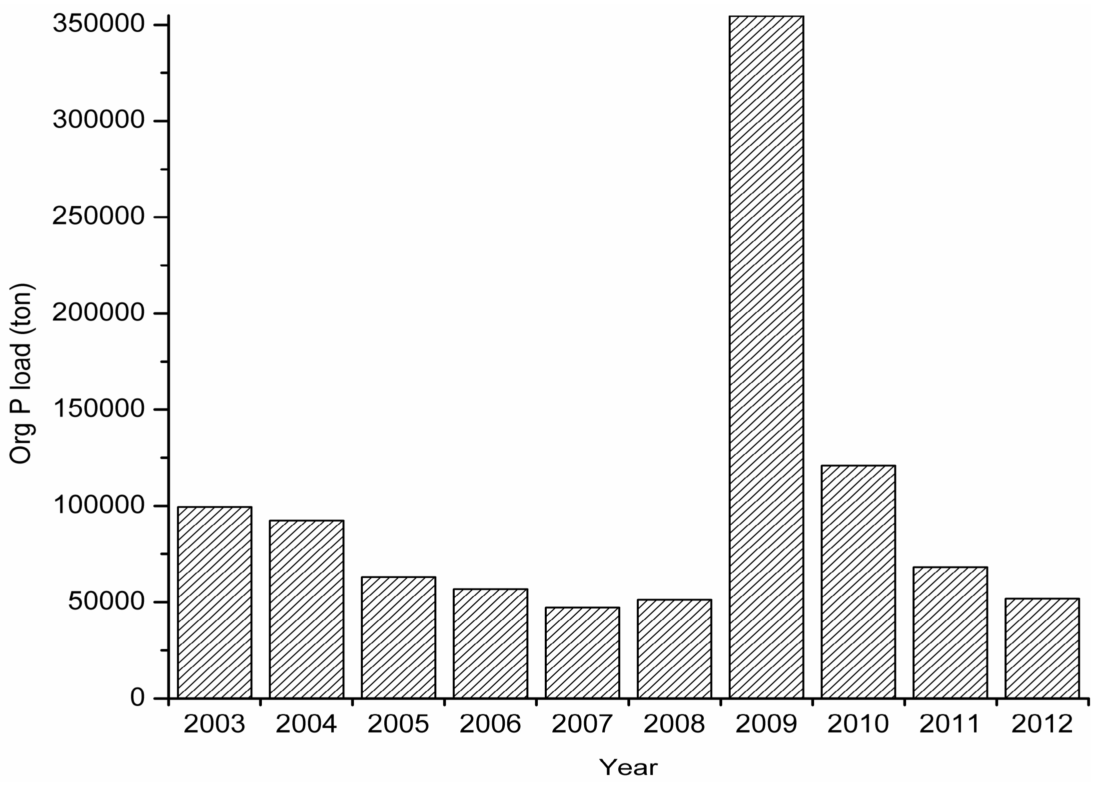


Figure 29: Yearly Org P load

4.10.2. Sol P

With respect to Soluble form P, large amount of sol P was loadedon 2009 which was around 1.9 × 10^3 tons/year (23.7 %) with minimum amount on 2012which about3 × 10^2 tons/year (3.9%)as shown in the Figure (28).The main reasons behind the increment of Sol P on this year largely due to high surface runoff as figured in the Figures (26)Further, increment in quantity of fertilizers used, the rate of applications of the fertilizers, the usage of additional manures/residues and corresponding weak management practices might befacilitating the rise of soluble P. As the soluble form of P is directly parallel with surface runoff, it would be suggestible to conserve the area to reduce the amount and impacts resulted by the runoff.

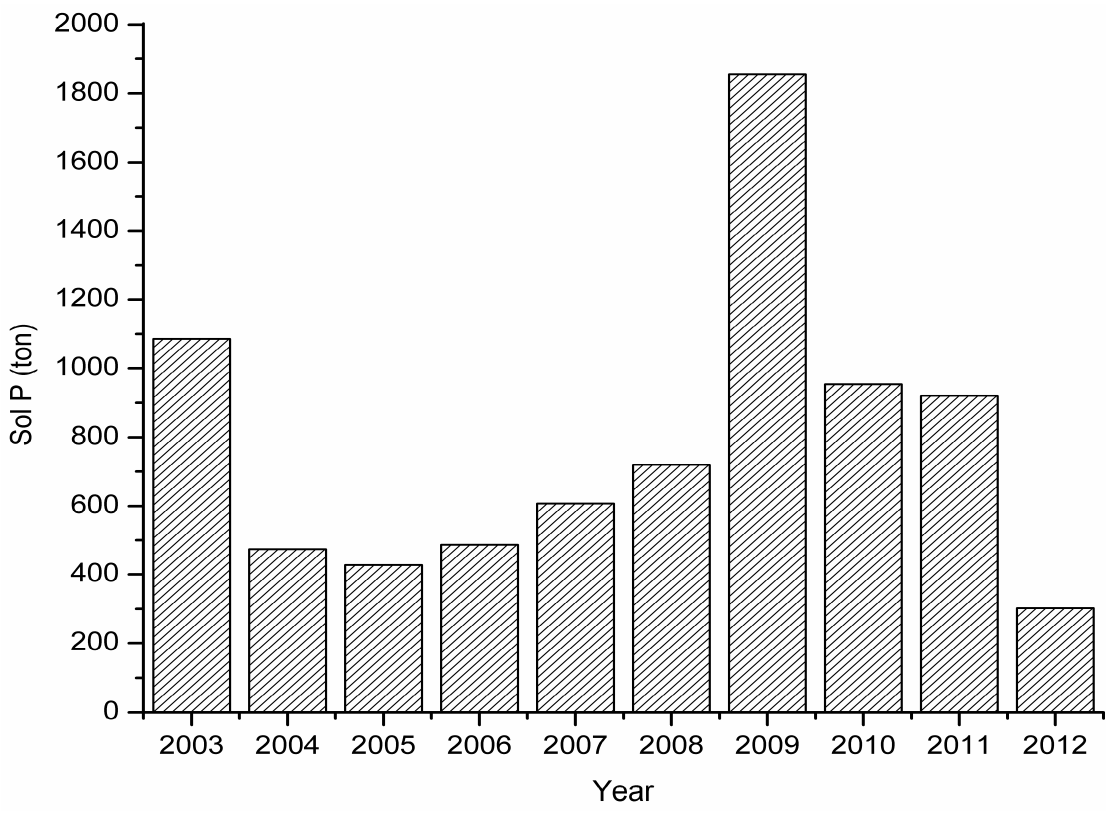


Figure 30: Yearly Sol P load

4.10.3. Sed P

Sed P is a mineral form of phosphorus that attached to sediment and transported by surface runoff towards the nearby reach. According to this assessment, the large amount of Sediment form of Pwas loaded on 2009 which holds around 8.4×10^{4}tons /year (29.5%) load. On the other side, the small quantity of P was exported from the area on 2007which was quantified as 9.1×10^{3}tons year (3.2%)load. This was happened that in the same year there was high amount of surface runoff and hence large magnitude of sediment load as shown in the Figures(26 and 27). Further, amountof fertilizer applied, rate of applications, amount and rate of manures consumptions and catchment management conditions could be another important factors for the rise. Therefore, since surface runoff is a prevalent mechanism of sediment load, it would be better to apply best conservation practices over the area by awaring communities residing there.

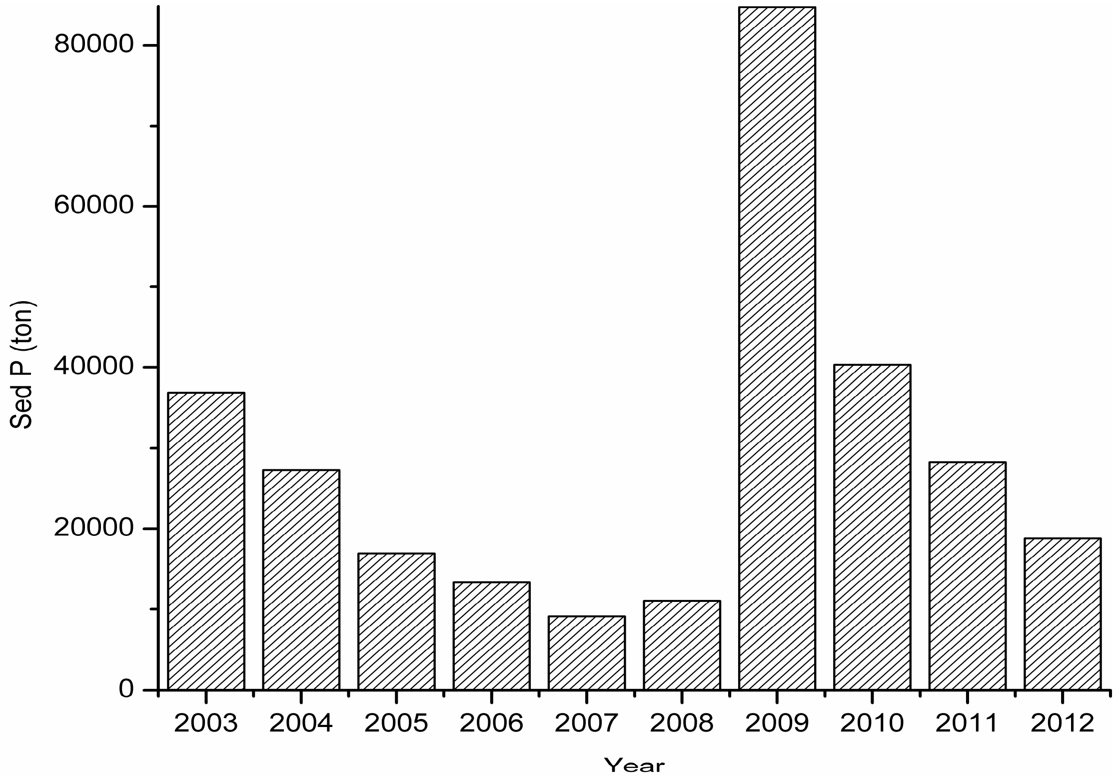


Figure 31: Yearly Sed P load

4.10.4. Total P

According to Haygarth et al. (2000), the three main pathways through which mobilized P can reach surface waters are surface runoff, subsurface flow and vertical flow to the groundwater–surface water interaction zone. These pathways depend on rainfall pattern and duration and the interval between rainfall events, natural and artificial drainage characteristics also play a key role. The highest risk of P transport to a water body arises when a significant source of P has good hydrological connectivity to surface waters and such areas are known as critical source areas as reported by Shapley et al. (2003b).

Hooda et al. (1997), measured P losses to stream water in agricultural catchments in Scotland, observing higher losses from agricultural intensive catchment in the form of particulate via surface runoff (overland flow).In addition,Heath Waite et al. (2000)found that particulate P is the most important fraction during storm runoff events from the agricultural field. Steegen et al.(2001), also proves that particulate P is highly related to the level of sediment erosion in a catchment that depends on catchment morphology, vegetation and land use.Based on the literatures reviews and physical condition of study area, the findings of this assessment implied that the maximum load of total P was discovered on 2009 which was about 4.4×10^{5} tons/year (33.9%) and minimum load was seen on 2007 that was around 5.69×10^{4} as figured in the Figure (32). The prevalent mechanism of load from the study area to nearby water resources was in the form of particulate agented by surface runoff.

The responsible causes for the rise of total P load on 2009 was directly associated with increment in surface runoff and hence rise in sediment load as shown in the Figure (26 and 27). Further, the following factors might be a significant contributors; lack of catchment management practices , increment of quantity of fertilizers used, unregulated rate applications of that fertilizers, minimum fixations of P around root zone, the increment of the rate and amount of decompositions of humic substance and microbial biomass over the area, the expansions of agricultural land throughout the area, the increment of precipitation and temperature intensity which facilitates transportations and reaction rate over the area and additional usage manures by resident farmers. Hence, it would be better to evaluate and prioritize these causes and take appropriate action to manage the area in integrated manner.

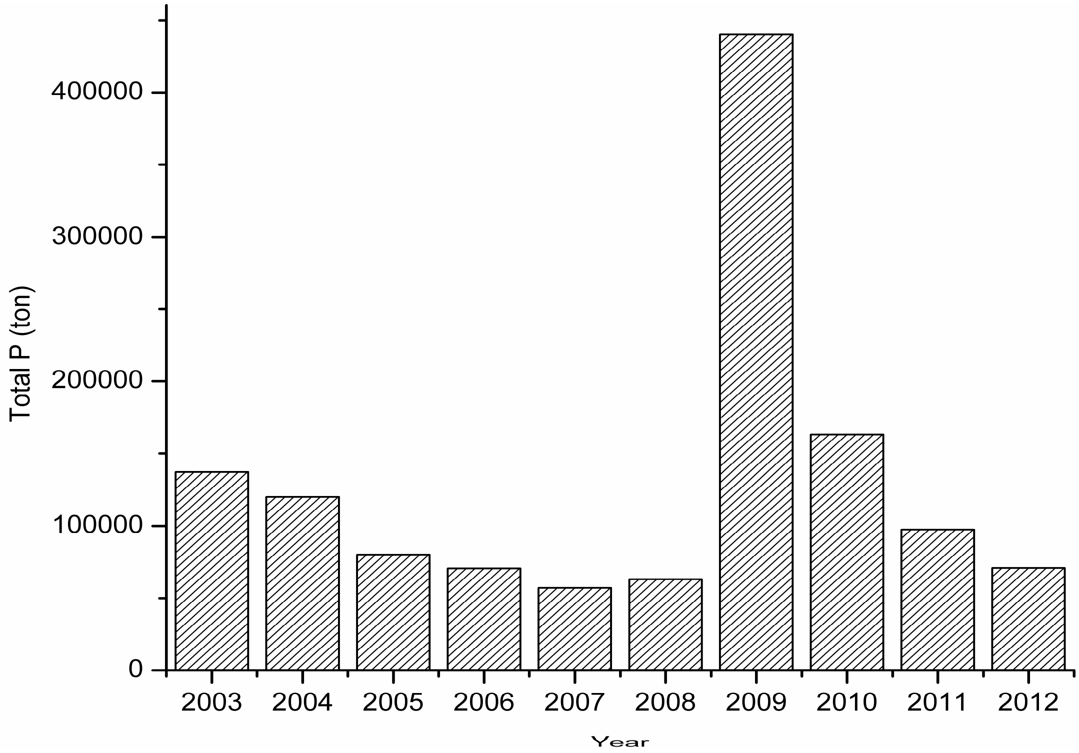


Figure 32: Yearly total P load

4.11. Prone Sub-basins

SWAT model delineate and classify the study area into 264 HRUs and 43 sub-basins as indicated in the Figure (33). Each sub-basin had itsown loading contribution of different forms of P to the nearby reach as clearly figured and discussed in the Figures (34, 35, 36, 37 and 39).

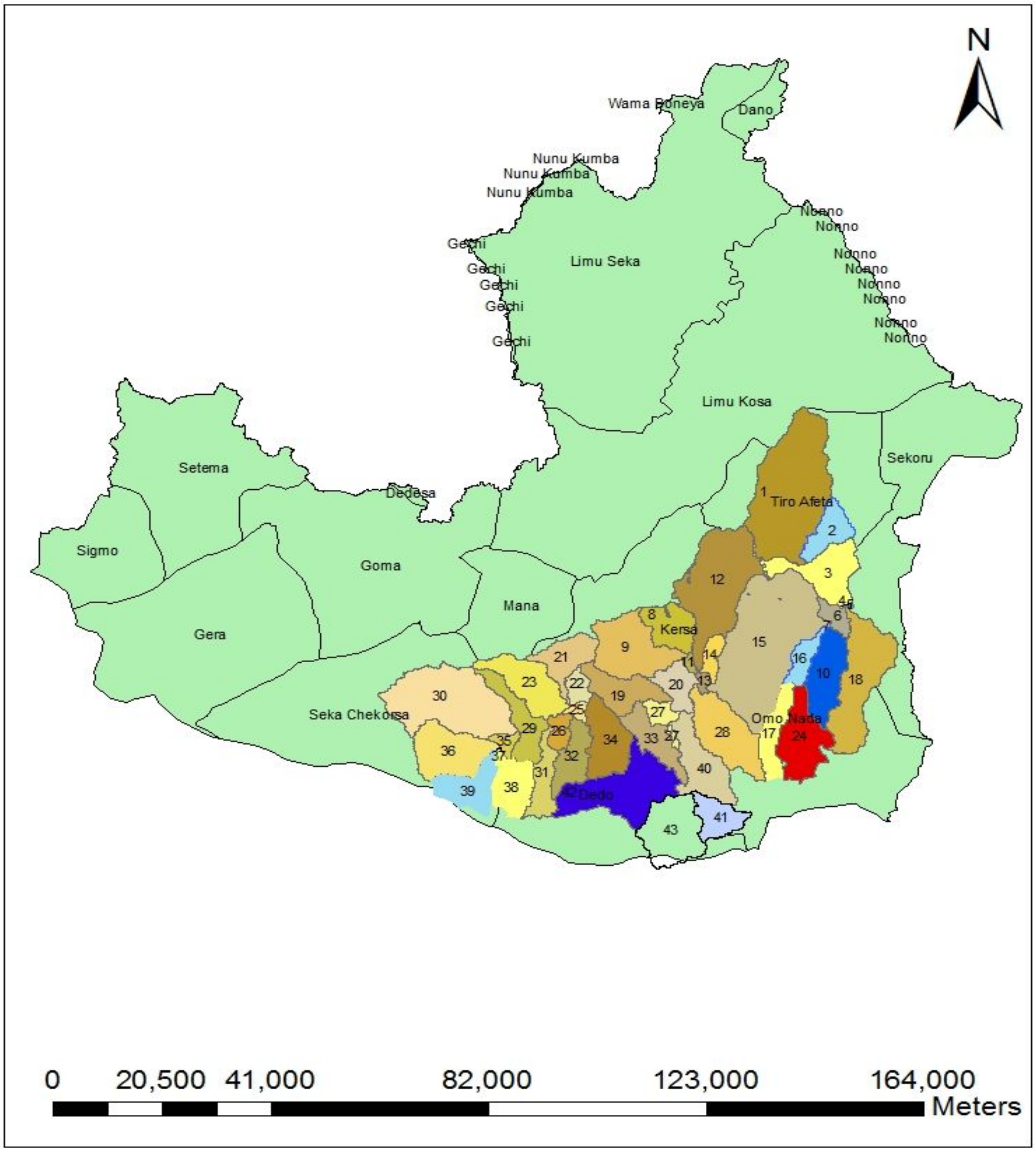


Figure 33: Prone sub-basins location

4.11.1. Runoff

As shown in Figure (34), large amount of surface runoff was initiated from sub-basins number 10 followed by sub-basin number 3 and 16 which accounts 2.51, 2.50,and 2.49% of P loadcontribution relative to the rest40 sub-basins,respectively. This might happened due to: change in LULC, highly elevated area, soil types, surrounding area LULC pattern and hydrological conditions over the area.

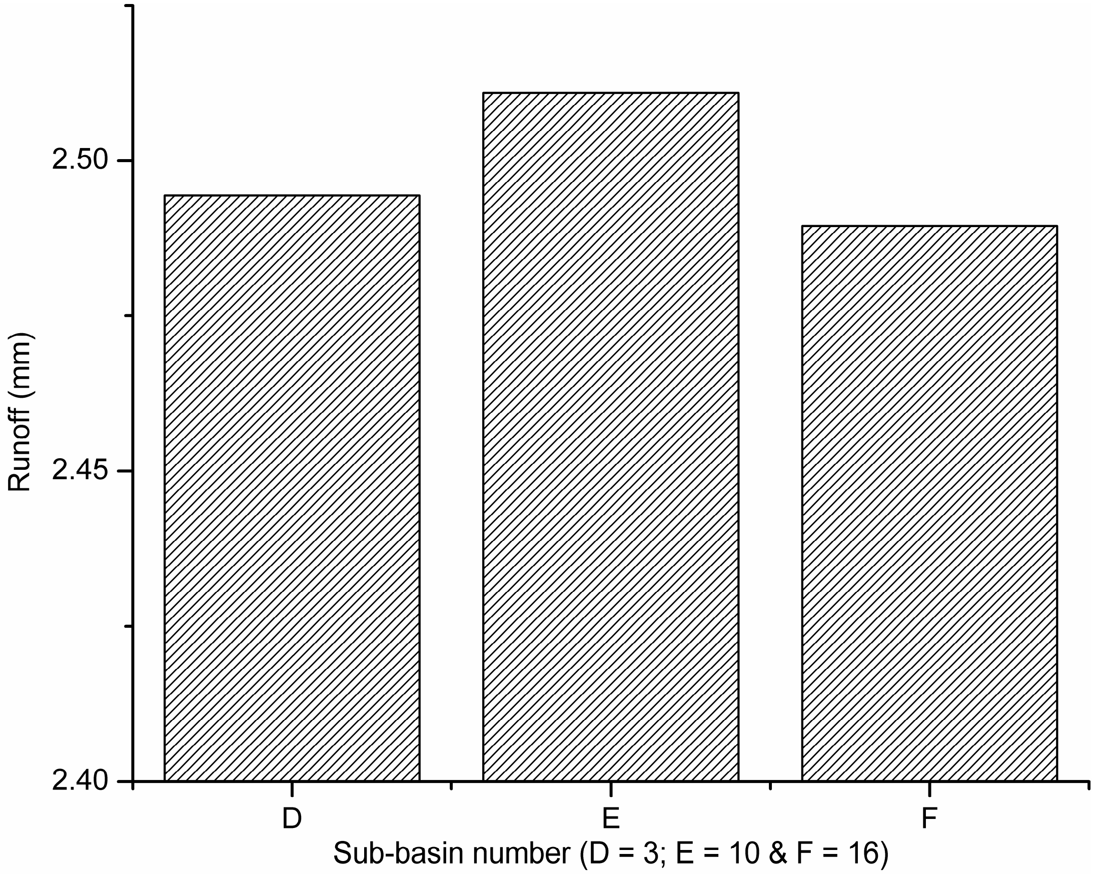


Figure 34: High runoff prone sub-basins

4.11.2. Sediment

Based on the Figure (35), the maximum amount sediment yield was observed from sub-basins number 41, 37 and 43 which hold 4.89, 6.12 and 4.45% ofP load with respect to the rest sub-basins. The main reasons behind why these areas contribute high P load might be; due to steep slope, soil physical and chemical properties, farming rate and pattern, LULC change, degreeof conservation practices, intensity of rainfall, neighborhood area conditions and associated hydrological events. Therefore, especial attention should have to give to means managing these factorsto combat the effects.

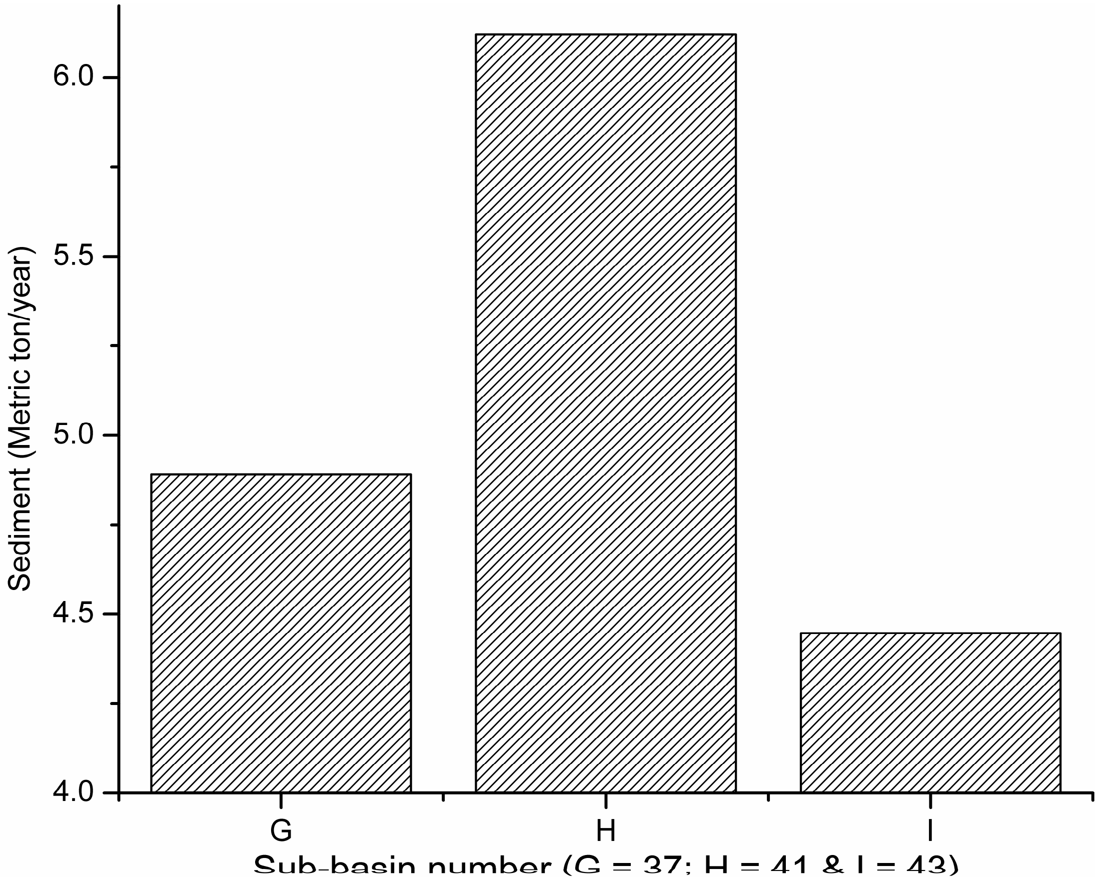


Figure 35: Prone sub-basins loading high sediment

4.11.3. Org P

At sub-basins level, the high amount of Org form of P was initiated from sub-basins number 37, 38, 39 as indicated in the Figure (33)and summarized in Figure (44). The possible main causes behindcould be due torise in slope (> 20%) which exposed the area to high runoff down to the slope.Further, the area management practices might be weak, high generation of plant, animal biomass and humic substance initiation might be greater. In addition, the area soil type coverage was dominantly Nitosols which is weak in infiltration and facilitates the surface runoff initiation. The land use land cover of the place was mainly agricultural generic and forest evergreen which had its own contribution in generation of high P plant biomass and humic substance and extreme hydrologic conditions.

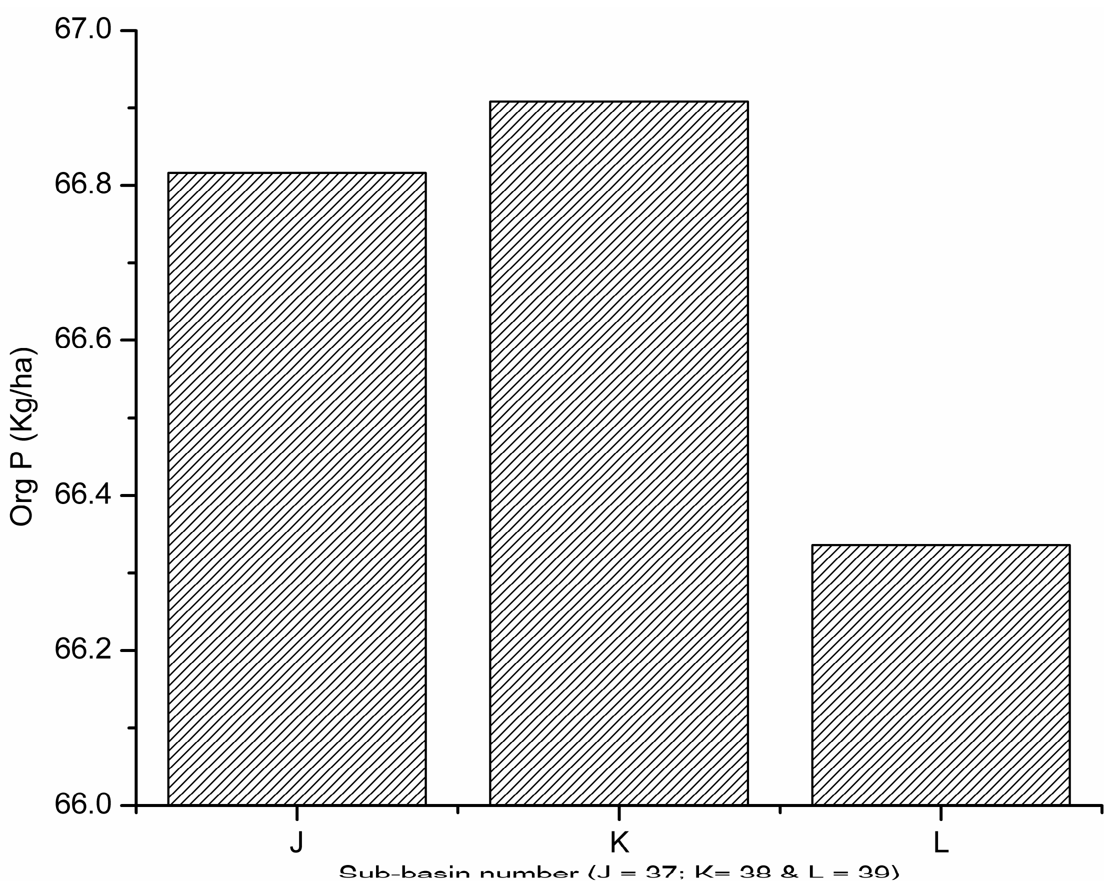


Figure 36: Prone sub-basins for high Org P load

4.11.4. Sol P

On agricultural catchment, the labile form of P dominantly found in the form of solution generated from applied fertilizers, manures and conversion from one form of P to Sol P form via mineralization process. This type of P is dissolved to surface runoff and driven towards nearby reach via surface runoff. According to this study, at sub-basin level, the high amount of Sol P was initiated from sub-basin number 7, 5, 4 (top three) which holds 5.84, 5.70 and 5.68% with respect to the entire 40 sub-basins respectively. These sub-basins were found around the reservoir which implies that a maximum amount of P in the form of solution were drive toward this area through surface runoff as indicated in Figure (35).

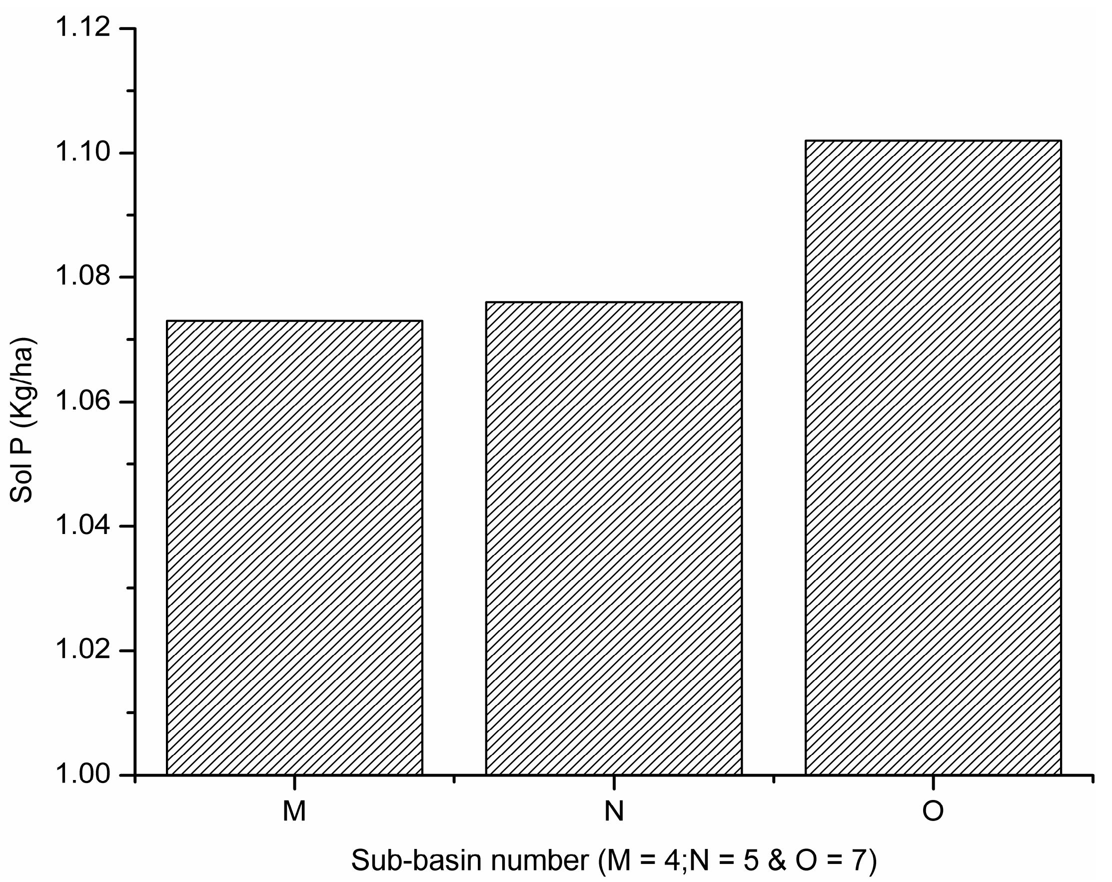


Figure 37: Prone sub-basins for high Sol P load

4.11.5. Sed P

Sed P is a mineral form of phosphorus that attached to sediment and transported by surface runoff into the nearby reach. From sub-basins level assessment, sub-basins number 2, 17, and 24 were the top three main sources of Sed form P load which takes 2.89, 2.86 and 2.81% of Sed P loading position as compared with the rest sub-basinsrespectively as shown in the Figure (36). The reasons behind might be high elevation (> 20%) which was highly suspected areas to erosion. Additionally, land use, land cover, amount and application rate of fertilizers, manures, rainfall amount, intensity, soil physical and chemical natureand related hydrological conditions. Therefore, it would be better to educate the stakeholders on means of best management plan to conserve these sub-basins.

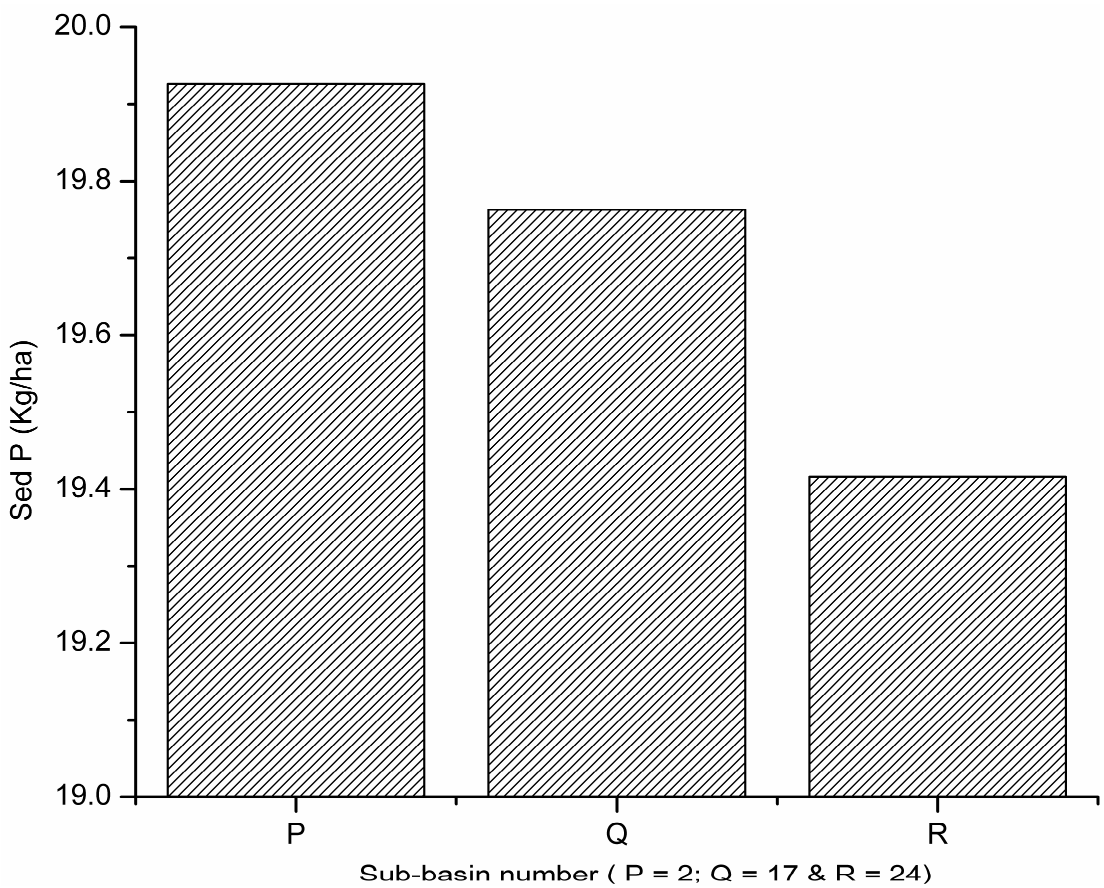


Figure 38: Prone sub-basins for high Sed P load

4.10.6. Total P

The total P implies that the sum of the Organic, labile and sediment form of P at sub-basins level. According to this study, the top three sub-basins responsible for high total P load were sub-basins number 38, 42 and 39 which accounts 2.69, 2.68 and 2.68% loading positions respectively relative to the rest sub-basins as shown in the Figure (37).

The reasons behind these facts were areas might be highly agriculture area which consumes high amount of fertilizer and unregulated rate of applications in these areas or neighborhood areas, high quantity of conventional fertilizers and related frequent rate applications over an areas or from nearby sub-basins in additions to industrially processed fertilizers. Further, it might be due to very poor area management practices in or around those sub-basins, possible there might be a point source that loads P in the area or from the neighborhood area, may be high precipitation that initiate a powerful runoff that drivers P from the area or area around it, a high temperatures over these area or neighborhood area that might enhance amount of humic substance to be converted to organic P to loaded via runoff. Thus, the better methods to control the effects would be expanding the awareness creation program through integrated approach.

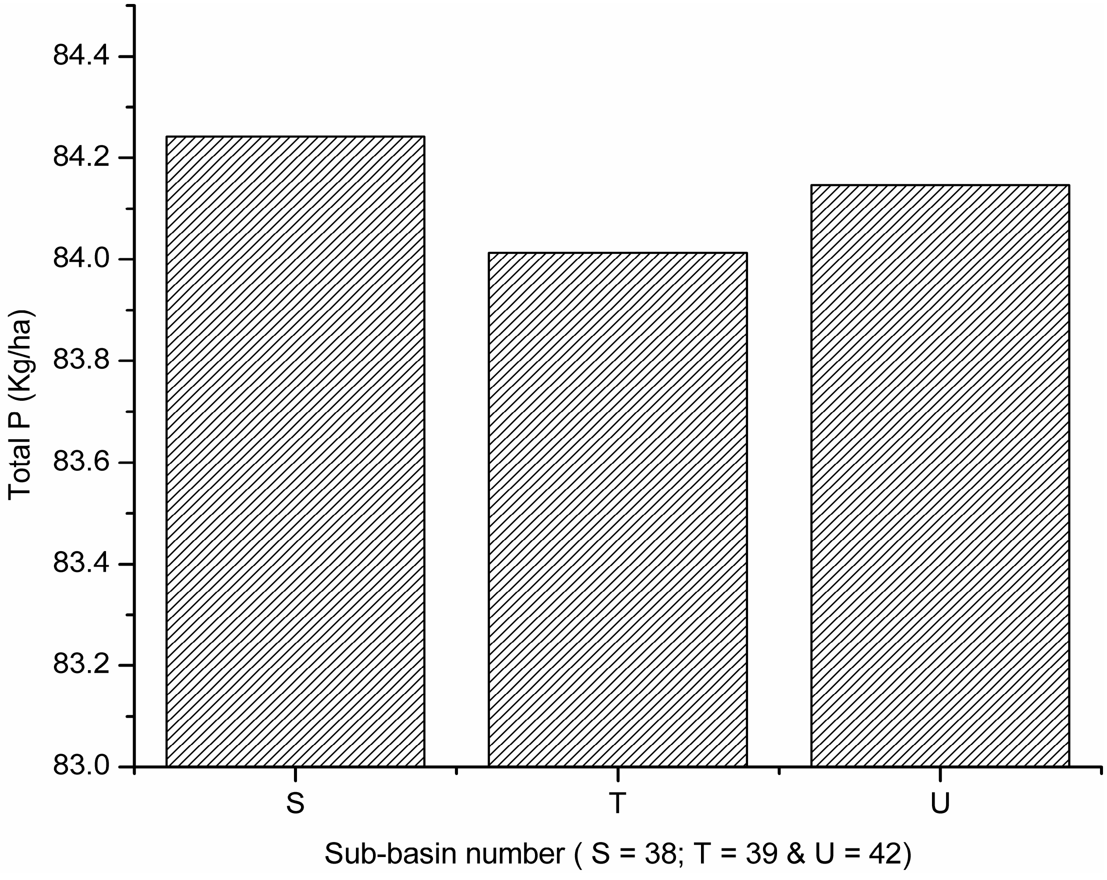


Figure 39: Prone sub-basins for high total P load

CHAPTER 5: CONCLUSIONS AND RECOMENDATIONS

5.1. Conclusions

A contamination of water resources by non-point source pollutant is a recent major global environmental issue. An agricultural based watershed is recognized as a single greatest contributor of NPS to water resources on international scale followed by urban and resource extraction. To arrive on sustainable environment, assessing the environmental impacts of NPS at global, regional and local level using hydrological models as tools is necessary rather than options. Gaining a detailed understanding of the operating processes in agricultural fields is important to explain how non-point sources of pollution affect the water quality of the aquatic environment. Phosphorus one elements of NPS pollutants has been known to its potential damage to aquatic environment once found in excess. For decades there are several research conducted to study the transport and effect of P on the water bodies. However, still more remain to develop efficient method that explicitly put the phosphorus fate. Therefore, assessing the phosphorus transport and fate has got an attention worldwide recently.

In this study, the SWAT model which is a physically based semi-distributed parameter model that performs all calculations on a daily time step to quantify effects of watershed management and climate conditions of flow, sediment, nutrient, and pesticide response from an agricultural watershed was used. Overall, it is a reasonable annual predictor of the watershed responses for assessing the impacts of different management systems on water supplies and nonpoint source pollution. The prediction efficiency of the model was evaluated over the catchment and found that NSE = 0.58,R^2 = 0.85 and NSE = 0.52, R^2 =0.81during calibration and validation respectively whichimplies that based on the model evaluation criteria, model prediction capabilityover the study area is satisfactory for water resource management for sustainable development. Further the model could able to analyze of the effect of climate and land use change, water quality analysis and sediment yield, for planning of dam construction in the future and flood disaster risk management. In contrast, based on this assessment finding and literature review the model prediction efficiency highly affected by extreme hydrological conditions and subsurface flow loaded from surrounding areas to study catchment.

There are three main pathways through which mobilized P can reach water resources are; surface runoff, subsurface flow and percolation to the groundwaterwhich depends on rainfall pattern, duration and intensity. According to this assessment, the P load, transport pathways, prone area was assessed using this model and found that the maximum P load around 4.4×10^{5} ton/year on 2009 was loaded from the area to the nearby water resources in the form of particulate via surface runoff and corresponding minimum loss was observed on 2007 which was around $5.6 * 10^{4}$ tons/year. Therefore, surface runoff was the predominant agent to transport the soluble and particulate form of P to the water resources. Lastly, top three sub-basins loading large amount of P in the form of Org P were 38,37,39, in the form of Sol P 7,5,4, in the form of Sed P 2,17,24, total P 38, 42 and 39,runoff 10,3,16, sediment 4,37 and 43.

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5.2. Recommendations

Based on findings, the following recommendations would be drawn as follows:

- SWAT model prediction efficiency highly affected by extreme hydrological conditions and subsurface flow loaded from surrounding areas to study catchment. Therefore, it is advisable to improve existing curve number method and incorporate external subsurface loadimpact analysis method into the model.
- SWAT daily based simulation capability is weak compared to monthly and annual simulation. Hence, it is better to propose and incorporate means of daily simulation improvement.
- For evaluating SWAT prediction capability statistically, R^2 and NSE are the only two preferred and most widely used coefficients in most literatures. Therefore, it is better to investigate new evaluation coefficients better than the existing ones or improve the existing ones.
- Extreme hydrological conditions affecting model forecasting capability might happen during data measurement, processing and management. So, it is better to amend methods of data management and recording technology.
- SWAT assumes a conversion of P from solution to active mineral pools is in equilibrium. But, in reality the transformation of P solution to P active is slow and the reverse is instantaneous. So that it is better to revise and update the assumption behind the SWAT model regarding the P conversion.
- SWAT incorporates high number of parameters which complicates parameterization and calibration process. Thus, it is advisable to reanalysis these parameters and incorporate those having a significant effect over the process.
- Inherent uncertainties in model development and application can affect the development and evaluation of water resource policy. Hence, definition and quantification of calibration uncertainty should have to be the subject of researchers in recently.
- Nutrients, sediments and agricultural chemicals are mainly loaded to the water resources via surface runoff. Hence, it is recommendable to apply Best Management

Plan which is simple, economical and adaptable over the study catchment for managing severe impact of surface runoff.

- The dominant mechanism of P load from the study area to water resources was the particulate/colloid/ forms of P agented by surface runoff. So that it would be recommendable to apply best conservation plan over the area to control LULC and pesticide consumption practices.
- The main source of P is processed fertilizers and conventional manures for agricultural intensive area. Therefore, it better to undergo detail re-examination over the physical and chemical properties of P in fertilizers and manures to propose the minimizing ,neutralizing, replacing strategies to reduce it at the source.
- Crop residues, manures, animal biomass, processed fertilizers and humic substances are the major factors for generation of high P over agricultural intensive watershed. Thus, it is better to aware the community, especially farmers on fertilizer consumptions methodology and land use land cover management.
- At sub-basins level, there are critical areas responsible for a significantly nutrient initiation. Consequently, it is consultable to give special attention to aware of the stakeholders and applying Best Management Practices continuously over those areas.
- Lastly, it is recommendable to undergo more advanced research on pollutants,sediments, chemicals,surface andsubsurface flowtransport mechanisms, loadings and associated impacts to control them efficiently and update the corresponding models predictions efficiency.

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APPENDIXES

Appendix A: P Transport Pathways

Loading Pathways	Amount (Ton)	Percentage (%)	Rank
Sum of ORG P Load (Ton)	1005218.67	77.3	1
Sum of SOL P Load (Ton)	7832.77	0.6	3
Sum of SED P Load (Ton)	286851.61	22.1	2

Appendix B: Yearly Org P load

Year	Yearly ORG P Load (Ton)	Percentage (%)	Rank
2003	99301.349	9.9	3
2004	92444.981	9.2	4
2005	62905.295	6.3	6
2006	56707.052	5.6	7
2007	47256.776	4.7	10
2008	51181.043	5.1	9
2009	354613.587	35.3	1
2010	120891.250	12.0	2
2011	68246.232	6.8	5
2012	51671.110	5.1	8

Appendix C: Yearly Sol P load

Year	Yearly SOIL P Load (Ton)	Percentage (%)	Rank
2003	1085.118	13.9	2
2004	473.883	6.1	8
2005	427.408	5.5	9
2006	486.747	6.2	7
2007	606.670	7.7	6
2008	719.539	9.2	5
2009	1854.867	23.7	1
2010	954.406	12.2	3
2011	921.624	11.8	4
2012	302.505	3.9	10

Appendix D: Yearly Sed P load

Year	Yearly SED P Load (Ton)	Percentage (%)	Rank
2003	36903.55	12.9	3
2004	27286.04	9.5	5
2005	16957.71	5.9	7
2006	13344.67	4.7	8
2007	9135.322	3.2	10
2008	11070.69	3.9	9
2009	84696.87	29.5	1
2010	40337.33	14.1	2
2011	28303.52	9.9	4
2012	18815.9	6.6	6

Appendix E: Yearly total P load

Year	Yearly Total P Load (Ton)	Percentage (%)	Rank
2003	137290	10.6	3
2004	120204.9	9.2	4
2005	80290.42	6.2	6
2006	70538.47	5.4	8
2007	56998.77	4.4	10
2008	62971.27	4.8	9
2009	440264.9	33.9	1
2010	163083.5	12.5	2
2011	97471.38	7.5	5
2012	70789.52	5.4	7

Appendix F: Yearly Surface Runoff

Year	Yearly sum of surface runoff (mm)	(%)	Rank
2003	12884.0	4.9	10
2004	13909.4	5.3	9
2005	14796.9	5.6	8
2006	21016.3	8.0	5
2007	15800.0	6.0	7
2008	19068.0	7.3	6
2009	53076.3	20.2	1
2010	44252.3	16.9	2

2011	42146.9	16.1	3
2012	25358.3	9.7	4

Appendix G: Yearly Sediment yield

Year	Yearly sum of sediment yield	(%)	Rank
2003	6183.7	4.4	10
2004	7220.2	5.2	8
2005	6475.7	4.6	9
2006	10050.8	7.2	5
2007	7671.9	5.5	7
2008	8923.7	6.4	6
2009	29872.4	21.3	1
2010	23757.8	17.0	3
2011	27229.4	19.5	2
2012	12572.9	9.0	4

Appendix H: Prone sub-basins loadingOrg P

Sub-basins	sum of ORG P (Kg_ha)	%	Rank
37	66.816	2.758	2
38	66.908	2.762	1
39	66.336	2.738	3

Appendix I: Prone sub-basins loading sol P

Sub-basins	Sum of SOL P (Kg_ha)	%	Rank
4	1.073	5.68	3
5	1.076	5.70	2
7	1.102	5.84	1

Appendix J: Prone sub-basins loading Sed P

Sub-basins	Sum of SED P (Kg_ha)	%	Rank
2	19.926	2.88	1
17	19.763	2.86	2
24	19.416	2.81	3

Appendix K: Prone sub-basins loading total P

Sub-basins	Total P (Kg_ha)	%	Rank
38	84.242	2.689	1
39	84.013	2.682	3
42	84.147	2.686	2

Appendix L: Prone sub-basins sediment load

Sub-basins	Sediment (Kg_ha)	%	Rank
37	6846.2	4.892	2
41	8566.544	6.121	1
43	6224.083	4.447	3

Appendix M: Prone sub-basins runoff

Sub-basins	sum of runoff (Kg_ha)	%	Rank
3	6543.0	2.494	2
10	6586.4	2.511	1
16	6530.2	2.490	3