WATER QUALITY FRAMEWORK FOR WATERSHEDS USING HYDROLOGICAL MODELLING

A Thesis submitted to Gujarat Technological University

for the Award of

Doctor of Philosophy

in

Civil Engineering

by

Shah Payal Vinitkumar
179999912016

under supervision of

Dr. Pradeep P. Lodha

GUJARAT TECHNOLOGICAL UNIVERSITY

AHMEDABAD

February – 2024

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ABSTRACT

Watershed management refers to the process of implementing land use and water management practices to protect and enhance the quality of the water and other natural resources within a watershed. Better management of watersheds leads to better water quality as an output from the watersheds. Watersheds in India are increasingly being polluted by the intense use of fertilizers and pesticides as well as the development of industrial & urban infrastructure. To counter this phenomenon of degradation of water quality from watersheds it is of immense and urgent requirement to have a policy framework at the national and regional level which mandates and counters the menace of pollution. This study proposes a framework that compares the output runoff water quality with the desired standards and provides watershed-level management solutions to achieve desired water quality.

The purpose of this study is to create a water quality framework for watersheds and to evaluate the impacts of land use and climate change on water quality at the watershed scale as well as to understand the relationships between hydrologic components and water quality under various land use, climate, and intervention scenarios. The study is applied to the Hathmati river which is the main tributary of the Sabarmati River, one of the largest rivers of Gujarat. The Hathmati watershed has been identified as a significant source of nutrient loading and as one of the areas that export some of the highest nitrate-nitrogen loadings into the Hathmati river. The Soil and Water Assessment Tool (SWAT) model, together with SWAT-Cup, has been used to provide a framework for the watershed's water quality. The simulation framework contains comprehensive data on land use, digital elevation model, soil, and various interventions, including crop rotation & change in land use cover with future predictions. The model has been used to simulate the quality and quantity of surface water as well as forecast the impact of climate change, land use cover, and crop rotation. This includes an evaluation of nutrient water quality as well as the calibration and validation of SWAT for stream flow and nutrient loadings in the watershed.

The watershed comprises mainly 6 land use (with more than 67% agriculture area coverage), slope mostly ranges from 0-15 (more than 80%). For model application, the watershed area was divided into 13 sub-watersheds. Physical properties of soil and land use, meteorological data, and, observed flow data were collected for 22 years from 1999 to 2020 and are used in

the model development and validation. For model simulation, three years (1999 to 2001) was considered as a warm-up period. Nitrate loadings and stream flow were calibrated for ten years (2002–2011) and then validated for an additional nine years (2012-2020). During the calibration and validation periods, model predictions performed very well on both an annual and monthly basis, as shown by the coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE) values that typically exceeded 0.7. For the calibration period, the correlation between the observed and simulated daily runoff was strongly accurate, as shown by the coefficient of determination value of 0.95. The calibrated model was applied to the validation data set. The model validation was a success too with the calibrated model. The coefficient of determination was 0.92 for the validation period. The Nash Sutcliffe coefficients obtained were 0.92 and 0.77 for the calibration and validation period, respectively. Since all model performance-statistical metrics showed great accuracy equivalent to the observed flow data, the model had a noteworthy success in predicting flow. After the successful validation, model simulation has been considered as a baseline scenario.

For operational water quality framework, crop rotation and land use change are represented by two other scenarios. Future predictions for RCP 4.5 climate change scenario have been considered for the above-said baseline scenario and two other scenarios. According to the results of a first scenario set, relatively few adjustments to crop rotation led to a large reduction in the amount of nitrate that was discharged at the watershed outflow. A land use change scenario showed a considerable advantage in lowering nutrients at the watershed outlet. Total nitrogen (N) and total phosphorous (P) inputs from the watershed to the river were lowered by predicted future land-use change (second scenario). This was due to increased crop nutrient uptake from the soil and decreased nutrient mineralization by microorganisms, as well as decreased nutrient leaching from the soil and decreased water yields on farmland. In comparison to land-use change, climate changes (precipitation and temperature) were predicted to have a stronger impact on increasing surface runoff, lateral flow, groundwater outflow, and water yield. The nitrogen loads and N and P uptake by crops increased under the projected climate change scenario. Under climate change scenarios, both organic nutrient mineralization and nutrient leaching increased. As a result, we anticipated that under climate change scenarios, yearly water yield and nutrient loading would rise. The majority of the nutrient loads in each climate change scenario emerged from agricultural land, which suggests that changing crop rotation and land use might be used as a viable mitigation technique to reduce the harmful effects of nutrient loads and climate changes on water quality.

To evaluate the effects of hydrological processes and water quality in scenarios involving changing land use and climate, the suggested method offers a relevant source of data. It was concluded that the model performance can be greatly improved by simulating the flow representing all the hydrological components and various interventions to solve water quality problems in the Hathmati watershed.

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List of Abbreviation

AGNPS	Agricultural Non-Point Source Pollution Model
ALPHA_BF	Baseflow Alpha Factor
AnnAGNPS	Annualized Agricultural Non-Point Source
AR4	Assessment Report
ArcSWAT	ArcGIS interface Soil and Water Assessment Tool
Avg.	Average
BISAG	Bhaskaracharya Institute for Space Applications and Geoinformatics
BMPs	Best Management Practices
C-WW	Corn- Winter Wheat
CARTOSAT-I	Cartography Satellite
CB	Chesapeake Bay
CCSM4	Community Climate System Model, Version 4
CESM1-CAM5	The Community Earth System Model, Version 1 - Community
CMhyd	Climate Model Data for Hydrologic Modeling
CMIP-5	Coupled Model Interpretation Program
CN	Curve Number
CO2	Carbon Dioxide
CPCB	Central Pollution Control Board
DBT	Direct Benefit Transfer
DEM	Digital Elevation Model
DOS	Disk Operating System
DRAINMOD	Drainage Model
EL	Elevation (m)
EMF	Environmental Management Frameworks
EPA	Environmental Protection Agency
EPCO	Plant Uptake Compensation Factor
EPIC	Environmental Policy Integrated Climate
ESCO	Soil Evaporation Compensation Factor

ET	Evapotranspiration
FLOW_OUT	Out Flow
FORTRAN	Formula Translation
GCMs	General Circulation Models
GEMS	Global Environment Monitoring System
GHG	Green House Gases
GIS	Geographic Information Systems
GLUE	Generalized Likelihood Uncertainty Estimation
GOG	Government Of Gujarat
GTP	Growth And Transformation Plan
GTU	Gujarat Technological University
GW_DELAY	Delay Time for Aquifer Recharge
GWQMN	Depth Of Water in Shallow Aquifer Required for Return Flow
GWSOLP	Soluble Phosphorus Concentration in Groundwater Flow
ha	Hectare
HOD	Head Of Department
hr	Hour
HRU	Hydrologic Response Units
HSPF	Heating Seasonal Performance Factor
HUMUS	Hydrologic Unit Model for The United States
IIT	Indian Institute of Technology
IMSD	Integrated Mission for Sustainable Development
INCA	International Congress of The Indian National Cartographic Association
IRS	Indian Remote Sensing Satellite
ISRO	Indian Space Research Organization
ISSN	International Standard Serial Number
IT	Information Technology
km	Kilometer
LISS	Linear Imaging Self-scanning Sensor
LULC	Land Use and Cover

LUS	Land Use Statistics
m	Meter
MAE	Mean Absolute Error
max	Maximum
min	Minimum
Min_N	Mineral Nitrogen
Min_P	Mineral Phosphorous
MINARS	Monitoring Of Indian National Aquatic Resources System
mm	Millimeter
Model-GIS	Geographical Information System Model
N_ORG	Organic Nitrogen
N2O	Nitrous Oxide
NATCOM	National Communication
NCAR	National Center For Atmospheric Research
NH4	Ammonia
NO	Nitric Oxide
NO3	Nitrates
NO3_SURQ	Nitrates In Surface Runoff
NPERCO	Nitrate Percolation Coefficient
NPS	Non-Point Source
NRCS-CN	Natural Resources Conservation Service Curve Number
NRM	Natural Resource Management
NSE	Nash-Sutcliffe Efficiency
Org_N	Organic Nitrogen
Org_P	Organic Phosphorous
P_Sol	Soluble Phosphorous
ParaSol	Parameter Solution
PBIAS	Percentage Of Bias
PCCs	Pollution Control Committees
PCP	Precipitation

PDEU	Pandit Deendayal Energy University
PHOSKD	Phosphorus Soil Partitioning Coefficient
PPERCO	Phosphorous Percolation Coefficient
PREC	Precipitation
PRECIP	Precipitation
PS	Point Source
PSO	Particle Swarm Optimization
QUAL2K	River And Stream Water Quality Model
RCMs	Regional Climate Model
RCP	Representative Concentration Pathways
RMSE	Root Mean Square Error
RS	Remote Sensing
RSR	Remote Sensing Research
SOI	Survey Of India
SOL_AWC	Available Water Capacity Of The Soil Layer
Sol_P	Soluble Phosphorous
SPARROW	Spatially-Referenced Regression On Watershed Attributes
SPCBs	State Pollution Control Boards
SRTM	Shuttle Radar Topography Mission
SST	Sea Surface Temperatures
SUFI-2	Sequential Uncertainty Fitting
SURLAG	Surface Runoff Lag Coefficient
SURQ	Surface Runoff
SWAT	Soil And Water Assessment Tool
SWAT-Cup	Calibration Uncertainty Program For SWAT
SWDC	State Water Data Centre
SWQMF	Surface Water Quality Management Frameworks
TMDL	Total Maximum Daily Load
TMP	Temperature
TN	Total Nitrogen

TMDL	Total Maximum Daily Load
USDA	United States Department of Agriculture
USDA-ARS	United States Department of Agriculture-Agricultural Research Service
WCCs	Winter Cover Crops
WQM	Water Quality Monitoring
YAP	Yamuna Action Plan

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CHAPTER – 1

INTRODUCTION

1.1 Introduction

In a current era of global warming, water quality has been degraded by natural or manmade activities, one of the main reasons to focus on this topic is to protect water quality, managing water resources – watersheds and identifying sources of pollution- point and non-point sources. Increased agricultural productions are having adverse impacts on water quality. Water quality is currently receiving a lot of attention, especially in the areas where it serves as the primary supply for drinking and irrigation.

Surface water is usually impacted by contamination in areas with intensive agricultural management because of the use of high quantities of fertilizers as well as improper irrigation techniques. According to J. Divya, S.L. Belagali (2012), increased use of agricultural fertilizers in India has led to a huge increase in agricultural production, but these practices have also led to watershed-level water quality degradation. The increase in nitrogen in waterways like rivers, canals, reservoirs and lakes, must be analyzed. Although nitrate leaching in these areas appears to be an unavoidable process, it is believed that various interventions at watershed level like crop rotation and change in land use land cover may reduce the nitrate contamination. Different types of land cover have an impact on watershed hydrology, which is directly related to how nutrients are transported within a watershed (Pikounis et al. 2003). Water quality monitoring is one of the major aspects of a watershed.

Water availability is frequently associated with climate change, drought, flooding and heavy rainfall. Water quality issues are linked with climate change, and it is not enough for the water to exist in enough quantity; it also needs to be sustainable. Globally, the annual average temperature has risen by about 1°C over the last century. It is predicted that by 2100, the average global surface temperature, will rise by 1.5 to 5.8°C (IPCC - Fourth

Assessment Report (AR4)). A wide variety of changes are anticipated by rising global temperatures. The frequency, duration, and intensity of other extreme weather events like floods are likely to rise due to changes in temperature and precipitation patterns, which will have a significant impact on water quality. Because flooding from climate change can transport pollutants into water bodies, it can also have an impact on the water quality. As it passed through farms and fields in rural regions, runoff from climate change would pick up nutrients (Edward Osei, Syed H. Jafri, Philip W. Gassman, Ali Saleh and Oscar Gallego, 2023). The SWAT model (Soil and Water Assessment Tool) was used in this study since it is one of the best models for long-term simulation in watersheds that are predominantly agricultural (Borah and Bera 2003), as well as reliable in estimating nutrient losses at the watershed scale, (Gassman et al. 2007, Ferrant et al. 2011, Cerro et al. 2014a). They usually focus on pollution mitigation scenarios through changes in land use (Wang et al. 2008, Ferrant et al. 2013, Liu et al. 2013, Boithias et al. 2014, Cerro et al. 2014b), fertilization doses, and other management practices (Ferrant et al. 2013, Liu et al. 2013, Cerro et al. Regardless, the model is often calibrated and validated prior to the application of the pertinent situations.

1.2 Water Quality

Water quality influences its suitability for a particular use, i.e., how well the quality fulfills the requirement of the user. The characteristics of water quality have become important in water resources planning and development for drinking, industrial and irrigation purposes (Shakoor, 2015). The current information is required, provided by water quality monitoring for optimum development and management of water for its proficient uses (Haydar et al., 2009). The major concerns in terms of water quality and quantity are due to its inadequate distribution on the surface of earth and the rapid declining of fresh useable water (Irfan et al., 2014). The possible contamination in water included organic matter, nutrients, suspended solids, heavy metals, pesticides and industrial chemicals.

1.2.1 Irrigation Water Quality

The substances which are dissolved in water determines its quality for irrigation use. Water used for irrigation should be within permissible limits of water quality criteria otherwise it could affect plant growth and crop production. Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts. Salts present in irrigation water are in relatively small but significant amounts. These salts are carried with the water to wherever it is used. In the case of irrigation, the salts are applied with the water and remain behind in the soil as water evaporates or is used by the crop. The suitability of a water for irrigation is determined not only by the total amount of salt present but also by the kind of salt. The water quality is degraded mainly due to natural reasons along with over withdrawal of water and increased application of fertilizers. The water being used for irrigation may contain many impurities which in turn maybe taken up by crops. Even when all other factors and practices are favorable or ideal, the quality of irrigation water can have an impact on crop yields and the physical characteristics of the soil. Additionally, the quality of the irrigation water varies depending on the crop.

1.2.2 Critical Sources of Poor Nutrient Water Quality

Critical sources of poor nutrient water quality are the sources having higher chemical use rates, increased field salinity and soil erosion, accelerated pollutant transport with drainage flows, degradation due to increased deep percolation to saline formations, and greater instream pollutant concentrations due to reduced flows. Poor-quality water contains a significant amount of organic matter and plant nutrients. Regular fertilizer usage in irrigated crops is also probably going to result in the presence of these residues in irrigation water, particularly in areas where there isn't much regulation and training on the application of these substances. A potential source of surface water contamination is the leaching and discharge of agricultural chemicals. Nitrate leaching from excessive fertilizer use has been extensively investigated.

1.3 Importance of Watersheds

The watershed affects the stream, river, or lake's water quality. Watersheds are found all throughout the world, come in all different sizes and shapes, and do not respect national or state boundaries. Simply said, a watershed is the region of land through which water flows and empties into a common body of water, such as a river, lake, ocean, or stream. The watershed boundary will roughly follow the highest ridgeline around the stream channels before coming together at the watershed's exit point, also known as the waterway's mouth. A watershed, or the area of land that drains to a stream, lake, or river, has an impact on the quality of the water in the body of water that it surrounds. In addition to assisting in the protection of water quality, healthy watersheds benefit the local population as well as the local wildlife more than degraded ones.

The health of the watershed is crucial for anything and everything that utilizes or requires water. Healthy watersheds not only have a positive impact on the water quality but also help the local wildlife and human populations more. The health of the watersheds around a body of water has a significant impact on its quality, mostly because pollutants from the land can wash into the water and have an adverse impact. Through their watersheds, streams, lakes, rivers, and other bodies of water are linked to the environment and all of its activities. They are impacted by naturally occurring variations in lake levels, groundwater inflow and outflow, and stream flow rates. The quantity and location of pollution sources, forest fires, stormwater runoff patterns, and other variables all affect the quality of our water.

Rainfall and stormwater runoff provide a significant portion of the water. All disturbances to the land, including mining, agriculture, roads, urban development, and human activities within a watershed, have an impact on the quantity and quality of stormwater. Normally, naturally raised places are used to divide watersheds from one another. Watersheds are important because the surface water features and stormwater runoff within a watershed ultimately drain to other bodies of water. It is essential to consider these downstream impacts when developing and implementing water quality protection and restoration actions.

Watersheds' water quality is impacted by a variety of variables. The quality of the water in watersheds is influenced by a variety of weather factors, including the quantity, intensity, and distribution of rainfall. During periods of intense rainfall, concentrations of nutrients, pesticides, and sediment loads can be significantly higher. A watershed's physical characteristics, such as its geology, soil types, vegetation, terrain, and slope, also have an impact on the water quality. Some rocks include minerals that can dissolve in water and alter the chemistry of the liquid. There is evidence that vegetation can filter out some pollutants from water. Nutrients and pesticides may adhere or stick to the soil surface. As a result, soil erosion - which is influenced by soil type, topography, and slope - can raise water quality indicators such as turbidity, sediment load, and concentrations of nutrients and pesticides. Water picks up and carries pollutants and particles as it flows over and through the watershed. If left untreated, these contaminants enter waterways by runoff from rain. These toxins may accumulate in streams and rivers before being transported farther down the watershed.

Watersheds are suitable as organizational units because they incorporate terrestrial, aquatic, and geologic characteristics into easily distinguishable landscape structures with borders. By concentrating on the entire watershed, efforts to reduce polluted runoff and point sources of pollution can be balanced with those to safeguard water quality. The watershed approach is a method of making decisions that incorporates a plan for gathering and analyzing data as well as knowledge of the obligations and priorities of all parties involved in a watershed. The watershed approach is based on the idea that it is the best to address many water quality issues at the watershed level, such as the buildup of contaminants. A watershed emphasis also aids in determining the most economical pollution management methods to achieve clean water quality objectives. The watershed approach's primary objective is identifying and prioritizing the watershed's water quality challenges. Healthy watersheds not only have a positive impact on the water quality but also help the local wildlife and human populations more.

A watershed's natural resources and water quality will be impacted in some way by every activity that takes place within it. The quality of the resources in a watershed can be impacted by new land development, runoff from already developed regions, agricultural operations, domestic activities including gardening and lawn care, septic system use and maintenance, water diversion, and vehicle maintenance.

1.4 Hydrological Modeling

A hydrologic model is a simplified representation of a real-world system that helps in understanding, predicting, and managing water resources (e.g., surface water, soil water, wetland, ground water). Fundamental scientific methods, such as hydraulic models, are used to predict, anticipate, and explain occurrences at various spatiotemporal scales where direct observation or investigation is impractical, unaffordable, or unethical. In order to help policy makers, define actions ensuring local to regional sustainability of water resources, models are used to assess the impact of stressors in a variety of scenarios, including climate variability and change, population growth, policies, and economics.

These models also help analyze societal interactions, such as agricultural production systems. A larger range of water resource-related challenges, such as aquifer contamination, resource conservation, and the development of best management practices for safeguarding ground and surface water quality, are investigated using hydrologic models (Hydrological Modeling – Current Status and Future Directions, 2017, National Institute of Hydrology Roorkee). Hydrologic models are often used in water quality and flow studies. By examining how climate, land use, land management, and water management affect water resources, hydrologic models are used to aid in water resource management. The extent and resolution of the spatial and temporal contexts, which can vary spatially from point to watershed and temporally from seconds to centuries, are studied at various scales when it comes to water-related concerns (C. Baffaut, S. M. Dabney, M. D. Smolen, M. A. Youssef, J. V. Bonta, M. L. Chu, J. A. Guzman, V. S. Shedekar, M. K. Jha, J. G. Arnold, 2015). Common applications of hydrologic models include management, planning, and pollution prevention. Different degrees of trust in the model's output are needed for each of these. Point (PS) and non-point (NPS) source pollution poses a threat to the water quality due to the effects of human economic activity, environmental deterioration, and activity zones (such as home water supply, agriculture, hydropower, and fisheries). Consequently, hydrologic models are crucial tools for decision-making about water quality. It is the best to analyze each water-related problem at a particular scale, which can vary in terms of space (point to watershed) and time (seconds to centuries). The size of the research region, the length of the simulation period, and the spatial and temporal resolution of the computations all affect the model's spatial and temporal scales. The smallest spatial element being simulated serves as the measure of spatial resolution, and the simulation's time step serves as the measure of temporal resolution. Models are typically employed to validate our understanding of physical and biological processes, such as reactive pollutant transport through a soil profile, when the spatial extent is a point or a plot. For environmental management, hydrologic models are crucial for forecasting changes in water supply and quality. Many different hydrologic models are widely used, yet each model has benefits and drawbacks in particular contexts. The three most significant trends for model development in the near future are: (1) combination models, which are necessary to get the best results because individual models can't fully solve complex problems; (2) application of artificial intelligence and mechanistic models combined with non-mechanistic models, which will yield more accurate results due to the realistic parameters derived from non-mechanistic models; and (3) integration with remote sensing technologies. To comprehend, predict, and manage the world's water resources, hydraulic and water quality models have been created. These are useful tools for bridging knowledge gaps about the mechanisms involved in solute transport and water flow. To manage the best use of water resources in a sustainable way, accurate estimation of the temporal and spatial distribution features of water resources is necessary. Geographic information systems (GIS) and remote sensing (RS) technologies have recently seen increased application in domains linked to hydrologic/water quality modelling, and therefore in settings relevant to decision-making. A variety of hydrologic and water quality models' input data have been effectively parameterized using GIS to represent the spatial and temporal characteristics of the factors affecting the hydrologic components (surface, subsurface, groundwater, etc.), as well as the generation of pollutants (nonpoint pollution) and their transportation with water via surface or infiltration, ultimately flowing into streams. In order to fill in the gaps between actual conditions and hydrologic modelling, the use of satellites for water resource management has the potential to be very helpful. In order to fill the gap left by the absence of on-the-ground monitoring of water resources at different scales, a number of satellites have been developed and are currently being used to deliver the essential data. In the past ten years, the analysis of water resources systems (ET, soil moisture, runoff, groundwater, soil erosion, etc.) has seen an increase in the usage of GIS and RS. In light of this, there is an increasing need to enhance present GIS/RS technologies and get a deeper comprehension of how they are used in hydrology. Additionally, in recent years, Machine-Learning/Deep-Learning applications have quickly advanced to the state-of-the-art, improving performance in a number of hydrological modelling applications that can be combined with GIS and hydrological modelling.

1.5 Water Quality Monitoring

Water quality monitoring is the long-term, reliable, consistent, routine collection of water quality data. Data management is a crucial aspect of any water quality monitoring program. It is a very difficult process in any monitoring program since there are so many prior records to use, different monitoring objectives, and different data management methods. The purpose of monitoring water quality is to give the information needed to protect the environment from the harmful impacts of pollution. Water quality monitoring is the process of making observations, gathering information on various water quality parameters, and then analyzing and reporting that data to provide comprehensive data on water quality at the watershed level. The analysis of the problems affecting the watershed and/or water quality and the identification of a defined purpose are the two most important steps for effective monitoring. Water quality monitoring is now necessary to protect water bodies due to greater awareness of the effects of land-use changes, climate change, numerous interventions at the watershed level, and their impact on water quality. Providing data of known quality is important for watershed planning and decision support systems. In order to build a framework for water quality monitoring and achieve significant goals, it is obvious to know the validity of the data that will be used. As a result, the data information for the monitoring framework may be improved. For water quality monitoring in general, there are three fundamental methods for evaluating data:

1. Assessment of extensive record-keeping with the purpose of identifying patterns and changes over time (for example, trend monitoring).
2. Analyzing the relationships between measured values for monitoring program variables to identify differences and their significance (e.g., for survey or compliance monitoring). This could involve comparing upstream and downstream areas, control sites, or other spatial or temporal variations; and
3. Assessment of how closely measured water quality adheres to established standards, criteria, or goals (e.g., for survey or compliance monitoring, or objectives established within a water quality index).

1.6 Water Quality Framework

The Water Quality Framework is an innovative way of considering how information systems and data on water quality might be better integrated to support decision-makers and better inform the public. The Framework will simplify the assessment of water quality and present a more comprehensive picture of the watershed's water quality. An efficient framework for managing diffuse discharges of contaminants into water bodies, attaining optimal water quality, and sustaining the numerous social, economic, environmental, and cultural aspects associated with water are all characteristics of good water quality frameworks.

1.7 Hypothesis/Problem Definition

One of the significant uses of surface water for agriculture in India is irrigation. Since there is enough water readily available for irrigation, its quality has been neglected. Due to the extensive use of all resources, new irrigation projects and existing ones looking for additional or replacement resources must rely on less desirable and lower-quality sources. Sound planning is required to make sure that the available water quality is utilized to its full potential in order to prevent issues when using these poor-quality water supplies. Despite the fact that water is primarily supplied for irrigation, the quality of the surface water is unfortunately not monitored. Surface runoff from agricultural areas, excessive fertilizer and pesticide use, and other factors all contribute to the steadily declining quality of irrigation water in India. In India, irrigation water has been contaminated at an alarming rate as a result of the excessive use of chemicals for agricultural activities and land reclamation, which is becoming a cause for concern. However, due to the country's rapid population growth and the need for irrigation to satisfy the rising needs for agricultural production, many areas of the nation are running out of available water resources, and the water quality has declined (Sachin Mourya, Anil K. Mathur, 2018). In this study, a framework proposal that incorporates the findings of an investigation of water quality parameters is presented. It is intended that such a plan will act as a guide for the basin in the future when discussing the various uses along the river with the purpose of approving and implementing the framework into place. Agricultural land produces much higher levels of nitrogen & phosphorus than other land surfaces. Nutrient pollution from urban and agricultural sources has contributed to a significant deterioration in the water quality of many water bodies (e.g., Kaushal et al. 2014; Howarth et al. 2006; Howarth 2008; Dubrovsky et al. 2010). Artificial sources of nutrients include fertilizers. Direct discharge of runoff can elevate concentrations of nutrients. Agricultural land produces much higher levels of Nitrogen & Phosphorus than other land surfaces. Higher concentrations of nitrogen & phosphorus can be found at d/s of Hathmati River due to fertilizers applied by farmers. Most of this expansion happened due to an increase in the area under irrigated crops, which contributed more than 80% of total growth which has increased the use of fertilizers. (DBT report, www.mfms.nic.in) The area under irrigation had shown an increase from 2.06 lac hectares (15.5 %) to 4.39 lac hectares (30.37 %) in the last twenty years, (District Irrigation Plan (2016-2020) Sabarkantha, Gujarat). Hathmati watershed falls under the agriculturally potential zone where nitrate concentration is exceedingly high. The probable reason is the increased use of nitrogen fertilizers in agricultural practice. (Barot J M, Agrawal Y K, "Evaluation of drinking water quality in Gujarat")

1.8 Research Objective

1.8.1 Overall Objective

The overall objective of this thesis is to conceptualize a water quality assessment framework for watersheds using hydrological modeling. This study involves the use of the physically-based, Soil and Water Assessment Tool (SWAT) model by simulating various scenarios like land use land cover change, crop rotation and effect of climate change on water quality parameters with future predictions. This objective can be satisfied by establishing a hydrologic and water quality modeling framework, calibrating and validating the model and developing various scenarios.

1.8.2 Specific Objectives

- Conceptualize a water quality assessment framework at watershed level with hydrological modeling.
- Assessment of various mitigation scenarios for water quality modeling.
- Operationalization of water quality framework with mitigation scenarios.

1.9 Significance of the Study

The potential for nutrient and sediment runoff in the Hathmati river basin can be determined by applying the model setup applied in this work. The existing model has the capability to ascertain the effects of changes in land use and land cover in the basin because it has previously been calibrated for hydrology and because nutrients yield analysis heavily relies on SWAT's capacity to simulate hydrological events. Given that this basin is heavily influenced by agriculture, crop management data can be provided to the model to ascertain the effects of various crops on the basin's water quality. SWAT model has been used in numerous research in the past to replicate optimum management practices in diverse watersheds throughout the world. (Arabi et al., 2006; Parajuli et al., 2008 and Xie et al., 2015). Since non-point source issues are the most prevalent in basins where agriculture is the dominant industry, such models can help watershed managers make better decisions and manage their watersheds more effectively.

1.10 Methodology

For establishing a water quality framework for watersheds and to satisfy the objectives defined in this this, methodology for proposed work has been shown as below.

- Problem identification
- Literature review and gap findings
- Research objective formulation
- Selection of study area
- Data collection for hydrological and nutrient water quality parameters
- Data processing for model input
- Model set-up and simulation
- Calibration and Validation of the model
- Developing a water quality framework
- Simulation of the model to estimate values of hydrological parameters and nutrient parameters for different scenarios
- Results & Discussions
- Operationalization of water quality framework
- Conclusions & recommendation

1.11 Scope of Study

The scope of the work was limited to:

- Performing calibration and validation with other methods such as Generalized Likelihood Uncertainty Estimation (GLUE), Particle Swarm Optimization (PSO), and Parameter Solution (ParaSol) to find out the differences between methods.
- Comparison study with the past land use cover and the present land use cover so that proper planning and management can be done.

- The observed Nitrate data for different stations were not available continuously. The data gaps may need to be filled in using statistical procedures. The model performance could be tested using the newer data with relatively continuous and that is free of errors.
- The stream flow data were not consistent with the observed precipitation in case of a few events. The stream flow should be monitored carefully for better calibration and validation of models.
- This framework is expected to be applied to other watersheds to balance economic and environmental benefits.
- Especially in the context of climate change, an area that is suitable for certain crop production can become unsuitable over time, or vice versa.
- The developed watershed model can be used to predict the flow, nutrient loads, and concentrations.
- Also, future work should incorporate the adoption of effective means to represent the physical processes of the hydrological model, use of land use land cover transitions and incorporation of multiple climate scenarios could significantly improve the outcomes of this study.

1.12 Thesis Outline

There are a total of 8 chapters in the thesis. The first chapter provides a brief overview of the entire project, outlining the overall context, problem definition, objectives, technique used, and study scope. The second chapter reviews the literature for a framework for monitoring water quality, including different hydrological modelling, and integrates ArcGIS and ArcSWAT to create a hydrological model for the Hathmati watershed. Case studies of ArcSWAT modelling in Indian and international scenarios are also included in this chapter. The third chapter discusses the study area for the Hathmati River and basin. This chapter also provides instances of the collection and acquiring of hydrological, geographical, and climatic data. The fourth chapter included water quality framework, its components, and applications. The fifth chapter gives brief about the methods used to create the hydrological ArcSWAT model and analyze the water quality framework. The calibration and validation of a model using parameters related to nutrient water quality and the sensitivity of the ArcSWAT model is discussed in the fifth chapter. The sixth chapter gives brief about all the scenarios generated in this research. The study of the findings from model simulation and water quality analysis was covered in the seventh chapter. The eighth and final chapter contain conclusions drawn from the findings and additional suggestions for strengthening work. It completely gives brief about recommendations and discussions for SWAT model and its all scenarios generation.

CHAPTER – 2

LITERATURE REVIEW

The set of literature in relation to water quality, water quality monitoring, hydrological modelling, integration of GIS and SWAT & its applications is the focus of this section of the thesis. After the critical analysis and research gaps, the references-which take the form of research papers, reports, and internet blogs-are offered. Based on the theme that might be used in the research, the review is primarily divided into five components. The first section focuses on water quality monitoring, hydrological modelling, integration of GIS and SWAT, and followed by various SWAT applications, including hydrologic assessment, pollutant load studies, climate change impact studies, water quality monitoring framework and effects of various interventions like crop rotation as well as change in Land use Land cover.

2.1 Water Quality

Water Quality refers as testing physical, chemical, and biological characteristics of the parameters and to match with its standard values which has been set by responsible authorities. It is most frequently used to check whether water can be used for domestic, industrial, irrigation or any other use. Standards of water quality may change according to its use. Water quality is one of the most important factors for an environment and ecology. Our actions or any other activities in nature may affect the quality of water. Any kind of pollutants, excessive nutrients used in fertilizers, excessive use of pesticides and sediment transport may affect any water resources like lakes, reservoirs and rivers via runoff from urban areas, agricultural fields and also through return flow. Increased population, intense urbanization, and human activities are having adverse impacts on water quality. Effective control of nonpoint sources has become a major concern in nearly all countries, especially in terms of increasing the nitrate content of drinking water sources and eutrophication of enclosed water bodies such as lakes and reservoirs. It has not been possible to find cost-effective and reasonably quick solutions once the problems become critical (Asit K Biswas, Eugenio Barrios, 1997). A hydrologic modelling research applying SWAT in the Sondu river basin in Kenya shows the model's potential for use in African watersheds and emphasizes the necessity of improved model input data sets being developed in Africa, which are essential for thorough analyses of water resources. The use of SWAT for the analysis of water quality in the Bosque River Basin, Texas, highlights the model's power for examining various management scenarios to reduce point and non-point pollution, as well as its potential for use in total maximum daily load (TMDL) investigations. Storm water runoff is a significant route for the transfer of sediment and other nonpoint-source contaminants from watersheds to stream networks and other 30 surface water bodies, according to Mishra A. (2007). In this study, the 17 km^2 Banha watershed in northeast India, which is distinguished by mixed land use and on-stream sediment control devices known as check dams, was assessed for sediment transport using the SWAT model. Using SWAT, surface runoff and sediment output were calibrated in 1996 and validated in 1997–2001 on a daily and monthly basis by comparing model predictions with measured data. For surface runoff, the calibration R^2 and Nash-Sutcliffe modelling efficiency (NSE) statistics were found to vary from 0.70 to 0.99, and for sediment loss, from 0.82 to 0.98. For surface runoff, the equivalent validation period numbers varied from 0.60 to 0.92, and for sediment loss, they were 0.58 to 0.89. The SWAT model was run both with and without check dams after calibration and validation to see how well it could depict the effects of sediment control structures on the watershed. According to the model's predictions, check dams might prevent more than 64% of the silt from leaving the watershed. The outcomes also demonstrated the possibility of utilizing SWAT to evaluate sediment movement from certain sub watersheds within a watershed and to prioritize the site of sediment control structures within a watershed to achieve the most efficient reduction of sediment losses to surface water. Overall, the study demonstrated that SWAT can be a helpful technique for researching the management and control of sediment loss from small watersheds found in sub-humid climate conditions using check dams.

2.2 Water Quality and Watersheds

Agriculture has an effect on soil and water quality at the watershed or catchment level as part of natural resource management (NRM) practice (Wani et al., 2003; Twomlow et al., 2008a). Observed in situ data and data computed using a geographic information system (GIS) were used to evaluate the relationship between the formation of river water quality and the land use of river watershed at Lake Kasumigaura (Ls. Nishiura and Kitaura). River water has significant NO3-N concentrations, especially in the L. Kitaura basin. Following rains, the NO3-N concentrations dropped with dilution after rising during a low water temperature interval. Principal component analysis was used to investigate the association between land use features in the river basin and river water quality (Yuichi Ishii, Tatsumi Kitamura, Keiji Watanabe, January 2009).

According To Toshikazu Tokioka, Kunihiko Amano, Masatoshi Denda, Kouzi Thushima in 2005, to conduct the water quality improvement properly, it is necessary to estimate the dynamics of pollutant loads at watershed scales. We have attempted to quantify the watershed information by GIS to estimate the relation between water quality and watershed information, and carried out the field observation and sample collection, and then we have analyzed the run-off of NO3-N in Chikuma Basin.

2.3 Water Quality Monitoring and Framework

Water Quality Monitoring is defined as monitoring water quality parameters by sampling, testing, analyzing, and comparing it with set standard values. Water quality monitoring programme aims to obtain qualitative information on the physical, chemical, and biological characteristics of any water body. Environmental water quality monitoring aims to provide the data required for safeguarding the environment against adverse biological effects from multiple chemical contamination arising from anthropogenic diffuse emissions and point sources (Rolf Altenburger, Werner Brack, 2019). The rapid urbanization and industrial development have resulted in water contamination and water quality deterioration at an alarming rate, dreaming its quick, inexpensive, and accurate detection imperative (Umair Ahmed; Rafia Mumtaz; Hirra Anwar; Sadaf Mumtaz; Ali Mustafa Qamar, 2019). Water quality monitoring practices are basically designed to achieve specific purposes which lead to various types of monitoring, i.e., trend monitoring, biological monitoring, ecological monitoring, compliance monitoring, and the similar (N. B. Harmancioglu, S. D. Ozkul, M. N. Alpaslan, 1998). Water quality monitoring (WQM) is crucial for managing and protecting riverine ecosystems (Serena Caucci, 2015). In India, A network of monitoring stations on rivers across the country has been established by the Central Pollution Control

Board (CPCB). In surface waters, the monitoring is done on monthly basis and in case of ground water, quarterly and on half yearly basis monitoring is implemented. CPCB in collaboration with concerned SPCBs/Pollution Control Committees (PCCs) established a nationwide network of water quality monitoring comprising 2500 stations in 28 States and 6 Union Territories. Presently the inland water quality-monitoring network is operated under a three-tier programme: Global Environment Monitoring System (GEMS), Monitoring of Indian National Aquatic Resources System (MINARS) and Yamuna Action Plan (YAP).

In Gujarat, Water quality monitoring programmes are carried out through,

- GEMS Project – Assessment of the quality of water of major rivers of the State, viz. Narmada, Tapi, Mahi and Sabarmati
- MINARS Project – Monitoring the water quality from 102 sampling station located on rivers like Sabarmati, Narmada, Tapi, Ambika, etc.

In present study, Water Quality Framework has been suggested by finding water quality of Hathmati river which is one of the main tributaries of Sabarmati River. Due to ample quantity of water and increased use of fertilizers by the farmers, the Hathmati river is under a continuous threat in terms of Water Quality Issues, (J. DivyaS.L. Belagali (2012).

As per United States Environmental Protection Agency, the Water Quality Framework aims to streamline the assessment and reporting of water quality by combining current IT systems. Integration of EPA and state water quality data systems is necessary to:

- Help water quality managers correctly and clearly characterize the state of the nation's waters and encourage them to base their decisions on evidence.
- Track the success or failure of efforts made to assist waters meet standards, ease state reporting requirements, and improve EPA procedures.

The European Commission states that the Water Quality Framework's main goals are to ensure both good qualitative and quantitative health, which includes removing and reducing pollution and making sure there is enough water to meet both human and wildlife needs. The Framework is based on the risk-based approach to managing water quality recommended by the World Health Organization, which emphasizes systematic risk identification, the implementation of water safety plans, efficient monitoring and evaluation, regulation, and the coordination of the roles and responsibilities of all relevant actors (Ministry of Water Resources, Works and Housing Government of Ghana June 2015). Technical paper of Water Programme of Action: The Effects of Rural Land Use on Water Quality (July, 2004) examines the present problems with controlling the pollutant discharges from diffuse (non-point) sources that result from rural land use on freshwater quality. It suggests potential solutions to enhance water quality management concerns in order to facilitate collaboration. The framework for addressing the effects of rural land use on water quality is examined in this research. It does not provide any water quality criteria, which should instead be established through other procedures. A subclass of policy instruments known as "environmental management frameworks" (EMF) that are focused on regulating and monitoring surface water pollution are surface water quality management frameworks (SWQMF). To maintain pollution levels below set limits, the EMF works by creating quantitative triggers and limitations and connecting them to management actions. The frameworks make an effort to address cumulative effects and regional environmental quality (Jason Unger, May 2022). The framework for water quality is complicated and complex, with numerous legal and nonlegal regulations intended to protect water quality and influence or educate local government decision-making. The framework for water quality addresses two important areas: safeguarding the quality of water via particular health-related criteria and the quality of freshwater through environmental regulations (Dave Cull, May 2018). The Ganga River is facing mounting environmental pressures due to rapidly increasing human population, urbanization, industrialization and agricultural intensification, resulting in worsening water quality, ecological status and impacts on human health, (Michael J Bowes, Daniel S Read, Himanshu Joshi, Rajiv Sinha, Aqib Ansari, Moushumi Hazra, Monica Simon, Rajesh Vishwakarma, Linda K Armstrong, David J E Nicholls, Heather D Wickham, Jade Ward, Laurence R Carvalho, H Gwyn Rees, 2020).

2.4 Hydrologic Modeling

A hydrologic model is a simplification of a real-world system (e.g., surface water, soil water, wetland, ground water) which aids in understanding, predicting, and managing water resources through study of quantity as well as quality of water. Number of widely used hydrologic as well as water quality models are SHETRAN (Stream hydrology and water quality), HSPF (Stream hydrology and water quality), AGNPS (Stream hydrology and water quality), INCA (Stream water quality), SPARROW (Stream water quality), QUAL2K (Stream water quality), SWAT (Stream and Ground water Quality) etc.

The Soil and Water Assessment Tool (SWAT), a distributed parameter model created by the United States Department of Agriculture, is one such model that is accessible to those working in the field of water resources. The Soil & Water Assessment Tool is a small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds. This tool can be used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. The SWAT model, a freeware, was developed by the USDA-Agricultural Research Service to assist with assessment of watersheds ranging in sizes from small (a few hundred square kilometers) to large watersheds (several thousand square kilometers) (Neitsch, Arnold, Kiniry, Williams & King, 2002). SWAT model was used to calculate the runoff and sediment output of a small agricultural watershed in eastern India using produced rainfall, according to Tripathi M. P. (2004). A total of 18 years (1981–1998) were used to examine the model's ability to produce runoff. Using a geographic information system (GIS), the boundaries of the watershed and sub watersheds, drainage networks, slope, soil series, and texture maps were created. For the purpose of classifying land use and cover from satellite images, a supervised classification algorithm was employed. For a span of 18 years, model-simulated monthly rainfall was contrasted with actual data. For the eight-year monsoon season (1991–1998), simulated monthly rainfall, runoff, and sediment production data were also verified with actual values. In general, the model's monthly average rainfall predictions and the observed monthly average values were very similar. Additionally, using generated rainfall, 29 monthly average values of surface runoff and sediment output were simulated. These values were then compared to observed values for the monsoon season of the years 1991–1998.

Monsoon regions are distinguished by considerable seasonality in rainfall, according to Wagner P. D. (2011). In such a setting, model-based study of water resources must consider the unique natural circumstances as well as the related water management. Water management, which strives to lessen water shortages, and plant phenology, which is mostly driven by water, are of utmost importance. This study's objective is to use the SWAT model in a rain-fed area of the Indian Western Ghats utilizing primarily publicly available input data and to assess the model's performance in that environment. The watershed of the Mula and Mutha Rivers (2036 km^2) upstream of the Indian city of Pune serves as the study's test site. The majority of the input data came from foreign archives or remote sensing products. In SWAT, forest growth was changed to take seasonal water availability into consideration. Additionally, a dam management plan was created by combining general dam management guidelines, reservoir storage capacity, and anticipated monthly river discharge outflow rates. When compared to mean daily discharge recorded in three of four sub catchments during the rainy season, SWAT generated reasonable results with these model changes (Nash-Sutcliffe efficiency 0.58, 0.63, and 0.68). The gauge downstream of four dams, where the simple dam management plan failed to match the 32 management effects of the four dams combined on river discharge (Nash-Sutcliffe efficiency 0.10), had the lowest performance. The model significantly overestimated water supply, particularly in the smallest (headwater) sub catchment (99 km^2). The extrapolation errors of rainfall estimates based on readings at lower elevations are anticipated to be significant due to the lack of rain gauges in these headwater locations. Additionally, there are some signs that evapotranspiration may be overestimated. However, it can be said that using widely accessible data in SWAT model investigations of monsoon-driven catchments yields reasonable findings if important monsoon region characteristics are taken into consideration and processes are parameterized appropriately.

According to Liangliang GAO and Daoliang LI (2014), Currently, the most important trends for future model development are: (1) combination models - individual models cannot completely solve the complex situations so combined models are needed to obtain most appropriate results, (2) application of artificial intelligence and mechanistic models combined with non-mechanistic models will provide more accurate results because of the realistic parameters derived from non-mechanistic models, and (3) integration with remote sensing, geographical information and global position systems (3S) - 3S can solve problems requiring large amounts of data. According to Narsimlu B. (2015), the Kunwari River Basin (KRB) requires comprehensive water resource management for sustainable agriculture and flood hazard reduction. For hydrologic modelling, the Soil and Water Assessment Tool (SWAT), a semi-distributed physically based model, was selected and set up in the KRB. Model calibration, sensitivity analysis, and uncertainty analysis were performed using the Sequential Uncertainty Fitting (SUFI-2) technique and SWAT-CUP (SWAT-Calibration and Uncertainty Programs). The model was calibrated for the years 1987 through 1999, with the first three years serving as a warm-up period (1987– 1989). The model was then verified for the remaining six years of data (2000–2005). Two indices, the p-factor (observations bracketed by the prediction uncertainty) and the r-factor (attainment of tiny uncertainty), are used to evaluate the accuracy of model calibration and uncertainty. According to the SWAT simulation results, the p-factor and r-factor during calibration was reported as being 0.82 and 0.76, respectively, whereas during validation they were found to be 0.71 and 0.72, respectively. After thorough calibration and validation, the goodness of fit was further evaluated by comparing the observed values to the final simulated values using the coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (NS). The findings showed that throughout the calibration, R^2 and NS were, respectively, 0.77 and 0.74. Along with a satisfactory performance, the validation showed an R^2 of 0.71 and NS of 0.69. The hydrological community, water resource managers interested in agricultural water management and soil conservation, as well as those concerned in mitigating natural disasters like droughts and floods, would all benefit from the findings. According to Nitesh Godara and Oddbjorn Bruland (2020), choosing the appropriate hydrologic model is very important for getting good results. Reliable results can be obtained if the right hydrologic model is chosen for a particular catchment having characteristics and the purpose of research. A hydrologic model represents the hydrologic processes in simplified form and mainly used for forecasting and understanding these processes. The best hydrologic model is the one, which is less complex but gives the result like the observed values by using the least input data (Devia, G.K., Ganasri, B., Dwarakish, G, 2015). For a period of 25 years (1985-2010), Abeysingha N. S. used the Soil and Water Assessment Tool (SWAT) to evaluate the water yield and evapotranspiration for the Gomti River basin in India. The model performed satisfactorily according to the findings of the streamflow calibration and validation (NSE: 0.68-0.51; RSR: 0.56-0.68; |PBIAS|: 2.5-24.3). While evapotranspiration per unit area dropped from upstream to downstream, it increased in the midstream sub-basins relative to the upstream and downstream sub-basins. Water yield at downstream sub-basins fell from 1985 to 2010, but evapotranspiration and water yield at upstream and midstream sub-basins both rose. They discovered that the regional climate and irrigation practices had a significant impact on the geographical and temporal patterns of evapotranspiration and water yield. The long-term patterns in water yield suggest that the downstream sub-basin, which includes the districts of Jaunpur and Varanasi, has a propensity to dry out.

2.5 Integration of GIS and SWAT

According to David J. Maguire (2008), it is an extensive and integrated software platform technology for building operational GIS. ArcGIS comprises four key software parts: a geographic information model for modeling aspects of the real world; components for storing and managing geographic information in files and databases; a set of out-of-the-box applications for creating, editing, manipulating, mapping, analyzing, and disseminating geographic information; and a collection of web services that provide content and capabilities (data and functions) to networked software clients.

According to Ling Bian, Hao Sun, Clayton Blodgett, Stephen Egbert, WeiPing Li, LiMei Ran, Antonis Koussis (2020), the hydrologic model, SWAT, is a semi-empirical and semi-physical model. To predict the effect of agricultural management practices on water and sediment yields for large ungauged rural watersheds, SWAT works as a practical model. Moreover, SWAT is an advanced lumped or a semi-distributed model because it allows a watershed to be divided into hundreds of units. Its semi-distributed characteristic is well suited for integration with GIS.

SWAT consists of major water budget components such as weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth, irrigation water transfer, groundwater flow, and channel routing. The model runs on a daily time step for short- or long-term predictions and operates in a semi-distributed manner to account for spatial differences in soils, land use, crops, topography, channel morphology, and weather conditions.

Using GIS data, SWAT has been applied to many major river systems in the United States with promising results (Koussis et al. 1994, Srinivasan et al. 1993). The SWAT model has become increasingly popular in recent years. As an advanced lumped model, SWAT accounts for spatial variability at the expense of data input. At the basin level, SWAT can take more than ten separate input files concerning agricultural management, water bodies, basin configuration, and weather information. At the subbasin level, SWAT can use up to nine input files containing detailed information for subbasin characteristics, surface and ground water bodies, channel routing, soils, weather, and agricultural practices. Using SWAT for a ten-subbasin watershed, a user may have to prepare nearly one hundred input files, with each containing ten to thirty parameters. SWAT provides a rather primitive user interface to facilitate data entry and editing and operates only in the DOS environment. All input files are fixed formatted and must be prepared separately. A more integrated, advanced user interface would significantly enhance the capability and usability of SWAT. Primary inputs for all these models can be obtained from

- Remote Sensing
- Digital Elevation Model (DEM) and
- Geographic Information System (GIS)

P. W. Gassman, M. R. Reyes, C. H. Green, J. G. Arnold suggested that the process of configuring SWAT for a given watershed has also been greatly facilitated by the development of GIS-based interfaces, which provide a straightforward means of translating digital land use, topographic, and soil data into model inputs. According to Yinping Wang, Rengui Jiang, Jiancang Xie, Yong Zhao, Dongfei Yan, and Siyu Yang (2019) reviewed three hot application fields such as runoff simulation, hydrological impacts under changing environment and non-point source (NPS) pollution, the results show that: (1) the research content of runoff simulation mainly focused on the adaptability and accuracy of the model; (2) the research content of hydrological impacts under changing environment mainly concentrated on analysis of historical changes in hydrological effects and prediction of future changes using the scenario analysis; (3) the research content of NPS pollution mainly focused on the spatial and temporal distribution of nutrients, the influencing factors and degree of nutrients, and the prediction of future to select Best Management Practices (BMPs). Arc SWAT is an ArcGIS-ArcView extension and interface for SWAT. ArcGIS is a geographical information system (GIS) software that allows handling and analyzing geographic information by visualizing geographical statistics through layer building maps like climate data or trade flows. Like many GIS software, ArcGIS creates maps that require categories organized as layers. Each layer is registered spatially so that when they're overlaid one on top of another, the program lines them up properly to create a complex data map. The base layer is almost always a geographical map, pulled out of a range of sources depending upon the visualization needed. According to Jayakrishnan in 2005, advances in computer technology have completely changed how hydrologic systems are studied and how water resources are managed. For use in hydrologic modelling and research of water resources, several computer-based hydrologic/water quality models have been developed. For basin scale research, distributed parameter models are essential, but they have a lot of input data needs. Model-GIS interfaces and geographic information systems (GIS) make it easier to create the input data files that these models need quickly. This paper discusses some recent developments in the management of water resources using SWAT and the SWAT-GIS interface. There are four case studies offered. Using SWAT, the Hydrologic Unit Model for the United States (HUMUS) study examined the impact of various management scenarios on water quantity and quality at the national level. We can add the geographical variability of rainfall into the modelling process by integrating the SWAT model with rainfall data from the radar network. This study highlights the value of radar rainfall data for distributed hydrologic studies and the promise of SWAT for use in the analysis and forecasting of floods. The basin-scale Soil and Water Assessment Tool (SWAT) model, relational databases of climatic, soil, crop, and management attributes, and GIS to manage geographical inputs and outputs were all discussed by Srinivasan R. in 1998. By considering both current and anticipated future climatic characteristics, water needs, point sources of pollution, and land management affecting non-point pollution, this research seeks to improve existing systems for producing national and river basin size estimates of water resource availability.

2.6 SWAT Applications

Nowadays SWAT model is used worldwide due to its clear and distinct applications in almost all fields of hydrology. Few major applications have been discussed here.

2.6.1 Hydrologic Assessment

Models require input data for weather, soils, land use, management, geology, and topography. The advantage of models is in their ability to simulate management and climate scenarios. Climate scenarios include changes in precipitation, temperature, radiation, humidity, and CO_2. Management scenarios include cropping systems, tillage, irrigation, fertilization, and reservoir management (J.G. Arnold, R.S. Muttiah, R. Srinivasan, P.M. Allen, 2000). As per Celine Conan, Ghislain de Marsily, Faycal Bouraoui, Giovanni Bidoglio, the general hydrologic model SWAT, which can consider the entire hydrologic cycle is well adapted to describing the changes from wetlands to dry lands due to human action (2003). He also suggested that the SWAT model has demonstrated that numerical modelling is an important tool for managing natural resources. As per St. Joseph's opinion, SWAT seemed to be unable to simulate the extremely wet hydrologic conditions, even after adjustments to measured data. Overall, the hydrology component of the SWAT model can perform an acceptable prediction of long-term simulations for management purposes but fails to have reasonable predictions for short time intervals (i.e., daily) (2004). M. Hosseini, M.S.M. Amin, A.M. Ghafouri and M.R. Tabatabaei, 2010 have successfully developed a customized SWAT model by SUFI-2 program to be used by water engineers and managers in their planning of future land and water developments in Taleghan catchment. They concluded that database system created in the study area, using dispersed datasets in GIS environment could be used not only for modeling purposes but also for decision making.

Huicheng Chien, Pat J.-F. Yeh, Jason H. Knouft, 2013 used the SWAT distributed hydrologic model in combination with the SUFI-2 multi-site calibration procedure to demonstrate that spatial and temporal variation in streamflow over large watersheds can be reasonably represented through multi-site calibration and validation.

By carefully describing and modelling the affected metropolitan region, Sisay E. (2017) was able to quantify and anticipate the effects of urbanization on hydrological processes and water supplies. To evaluate its applicability in the ungauged urban watershed of Vadodara city, Gujarat, India, the SWAT model has been used. To understand the status of the hydrological processes and water resources in that area, the primary goal of this work is to study the SWAT model and its applicability, i.e., test and evaluate the capabilities, performance, and suitability of SWAT model for Vadodara city, which is an ungauged urban area. The watershed of the city of Vadodara remains unmeasured. Consequently, a regionalization approach has been employed to forecast the river discharge at the watershed's exit. The runoff process has been calibrated and validated using the SUFI-2 algorithm utilizing SWAT-CUP 2012 monthly. Based on a comparison of the simulated and actual flow rates at the basin outflow during the time periods 1979–2001 and 2002–2013, respectively, the model was calibrated and validated. As a result, for the monthly time step, the NSE values were applied at 0.53 and 0.61, the determining coefficient (R^2) at 0.69 and 0.51, the PBIAS value at 5.3 and 10.4%, and the RSR values at 0.71 and 0.63 for the calibration and validation processes, respectively. The outcome implies that the simulated and observed flow closely matched each other. As a result, the model's performance has good forecasting power for Vadodara City's unmeasured watershed. According to Nguyen V. T. (2018), one of the most used hydrologic models is the SWAT. However, SWAT's review and testing are correspondingly constrained, particularly the flood routing capabilities. In this study, a well-observed section of the Weser River in Germany was used to examine and test the daily flood routing subroutines of several SWAT versions. Results reveal a number of issues with SWAT's flood routing subroutines. The flood wave is not transformed by the SWAT variable storage function. The SWAT variable storage routing could provide nonphysical outcomes. A bias of 14% to 19% in streamflow results from the Muskingum subroutine of SWAT overestimating channel evaporation and underestimating transmission losses. The time and shape of the flood wave could be improved, according to simulation data, using a modified Muskingum subroutine. We advise the SWAT user community to assess their current SWAT models considering the findings of this study to determine how the problems will impact their research techniques, findings, and conclusions.

2.6.2 Pollutant Load Studies

Abhinav Wadhwa (2017) suggested that SWAT is one among the techniques for deterministic, continuous, watershed-modelling to the pollutographs and load graphs, thereby, estimating the ecological changes in a water stream. SWAT modelling gives definitive idea about the pollutant and flow characteristics to optimally and effectively manage existing drains to bring the pollutants concentration to minimal amount during high flood conditions. SWAT calibration and validation suggested it is a reliable method of measuring the NPS pollution in Miyun reservoir watershed. This study estimated and analyzed spatial and temporal variations in NPS pollution loads in Miyun Reservoir watershed (Mingtao Li and Qianqian Guo, 2020). Modified SWAT model was a promising tool for analysis of the pollution load of manganese in rainwater runoff from a manganese mine (Bozhi Ren, Kejia Liu, Hongpu Ma, Hongtao Zhou and Xie Zheng, 2014). C. Baffaut, V. W. Benson, 2009 mentioned that water quality results in his research indicated that the SWAT model can be used to simulate the frequency of occurrence of pollutant concentrations and daily loads. G.C. Heathman, D.C. Flanagan, M. Larose, and B.W. Zuercher, 2008 in their research evaluated the performance of two water quality models in accordance with specific tasks designated in the USDA Agricultural Research Service

Conservation Effects Assessment Project. The SWAT and the Annualized Agricultural Non-Point Source (AnnAGNPS) models were applied uncalibrated to the Cedar Creek watershed within the St. Joseph River watershed in northeastern Indiana to predict stream flow and losses. Overall results suggest that for Conservation Effects Assessment Project modeling applications at the Cedar Creek watershed scale in this study, the use of the SWAT model would be preferable to AnnAGNPS in terms of overall model performance and model support technology (e.g., model interface and documentation).

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2.6.3 Climate Change Impact Studies

Sadegh Khalilian and Negar Shahvari, 2018 worked on for evaluating SWAT for the Effects of Climate Change on Renewable Water Resources in Salt Lake Sub-Basin, Iran and concluded that the decrease in rainfall and increase in temperature will be the main factors for the decrease in water availability for the predicted climate change scenarios. Taha Aawar & Deepak Khare, 2020 investigate the impact of climate change on the surface flow as well as land use/land cover change using calibrated SWAT model and showed the importance of climate change effect on water resources, where it does not have only an effect on precipitation and temperature, but the streamflow is also directly influenced by climate change.

According to Mishra V. (2016), climate change may have a significant impact on the hydrologic processes in the river basins of the Indian subcontinent. We demonstrate that the majority of the river basins in the Indian subcontinent are anticipated to experience a climate shift towards a warmer and wetter one in the future using downscaled and bias corrected future climate predictions and the SWAT. The mean air temperature is predicted to rise by more than 0.5 (0.8), 1.0 (2.0), and 1.5 (3.5) °C in the near (2010-2039), mid (2040-2069), and End (2070-2099) term climates, respectively, during the monsoon (June to September) season under the representative concentration pathways (RCP) 4.5 (8.5).

Furthermore, under the predicted future climate, the post-monsoon season temperature in the sub-continental river basins could rise by 3 to 5 degrees Celsius. Strong increases in precipitation are anticipated in several subcontinental river basins under the projected future climate, particularly in the mid- and long-term climate, notwithstanding the significant intermodal uncertainty. Surface runoff, as compared to evapotranspiration (ET), is more susceptible to changes in precipitation and temperature, according to a sensitivity analysis for the Ganges and Godavari River basins. The projected future climate shows an amplification of the hydrologic cycle in the basins of the Indian subcontinent. For example, under the RCP 4.5 and 8.5 scenarios, ET is expected to rise to 10% for the most river basins in the mid- and long-term climate. By the end of the 21st century, mean surface runoff is predicted to increase by more than 40% in 11 (15) basins during the monsoon season under the RCP 4.5 (8.5) scenarios. In addition, the RCP 4.5 (8.5) scenarios predict that streamflow will rise by more than 40% in 8 (9) basins during the monsoon season. According to the findings, variations in precipitation during the monsoon season have a greater impact on water availability in sub-continental river basins than do changes in air temperature. Water availability in most sub-continental river basins is anticipated to grow, although under the forecast future climate, there may be significant geographical and temporal (interannual) variability in monsoon season precipitation. Future water management techniques in the river basins of the Indian subcontinent may require significant effort, according to changes in the hydrologic processes under the expected future climate.

Lin, Tzu Ping; Lin, Yu Pin; Lien, Wan Yu, 2015 adopted combined climate and land use change scenarios as input data of the hydrological model, the SWAT model, to estimate the future stream flows and observed that with the increasing precipitation, increasing urban area and decreasing agricultural and grass land, the annual streamflow in the most of twenty-three subbasins were also increased. They also observed that due to the increasing rainfall in wet season and decreasing rainfall in dry season, the difference of streamflow between wet season and dry season are also increased which indicates a more stringent challenge on the water resource management in future. Therefore, in his research he concluded, impacts on water resource caused by climate change and land use change should be considered in water resource planning for the Datuan river watershed. Climate change, which has a detrimental impact on food production, water supply, health, way of life, energy, and other aspects of the entire earth system, is one of the most significant worldwide environmental issues, claims Bhumika U. (2015). The goal of the current study was to use the ArcSWAT model to evaluate the effects of climate change on the water balance components in the Upper Baitarani River basin in Eastern India, which was data strapped. The SUFI-2 approach was used to calibrate the ArcSWAT model. For calibration and validation, daily observed streamflow data from 1998 to 2003 and 2004-2005 were used. With a Nash-Sutcliffe efficiency (NSE) and mean absolute error (MAE) for the daily time step of 0.88 and 9.70 m^3/s, respectively, the calibration findings were deemed to be good. Additionally, the model was successfully tested to simulate daily streamflow (NSE = 0.80 and MAE = 10.33 m^3/s). The basin's response to the predicted climate changes by the end of the twenty-first century was then assessed using the calibrated and verified model. To assess the effect of climate change on the basin's hydrology, twelve independent and twenty-eight combined area-specific climate scenarios were taken into consideration. The analysis of model results for the 12 independent climatic scenarios indicated a reduction in the surface runoff ranging from 2.5 to 11 % by changing the temperature from 1 to 5 °C, whereas the increase in rainfall by 2.5 to 15 % suggested an increase in surface runoff by 6.67 to 43.42 % from the baseline condition. In case of 28 combined scenarios compared to the baseline condition, the changes in surface runoff would vary from − 4.55 to 37.53 %, the groundwater recharge would change from −8.7 to 23.15 % and the evapotranspiration would increase from 4.05 to 11.88 %. It is concluded that future changes in the climatic condition by the end of the 21st century are most likely to produce significant impacts on the streamflow in the study area. The results of this study, together with those from a subsequent investigation in this area, will be helpful in directing appropriate adaptation strategies for basin-wide sustainable water management in the face of imminent climate change.

According to BNan Y. (2011), researching how climate change is affecting hydrology and water resources can help us understand and address some issues with these resources, such as managing plans, operations, protecting the environment, and maintaining ecological balance. Furthermore, there are close connections between the hydrology and water resource systems and the economic, industrial, agricultural, and urban development sectors. This research examines the connection between water supplies and climate change, as well as how water circulation affects climate change. And then summarizes some study methods of analyzing the impacts of climate change on hydrology and water resources, such as generation technology for climate change scenario and hydrologic simulation. At last, it raises problems in study and puts forward the development trend, including perfecting the distributed hydrological model, improving the precision of climate models and hydrologic models, and developing the two-way coupling techniques of climate models and hydrological models. Faith Githui, Wilson Gitau, Francis Mutuab and Willy Bauwens, 2009 generated climate change scenarios, the SWAT model was calibrated and validated, determined the effects of climate change scenarios on runoff and baseflow, established regression relationships between changes in climate (rainfall) and runoff, and finally the probability of flood exceedance under the generated climate change scenarios was calculated as an example of the implications of climate change on water resources. Vaskar Dahal, Rabin Bhattarai, Narendra Man Shakya, Rocky Talchabhadel, Sumit Dugar, 2015 worked together for estimating the impact of climate change on streamflow in Bagmati watershed, Nepal and concluded that Uncertainty remains regarding the future hydrologic changes due to the uncertainty of future climate changes, especially precipitation patterns, the future dynamics of vegetation and land use, and partly due to the SWAT model processes uncertainty. SWAT as a rainfall-runoff conversion tool, together with the implemented models and climate change scenarios, are suitable in an area with subhumid and semi-arid climate and can be used in other regions with similar climatology (Jodar-abellan; Ruiz, and Melgarejo, 2007). Bhumika Uniyal & Madan Jha & Arbind Verma, 2015 concluded that future changes in the climatic condition by the end of the 21st century are most likely to produce significant impacts on the streamflow in the study area by assessing climate change impact on water balance components of a River Basin Using SWAT Model. The authors Afsheen Maryam, Sardar Khan1, Kifayatullah Khan, Muhammad Abbas Khan, Fazli Rabbi, Shahid Ali, 2014 investigated the perceptions of locals regarding the effects of climate change on their lives both qualitatively and quantitatively, which have not been studied previously. Mekonnen H Daba, 2018 revealed that change in climate variables such as decrease in rainfall and increase in temperature would have a significant impact on the stream flow and surface runoff, causing a possible reduction on the total water availability in the sub-basin. According to Sujana Dhar in 2009, India is a developing nation with over two thirds of the population directly reliant on climate-sensitive industries including agriculture, fisheries, and forests. In order to assess projected parameters for agricultural activities, a highly calibrated soil and water assessment tool (R^2 = 0.9968, NSE = 0.91) was applied over the Kangsabati river watershed in the Bankura district of West Bengal, India, for a year that included monsoon and non-monsoon periods. The years 2041–2050 are used to analyze evapotranspiration, transmission losses, prospective evapotranspiration, and lateral flow to reach in order to paint a picture of the river basin's and its residents' sustainable growth. Under many scenarios, the expected climate change is likely to have an impact on food production, water availability, biodiversity, and livelihoods. India has a big interest in advancing science as well as international cooperation to support mitigation and adaptation. This calls for more scientific knowledge, capacity development, networking, and extensive consultation procedures. This report makes a commitment to the planning, management, and development of the Kangsabati river's water resources by outlining specific future scenarios for the river basin during the specified time. The main conclusions of this study were that over the period of years 2041–2050, transmission losses, soil water content, potential evapotranspiration, evapotranspiration, and lateral flow to reach all show an increasing tendency.

Then, in 2007, Dash S. K. conducted research on climate change in India and said that solid evidence is a cause for concern, especially given that it is well known that the poor are particularly susceptible to climate change. Due to India's enormous size and intricate geography, the climate in this region of the world varies greatly throughout both space and time. Floods, droughts, monsoon depressions and cyclones, heat waves, cold waves, protracted fog, and snowfall are significant meteorological occurrences that have an impact on India. The air surface temperature in India has increased by around 1 and 1.1°c throughout the past century, respectively, according to the findings of this extensive study based on observable data and model reanalyzed fields. Additionally, the seasonal temperature anomalies have a substantial variation of roughly 0.8°c due to the fall in the minimum temperature during the summer monsoon and its increase during the post-monsoon months, which may result in seasonal asymmetry and consequent changes in atmospheric circulation. The inter-annual variability has revealed opposite stages of lowest temperature growth and decline in India's southern and northern areas, respectively. Between 1955 and 1972, the minimum temperature in north India displays a strong fall in magnitude, followed by a sharp climb up till the present. However, the minimum temperature is steadily rising in south India. The Arabian Sea and Bay of Bengal's sea surface temperatures (SST) likewise exhibit an upward trend. Observations show that the east coast of India has recently experienced more extreme temperature episodes. The frequency of depressions (low pressure zones) is trending either down or up throughout the summer monsoon season. The frequency of cyclonic storms has increased during the past century, especially in the month of November. Additionally, the number of powerful cyclonic storms that pass the Indian Coast has increased. The summer monsoon rainfall over the Indian subcontinent is trending downward, whereas pre-monsoon and post-monsoon months rainfall are trending upward, according to an analysis of rainfall amounts over different seasons. According to Mall R. K. again in 2006, several recent research conducted all over the world indicate that the availability of freshwater resources will likely be considerably impacted by climatic change. Due to urbanization, agricultural expansion, population growth, rapid industrialization, and economic development, India's need for water has already multiplied throughout time. In several Indian climate areas and river basins, the hydrological cycle is now being altered by changes in agricultural and land-use patterns, over-exploitation of water storage, and changes in irrigation and drainage. For appropriate national and regional long-term development strategies and sustainable development, an assessment of the availability of water resources in the context of future national requirements and predicted impacts of climate change and its variability is essential. The potential for sustainable development of surface water and groundwater resources in India is examined in this article, taking into account the limitations imposed by climate change and upcoming research requirements. Xin Xu,Yu-Chen Wang, Margaret Kalcic , Rebecca Logsdon Muenich, Y.C. Ethan Yang, Donald Scavia incorporated climate projections into the SWAT model to estimate daily streamflow, then quantify flood risk using indices related to flood probability, duration, magnitude, and frequency and indicated that rising temperatures may counteract small increases in precipitation, likely due to increased evapotranspiration. They also gave brief review that climate model data without bias correction used in SWAT produced reasonable future streamflow changes like the perturbation of historical climate therefore retaining the predicted change in the flood frequency distribution. Son Ngo, Huong Hoang, Phuong Tran, Loc Nguyen, 2020 in his research on Application of SWAT model to Assess Land Use and Climate Changes Impacts on Hydrology of Nam Rom River Basin in Vietnam indicated that SWAT proved to be a powerful tool in simulating the impacts of land use and climate change on catchment hydrology. According to Mall R. K. in 2002, the scientific community has placed a greater emphasis on food security and its regional effects in recent years due to the growing acceptance of the possibility of climate change and the abundant evidence of observed changes in the climate during the 20^{th} century. In recent years, the influence of climate change on agricultural production and food security has been intensively studied using crop simulation models. The simulation models' output can be used to help farmers and others choose the best solutions for their farming system and to make informed crop management decisions. Significant research has been conducted in India over the past ten years to determine the type and scope of crop yield changes anticipated because of predicted climate change. An overview of the current level of knowledge about the potential impact of climatic variability and change on the production of food grains in India is provided in this paper. With the growing acceptance of climate change in the last ten years and the unequivocal evidence of observed changes in climate during the 20th century, the scientific community has begun to place a greater emphasis on food security and its regional effects. In recent years, the influence of climate change on agricultural production and food security has been intensively studied using crop simulation models. The simulation models' output can be used to help farmers and others choose the best solutions for their farming system and to make informed crop management decisions. With the rising usage of computers in the coming decades, it is anticipated that policymakers, professionals, and farmers would all use simulation models more frequently. Significant research has been conducted in India over the past ten years to determine the type and scope of crop yield changes anticipated because of predicted climate change. An overview of the current level of knowledge about the potential impact of climatic variability and change on the production of food grains in India is provided in this paper. Yu P. (2002) examined how paddy fields' ET has changed because of climatic change. Data from the weather station in Kao-Hsiung are subjected to a sensitivity analysis. Only the temperature and relative humidity exhibit significant trends at the end. ET for paddy exhibits a favorable trend under a variety of climatic situations. This study's main goal was to investigate how evapotranspiration from paddy fields is affected by climate change. The modified Penman formula was used to conduct a sensitivity analysis of meteorological variables at the Kao-Hsiung station, one of Taiwan's meteorological stations. The database included 48 years' worth of data on temperature, relative humidity, sunlight hours, wind speed, and precipitation depth. The Mann-Kendall test, Cumulative Deviation test, Linear Regression, and Autocorrelation Coefficient were used to assess the data for trends and persistence. The findings showed that the only variables with substantial long-term trends and persistence are temperature and relative humidity. In order to study the impacts of climate change on evapotranspiration, two climatic scenarios, namely (1) linear extrapolation of climatic trends and (2) the projections of General Circulation Models (GCMs), were considered. The study found that under both studied climatic situations, evapotranspiration from paddy fields rose. As part of the National Communication (NATCOM) project undertaken by the Ministry of Environment and Forests, Government of India, the study by Gosain A. K. in (2006) had been taken up to quantify the impact of the climate change on the water resources of Indian river systems, the present study has been taken up. The daily meteorological data are used in the study to calculate the spatiotemporal water availability in the river systems. The SWAT distributed hydrological model was utilized. 40 years of simulated weather data were used to model over 12 river basins in the nation (20 years for the control or current and 20 years for the GHG (Greenhouse Gas) or future climate scenario). According to the preliminary estimate, the severity of droughts and the intensity of floods in different sections of the country may worsen under the GHG scenario. Additionally, it has been expected that the available runoff will generally decrease under the GHG scenario. In this research, two river basins that are expected to be most negatively impacted—one due to flooding and the other due to drought—are thoroughly examined.

2.6.4 Water Quality Monitoring Framework

Sam D. Taylor a, Yi He, Kevin M. Hiscock, 2016 applied SWAT to the River Wensum catchment in eastern England with the aim of quantifying the long-term impacts of potential changes to agricultural management practices on river water quality and highlighted the need to consider multiple pollutants, the degree of uncertainty associated with model predictions and the risk of unintended pollutant impacts when evaluating the effectiveness of mitigation options, and showed that high-frequency water quality datasets can be applied to robustly calibrate water quality models, creating DSTs that are more effective and reliable. Valentina Krysanova and Mike White, 2015 addressed: nutrients and related best management practices (BMPs); sediments and related BMPs; impoundment and wetlands; irrigation; bioenergy crops; climate change impact; and land-use change impacts, covering the themes: surface runoff and sediments; nonpoint-source pollution; surface water and groundwater; impacts of climate and land-use change; and large-scale SWAT applications. Hafiz Qaisar Yasin ·Roberto S. Clemente, 2014 in his concluded that SWAT model has huge potential in studying hydrology of watersheds even under data scarcity, he also suggested that calibrated model can be employed for studying land use change scenarios and probable climate change impacts on basin hydrology depending on availability of data. The SWAT model has the capacity of detailed input information and may produce accurate predictions concerning the nitrates and phosphorus loadings at a selected outlet provided that the point sources are integrated in detail (Daniel Dunea, Petre Bretcan, Danut Tanislav, Gheorghe Serban, Razvan Teodorescu, Stefania Iordache, Nicolae Petrescu and Elena Tuchiu, 2020). Gangsheng Wang, Henriette I. Jager, Latha M. Baskaran, Tyler F. Baker, Craig C. Brandt developed three innovations to overcome hurdles associated with limited data for model evaluation: 1) An auto-calibration approach to allow simultaneous calibration against multiple responses, including intermediate response variables, 2) Identified empirical spatiotemporal datasets to use in our comparison, and 3) Compared functional patterns in land use-nutrient relationships between SWAT and empirical data.

C. Santhi, R. Srinivasan, J.G. Arnold, J.R. Williams, 2006 showed that a modeling approach can be used to estimate the impacts of water quality management programs in large watersheds. Orville P. Grey, Dale F. St. G. Webber, Shimelis G. Setegn & Assefa M. Melesse, 2014 suggested that projected land use changes will have serious impacts on available water (streamflow), stream health, potable water treatment, flooding and sensitive coastal ecosystems. Michael F Winchell, Natalia Peranginangin, Raghavan Srinivasan, and Wenlin Chen, 2017 conducted their research to assess the ability of the uncalibrated SWAT to predict annual maximum pesticide concentrations in the flowing water bodies of highly vulnerable small to medium-sized watersheds and observed situations in which SWAT over or underpredicted the annual maximum concentrations, indicating that the model and uncalibrated parameterization approach provide a capable method for predicting the aquatic exposure required to support pesticide regulatory decision making. Amy S. Cotter, Indrajeet Chaubey, Thomas A. Costello, Thomas S. Soerens, and Marc A. Nelson, 2003 indicated comparison of the absolute values of relative error in the SWAT model predictions induced by various resolutions of DEM, land use, and soils and concluded that DEM was the most sensitive input variable that affected flow, sediment, NO3-N, and TP predictions, SWAT model output was most sensitive to input DEM data resolution, A decrease in DEM data resolution resulted in decreased watershed area and slope and increased slope length and significantly affected flow and water quality response predictions, Flow predictions were not significantly affected by land use data resolutions, Soils data resolution had no significant effect on sediment, NO3-N, and TP predictions up to 500 m data resolution, Minimum resolution for input GIS data to achieve less than 10 percent model output error depended upon the output of interest. As per EPA, the Water Quality Framework streamlines water quality assessment and reporting by integrating existing systems. A well-established framework has been developed to represent the integrated nature of monitoring activities and tasks, as a monitoring framework and a monitoring cycle by the U.S. National Water Quality Monitoring Council and the UN/ECE Convention for Protection and Use of Transboundary Waters. A framework might incorporate all the monitoring strategies to obtain more information about a catchment and its water quality. The future of monitoring will involve satellite, in-situ and air borne devices with data analytics playing a key role in providing decision support tools (Joyce O’Grady, Dian Zhang, Noel O’Connor, and Fiona Regan, 2020).

2.6.5 Crop rotation

The SWAT model was used to the river Wensum basin in eastern England in 2016 by Sam D. Taylor, Yi He, and Kevin M. Hiscock with the goal of calculating the long-term effects of anticipated modifications to agricultural management practices on river water quality. As a result of adding a red clover cover crop to the agricultural rotation plan used in the catchment, nitrate losses were decreased by 19.6%, according to the results. The most successful solutions for reducing total phosphorus losses were buffer strips, which may achieve reductions of 12.2% and 16.9%, respectively, with widths of 2 m and 6 m. This is one of the first studies to provide estimates of the uncertainty associated with the consequences of agricultural mitigation methods on long-term water quality for nitrate and total phosphorus at a daily level. The SWAT model was used by Eric G. Mbonimpa, Yongping Yuan, Megan H. Mehaffey, and Michael A. Jackson to evaluate the effects of continuous-corn farming on sediment and phosphorus loading in Wisconsin's Upper Rock River watershed. It was anticipated that as corn became more economical, farmers in the region where corn and soybean were cycled would gradually switch to continuous corn. SWAT simulations showed that changing from corn-soybean to corn-corn-soybean will result in an increase in sediment yield and TP loss of 11% and 2%, respectively. The increase in sediment yield and TP loss following the switch from corn-soybean to continuous corn was 55% and 35%, respectively. Winter cover crops (WCCs) were adopted in 2016 by Sangchul Lee, In-Young Yeo, Ali M. Sadeghi, Gregory W. McCarty, W. Dean Hively, and Megan W. Lang as an efficient conservation management practice to assist decrease agricultural nutrient loads in the Chesapeake Bay (CB). The WCC's potential to improve water quality hasn't, however, been completely realized at the watershed level. According to the simulation results, WCCs are efficient at lowering NO3-N loads, and their efficacy varies depending on the species, crop rotations, planting dates, and soil properties. The efficacy of WCCs varied depending on crop rotations (i.e., continuous corn and corn-soybean), with greater N uptake occurring after soybean crops because soybean residue has been mineralized more than corn residue, increasing the soil's availability of N. In order to reduce TN, TP, and sediment losses based on soil characteristics while retaining a similar production area for each rotation, Fei Jiang, Patrick J. Drohan, Raj Cibin, Heather E. Preisendanz, Charles M. White, and Tamie L. Veith relocated crop rotations within existing agricultural land in 2021. While corn-soybean rotations were relocated to less risky locations, hay was placed on landscapes most susceptible to erosion and nutrient loss. In the reallocated scenario, 72% of agricultural areas were reassigned while only 28% of them continued to use the same crop rotation as in the baseline scenario. TN, TP, and sediment losses were decreased by 15%, 14%, and 39%, respectively, at an average yearly scale in a SWAT simulation of the reallocated scenario. These findings demonstrate that even without additional structural best management practices, redistributing agricultural rotations within a watershed with a problem can significantly enhance water quality.

Crop rotation is one of the field-based BMPs used to preserve the total soil fertility and minimize the displacement of the topsoil layers by surface water runoff throughout the agricultural watersheds, according to Seyedeh Nayyer Mirnasl Bonab in 2019. The fundamental idea behind this BMP's implementation is to deviate from the monoculture cropping method by incorporating several crops into the farming process. In this approach, the productivity of all crops in the landscape is unaffected and important nutrients that are essential for crop growth are not lost from farmed soils.

The planning of the rotation process, which is influenced by a variety of environmental, structural, and managerial factors, including the size of farmlands, climate variability, crop type, level of implementation, soil type, and market prices, among other factors, is crucial for the successful implementation of crop rotation. Depending on the unpredictability of other parameters, the complexity of the watersheds where this BMP is applied, and the overall goals of the BMP adoption, each of these decision variables is liable to change.

2.6.6 Change in Land use Land cover

In 2014, Bano B. Mehdi worked on a comparative study in two mid-latitudes, developed agricultural watersheds (Altmühl River, Germany, and Pike River, Canada), where she looked into the effects of potential future land use change and climate change on surface water quality. The goal of the research was to create agricultural land use scenarios that could be applied to a hydrological model and climate change simulations at the same time. The overall effects on streamflow, sediment loads, nitrate-nitrogen loads and concentrations, as well as total phosphorus loads and concentrations to the 2050-time horizon, could be quantified thanks to this modelling approach. First, the effects of climate change alone, and then those of land use change, were assessed. It was found that the hydrological model's simulation of the combined effects of climate change and land use change in both watersheds is non-linear. Since the direction and extent of prospective changes in water quality in a basin cannot be predicted from the individual changes alone, it is vital to examine the overall impacts. According to research done in 2021 by Dipak R. Samal and Shirish Gedam, the form of LULC change has varied effects on basin and sub-basin scales. However, at the sub-basin level, the surface runoff and water yield have grown up to 13.6% and 8%, respectively. At the basin level, the overall consequences of LULC shift on hydrological parameters are minor. The 5-year Growth and Transformation Plan (GTP) has prompted the Tigray Regional Government to propose changes to land use and cover (LULC) in 2020. Hydrological flow could be impacted by this LULC alteration. For this reason, it's crucial to estimate the hydrological flow brought on by the LULC shift. In light of this, we set out to compare three LULC scenarios to the base year (2010) in order to evaluate the effects of LULC change on the hydrological flow of the Gibe watershed. The three scenarios involved increasing the amount of forest, plantations, or grasslands by 400, 200, and 200%, respectively, from the base year. The hydrological flow was simulated using the SWAT model. The model was tested over a 7-year period using a daily time series; it was calibrated over a 5-year period (1998-2002) and validated over a 2-year period (2003-2004). With NSE = 0.81, R^2 = 0.78, and PBIAS = 6.85% for calibration and NSE = 0.79, R^2 = 0.75, and PBIAS = 7.52 for validation, the simulated daily flow demonstrated a good agreement to the observed flow. According to the hydrological flow modelling results, the yearly flow was decreased by 8.61, 4.65, and 1.45%, respectively, with increasing forest cover, plantation/area closure, and grassland. Land use-land cover change (LULC) has a significant impact on hydrologic responsiveness at the watershed level, according to Santosh Babar and H. Ramesh's 2015 study. For the development of water resources, a quantitative study of LULC effects on runoff generation is essential. Disse, Markus, Fenta Mekonnen, Dagnenet, Duan, Zheng, Rientjes, and Tom concluded in 2018 that the LULC modification greatly impacts base flow and surface run-off based on the analysis of its single influence on streamflow. This may be ascribed to the 4.6% increase in cultivated area and 5.1% decrease in forest cover. Temesgen Mekuriaw noted a substantial impact of LULC change in 2019 that was reflected in changes to the region's hydrologic system and had significant management implications for this region as well as other places in Ethiopia that were similar. To understand the availability and distribution of water for various applications soon, it is important to quantify the impact of climate change and land use change on the hydrologic variables of the watershed (Kumar et al., 2022). It is anticipated that the hydrological state of the region has changed as a result of catchment LULC modification and climate change (Huyen 2017; Boru et al., 2019). The watershed's overall volume, peak flows, and flow routing time can all be affected by changes in climatic variability (Changnon and Demissie, 1996; Prowse et al., 2006). However, LULC change because of deforestation, urbanization, and cultivation with different tillage practices led to alteration of the surface runoff and ultimately causes change in flood frequency, severity, base flow, and annual mean discharge of any watershed (Crooks and Davies, 2001; Binh and Trung, 2005; Brath et al., 2006). Megersa Kebede Leta, Tamene Adugna Demissie, and Jens Tränckner shown in 2021 that changes in land use and land cover from 2019 to 2035 reveal a decrease in evapotranspiration, lateral flow, ground water flow, and water yield as well as an increase in surface runoff and water yield. This shows that in the future, the terrain will shift from being mostly forested to being more agricultural and urban, which will make the watershed more vulnerable.

CHAPTER-3

STUDY AREA AND DATA COLLECTION

3.1 General

The Hathmati River, one of western India's most vulnerable tributaries, serves as the location for the framework's demonstration. Out of other important tributaries including Wankal, Harnay, Vatrak, and Meshwa, the Hathmati river basin is one of the major tributaries of the Sabarmati River. All of these tributaries receive their water from rainfall. According to Dave H.K. (2012), the Hathmati basin experiences the greatest spatial variation in rainfall of all the sub-basins of the Sabarmati River. It rises from the Gujarat Malwa Hills in Bhiloda (Sabarkantha district). After travelling a course of 98 km it meets Sabarmati near village Ged, 20 km south west of Himmatnagar in Sabarkantha district.

3.2 Study Area

The study areas fall in Survey of India (SOI) Topographical maps (Topo sheets) No. 46-A-13, 46-A-14, 46-E-01, 46-E-02, 46-E-05 and 46-E-06. The total catchment area is 1317.41 square kilometers (131741 hectares). Two main tributaries of Hathmati are Bodoli & Guhai having catchment areas of 119 km^2 and 505 km^2, respectively. The yearly rainfall variation coefficient is fairly considerable and ranges from 42-65% (Dave 2012). By the middle of June, the Wet Season begins, and by the middle of October, it ends. The wet season (June to October) sees about 90% of the rainfall, whereas the rest of the year (the dry season) has very little rain that doesn't follow a predictable pattern. The basin experiences a majority of the year's typical tropical weather. For practical purposes, the area has two seasons: dry (December to May) and wet (June to November). The catchment is described as being of the "leaf or fern type," with gently sloping pediments to a gently sloping alluvial plain. The river and its tributaries traverse many topographies with a variety of climatic conditions, soil types, plant life, and agricultural practices. The river Hathmati's water supply is mostly used for irrigation, drinking water, industry, and flood control. Figure 3.1 displays the

ArcGIS-generated location map for the study area, the Hathmati watershed, which is located at 23°30′49″N and 72°49′29″E. Fig. 3.2 shows Hathmati river map. The Hathmati watershed's general characteristics are shown in the table 3.1 below.

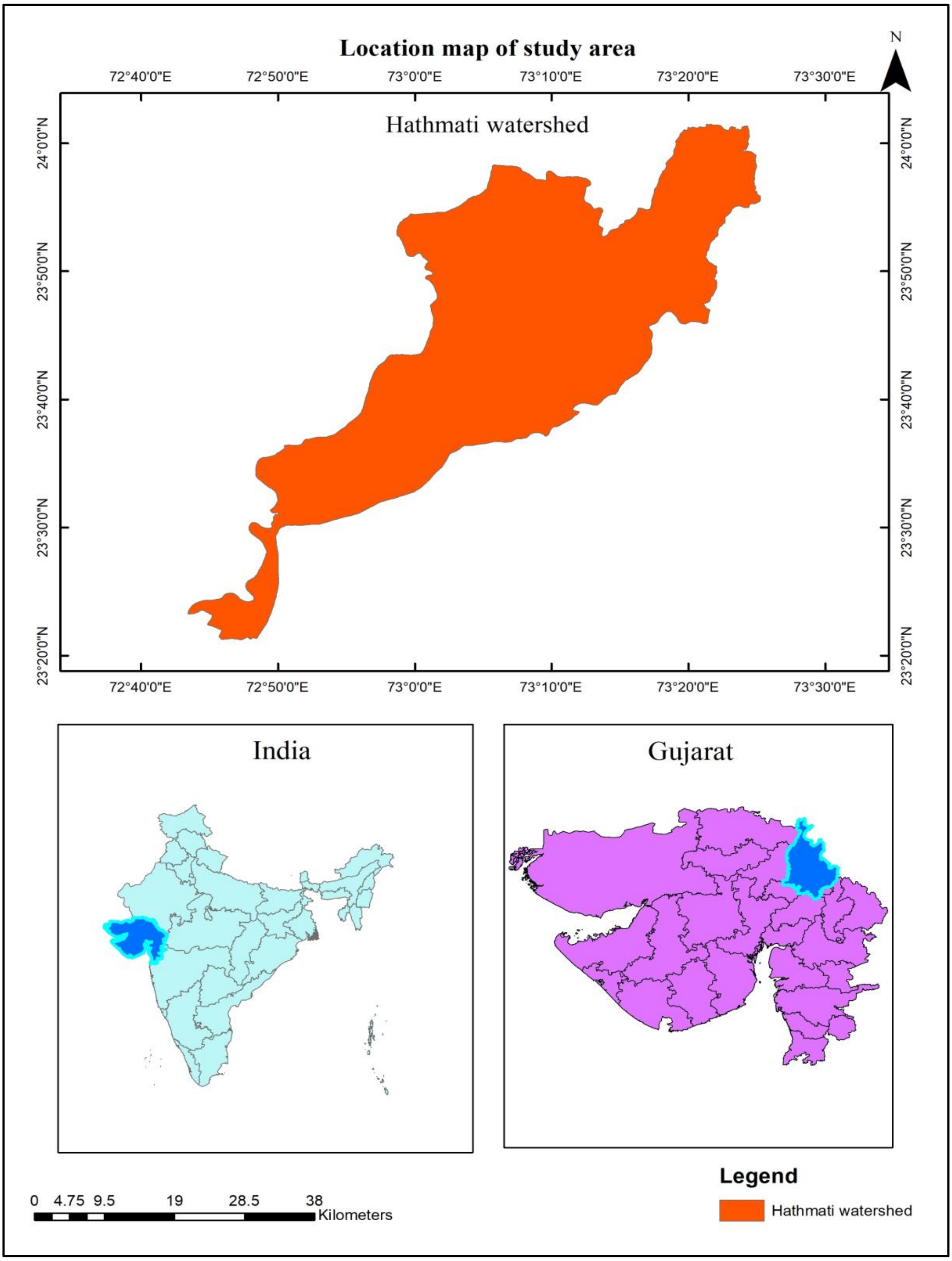

Fig. 3. 1 Location map of Hathmati watershed, Sabarkantha, Gujarat, India

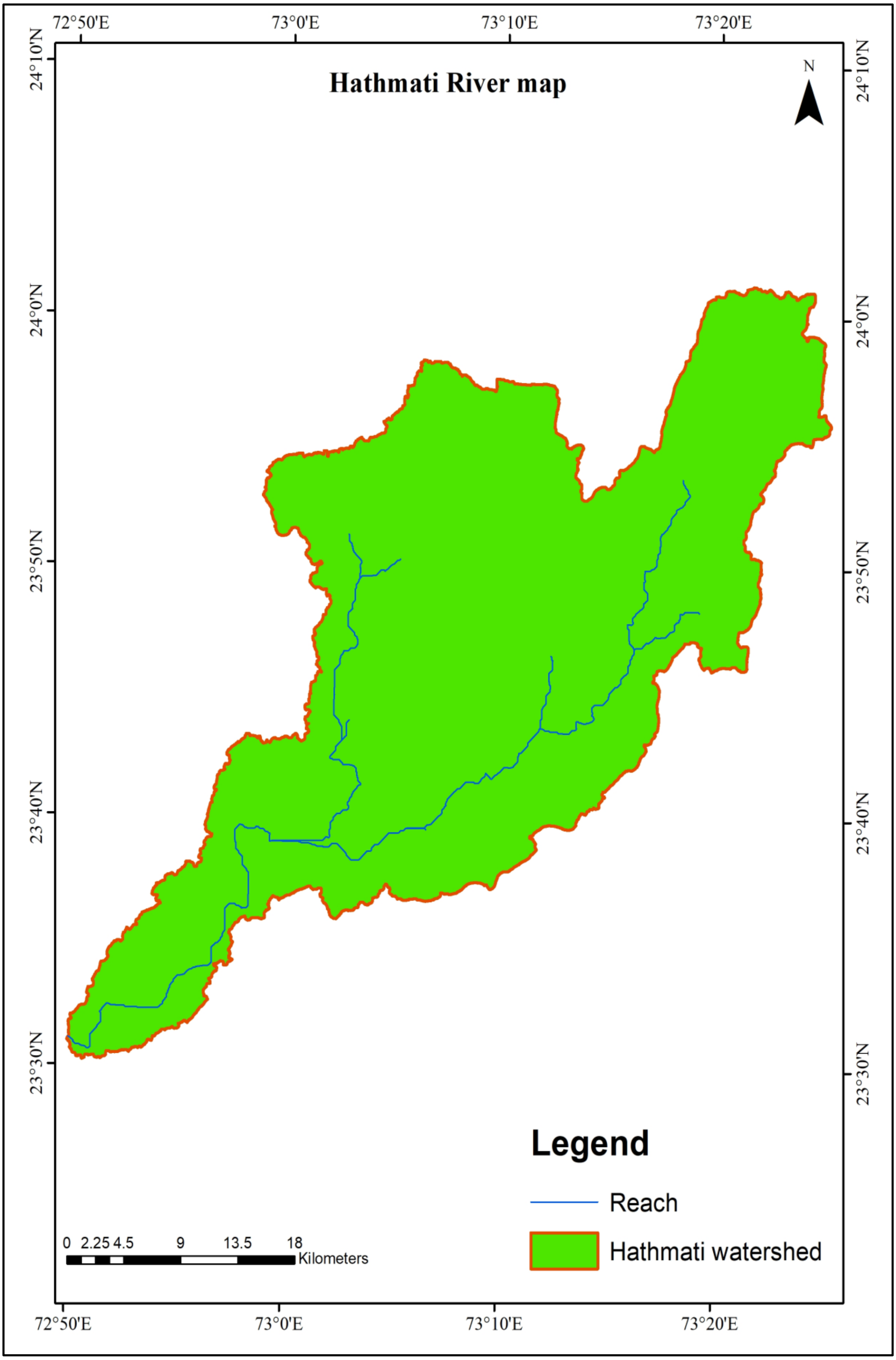

Fig. 3. 2 Hathmati river map

Table 3. 1 General Features of Hathmati Watershed

Geology	Rocks followed by alluvial plains
Physiography	Gently sloping pediments to gently sloping alluvial
Runoff	High to low
Water Holding Capacity	Good
Groundwater Formation	Semi confined to and unconfined aquifers
Irrigability	Good
Forests	Traditionally well forested, now degraded

3.2.1 Physiography

The Hathmati basin can be (broadly) divided into three units physiographically.

A) Alluvial plains with a moderate to gentle slope.

B) Gently sloping alluvial plains.

C) Alluvial plains that are leveled or nearly leveled.

3.2.2 Hydrometeorology

The Hathmati River Basin experiences three distinct seasons: the monsoon (kharif, which lasts from late June to October), the milder rabi (November to February), which is dry except for occasional rain in November and along the coast, and the hot summer season (from March to mid-June). The monsoon season (June to September) accounts for approximately all of the rainfall, which has an average annual rainfall of approximately 895 mm with significant regional differences.

3.2.3 Temperature

Because of its location in a semi-arid climate, the study area experiences extremely high temperatures. The average maximum and minimum temperature in the basin are about 38°C & 16°C. As per IPCC, due to effect of climate change there will be increase in temperature in upcoming years. Again, due to the change in temperature and precipitation, the nutrient water quality parameters may degrade. Figure 3.3 displays average yearly temperature.

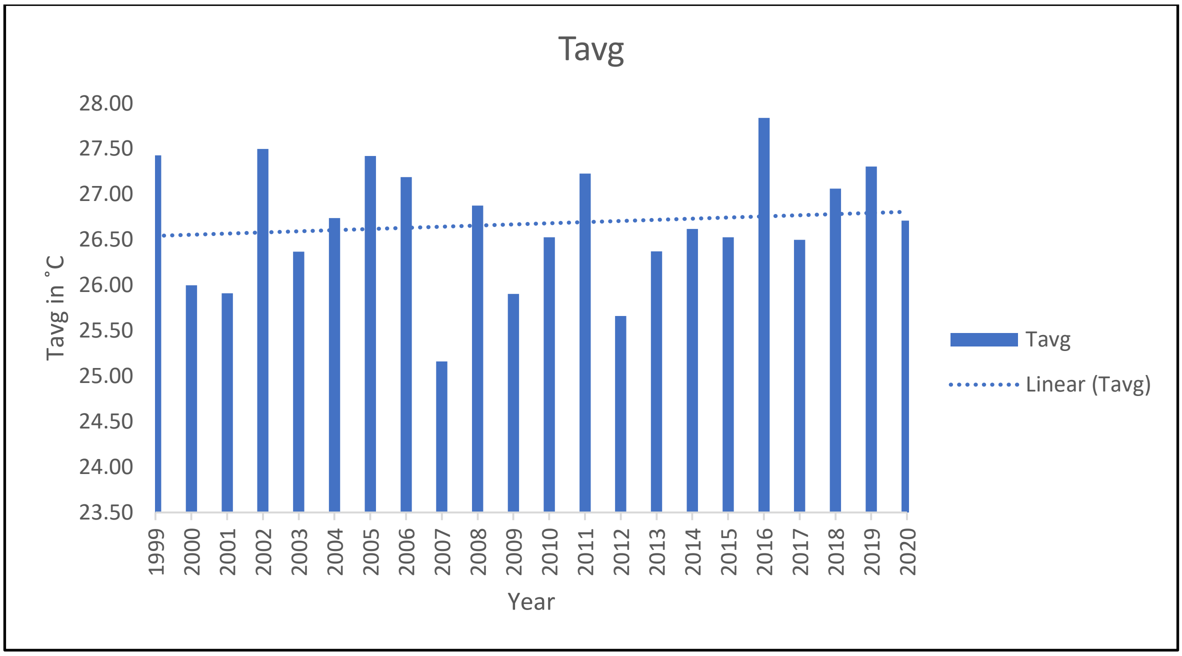

Fig. 3. 3 Yearly mean average temperature in ˚C.

In general, the temperature changes from pre-monsoon to post-monsoon. After February, the temperature gradually increases until it reaches its peak in May and June, just before the monsoon season begins. With an average temperature of 11°C in December and January, the winter season is fairly pleasant. Figures 3.6 and 3.7 display the study area's maximum and minimum temperatures.

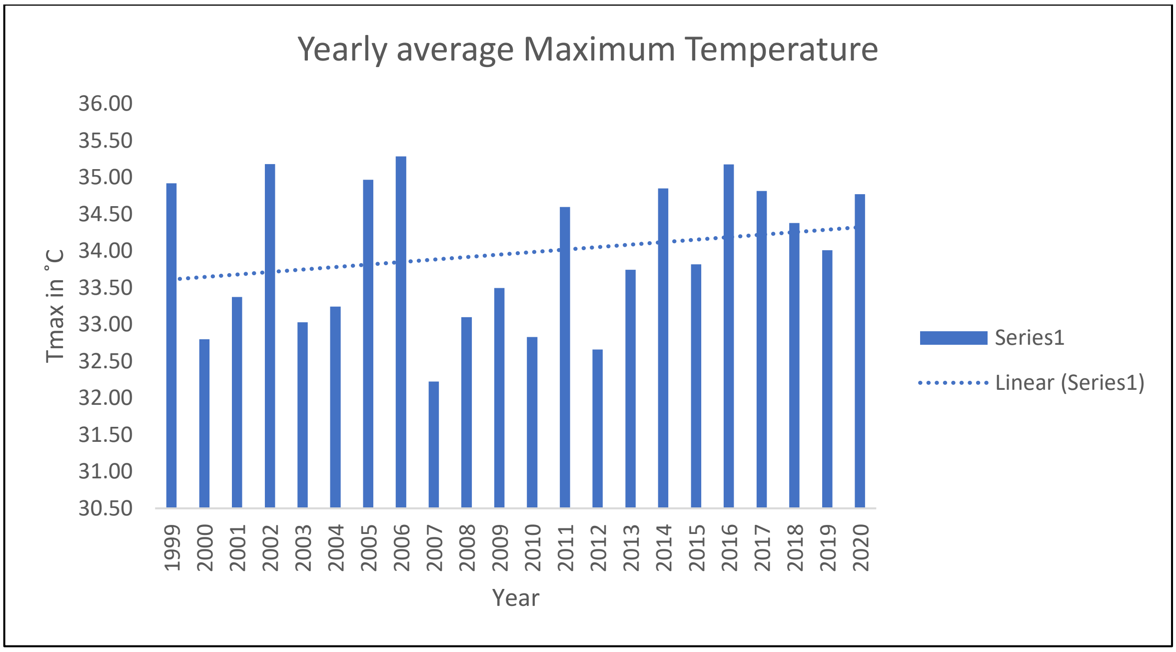

Fig. 3. 4 Yearly mean maximum temperature in ˚C.

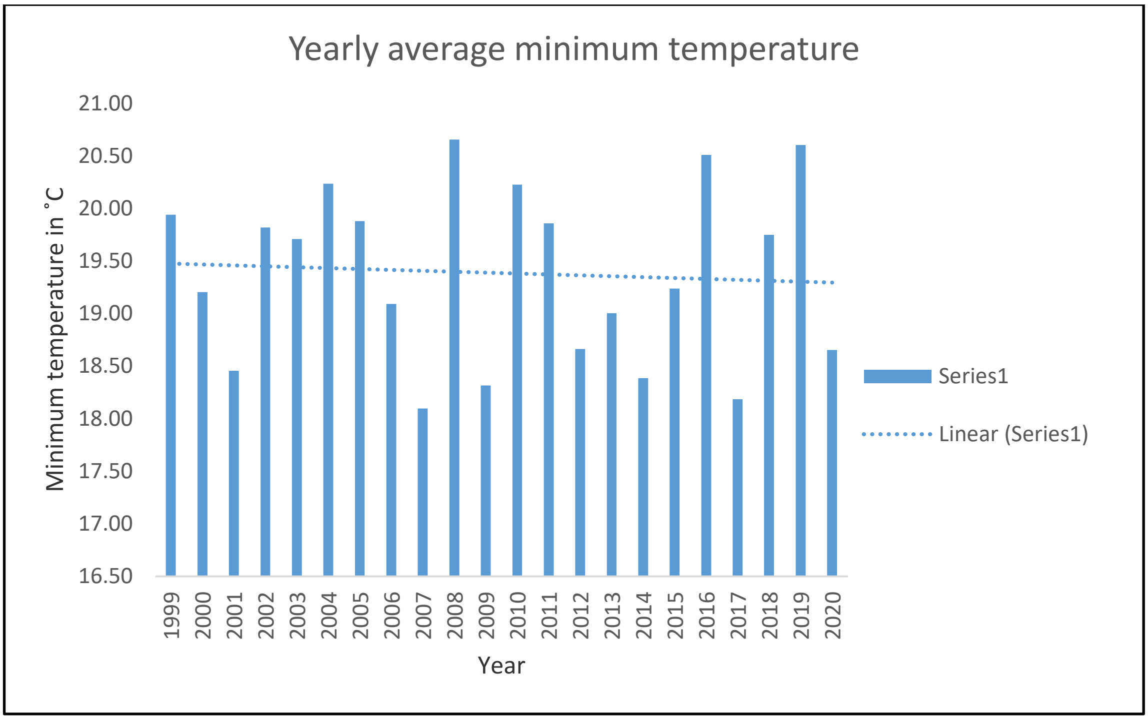

Fig. 3. 5 Yearly mean minimum temperature in ˚C

3.2.4 Wind

Between May and September every year, 72% of the days have wind, with a mean wind speed of 38 km/h. These winds, which begin in mid-June and last in mid-September, comprise the southwest monsoon system.

3.2.5 Relative Humidity

The monthly mean relative humidity and the overall average relative humidity both are about 80% during the monsoon season. The afternoons are often drier than the mornings, with the exception of the monsoon months.

3.2.6 Rainfall

The rainfall data shows both seasonal and yearly fluctuation. Average annual rainfall for current research region is estimated to be around 1005 mm based on the rainfall data. Fig. 3.6 displays the location map of 2 rain gauge stations. Table 3.2 displays locations of 2 rain gauge stations in the study region and figure 3.7 displays the yearly rainfall average.

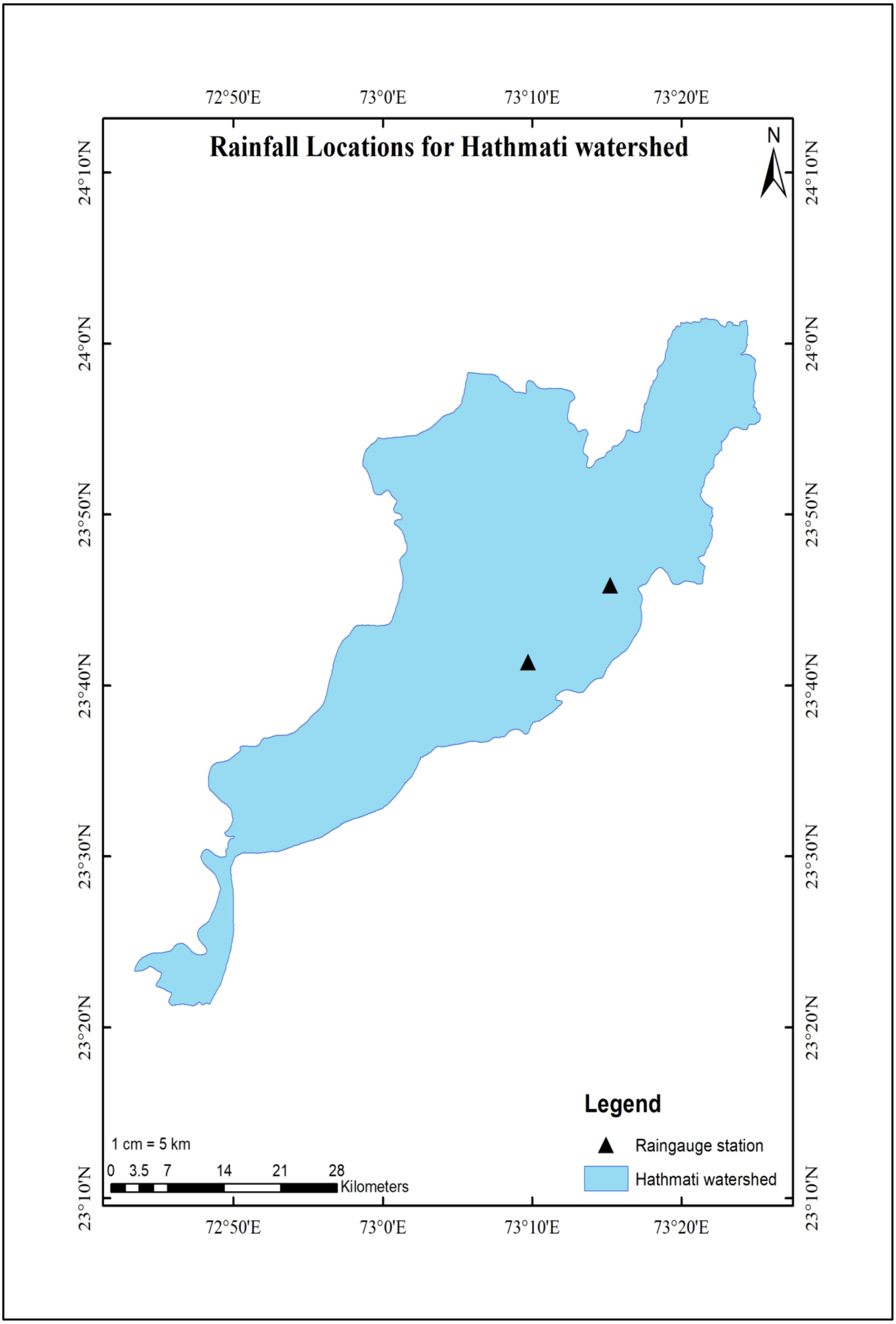

Fig. 3. 6 Location map of rain gauge stations

Table 3. 2 Rain gauge stations and their locations

Sr. No.	Location of rain gauge station	Latitude	Longitude
1	Bhiloda	23˚46’10’’	73˚24’45’’
2	Mankdi	23˚42’21”	73˚9’20”

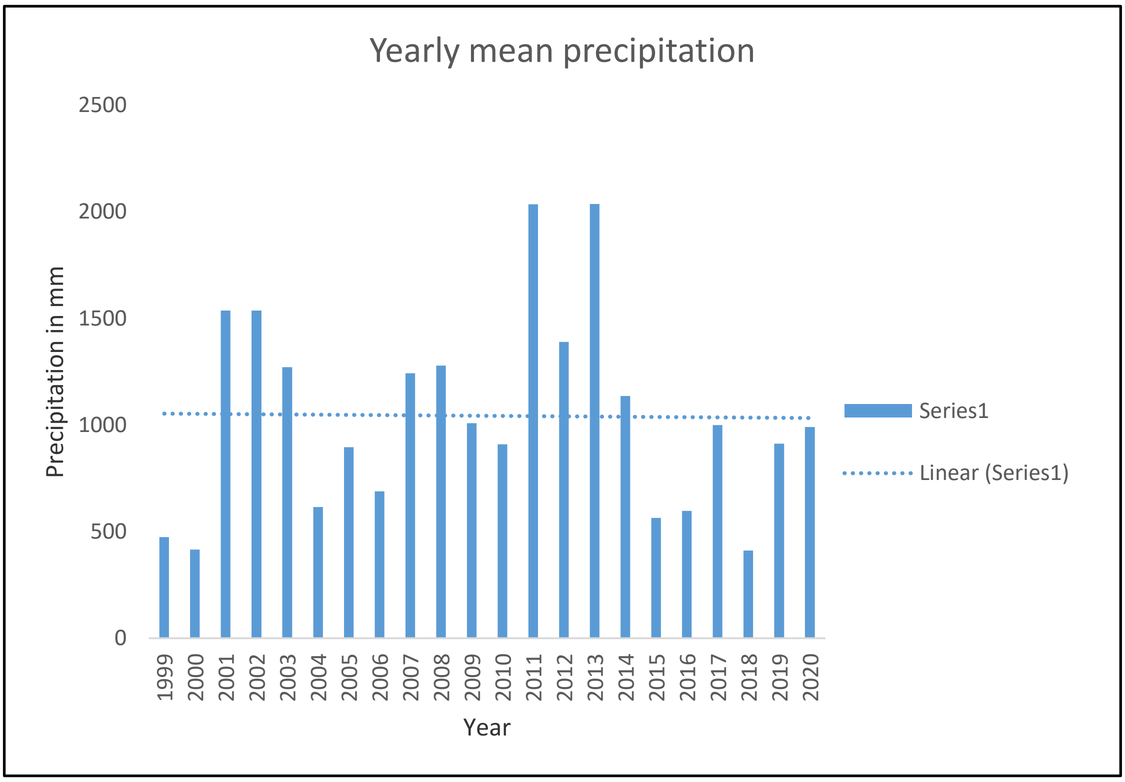

Fig. 3. 7 Yearly mean precipitation

3.2.7 Soil Type

The Hathmati Basin contains a variety of soil types. An overview of the region's three most prevalent soil series, the Verticustochrepts, lithic ustorthents, and typicustorthents, is provided in table 3.3.

Table 3. 3 Soil type in Hathmati watershed

Soil Series Unit	Soil Name	% Area	Clay	Silt	Sand
Typicustorthents	A	24.67	34.57	26.64	38.79
Verticustochrepts	B	55.31	23.00	13.00	64.00
Lithic Ustorthents	C	20.02	25.00	35.00	40.00

3.2.8 Land use / Land Cover

Forest and agricultural land are the main land uses in the watersheds of the Hathmati Basin. Agriculture makes the largest contribution to the landcover, followed by the dense forest.

3.2.9 Slope

Slope is a crucial consideration when prioritizing a watershed. Higher slopes have a potential of producing greater runoff, less infiltration, and consequently more erosion. Finding the research area to have a very slight slope.

3.2.10 Hydrogeology

Rocks belonging to pre-Cambrian period are found in its northern and eastern parts, while its western and southern regions are occupied by more recent alluvial deposits. Two main formations of the plain are sand and clay. These alluvial deposits' sandy layers have strong porosity and permeability and form good aquifers. The sediments here can be as thick as 2,600 m. In the southern region of the basin, lava eruptions from the Cretaceous and Eocene formed basalt in a dispersed pattern. (INREMF, 2001; GOG, 1996)

3.2.11 Water quality

Daily water quality data for nutrient parameters have been collected on for three locations – Khandhol, Vanej and Mankadi from State Water Data Centre, Gandhinagar. Water quality parameters for Irrigation water has been finalized as Nitrate, Organic N, Organic P, Mineral N, Mineral P, Soluble P, Total Nitrogen and Total Phosphorous with the help of some best suited literature. Table 3.4 shows the locations of three water quality stations.

Table 3. 4 Water Quality stations and their locations

Sr. No.	**Location of rain gauge station**	**Latitude**	**Longitude**
1	Himmatnagar	23°38'4"	72°58'56"
2	Khandhol	23°42'1"	73° 3' 6"
3	Mankdi	23˚42’21”	73°9'20"

Fig. 3.8 displays location map for water quality stations. Table 3.5 displays analyzed nutrient water quality parameters for three water quality stations.

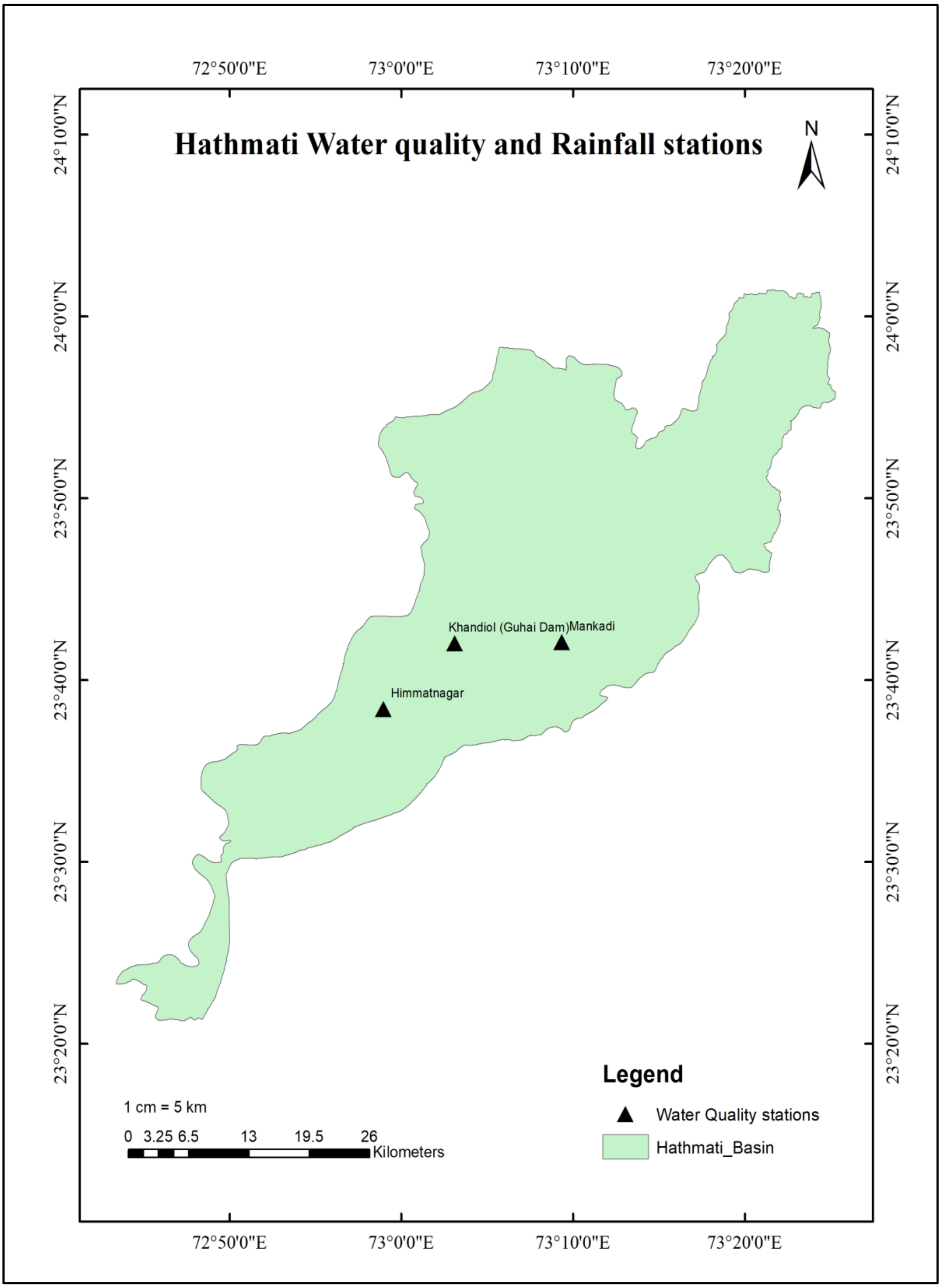

Fig. 3. 8 Location map of water quality stations

Table 3. 5 Nutrient Water Quality Parameters

Year	Nitrate	Org_N	Org_P	Min_N	Min_P	Sol_P	TN	TP
	Kg/ha	Kg/ha	Kg/ha	Kg/ha	Kg/ha	Kg/ha	Kg/ha	Kg/ha
2002	0.0083	18.28	2.25	18.72	6.31	0.0048	14.45	2.99
2003	0.0059	23.84	2.93	38.43	14.59	0.0083	12.51	2.05
2004	0.0162	1.92	0.24	3.10	1.32	0.0015	5.23	0.89
2005	0.0036	1.73	0.21	3.77	1.50	0.0012	2.59	0.32
2006	0.0026	8.28	1.01	14.60	4.89	0.0038	4.36	0.81
2007	0.0984	44.21	5.45	54.05	18.84	0.0105	22.5	5.19
2008	0.113	27.14	3.34	37.71	15.65	0.01	38.74	8.41
2009	0.122	12.69	1.58	13.46	4.56	0.0034	29.93	6.61
2010	0.0028	5.53	0.68	9.25	3.10	0.002	2.58	0.36
2011	0.1713	76.89	9.52	62.98	22.13	0.0143	84.08	19.49
2012	0.0051	13.73	1.71	20.17	6.94	0.003	2.72	0.28
2013	0.03	21.83	2.73	31.44	13.02	0.0084	25.66	5.83
2014	0.1671	27.48	3.49	23.87	9.01	0.0062	31.62	7.21
2015	0.0319	2.86	0.37	3.84	1.68	0.0016	6.56	1.34
2016	0.0003	2.15	0.27	3.37	1.24	0.0007	1.58	0.16
2017	0.0022	17.65	2.19	21.00	7.37	0.0045	7.45	1.53
2018	0.0009	0.23	0.03	0.52	0.20	0.0002	1.25	0.18
2019	0.0048	3.97	0.5	6.04	2.29	0.0016	3.17	0.66
2020	0.0024	2.97	0.37	5.42	1.99	0.0016	3.91	0.8

3.3 Generation of Thematic Maps

New material needed to be mapped as earth science research expanded. New information needed to be mapped thanks to advancements in the evaluation and knowledge of natural resources like geology, geomorphology, soil science, ecology, and land that started in the 19th century and have since continued. Maps of the distribution of rock types, soil series, or land use are developed for more restricted and specific reasons as opposed to topographical maps, which might be regarded as broad purposes because they do not set out to achieve any specific intent. Because they contain information about a single subject or themes, the maps for specific purposes are frequently referred to as "thematic" maps. Thematic maps are frequently created over a simplified topographic base so that the user may easily locate themselves and understand the thematic material. For the research area, various thematic maps were created using SOI Toposheet, satellite data, and other auxiliary data. These maps were created at a scale of 1: 12,500. These have been gathered and examined both alone and in connection to one another.

3.4 General Methodology for Preparation of Thematic Maps

For the research area, various thematic maps were created using SOI Toposheets, satellite data, and other auxiliary data. These maps were created at a size of 1:12,500. The data for the study includes a variety of spatial data, such as DEM, LULC, soil maps created from CARTOSAT-I, SRTM, BHUVAN, and IRS-ID LISS IV satellite data and prepared in ArcGIS 10.5 with a resolution of 30m, as well as a number of collateral data, such as weather files (from 1999 to 2020) gathered from rain gauge stations and climate stations. Different thematic classes were established and cross-verified with the real world using visual interpretation or identification elements as tone, texture, size, shape, association, feature, etc. After transferring the interpreted thematic information, the subsequent specific thematic maps were created.

- Base map
- Drainage map
- Watershed map
- Slope map
- Land use/Land cover map
- Contour map
- Elevation map (DEM)

3.4.1 Base Map

The satellite photos are used to refresh this information. The study area border and other information are displayed in the basic information that has been created. The essential data of the research area, such as the road and rail networks, rivers, settlements, tanks, and canals, was derived directly from the SOI Toposheets maps Fig. 3.9 and 3.10 displays grid map, toposheets map and from these both maps, Hathmati basin map has been generated and shown in fig. 3.12.

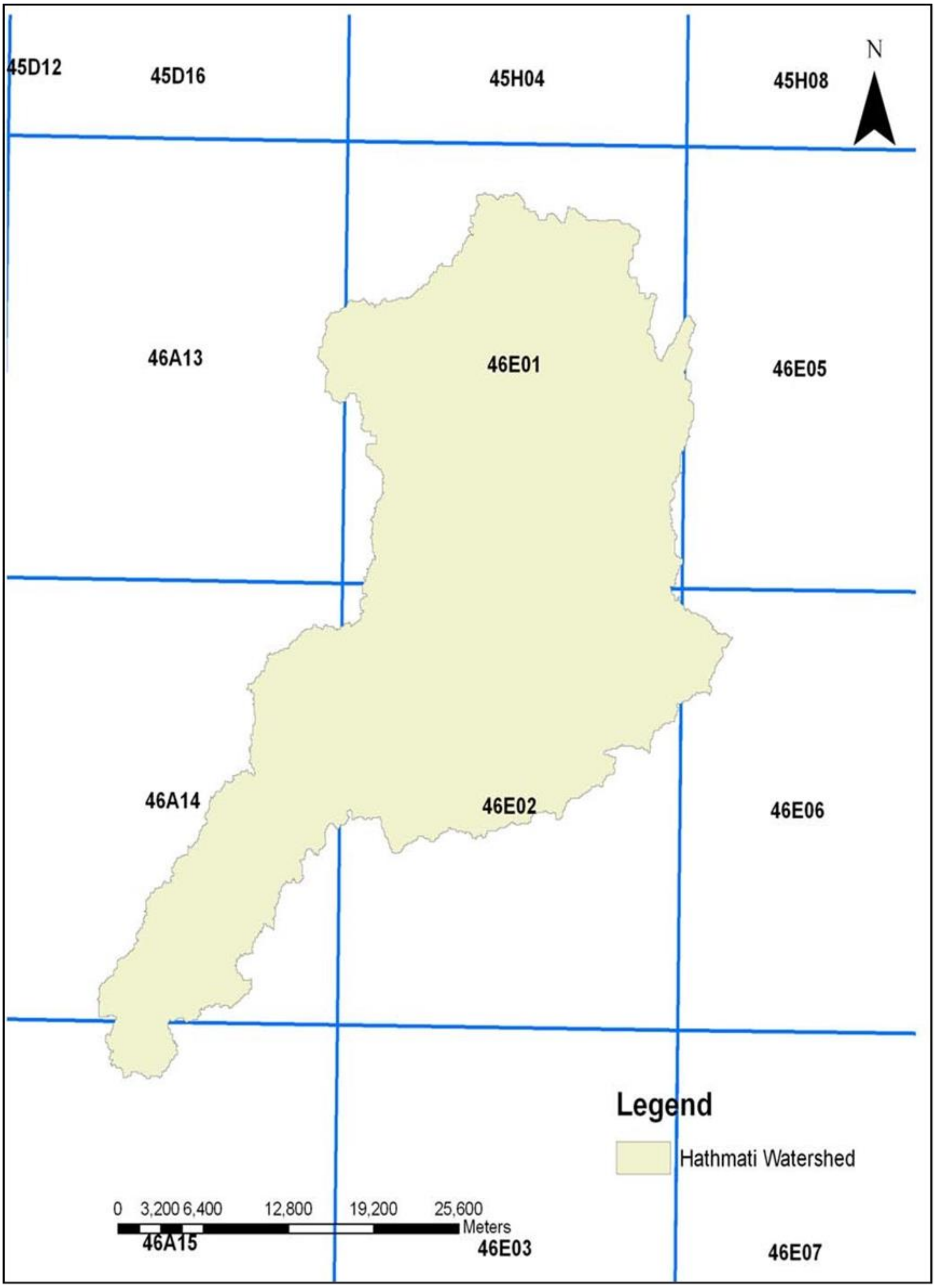

Fig. 3. 9 Grid map of Hathmati watershed

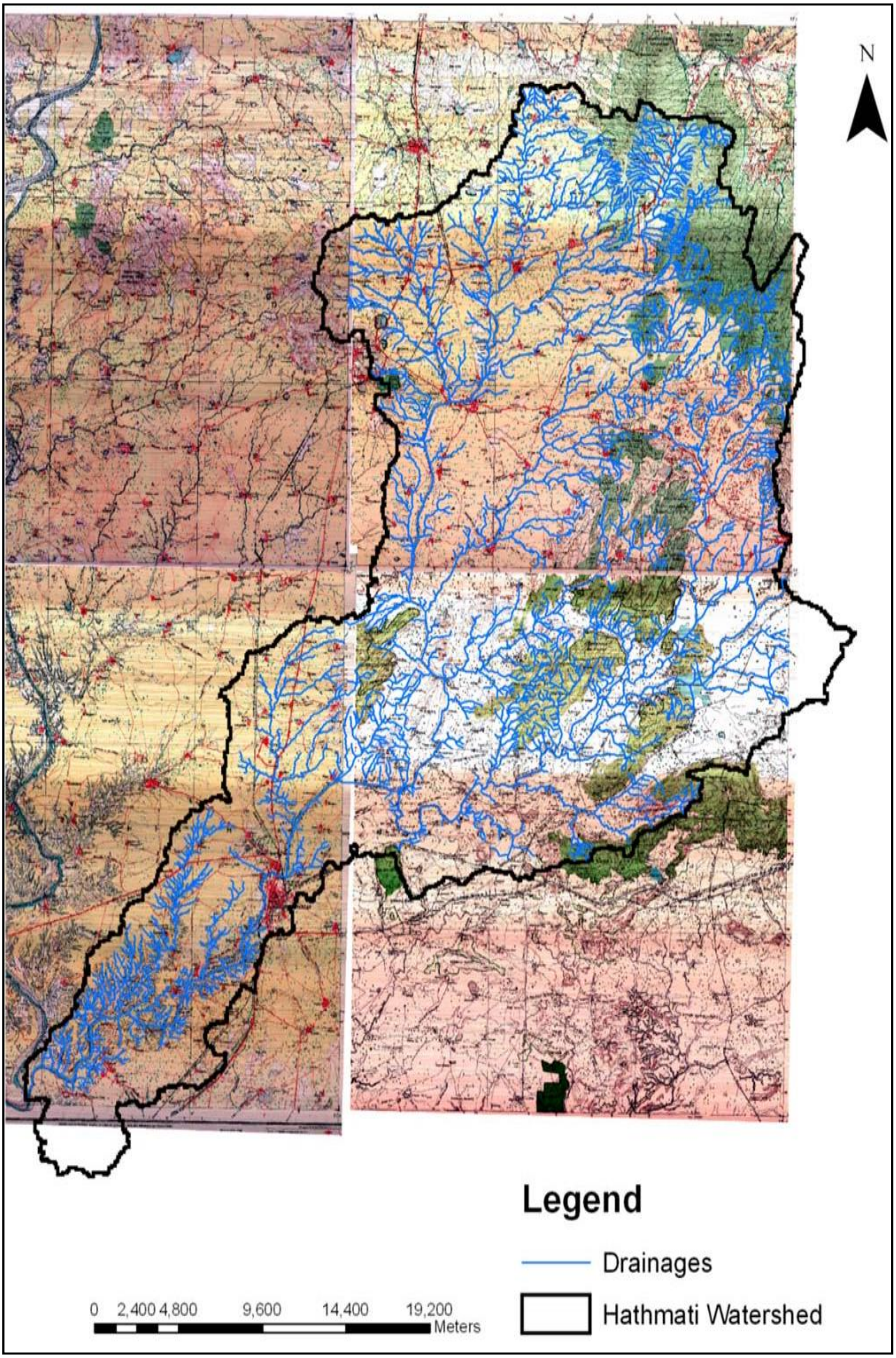

Fig. 3. 10 Toposheets map of Hathmati watershed

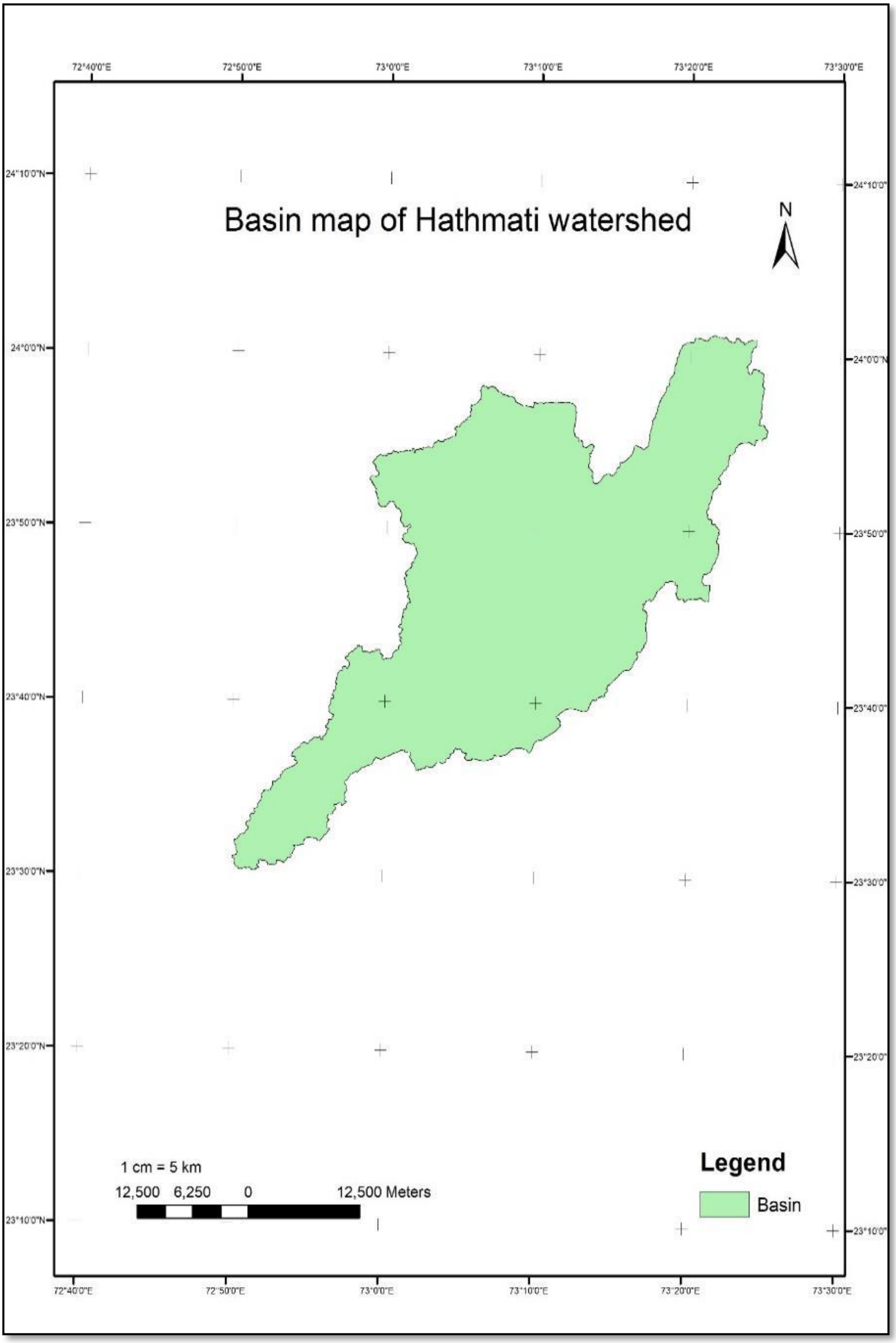

Fig. 3. 11 Basin map

3.4.2 Drainage Map

Using data from Toposheet and satellite photos, a drainage map of the study area has been created. A map was created after tracing out every drainage system. The alterations in the drainage courses were then mapped after this drainage was superimposed with satellite image data. In Fig. 3.12, the drainage map was displayed. The boundaries of watersheds have since been drawn using the drainage map.

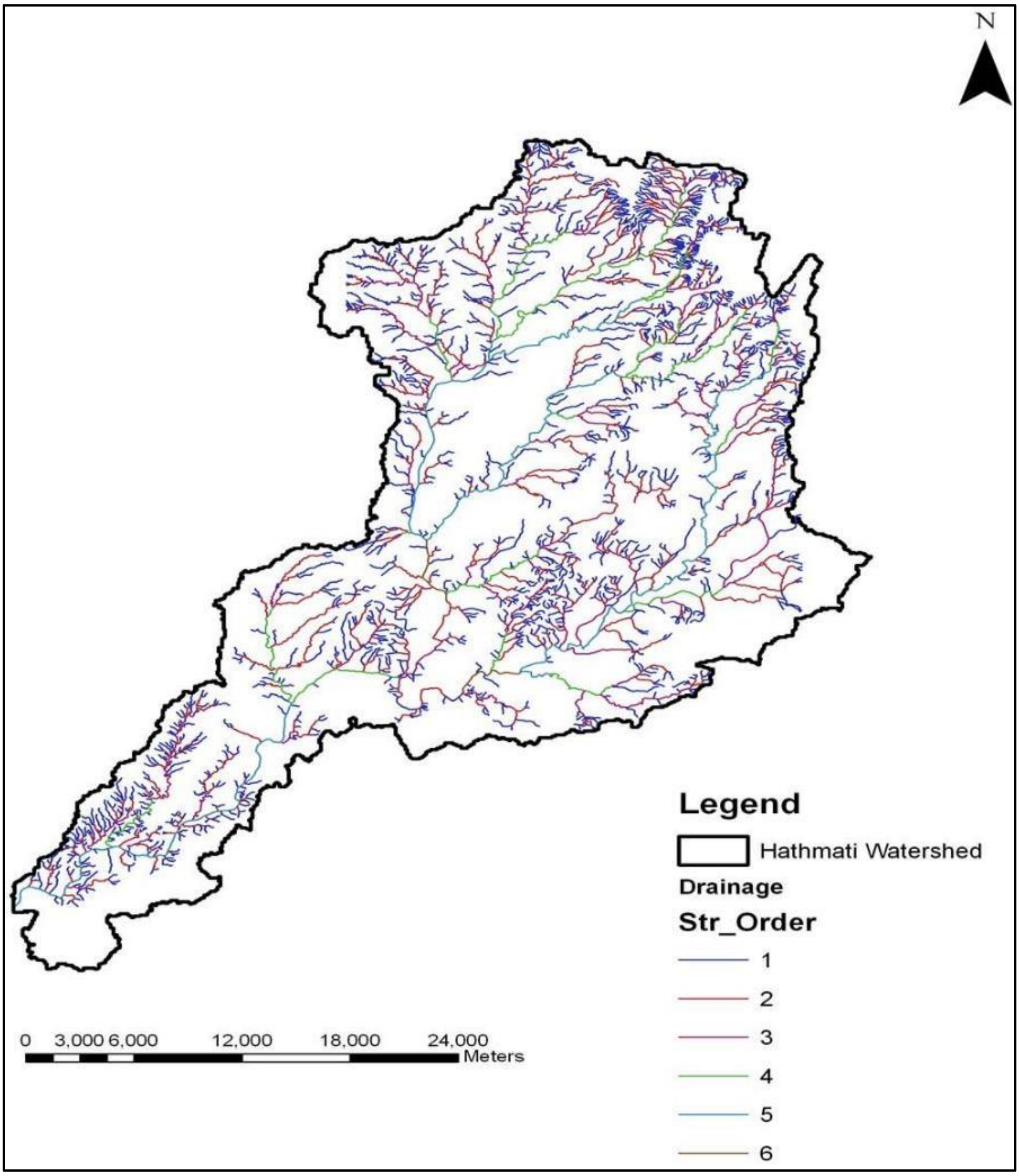

Fig. 3. 12 Drainage map

3.4.3 Watershed Map

A watershed is a region of land that is covered by natural hydrological entities that allow precipitation to flow to a certain gully, stream, or river at any given location. The density and distribution of drainage as well as the size of the stream or river and its point of interception all affect the size of the watershed. Watershed delineation systems, such as water resources Region, Basin, Catchments, Sub catchments, and watershed, have been created by the All-India Soil and Land Use Survey, Ministry of Agriculture and Cooperation (AIR & LUS), New Delhi. Using satellite photos, the surface water bodies have been examined and identified. Maps of surface water bodies and drainage systems are used to define watershed borders. The watershed-wise area is shown in Table 3.6. Figure 3.13 displays a watershed map with the location of water bodies and the outline of a watershed.

Table 3. 6 Watershed wise areas

Sr. No.	**Watershed Code**	**Area (Sq. Km.)**
1	MW 1	106.23
2	MW 2	45.32
3	MW 3	50.26
4	MW 4	175.85
5	MW 5	77.39
6	MW 6	65.50
7	MW 7	102.11
8	MW 8	94.79
9	MW 9	52.73
10	MW 10	125.94
11	MW 11	92.67
12	MW 12	154.90
13	MW 13	173.72
	Total	1317.41 km^2

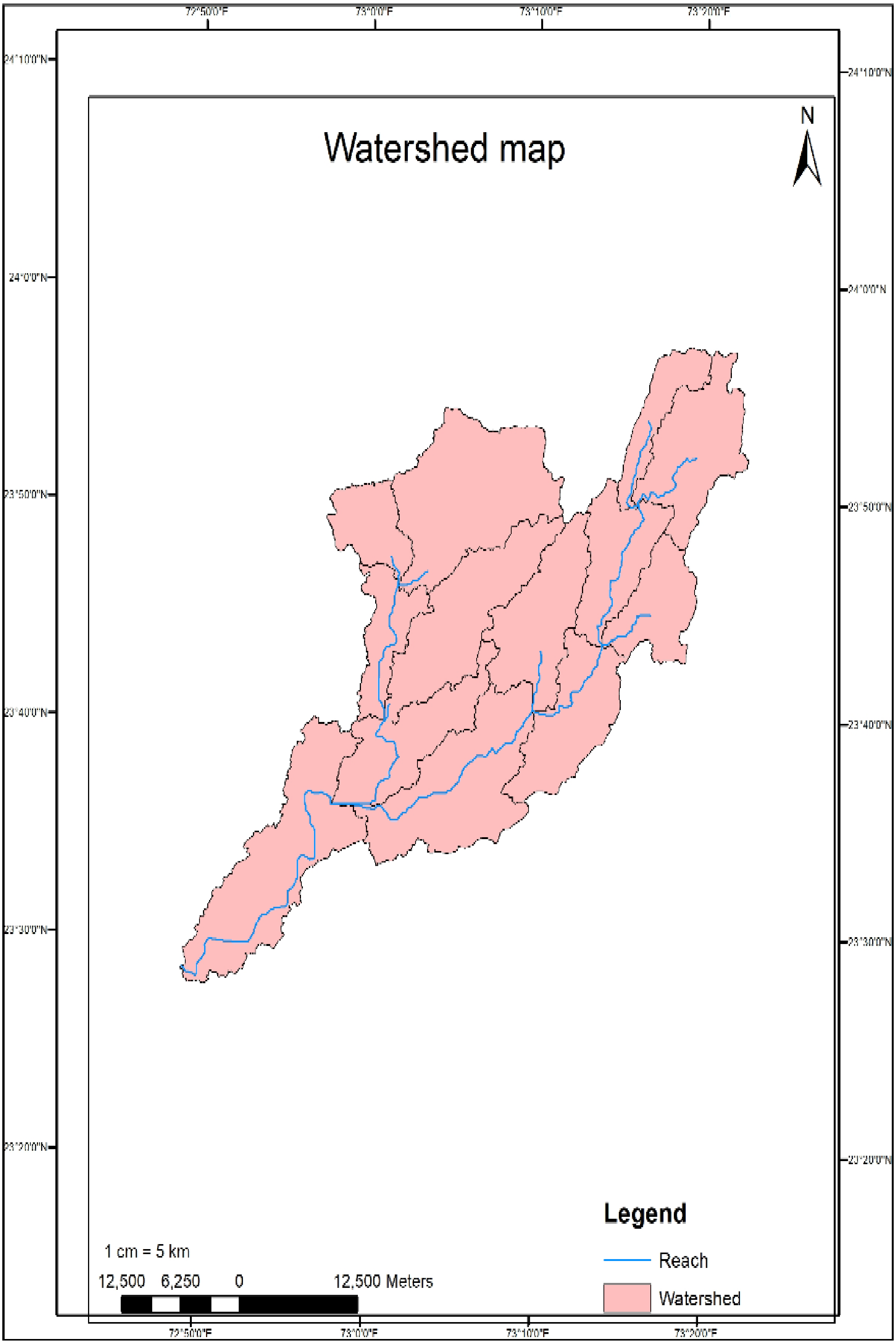

Fig. 3. 13 Watershed map

3.4.4 Slope Map

Slope is a crucial consideration when prioritizing a watershed. Higher slopes have a potential of producing greater runoff, less infiltration, and consequently more erosion. According to the criteria listed in the Integrated Mission for Sustainable Development (IMSD) document, slopes studies are categorized. Slope coverage has also been prepared as a component of the integrated study. Finding the research area to have a very slight slope. Figure 3.14 depicts the slope map, and Table 3.7 lists the various slope classifications that were discovered and their geographic distribution in the study area.

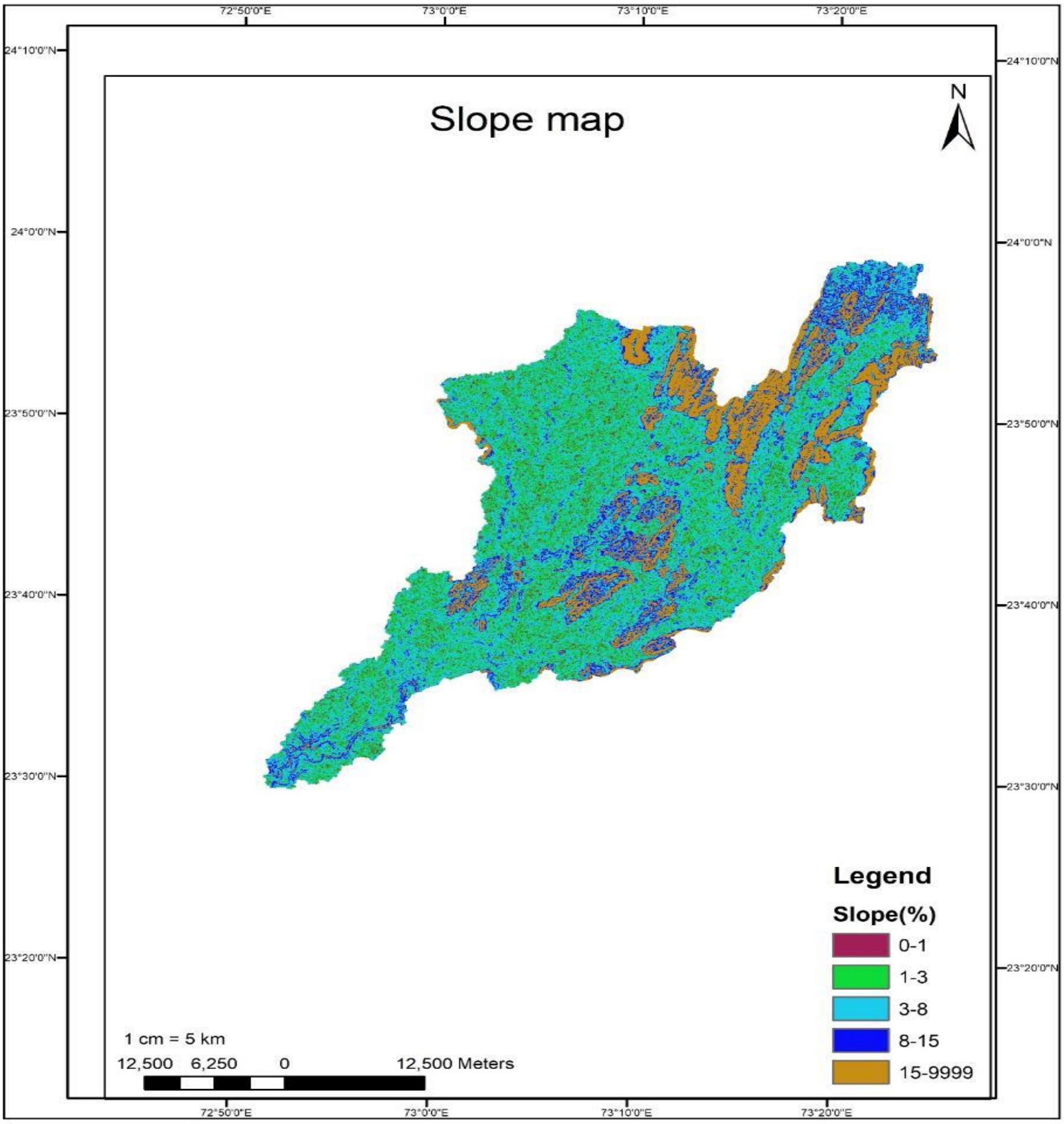

Fig. 3. 14 Slope map

Table 3. 7 The percentage falls into different slope classes

Slope class	Category	% Slope
1	Nearly level	0-1
2	Very gently sloping	1-3
3	Gently sloping	3-8
4	Moderately sloping	8-15
5	Strongly sloping	>15

3.4.5 Land use Land cover Map

Satellite imagery of year 2018 is utilized to assess the state of the study area's land use and land cover. The comparison of the spectral responses of each type of object with its features was necessary for understanding and correlation of imagery with objects. To confirm interpretation and questionable areas, interpreted details are reviewed on the ground. The borders of various land use/land cover units are decided upon based on ground verification. The majority of double-cropped land is located in regions with irrigation infrastructure. Table 3.8 displays land use land cover of Hathmati watershed in percentage.

Table 3. 8 Land use / Land cover in Hathmati watershed

LULC class	Category	% Area
1	Agriculture	67.30
2	Built up	1.45
3	Forest	18.22
4	Others	3.35
5	Grass land/ Waste land	7.59
6	Water bodies	2.09

Fig. 3.15 displays map of land use and land cover. Due to increase in fertilizers applied on soil, there is a tremendous increase in agricultural land as well as due to increase in temperature, there is increase in precipitation also as per IPCC. There is decrease in forest land so nutrient water quality has been little bit difficult to manage so by considering some land use land cover change, we can improve the nutrient water quality.

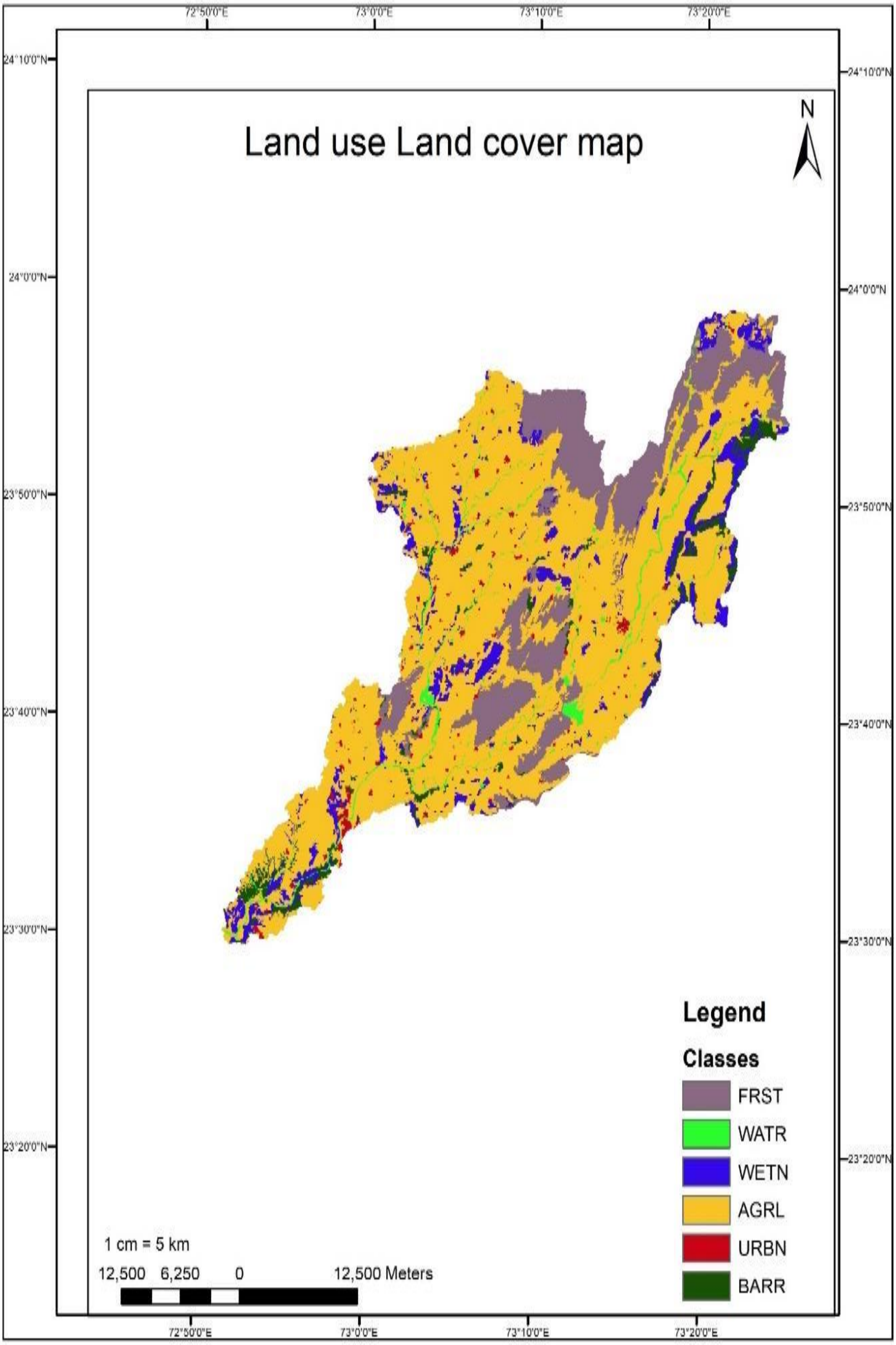

Fig. 3. 15 Land use Land cover map

Mohdzuned Mohmedraffi Shaikh, Pradeep Lodha, Prashant K. Lalwani in 2021 compared land use change for the Hathmati watershed which has been shown in table 3.9.

Table 3. 9 Comparison of Land use / Land cover in Hathmati watershed in percentage

LULC class	1985	1995	2005	2015	2020
Agriculture	57	59	60	61	67.30
Built up	9	9	10	10	1.45
Forest	25	24	21	18	18.22
Others	1	4	5	2	3.35
Grass land/ Waste land	2	2	2	6	7.59
Water bodies	6	2	2	3	2.09

3.4.6 Contour Map

A topographic map, for example, which displays valleys, hills, and the steepness or gentleness of slopes, is an example of a map with contour lines. The elevation difference between successive contour lines is known as the contour interval in a contour map. Fig. 3.16 shows contour map of Hathmati watershed.

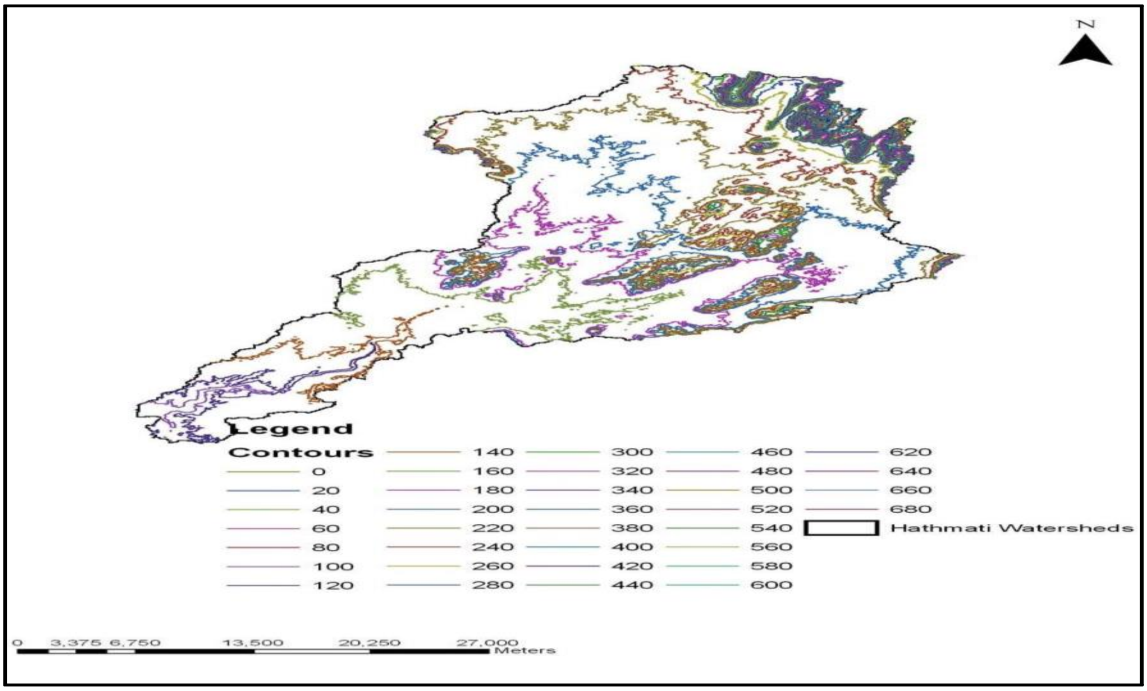

Fig. 3. 16 Contour map of Hathmati watershed

3.4.7 Elevation Map

With the use of elevation maps, you may identify the highest points and regions with high heights in a given nation or state. These maps fall within the topographic map genre. The Survey of India in India is in charge of directing all topographic mapping, surveys, and guides for the nation. Fig. 3.17 displays Digital Elevation Model of Hathmati watershed. Fig. 3.18 shows soil map and fig. 3.19 shows reach & outlet of study area.

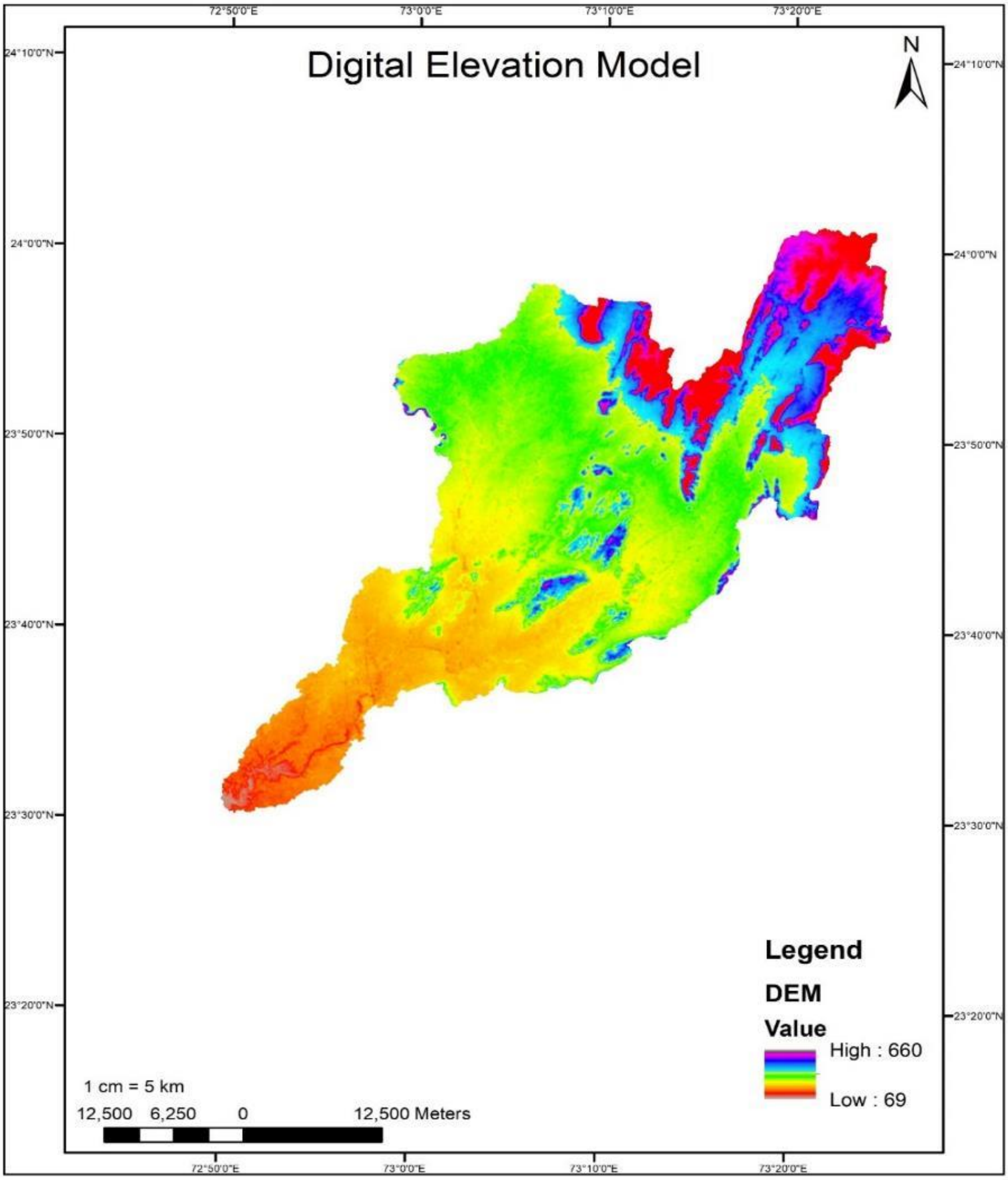

Fig. 3. 17 Digital Elevation Model

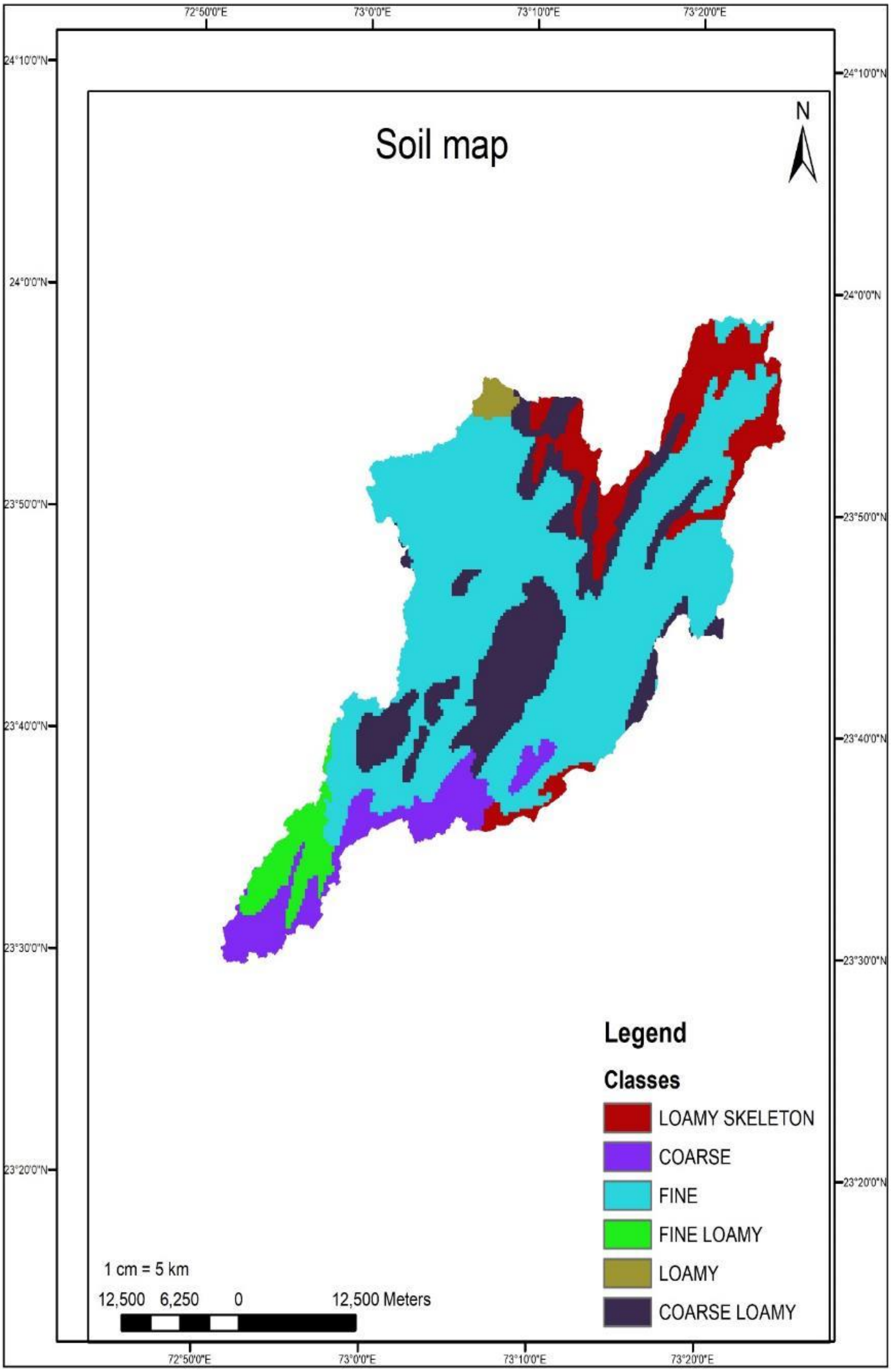

Fig. 3. 18 Soil map

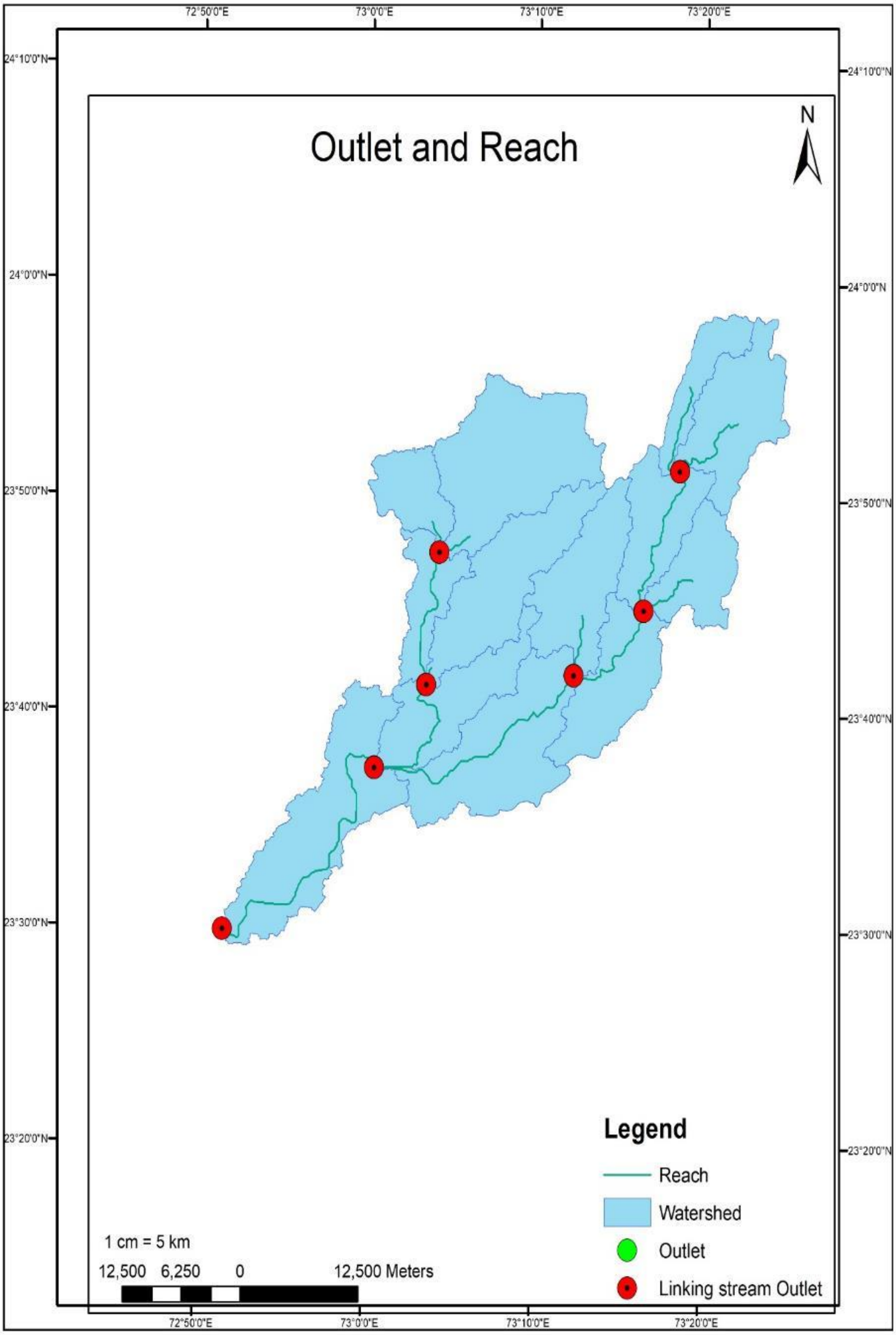

Fig. 3. 19 Reach and Outlet of Hathmati watershed map

3.5 Meteorological Data

The State Water Data Centre in Gandhinagar provided the daily rainfall, water quality, runoff, and meteorological data for the twenty-two years (1979-2020) those were used in the study. The India Meteorological Department's weather station has also provided the statistical information required for producing weather. It produces daily precipitation, maximum and minimum temperatures, solar radiation, wind speed, and relative humidity.

CHAPTER-4

WATER QUALITY FRAMEWORK

4.1 Introduction

Many programs established and developed data tracking systems to track water quality data to fulfil their unique program demands in the early to mid-2000s. Since there are many different data systems for tracking water quality data, it has been challenging to link data from different systems, which has occasionally led to ambiguous and inconsistent water quality communication. The Water Quality Framework integrates current IT technologies to simplify the assessment and reporting of water quality. It represents a new way of thinking about how data and information systems on water quality may be better integrated to support decision-makers more effectively and better inform the public. The Framework will simplify the evaluation and reporting of water quality, do away with paper reporting, and present a more comprehensive picture of the nation's water quality.

Water quality can be determined by the chemical, physical and biological parameters. It is a measure of the state of the water with respect to the necessities of human needs or purposes (Abbasi and Abbasi, 2012). The water pollution of rivers requires great efforts, and water quality is an important issue in the field of water resources planning and management and requires data gathering, analysis, and interpretation (Yehia and Sabae, 2011). Water Quality Monitoring Framework illustrates a systematic process which will help monitoring authorities produce and convey the information needed to understand, protect, and restore our waters. The identification of critical pollutants and the target concentrations will be strongly influenced by the intended use of the irrigation water.

An effective approach for assessing water quality should be able to:

- Obtain desired water quality by successfully controlling diffuse releases of pollutants into water bodies.
- Promote the numerous social, economic, environmental, and cultural values.

4.2 Components of Water Quality Framework

To effectively manage the effects of diffuse discharges from rural land use on water quality, a framework for water quality management must have seven key components. These features may also be useful for managing other problems with water quality (such as urban storm water, runoff from parking lots and roadways, and point source discharges).

1. Roles and connections

- To effectively handle problems with water quality, the government need to have clear roles and responsibilities.
- To achieve the defined water quality targets, effective partnerships and involvement are needed between farmers, industry, and landowners at all levels of government.

2. Strategic planning

Exceptional strategic resource management planning and decision-making for water quality management results that:

- Solve water quality challenges.
- Considers the demands of both the present and future generations by identifying and balancing the interests of national, regional, and local communities in relation to economic, environmental, cultural, and social values.
- Identifies complementary strategies, values, and interests, suggests courses of action, and offers solutions that maximize results across values and interests. This process results in explicit, transparent, and difficult decisions and, when necessary, calls for making trade-offs between values, which encourages innovation and research.

Adopting an integrated management strategy, in which problems with water management (including water allocation and water quality) and land use activities are dealt with jointly. Water allocation is a crucial process because the amount of water abstracted affects a water body's ability to absorb and convey impurities as well as its capacity for regeneration. Given the lack of knowledge on the effects of the discharges on environmental outcomes that means the delay before pollutants become obvious, the transitory character of the freshwater ecosystems, and the potential for shifting the community priorities, flexibility, and adaptability are required for the most.

3. Consultation

Effective and effective consultation on issues related to water quality involving all levels of government.

4. Research, Information, and Technology

Good scientific information on the impacts of discharges, including:

- Appropriate data collection and analysis.
- The relationship between land use and other factors (e.g., point source discharges, urban storm water).
- Impacting water quality, water quality management and planning processes that foster innovative and holistic solutions to water quality issues.
- Traditional knowledge.
- The limitations of what is now known and places where more information is needed.
- Information on the various values of water and how those values interact; and the costs and benefits of attaining specific water quality outcomes.

5. Effective tools

- Appropriate methods for establishing agreed-upon minimum water quality criteria for various water body categories with various values.
- Having access to a suitable set of policy tools, such as the ability to designate discharge rights and regulatory and market measures to affect land user conduct, to enable control of water quality.

6. Public awareness

Providing guidance on implementing and cooperating with the pertinent legislation, encouraging the use of best management practices, encouraging understanding of the science relating to water quality management, and developing innovative technologies to minimize contaminants at the source are all examples of effective education.

7. Capacity

Adequate capacity, information, and abilities among the farmer, local and governments to comprehend all the values and problems connected to water quality management.

4.3 Advantages of Water Quality Framework

The water supply agencies gain from management of drinking water quality through a thorough preventive approach by offering a general framework that:

- Promotes public health by ensuring safer drinking-water for consumers.
- Promotes an all-inclusive strategy for managing the quality of drinking water by enabling a thorough, systematic study of water systems, the identification of risks and hazards, and the assessment of risks.
- Emphasizes risk reduction through preventive and assigns proper verification duties to water testing.
- Introduces a methodical approach to implementing water quality policies that reduces the likelihood of failure due to oversight or managerial error. It also offers backup strategies for handling unexpected dangerous situations or system breakdowns.
- Gives different agencies and stakeholders the chance to participate by identifying their areas of duty and offering the results of a cooperative and coordinated approach with increased understanding of each party's obligations.
- Offers a framework for interaction between the public and employees.
- Participate in the discussion on establishing rules and guidelines for water quality and public health that are responsive to system failures or unexpected dangerous events.
- Water safety plans can be created in a generic manner for modest supplies as opposed to for specific supplies.

4.4 Application of Water Quality Framework

The graphic below outlines the numerous elements for preserving freshwater, as well as how they work together to build a system for assuring water quality. Fig. 4.1 shows irrigation water quality framework for identifying critical sources of pollution and the same can be adopted for domestic and industrial purpose considering water quality parameters as per Indian standards. Hathmati watershed is having water from Hathmati river maximum for irrigation purposes. This framework can also be applied for any watershed and any purpose for use. This framework can be divided into mainly three phases which includes data collection, analysis and identifying critical source of water pollution.

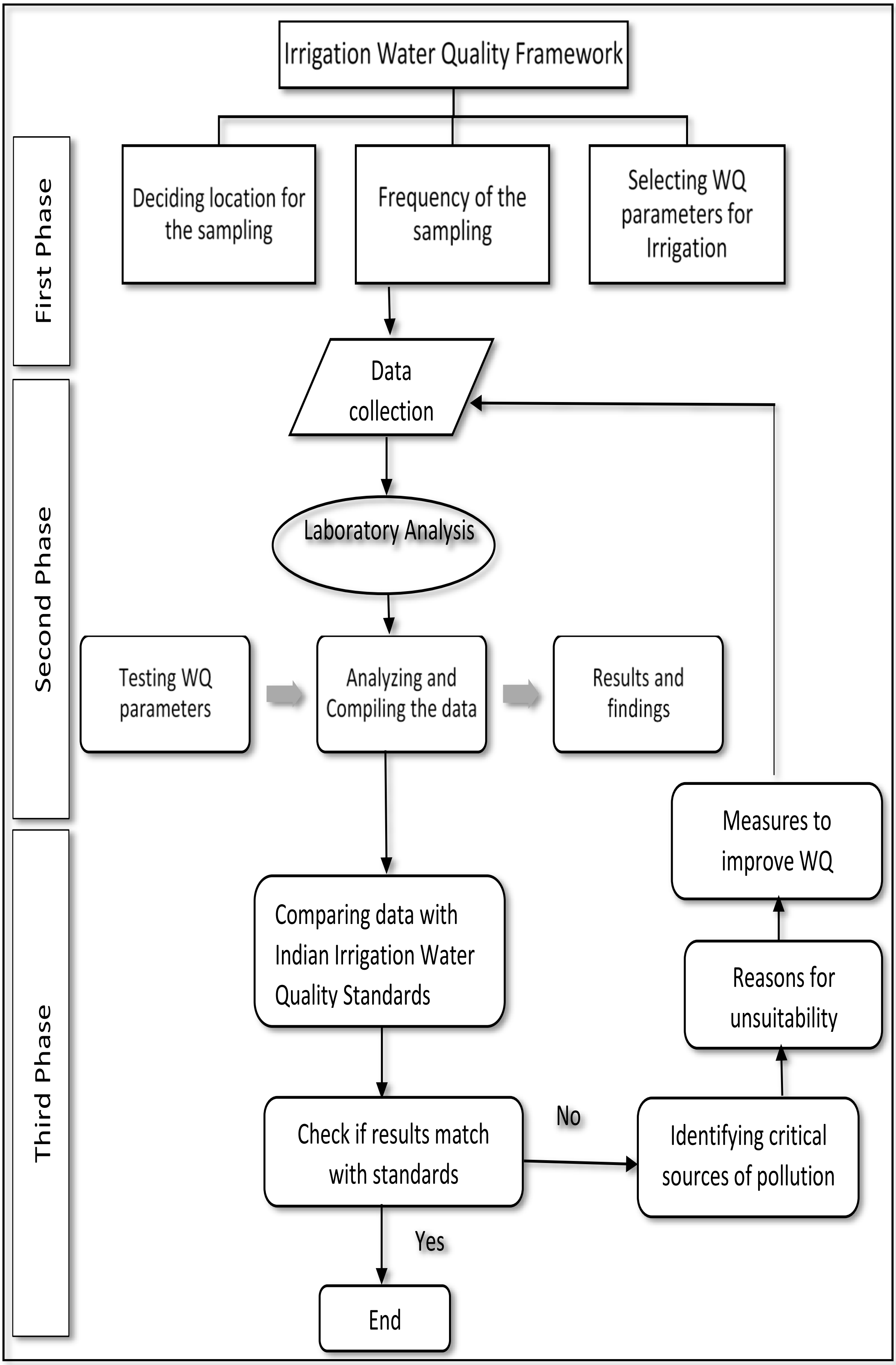

Fig. 4. 1 Irrigation Water Quality Framework

This monitoring framework encompasses three main phases.

1. The first phase comprises design of monitoring framework, which should consider and include:

- The planning of a monitoring framework by choosing location for the sampling, with the help of preliminary surveys needed before the design is started, so that issues, problems, and risk factors can be clearly identified and evaluated.
- The planning of frequency of sampling.
- The selection of physical, chemical, and biological variables, i.e., which variables are to be monitored for irrigation and in relation with different non-point pollution sources.
- Defining sampling procedures and operations, such as in situ measurements with different devices, manual or automated measurements.

2. The second phase defines laboratory facilities required for the monitoring program.

- Setting up a system for ensuring the reliability of information obtained by monitoring which covers field and laboratory work, data analysis and compiling, as well as the application of WQ standards; and
- Managing the data and reporting results and findings.

3. The third phase comprises by implementing the framework, with comparing data with Irrigation water quality standards. If data does not match the standards, then finding out critical sources for pollution and reasons for unsuitability for using water for Irrigation purpose.

- Suggest some remedial measures for improving those unsuitable parameters.

CHAPTER-5

APPLICATION OF SWAT MODEL

5.1 Introduction

India has the second-largest population in the world, a massive economy, and uncertain strategies to manage its water supply in the future. It is not at all surprising that some river basins in India are currently experiencing physical water scarcity because of water quality degradation and hydrological regime changes. In the river basin, changes in land use such as afforestation, agriculture, and urban growth, can have an impact on the hydrological regime and water quality. To create sustainable river basin management strategies, it is essential to understand the hydrological responses of streamflow and water quality due to changes in the climate and land use. The interactions between the main physical components (rivers, lakes, groundwater, soil, etc.) in the water system are mathematically described by hydrological models. The hydrological cycle of the catchment describes the water balance related to the processes occurring in the river basin. In this chapter, an effort has been made to create a hydrological model that uses the SWAT model to analyze and predict the water quality.

5.2 Swat Modeling

Because it can handle a variety of management scenarios and environmental variables, the SWAT model was chosen (Ahmad, Gassman, and Kanwar, 2002). It was also chosen because, in earlier studies in medium to large sized catchments in the USA, Canada, and Germany (e.g., Huisman et al., 2004), it accurately predicted daily flow. Santhi et al., 2001; Lenhart et al., 2003; Grizzetti et al., 2003; Bouraoui et al., 2004; and other recent papers have demonstrated the potential of SWAT to estimate N export at the catchment outlet. When there is good agreement between actual and simulated data, such as in large river basins covering thousands of square kilometers, SWAT is typically used (Jayakrishnan et al., 2005). Nevertheless, the SWAT model can also be verified and used at the level of a small watershed (Arnold et al., 1996; Arnold et al., 1999; Arnold and Williams, 1987). The dispersed nature of the model enables separate estimates of both physical and nutrient cycling processes at the sub-watershed scale, which is why the Hathmati watershed was chosen for this thesis's case study. SWAT is the outcome of more than 30 years of modeling work by the U.S. Department of Agriculture's Agricultural Research Services (USDA-ARS; Arnold et al., 51 1998; Arnold and Fohrer, 2005). The USDA-ARS in Texas actively supports SWAT, a model that is in the public domain. It has developed into a useful tool for assessing problems with non-point source water resources (flow, sediment, and nutrients). As new components are introduced, SWAT is consequently continually evolving and changing. Predictive accuracy has been tested for the SWAT model's performance. Results show that SWAT forecasts for hydrological and chemistry loadings are more accurate for long-term simulations (e.g., annual) and larger basins than for short-term simulations (e.g., daily) and smaller basins.

It was determined that SWAT is a suitable watershed-scale model for long-term modelling (Chu & Shirmohammadi, 2004; Chu et al., 2004; 51 1998; Arnold and Fohrer, 2005). SWAT is frequently used to assess hydrologic regimes at daily, monthly, and annual time scales (Bouraoui et al. 2005). Due to its sophisticated model configuration and impressive features, such as modelling regions with limited data and assessing various scenes and agricultural managements, the SWAT model has gained widespread acceptance as a cost-effective tool (Engle et al. 1993; Spuill et al. 2000; Bosch et al. 2004; Sang et al. 2010).

According to Arnold and Fohrer (2005), SWAT has been used successfully to simulate effects of LULC and climate change on hydrologic and biogeochemical cycle. Watershed is divided into sub-basins for purposes of SWAT, and these sub-basins are often further divided into hydrologic response units (HRUs). HRUs are thought to be homogeneous with distinct LULC, soil type, and topography slope values. SWAT needs a greater variety of input data, including rainfall, LULC, a digital elevation model, streamflow, meteorological information, soil information, etc. SWAT model has good potential for use in hydrologic/water quality research in many nations as well as a tool to create time and money effective evaluations for managing watershed/water resources (Jayakrishnan 2005). SWAT needs details regarding weather, soil characteristics, topography, vegetation, and land management techniques used in watershed rather than using regression models to characterize link between input and output variables (Neitsch 2001).

5.3 Methodology for Model Set-up

The proposed water quality model and SWAT development are discussed in this section. Using ArcSWAT, a hydrologic model is developed as the overarching methodology. The inputs for the widely used ArcSWAT model include meteorological, topographical, hydrological, soil, and LULC data. On the other hand, not much meteorological information is monitored at the basin or sub-basin level. First, a SWAT model for the Hathmati river basin has been created. The created SWAT model has undergone validation and calibration. Fig. 5.1 shows methodology for SWAT modeling.

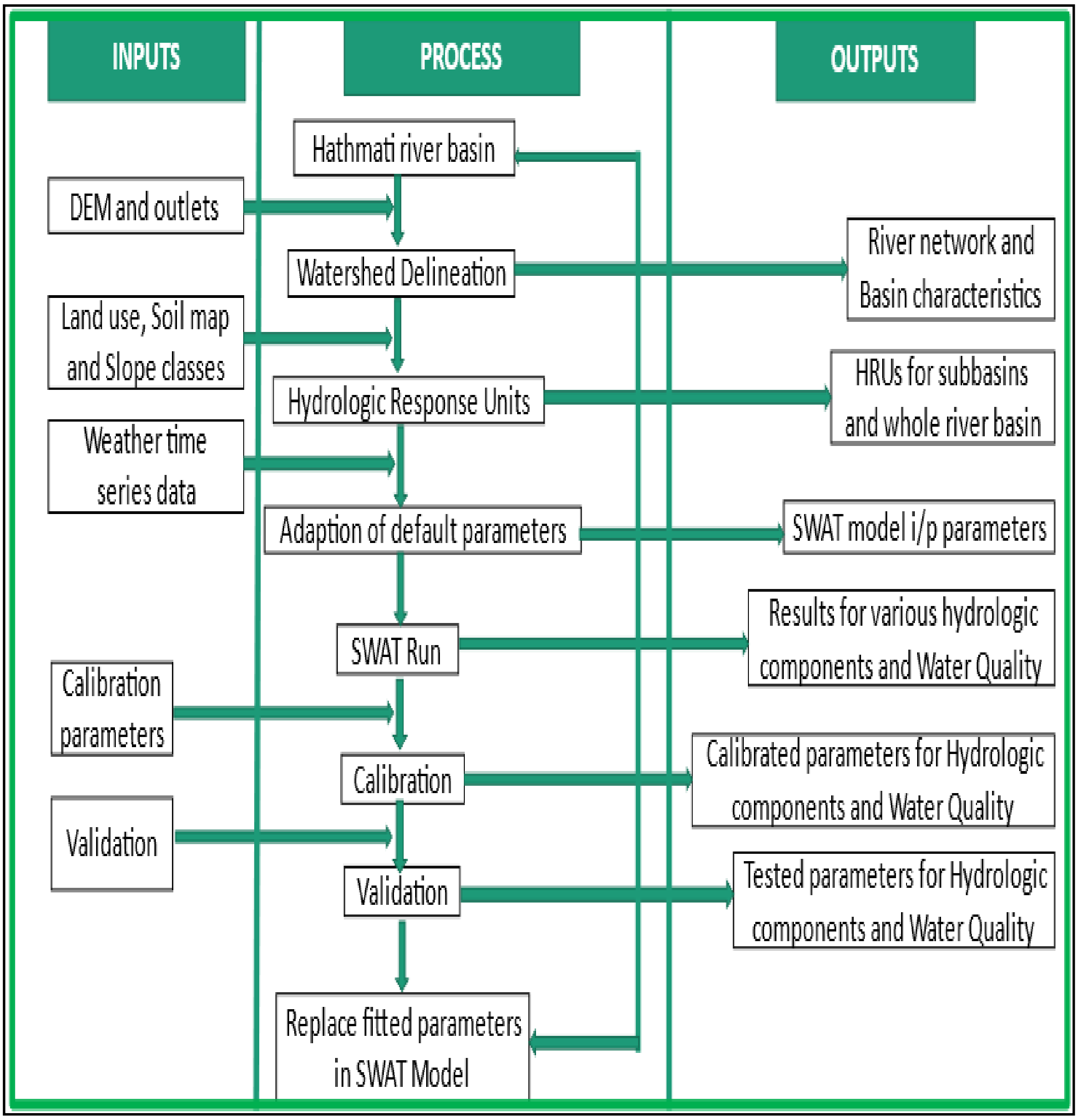

Fig. 5. 1 Methodology for SWAT modeling

5.3.1 Watershed Delineation

For use in hydrological modelling with SWAT, the watershed delineation helps the user to divide the watershed into several hydrologically connected sub-basins. Digital elevation models (DEMs) in Arc Info grid format are necessary for the demarcation procedure. An extensive topographic report is produced by the delineation operation.

The statistical summary and distribution of discrete land surface elevation throughout the watershed, as well as all the sub-basins, are described in the topographic report. Sub-basin outlets are the locations where all the runoff from sub-basins is accumulated to create streamflow. At the measuring station, the streamflow from the sub-basins' outlet is then aggregated. This is helpful for comparing flows that were simulated.

Thirteen sub-basins have been created in this study depending on the topography. Using ArcSWAT-2009, the Hathmati stream network and sub basins have been identified. For sub basins, the drainage areas at the sub-basins outflow are shown in table 5.1.

Table 5. 1 Drainage areas for different sub basins

Sub watershed No.	**Drainage area in sq. km**
1	106.23
2	45.32
3	50.26
4	175.85
5	77.39
6	65.50
7	102.11
8	94.79
9	52.73
10	125.94
11	92.67
12	154.90
13	173.72

5.3.2 *Land use/Soil/Slope Definition*

For each sub-basin, SWAT calculates runoff using the Natural Resources Conservation Service Curve Number (NRCS-CN) approach. To calculate CN for any combination of land use, soil and slope category, the NRCS-CN method needs data on land use, soil, and slope. The procedure of specifying the data to be used is made easier by the land use, soil, and slope categorization tool. The models can load land use, soil, and slope themes into a project and choose which land use/soil class combinations to utilize by using the land use, soil, and slope description. A thorough report is produced for the current project once the application is finished. The generated report details the distribution of slope, soil classes and land use for each sub-basin. Land use/Soil/Slope Definition reports for Hathmati watershed has been shown in Appendix B.

5.3.3 *HRU Definition*

The watershed is defined using a digital elevation model and further separated into subbasins that are classified into Hydrologic Response Units (HRU) for the purpose of setting up a site-specific model (Neitsch et al., 2002). For each HRU, simulations are done of the processes of evapotranspiration (ET), infiltration, surface runoff, subsurface flow, percolation, sediment erosion, crop growth, and N cycling. SWAT's hydrological and nutrient routing systems are configured using the methodology outlined by Arnold et al. (1994). Within the basin, water can be moved from any reach to another reach.

By combining sub watersheds and hydrologic response units (HRUs), the model replicates a basin. According to Green and van Griensven (2008), distinct soil and land use combinations produce the HRUs. To take into consideration the complexity of the landscape within the sub-basin, the hydrological response units (HRUs) are the areas of a sub-basin that have unique combinations of soil, land use, and slope. The watershed has been divided into regions with unique combinations of slope, soil types and land uses, allowing the model to account for variations in evapotranspiration and other hydrologic conditions for various slope, soil types and land uses. To calculate the overall runoff for the watershed, runoff is predicted separately for each HRU and routed. This improves the description of water balance and increases accuracy. After importing the slope, soil, and land use data layers, it is necessary to identify how the watersheds' hydrologic response units (HRU) are distributed. Every sub-basin goes through this process. An understanding of the land use, slope and soil distribution will come through the HRU definition processes. Following the application of the HRU overlay for the basin and sub-basin, this will provide a full description of the land use, slope, and soil classes. Each HRU generates water and nutrient fluxes, which are then aggregated in the sub watersheds that correspond to them and distributed to the main reach of the watershed. Either the variable storage routing approach (Arnold et al., 1995) or the Muskingum River routing method (Chow et al., 1988) are used to route discharge and matter fluxes within the stream network from one subbasin to another, and ultimately to the outflow of the watershed. For each sub-basin, the number of HRUs together with the land use/soil /slope types and area are provided. The model suggests 30 HRUs to delineate each sub-basin in the current study up to the outlet point using the data that is currently available. Report of HRU has been shown in Appendix A.

5.3.4 Weather Data

After the HRU distribution is complete, the meteorological data for the watershed simulation is combined. The sub-basins are given the locations of the weather stations and the meteorological data. The SWAT model can be performed using weather information such as measured rainfall, relative humidity, temperature, wind speed, and solar radiation.

5.3.5 Model Simulation

Once you have finished creating HRUs in step 2, only then can this module be made active. In this step, all the model's collateral data are incorporated in a predetermined format. In addition, SWAT offers a simulation option for any collateral data if the observed values are not accessible. In the current study, observed data were used, and the model was updated to include information from climate and rain gauge stations. If this stage is completed successfully, the model can produce several output tables, such as. hru, rch, sub, etc.

5.4 Hydrologic Assessment of the SWAT Model

The SWAT model represents hydrology as a two-component system made up of channel and land/soil hydrology. A water mass balance underlies the hydrologic cycle's soil component. The main factor considered by the model in each HRU is the soil water balance, which is denoted as (Arnold et al., 1998):

SWt = Swo + ∑ (Rday – Qsurf – Ea – wseep – Qgw)………………………………………….(5.1)

Where, SWt is the soil's final water content,
Swo is its initial water content, and
Rday is its daily precipitation on day i,

Assuming a specific slope, Qsurf is the amount of surface runoff,
Ea is the amount of evapotranspiration,
wseep is the quantity of water entering the vadose zone, and
Qgw is the amount of return flow to the upper layer.

By using a probability function and converting the precipitation data to daily output values indicated by Rday, algorithms in the weather generator subroutine interpolate the precipitation data for missing values. The "regenerated" results typically differ from the measured data collected over comparable time periods. The results of model simulations are frequently complicated by this disparity since hydrographs can be misleading. Figure 5.2 displays the hydrologic cycle simulation created using SWAT.

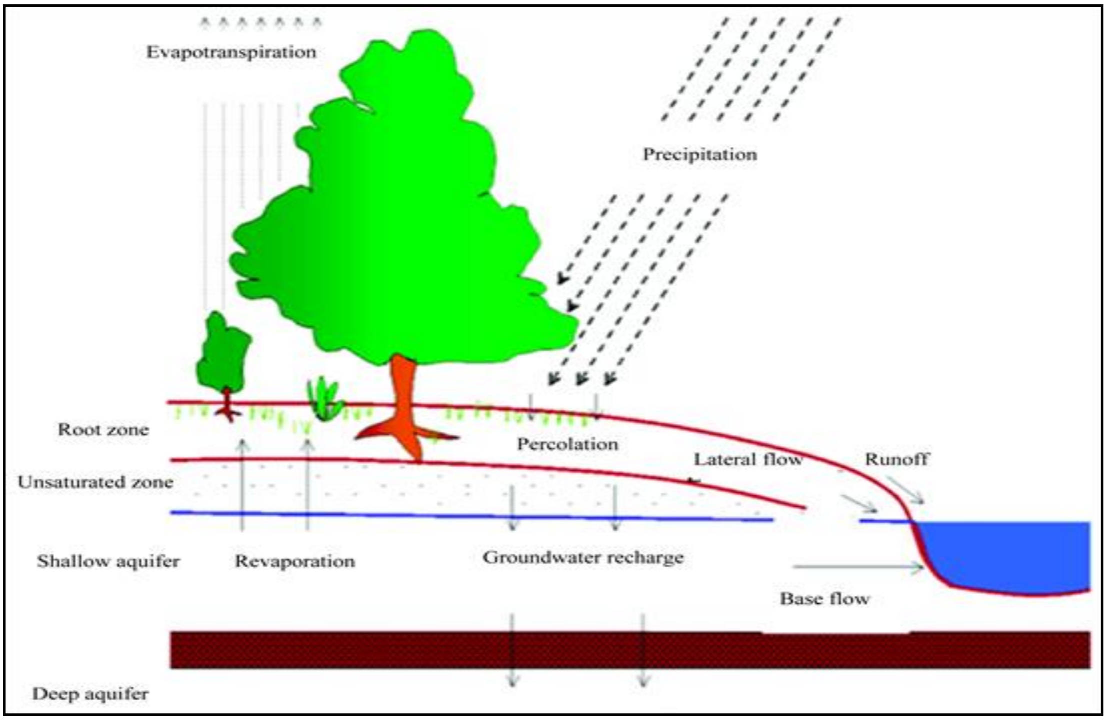

Fig. 5. 2 The hydrologic cycle simulation

Most of the water entering the SWAT model's watershed system boundary is precipitation, apart from areas where irrigation is used. The SWAT model's weather generator can be used to simulate precipitation inputs or measure those using data for hydrologic calculations. The weather generator extrapolates missing values for missing days in the parameter input database by simulating missing values for daily precipitation, wind speed, minimum and maximum air temperature, solar radiation, and relative humidity.

Depending on the soil, land cover, and geomorphic features of the watershed, precipitation is divided into many water paths as it hits the ground. There may be several vertical layers in the soil profile. Infiltration, percolation, evaporation, plant absorption, and lateral flow are some of the soil-water processes. SWAT uses the SCS curve number procedure (SCS, 1972) and the Green and Ampt infiltration method (Green and Ampt, 1911) to estimate the volume of surface runoff and infiltration. This study evaluated the runoff component of the Modified DRAINMOD (Skaggs, 1980) runoff technique incorporated into SWAT using the SCS curve number approach because it has been extensively tested and utilized to many SWAT projects. The watershed time of concentration is calculated using Manning's formula for the peak rate component, which also considers channel and overland flow. The way a watershed reacts to a precipitation event is known as the time of concentration. It is the amount of time required for water to travel from a watershed's furthest point to the watershed.

The SWAT model allows for the possibility of lateral subsurface flow in the soil profile, and it simulates flow out of the shallow aquifer to produce groundwater flow, which contributes to total streamflow (Arnold et al., 1993). A recession constant computed from daily stream flow measurements is used to lag the flow from the shallow aquifer to the stream (Arnold and Allen, 1996). According to SWAT, percolation is computed for every soil layer in the profile (Neitsch et al., 2002a). If the water content in a layer exceeds the field capacity for that layer while the layer below is not saturated, water may percolate. The conveyance of this water will happen as the water table rises above the tile base if tile drainage is implemented. In SWAT, tile drainage is computed using one of two methods. When the user specifies the depth from the soil surface to the tiles, the length of time needed to drain the soil to field capacity, and the amount of delay between the time water enters the tile and the time it exits the tile and enters the main channel, tile drainage in an HRU can be simulated according to the original approach (Arnold et al., 1999).

5.5 Nitrogen assessment of the SWAT model

This study considers the N cycle of the land phase, which is based on the EPIC model (Williams et al., 1984) of erosion-productivity impact. One passive and one active organic N pool are distinguished by the SWAT conceptual framework. Since plants can only absorb nitrogen in the forms of ammonium and (NH_4^+) and nitrate (NO_3^-), which can be depleted during the process of denitrification, gaseous nitrogen losses are not directly modelled in the SWAT model, which is a net mineralization model. Under anaerobic soil conditions, denitrification is the conversion of nitrate (NO_3^-) to gaseous compounds (such as N_2O, N_2, and NO). Denitrification is based on the EPIC model in the original function used in the SWAT model (Williams et al., 1984). Accordingly, the rate of denitrification depends on the soil temperature and the amount of organic carbon present in the specific soil layer where denitrification takes place. It is assumed that when soil moisture reaches 95% of the moisture content at field capacity, denitrification takes place. Pohlert et al. (2007) claim that in circumstances where the threshold is crossed in relatively moist soils, this can result in unreasonably high denitrification rates. Denitrification and N-leaching are two processes that are fiercely competitive when it comes to the conceptualization of SWAT, according to Pohlert et al. (2005). As a result, water only percolates into an underlying, unsaturated soil layer because of the cascading (downward) percolation process when the field capacity of the overlaying layer is surpassed. As a result, denitrification at the uppermost layer happens before water begins to percolate, resulting in extremely high N losses and possibly a significant reduction in the amount of accessible N in the pools of each previous soil layer (Pohlert et al. 2007). Further advancements have been made by substituting methods from the Denitrification-Decomposition model (DNDC; Li et al., 1992; 2000) to address the issues mentioned above. The model is a gross mineralization model since N-emissions are explicitly considered and a portion of the mineralized N is utilized for microbial growth (immobilization). Step-by-step simulations of mineralization begin with the production of ammonium (ammonification). The leftover ammonium is further mineralized or absorbed by plants, while some of it is adsorbed on clay particles (Pohlert et al. 2007). After that, nitrification takes place and nitrite ($NO2^-$) is converted to nitrate while explicitly accounting for gaseous emissions of N2O and N2. Figures 5.3 shows the elements of the conventional nitrogen cycle respectively.

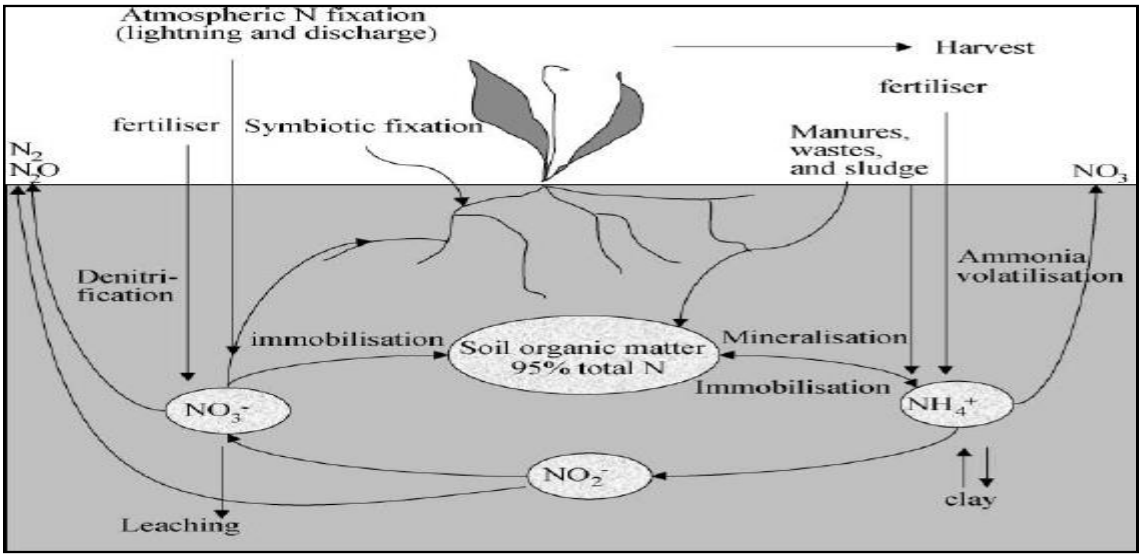

Fig. 5. 3 The Nitrogen cycle

Nitrate is a mobile anion and may be transported with overland flow to the main channel, or through subsurface flow or percolation to deeper soil profiles. The separation of $NO3^-$ output in SWAT resulting from subsurface tile flow was the focus of another modification of SWAT that was recently undertaken in the current study. SWAT monitors five different pools of nitrogen in the soil. Two pools are inorganic forms of nitrogen: $NH4^+$ and $NO3^-$, while the other three pools are organic forms of nitrogen (Figure 5.4). Here, nitrogen is allowed to move between the active and stable organic pools in the humus fraction.

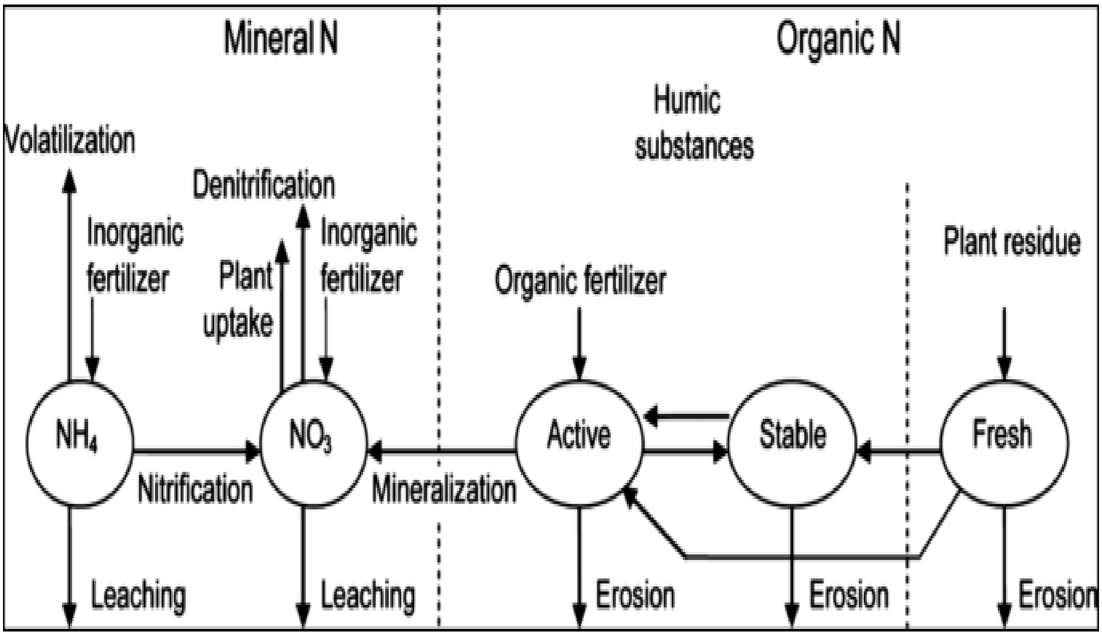

Fig. 5. 4 Organic and Inorganic forms of Nitrogen

While the active and stable organic N pools are related with the soil humus, fresh organic N is linked to crop residue and microbial biomass. To account for variations in the availability of humic compounds for mineralization, the organic nitrogen linked with humus is divided into two pools. When the soil is unable to meet the nitrogen needs of the plants, SWAT additionally simulates nitrification and ammonia volatilization, calculates the quantity of nitrate lost to denitrification, and considers nitrogen fixation (if any). All soil N processes are simulated in the SWAT model using relationships described in the model's theoretical documentation (Neitsch et al, 2005).

5.6 SWAT Output Viewer

SWAT outputs can be visualized in a variety of ways. The model outputs are displayed spatially as a map. The distribution of the chosen results among subbasins or reaches will be made very evident. Finding the hotspots in the watershed is helpful. The outputs are presented flawlessly in this new application created by Michael Yu (GIS Programmer and Developer, Hydrologist, Water Resource Engineer, ArcGIS, .NET, C++, Flex, FORTRAN, SWAT). SWAT output viewer has been used in the current study to display the outputs. Figure 5.5 illustrates the watershed as seen in the SWAT output viewer.

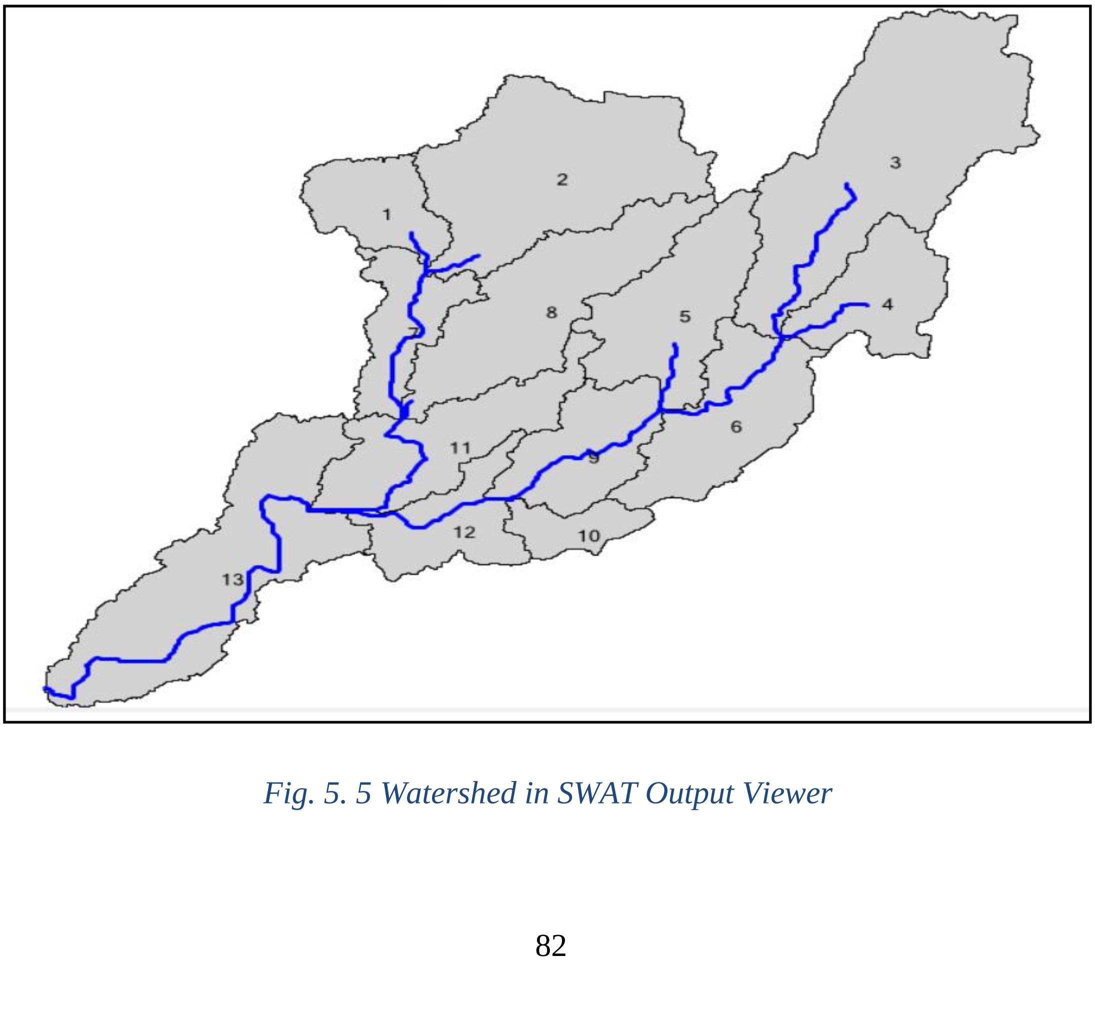

Fig. 5. 5 Watershed in SWAT Output Viewer

5.7 SWAT-CUP

SWAT-CUP 2012, VERSION 5.1.6 has been used in this study for calibration purpose. The SWAT-CUP programme is used to calibrate SWAT models. The programme connects SWAT with SUFI2, GLUE, ParaSol, MCMC, and PSO. A SWAT model's calibration and uncertainty analysis could be carried out using any of the methods. In the fields of land use change, climate change, water allocation, and pollution control, distributed watershed models are being utilized more and more to inform decisions on different management techniques. It is crucial that these models undergo a comprehensive calibration and uncertainty analysis because of this. The meaning of a calibrated model, its domain of application, and its uncertainty should also be evident to the analyst and the decision maker because calibration model parameters are always conditional in nature. Because of the significant model uncertainty, input uncertainty, and non-uniqueness of the parameter, large distributed models are particularly challenging to calibrate and interpret the calibration.

Many approaches have been available in recent years to do calibration and uncertainty analysis. We have linked, for the time being, three programs to the hydrologic simulator Soil and Water Assessment Tools (SWAT) (Arnold et al., 1998) under the same platform, SWAT-CUP (SWAT Calibration Uncertainty Procedures), as only one technique cannot be applied to all situations and different projects can benefit from different procedures. These techniques include Sequential Uncertainty Fitting (SUFI-2) (Abbaspour et al., 2007), Parameter Solution (ParaSol) (van Griensven and Meixner, 2006), and Generalized Likelihood Uncertainty Estimation (GLUE) (Beven and Binley, 1992). To achieve an accurate portrayal of a basin's processes, such as streamflow, ET, ecological change, etc., several model parameters must be optimized during the calibration of a semi-distributed and physically based model, such as SWAT. Therefore, in many large-scale applications, the calibration process may become challenging and nearly impossible (Arnold et al., 2012). In order to support the solution of this issue, a number of auto-calibration and uncertainty analysis tools for SWAT were created. These tools are currently accessible to support the optimization procedure. To obtain a good calibration, this study relies on SWAT-CUP and its Sequential Uncertainty Fitting algorithm (SUFI-2). An auto-calibration and uncertainty analysis module program based on the SWAT engine is called the SWAT-CUP (Abbaspour et al., 1997; Abbaspour, 2015). The reasonably sophisticated optimization system SWAT- CUP can handle a variety of input parameters. Because of SWAT-CUP's intelligence, model parameters can be established, optimized, and manually modified iteratively between calibration batches or throughout the auto calibration process. This feature makes SWAT-CUP ideal for both novice and experienced users of hydrological models, even if it is generally advised to have a solid grasp of hydrologic processes and parameter sensitivity (Arnold et al., 2012). A freeware auto-calibration program called Swat Cup 2012 enables the use of several algorithms for improving SWAT outcomes in hydrological modelling. It can be utilized for watershed visualization as well as sensitivity analysis, calibration, validation, and uncertainty analysis of SWAT models. However, SWAT-Cup was only used in this work for automatic calibration and sensitivity analysis utilizing an SUFI2 optimization program by modelling uncertainty from multiple sources. It is crucial to choose the objective function on which the iteration will estimate the best parameter and best simulation flow while calibrating a model in SWAT CUP. Therefore, to compare model outcomes with observation data, the Nash- Sutcliffe model efficiency coefficient (NSE) was chosen as an objective function. In addition, SWAT-CUP offers graphical modules that allow users to view simulation results, uncertainty bounds, sensitivity graphs, watershed visualizations on the Bing map, and statistical reports.

5.8 SWAT Run

The model run is divided into four modules:

1. Model setup
2. Model calibration (Sensitivity analysis)
3. Model validation
4. Simulation utilizing predicting scenarios

5.8.1 Model setup

To initialize and aid in the formation of model variables, a warm-up phase is typically advised (Tolson and Shoemaker, 2007). The first three years in this study served as a model warm-up period to reduce the impact of initial conditions that were unknown. The model is set up for simulation for 1999 to 2020 (22 years) duration in which 3 years of warm-up period was chosen and results were obtained. The results are acquired after successfully completing each of the processes listed in point 5.7. The model's Nash

Sutcliffe efficiency between observed and simulated values of discharges and nitrate in mm is 0.87 and 0.89 due to the default database that was installed.

5.8.2 Model calibration

The objective of the study is to calibrate the model to be as hydrologically similar as possible to the actual watershed. The "Sequential Uncertainty Fitting" (SUFI-2) algorithm, which is interfaced with SWATCUP, is used to calibrate the model. Surface runoff and nitrate across the reach is considered as a variable, and twelve sensitive parameters are selected, as indicated in table 5.2.

Table 5. 2 Sensitive parameters for calibration

S. No.	Parameter_Name	Parameter Description
1	CN2.mgt	Curve number
2	ALPHA_BF.gw	Base flow recession constant
3	GW_DELAY.gw	Delay time for aquifer recharge
4	GWQMN.gw	Depth of water in shallow aquifer required for return flow
5	SOL_AWC (.).sol	Available water capacity of the soil layer
6	ESCO.bsn	Soil evaporation compensation factor
7	SURLAG.bsn	Surface runoff lag coefficient
8	NPERCO.bsn	Nitrate percolation coefficient
9	PPERCO.bsn	Phosphorous percolation coefficient
10	PHOSKD.bsn	Phosphorus soil partitioning coefficient
11	GWSOLP.gw	Soluble phosphorus concentration in groundwater flow
12	EPCO.bsn	Plant uptake Compensation factor

To determine the new limitations, 500 simulations were run for each of the 12 parameters. The validation phase then made use of the updated parameter values. Between the years 2002 and 2011, the calibration is done monthly. The monthly data below indicate that NSE is as good as 0.92 and 0.70 for surface runoff and nitrate respectively. The stream from sub basin thirteen, which makes up the watershed, is selected for calibration. "FLOW_OUT_13" and "NO3_OUT_13" is used in the study as variables, where FLOW_OUT and NO3_OUT denotes the variables and 13 denotes the number of reaches.

Figure 5.6 and 5.7 illustrates how the algorithm integrates the observed data.

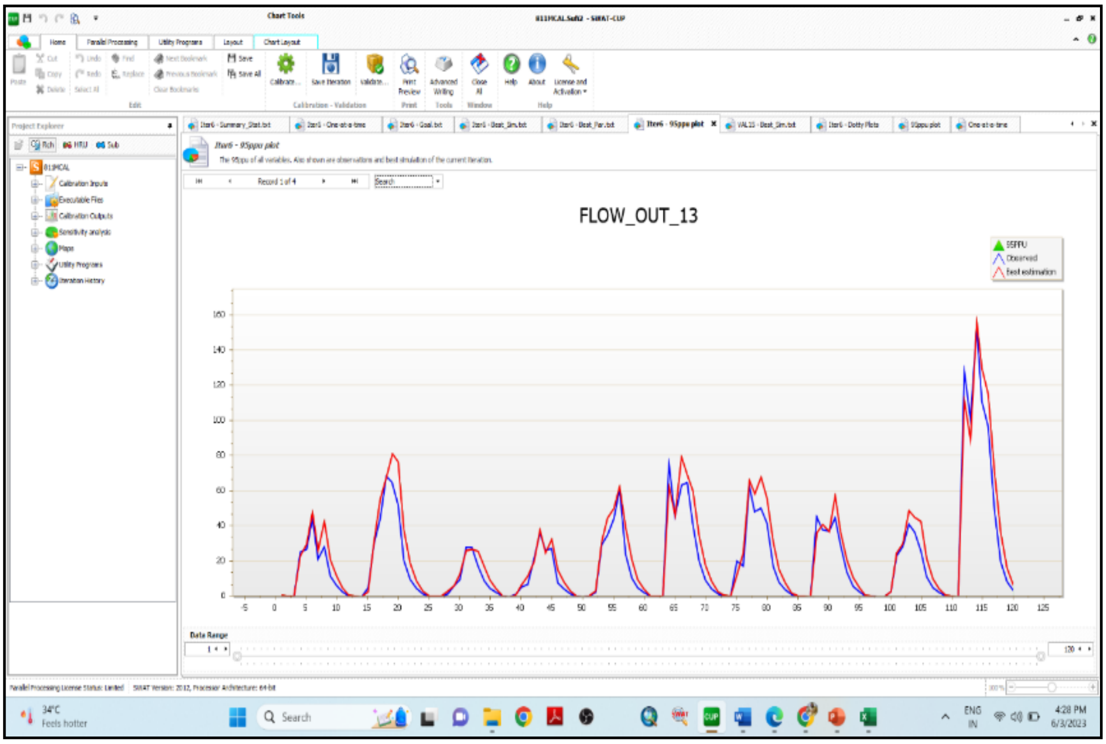

Fig. 5. 6 SWAT Cup calibration outputs for Surface Runoff

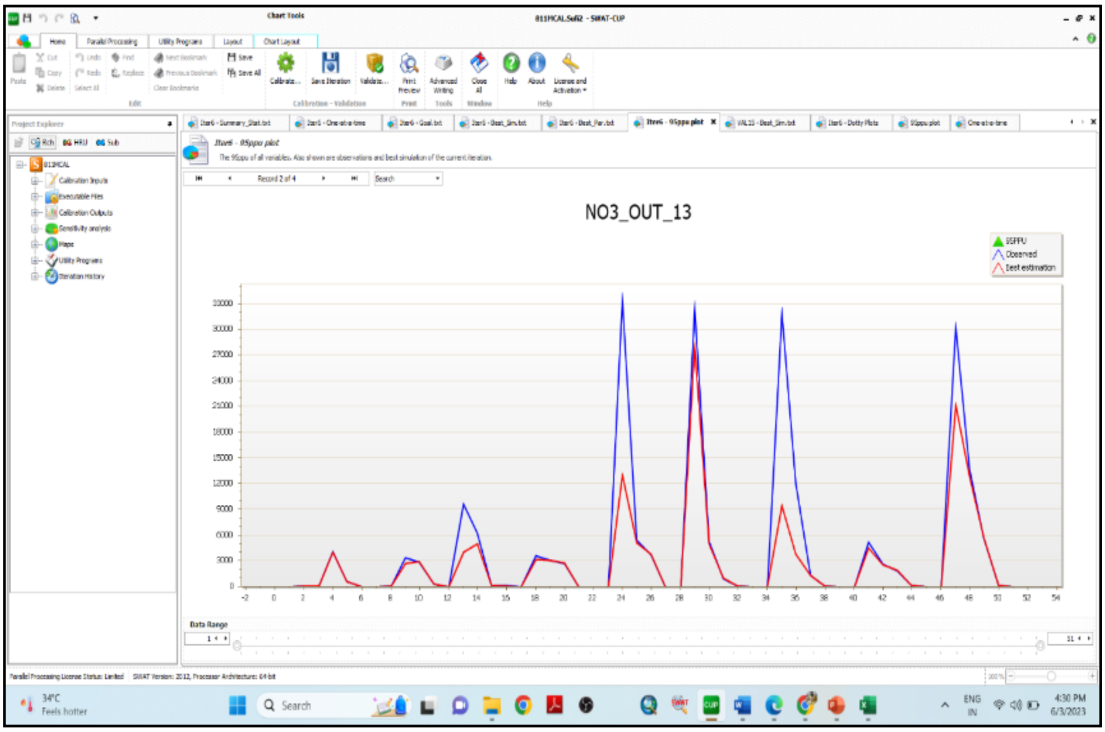

Fig. 5. 7 SWATCup calibration outputs for Nitrate

After incorporating the necessary data, the algorithm is made to execute. Figure 5.8 and 5.9 shows the stages of program execution and simulation.

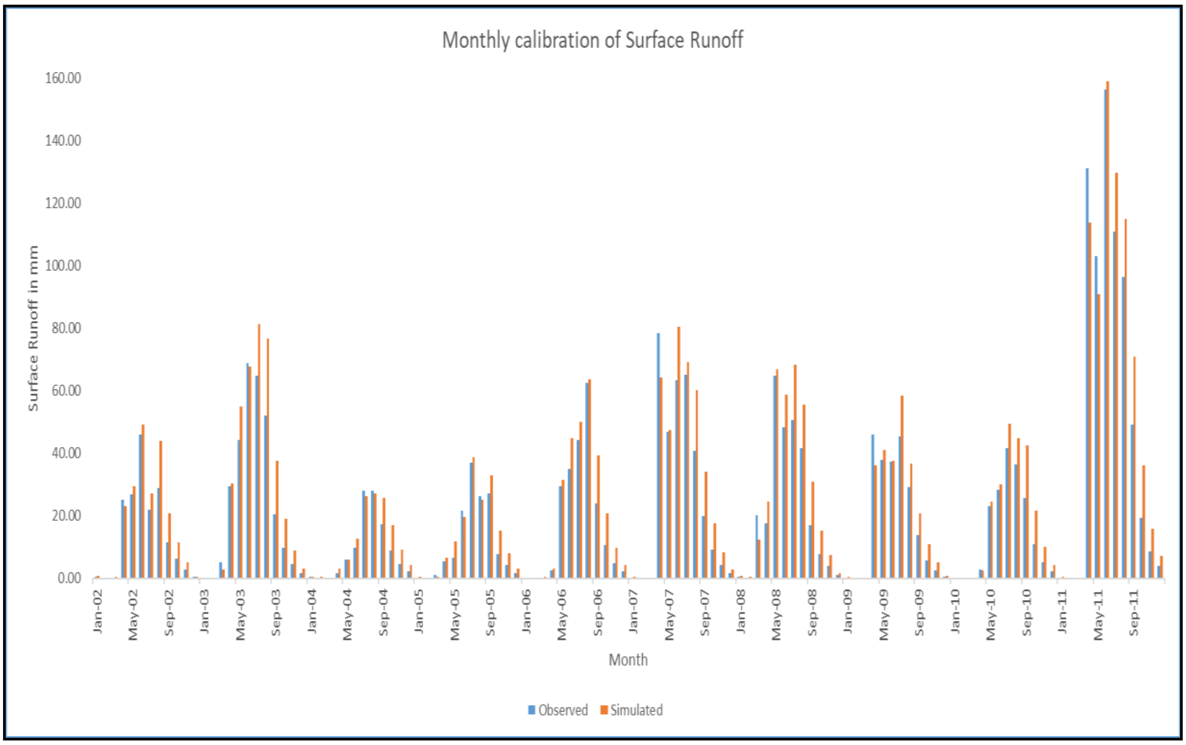

Fig. 5. 8 Monthly calibration of surface runoff from 2002 to 2011

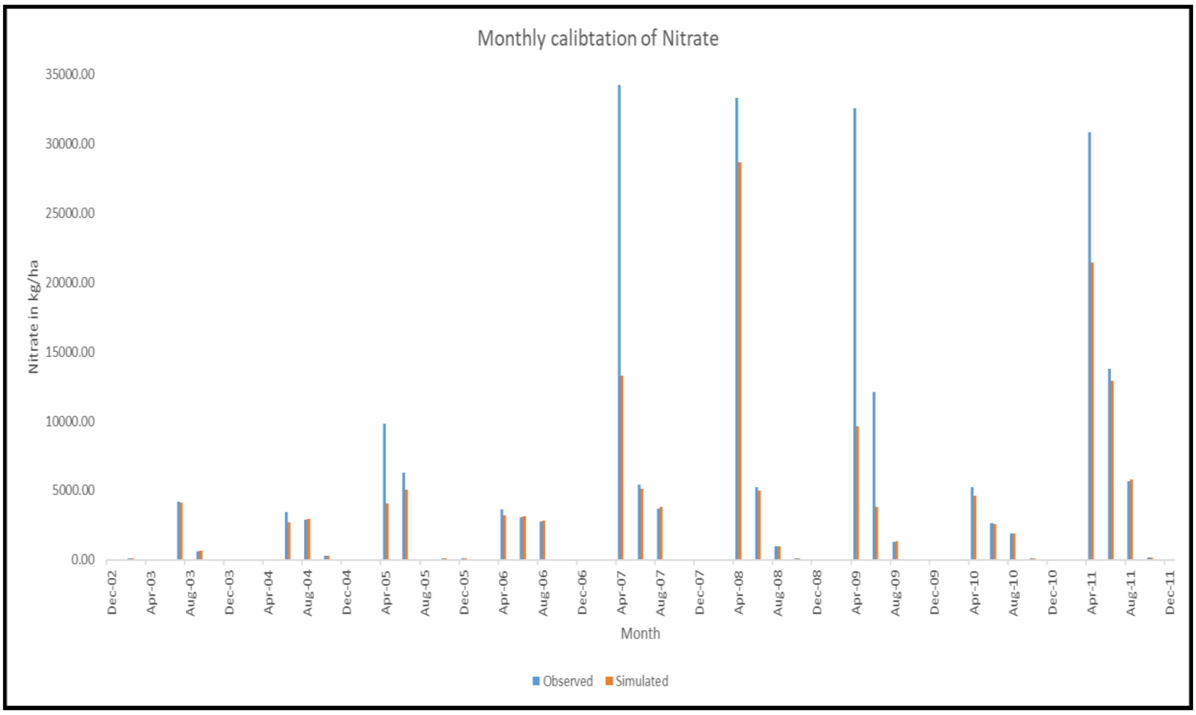

Fig. 5. 9 Monthly calibration of nitrate from 2002 to 2011

The parameters in the table 5.3 are suggested by the model's successful SUFI-2 calibration.

Table 5. 3 Absolute values of sensitive parameters after calibration

	Parameter_Name	**Fitted_Value**	**Min_value**	**Max_value**
1	CN2.mgt	44.450	35	98
2	ALPHA_BF.gw	0.25	0	1
3	GW_DELAY.gw	125	0	500
4	GWQMN.gw	4250	0	5000
5	SOL_AWC (..).sol	0.35	0	1
6	ESCO.bsn	0.15	0	1
7	SURLAG.bsn	20.407	0.05	24
8	NPERCO.bsn	0.75	0	1
9	PPERCO.bsn	14.125	10	17.5
10	PHOSKD.bsn	125	100	200
11	GWSOLP.gw	950	0	1000
12	EPCO.bsn	0.95	0	1

5.8.3 Model validation

Model validation is an assessment of the calibrated watershed model carried out inside a quantitative framework, computing one or more indices of the model's performance in relation to the provided observations. The calibrated model needs to be validated by running it for the necessary duration of time, then comparing the output to the findings that are already available. The model will be approved if the model validation is successful. Otherwise, the entire calibration procedure must be repeated. Model validation is crucial since it confirms the model's accuracy. The model will be assessed by comparing the Hathmati flow with the collected data. By adding the values of all twelve sensitive parameters to the swat run project and running the model again for 9 years, the programme is made to run again for validation between the years 2012 and 2020. A strong correlation between the observed and simulated streamflow was also demonstrated by the graphical comparison (Bouslihim et al., 2020). The monthly data below indicate that NSE is as good as 0.77 and 0.93 for surface runoff and nitrate respectively. The Nash Sutcliffe Model

Efficiency Estimator E has been shown by KRAUSE et al. (2005) to overestimate the effects of high peak flows. The logarithms of the observed and predicted values can be calculated to lessen the sensitivity to extreme values (KRAUSE et al. 2005). The findings demonstrate that NSE, particularly for the years 2012 to 2020, when numerous decreased flow years are seen, is much lower.

The SWAT model's monthly streamflow and nitrate output during validation has been compared with actual streamflow. The visual interpretation demonstrates how well the modelled values match the observed values. Therefore, streamflow predictions for various scenarios may be made using the validated model. This is supported by the Nash-Sutcliffe Model Efficiency Index and the Coefficient of Determination.

Since observed discharge data accounts for a significant portion of the river flow, a good fit between the simulated and observed data is expected. To compare the monthly findings to the observed data, see graphical representation of figure 5.10 and 5.11.

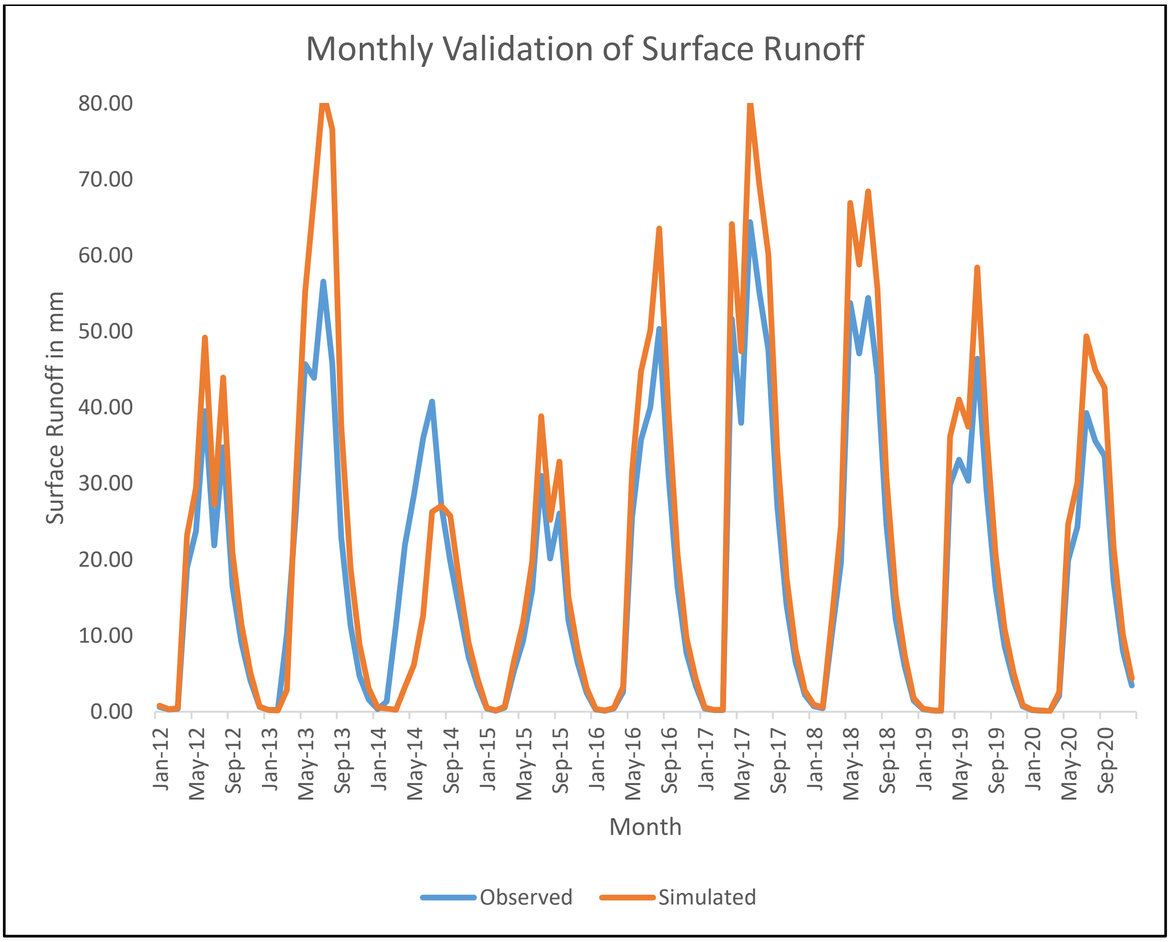

Fig. 5. 10 SWATCup validation outputs for Surface Runoff

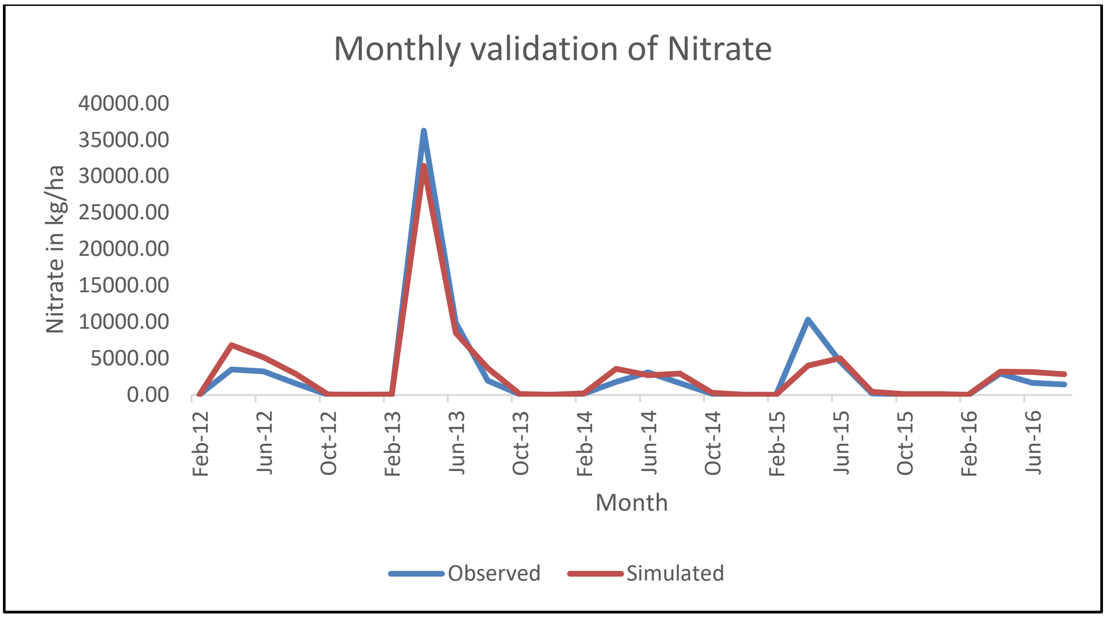

Fig. 5. 11 SWATCup validation outputs for nitrate

The model is made to run (simulate) for 22 years (1999-2020) for components related to precipitation and water quality after validation. Table 5.4 shows Evaluation of SWAT simulation against measured monthly Discharge and Nitrate.

Table 5. 4 Evaluation of SWAT simulation against monthly Discharge and Nitrate

Period	**Discharge**		**Nitrate**	
	R^2	**NSE**	**R^2**	**NSE**
Warm up (1999-2001)	0.91	0.74	0.91	0.79
Calibration (2002-2011)	0.95	0.92	0.81	0.70
Validation (2012-2020)	0.92	0.77	0.94	0.93
Overall (2002-2020)	0.93	0.87	0.90	0.89

Table 5.5 provides a summary of the hydrological modeling, giving the yearly average values of different hydrological as well as nutrient water quality parameters.

Table 5. 5 Summary of the hydrological modeling

PCP mm	**SURQ mm**	**ET mm**	**NO3_ SURQ Kg/Ha**	**N-Org Kg/Ha**	**P_Sol Kg/Ha**	**P_Org Kg/Ha**	**MinN Kg/Ha**	**MinP Kg/Ha**	**TN Kg/Ha**	**TP Kg/Ha**
1009.140	85.521	472.286	0.042	16.493	2.046	0.005	6.010	1.320	20.24	3.17

Fig. 5.12 provides summary of hydrological modeling, giving the yearly values of PCP, SURQ and ET.

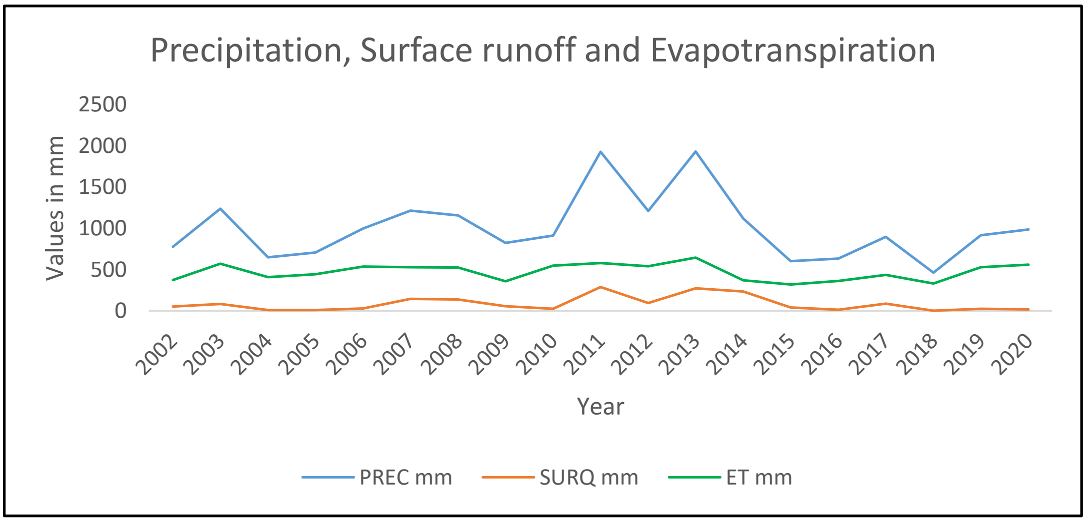

Fig. 5. 12 PCP, SURQ and ET after calibration

Fig. 5.13 provides summary of hydrological modeling, giving the yearly values of NO3_ SURQ, N-Org, P_Sol and P_Org.

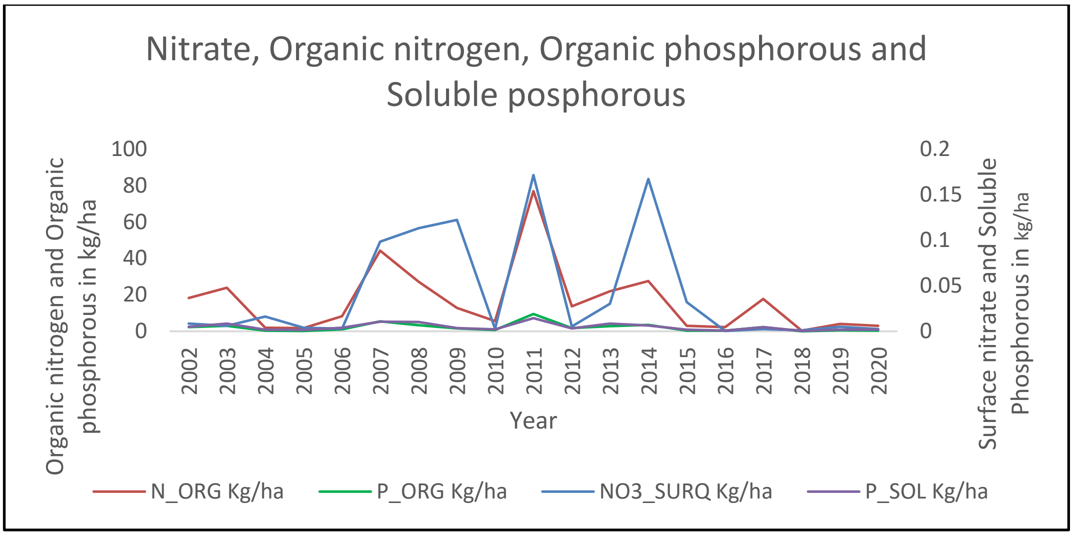

Fig. 5. 13 NO3_ SURQ, N-Org, P_Sol and P_Org after calibration

Fig. 5.14 shows values of the hydrological parameters. Average Annual value of Precipitation is 1009 mm, Surface Runoff comes as 86.37 mm, Evapotranspiration id 469 mm, lateral flow comes as 133 mm return flow in the river water is 251 mm and 321 mm of water is meeting ground water aquifer through deep percolation.

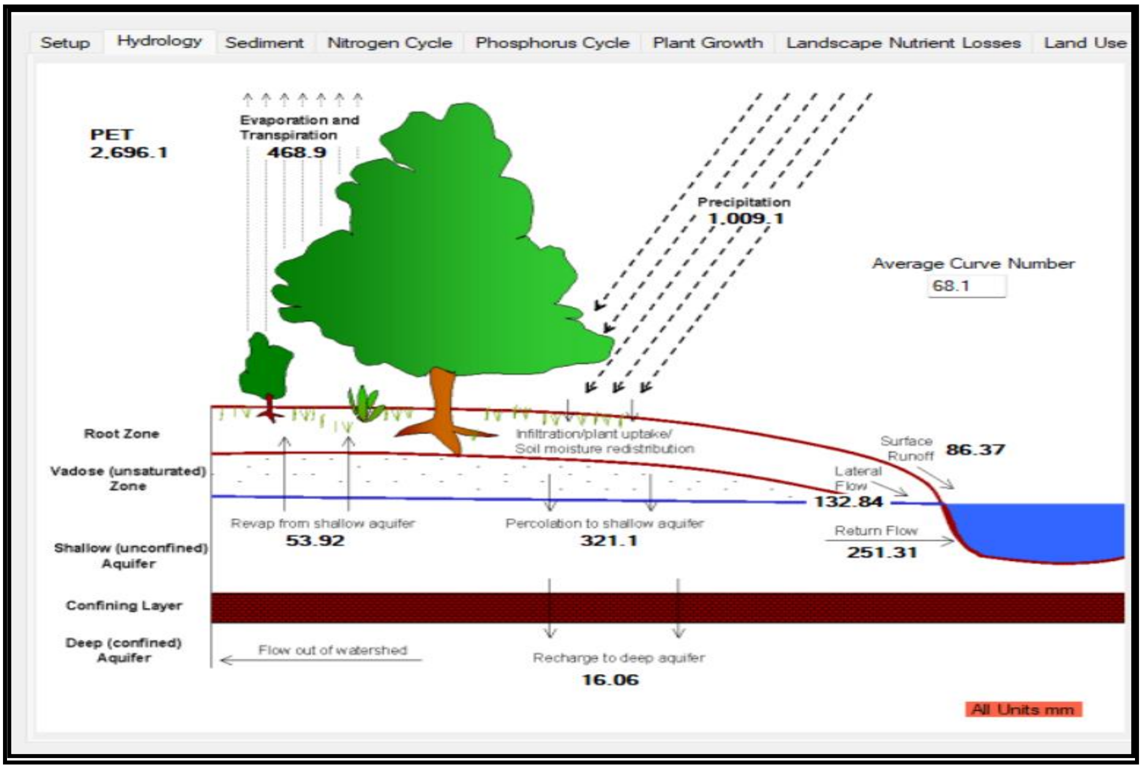

Fig. 5. 14 Hydrology of the Hathmati watershed

The graphs of the average annual precipitation, average annual evapotranspiration, average annual surface runoff and average annual nutrient water quality parameters over the sub watersheds have been created through SWAT Output viewer are shown in fig. 5.15 to fig. 5.23.

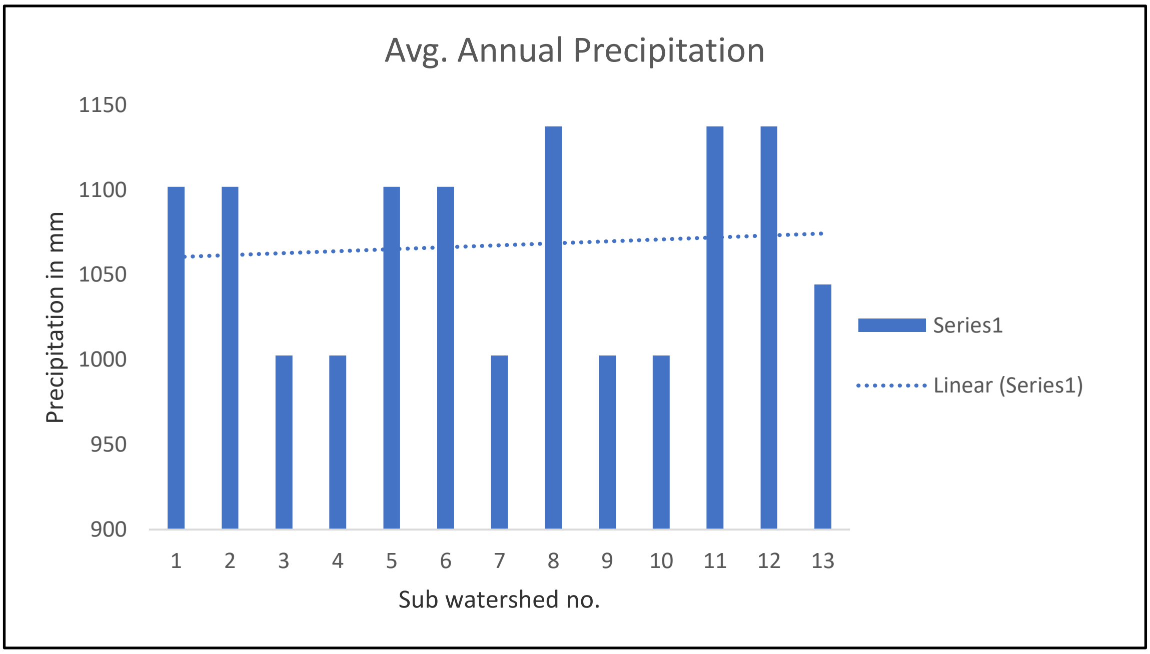

Fig. 5. 15 Rainfall distribution over sub-basins

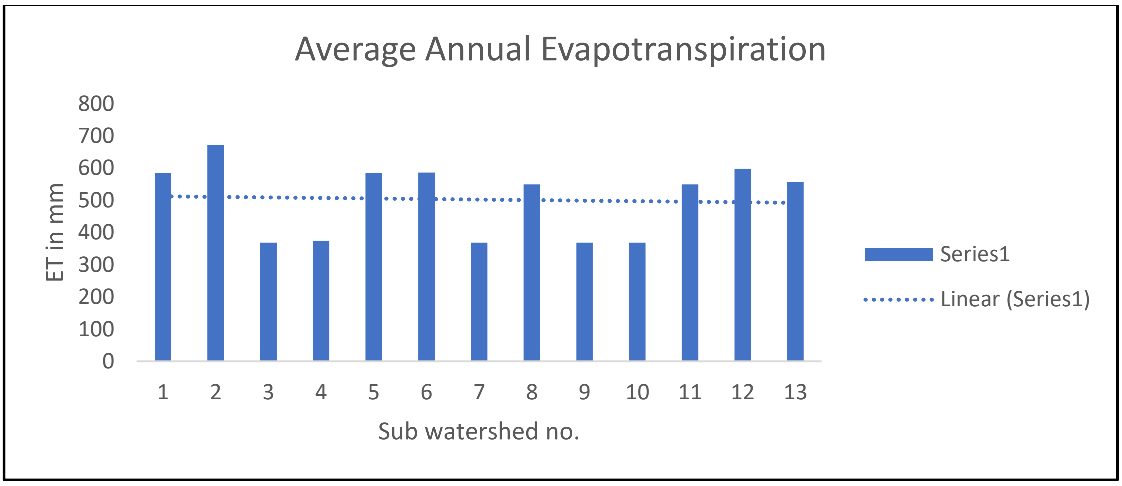

Fig. 5. 16 Evapotranspiration distribution over sub basins

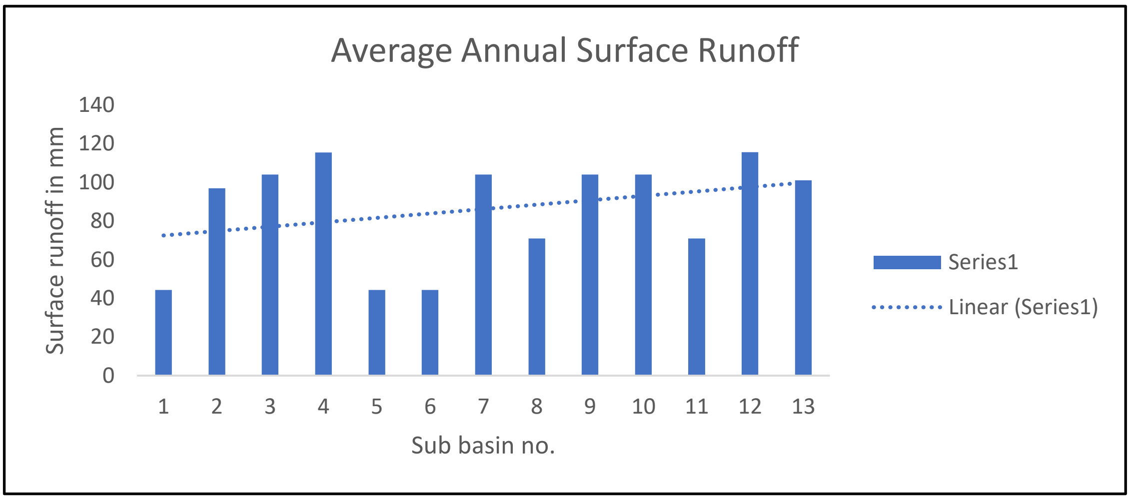

Fig. 5. 17 Surface runoff distribution over sub basins

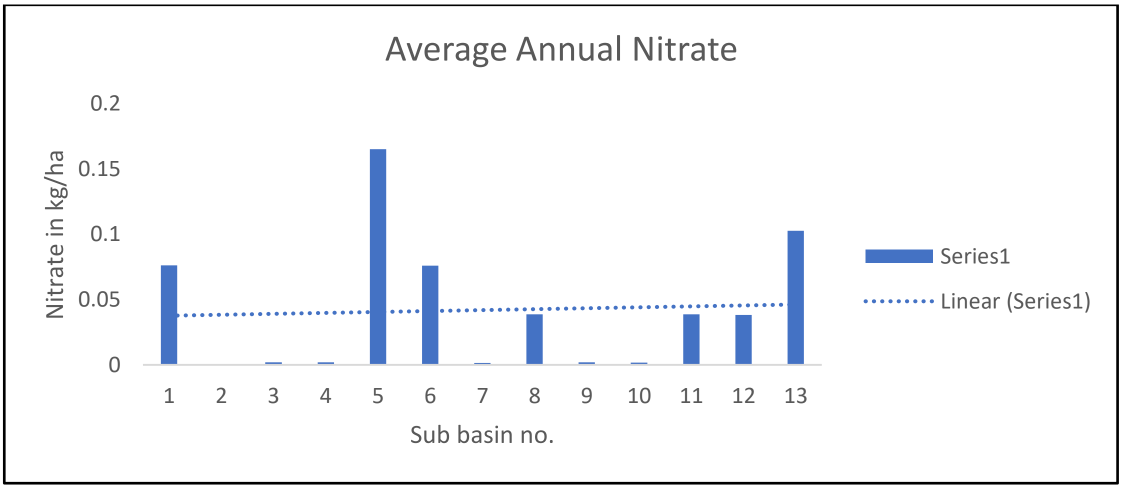

Fig. 5. 18 Nitrate distribution over sub basins

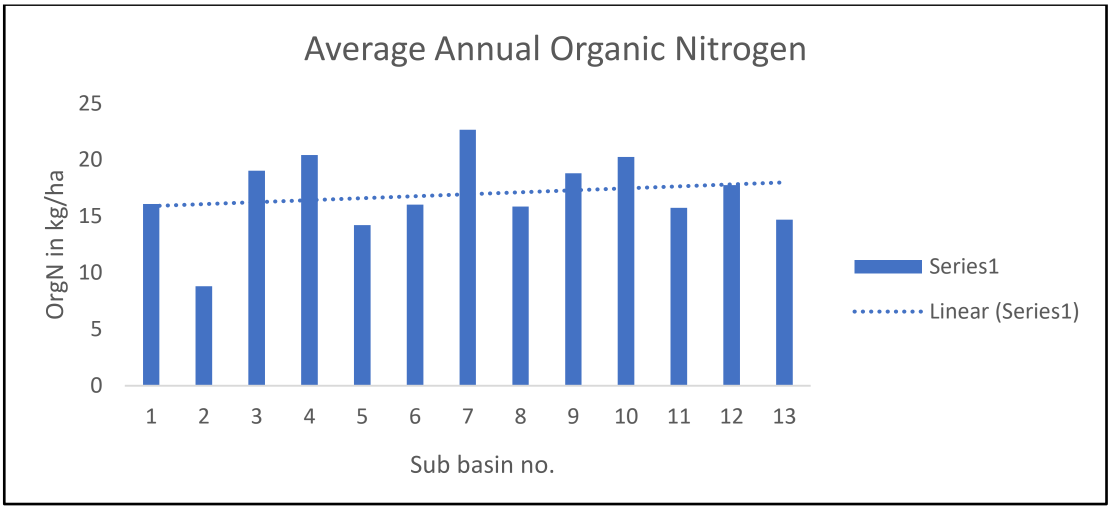

Fig. 5. 19 Organic nitrogen distribution over sub basins

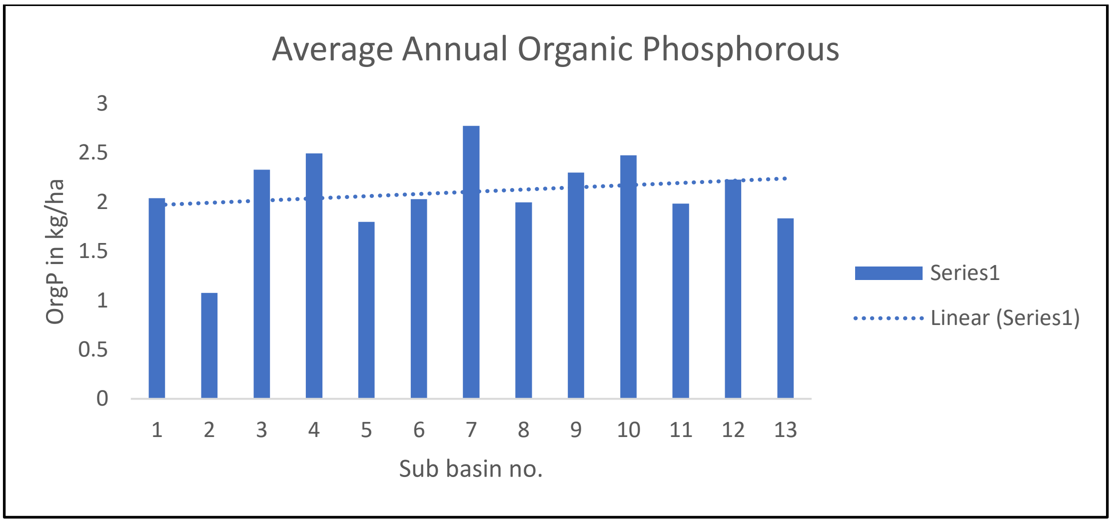

Fig. 5. 20 Organic nitrogen distribution over sub basins

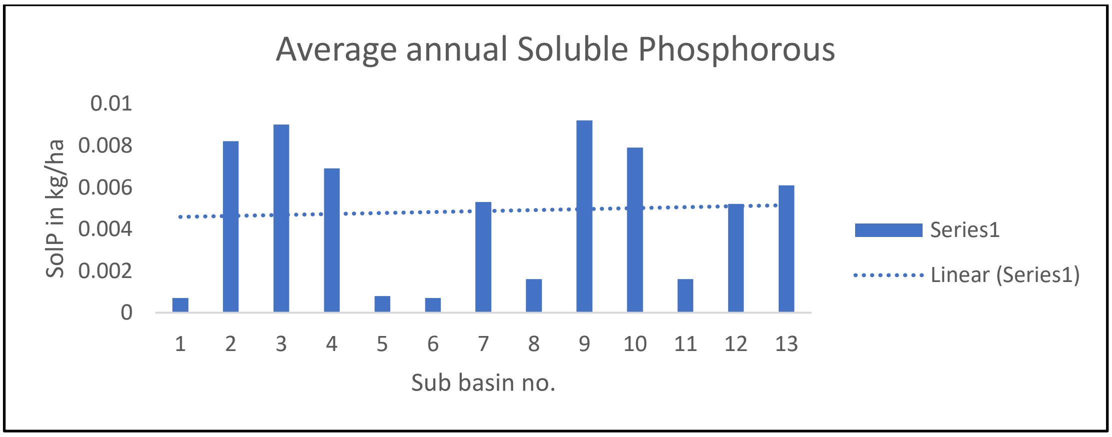

Fig. 5. 21 Soluble Phosphorous distribution over sub basins

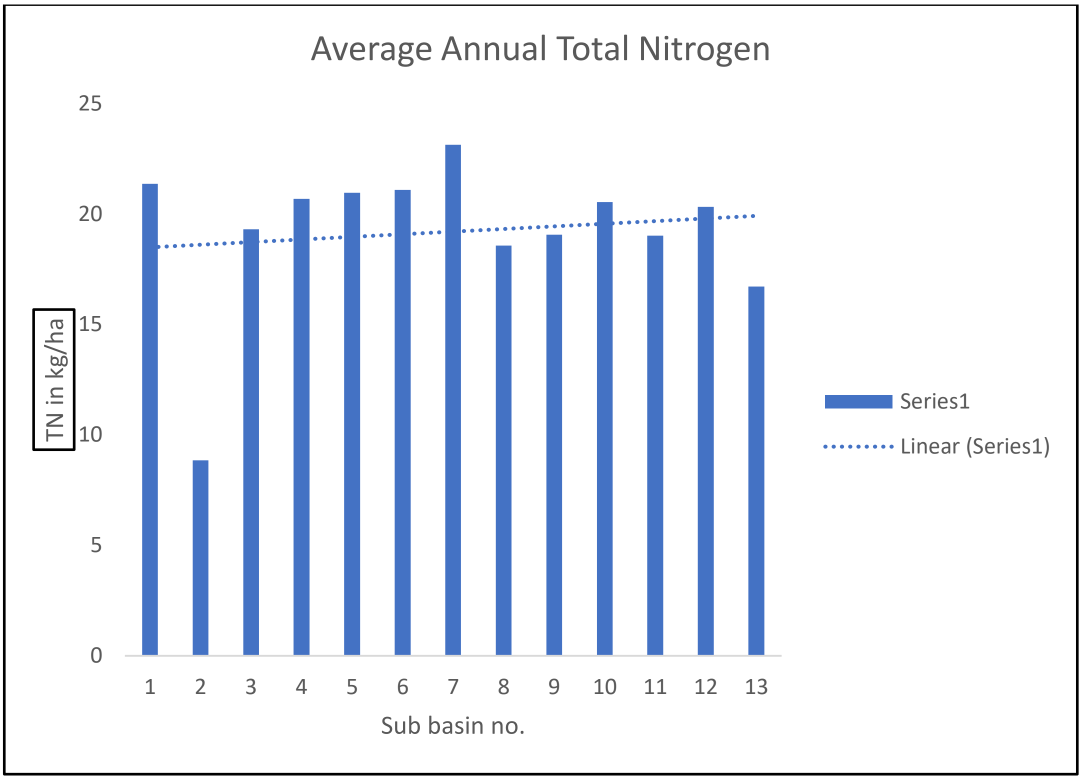

Fig. 5. 22 Total Nitrogen distribution over sub basins

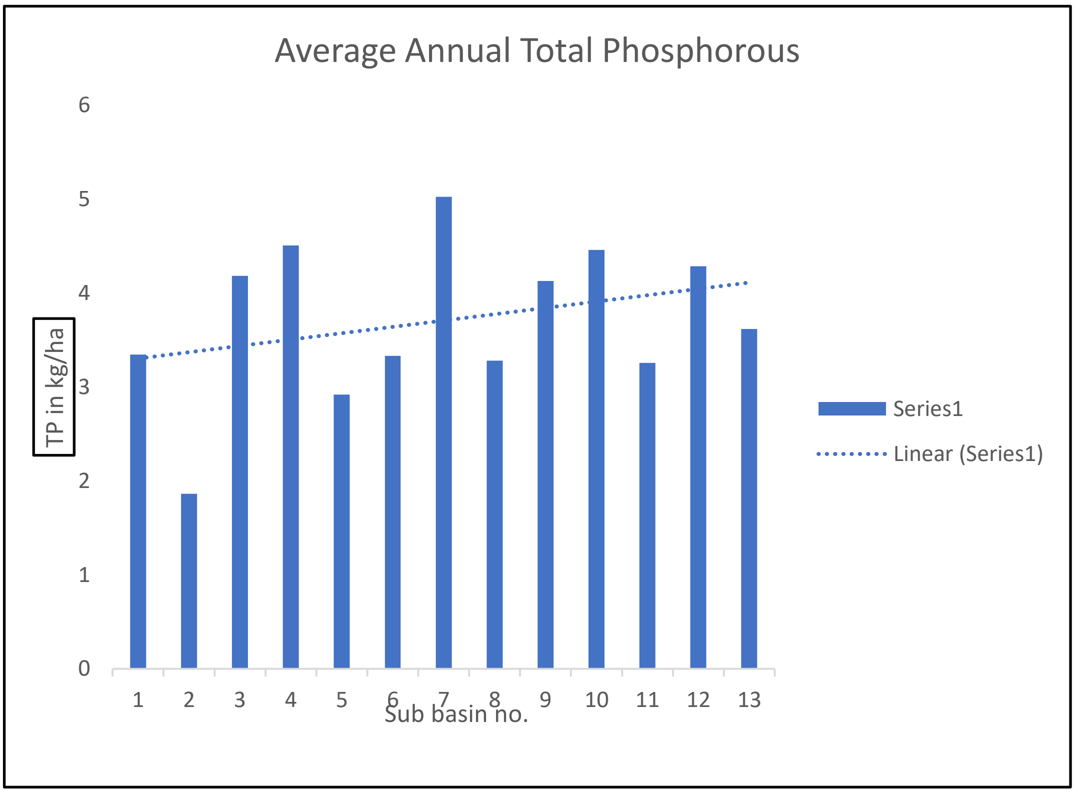

Fig. 5. 23 Total Phosphorous distribution over sub basins

5.8.4 Hydrological Modeling Summary

After completing the model run successfully, the results are summarized as Outputs of hydrological and Water quality parameters after calibration and validation. Table 5.6 gives Outputs of hydrological and Water quality parameters.

Table 5. 6 Outputs of hydrological and Water quality parameters

Year	PREC mm	SURQ mm	ET mm	NO3_SURQ Kg/ha	N_ORG Kg/ha	P_ORG Kg/ha	P_SOL Kg/ha	TN Kg/ha	TP Kg/ha
2002	778.61	52.44	373.11	0.0083	18.28	2.25	0.0048	14.45	2.99
2003	1240.82	82.42	573.72	0.0059	23.84	2.93	0.0083	12.51	2.05
2004	648.30	9.28	410.03	0.0162	1.92	0.24	0.0015	5.23	0.89
2005	706.03	8.20	443.05	0.0036	1.73	0.21	0.0012	2.59	0.32
2006	997.15	29.81	535.28	0.0026	8.28	1.01	0.0038	4.36	0.81
2007	1214.84	144.66	530.83	0.0984	44.21	5.45	0.0105	22.50	5.19
2008	1156.85	138.64	527.21	0.1130	27.14	3.34	0.0100	38.74	8.41
2009	823.50	55.31	357.40	0.1220	12.69	1.58	0.0034	29.93	6.61
2010	914.49	26.62	549.58	0.0028	5.53	0.68	0.0020	2.58	0.36
2011	1930.53	287.63	578.03	0.1713	76.89	9.52	0.0143	84.08	19.49
2012	1211.71	93.28	539.20	0.0051	13.73	1.71	0.0030	2.72	0.28
2013	1931.46	271.93	647.19	0.0300	21.83	2.73	0.0084	25.66	5.83
2014	1119.43	236.10	371.84	0.1671	27.48	3.49	0.0062	31.62	7.21
2015	602.58	42.50	318.57	0.0319	2.86	0.37	0.0016	6.56	1.34
2016	633.23	13.86	363.08	0.0003	2.15	0.27	0.0007	1.58	0.16
2017	896.03	86.15	435.08	0.0022	17.65	2.19	0.0045	7.45	1.53
2018	464.68	2.22	330.88	0.0009	0.23	0.03	0.0002	1.25	0.18
2019	916.51	25.28	530.60	0.0048	3.97	0.50	0.0016	3.17	0.66
2020	986.93	18.58	558.75	0.0024	2.97	0.37	0.0016	3.91	0.80

As per the results of the model simulation, it highlights some important points for the analysis which has been shown as below.

- Soil contains a large amount of organic nitrogen in the form of organic matter.

- Large changes in initial and final nitrogen contents (organic N) may indicate under or over fertilization during the simulation.
- Crop is consuming less than half the amount of applied N.
- Large increases in mineral phosphorus content during the simulation often result from overfertilization with either commercial or manure phosphorus sources. This also means that phosphorus concentrations in runoff also increased during the simulation period.
- Total nitrogen losses are greater than 40% of applied Nitrogen.
- Nitrate losses in surface runoff may be low.
- Soluble phosphorus losses in surface runoff may be low.
- Solubility ratio for nitrogen in runoff is low.
- Solubility ratio for phosphorus in runoff is low, may indicate a problem.
- Nitrate leaching is more than 38% of the applied fertilizer, may indicate a problem.

CHAPTER - 6

OPERATIONALIZATION OF FRAMEWORK

6.1 Scenario Building for Decision Making

Making decisions involves choosing the best course of action from a variety of options. To find a solution for a specific issue, it involves choosing a course of action from among two or more feasible alternatives. In other words, decision-making is the study of locating and selecting options in accordance with the decision-maker's values and preferences. The decision-making process eliminates uncertainty and confusion regarding options to enable rational selection among them. So, choosing a plan of action from among numerous potential outcomes is a mental process of decision making. The main objective of this study is to find out the best scenario for Hathmati watershed based on water quality framework. This is very innovative concept for local as well as global level. Success of this concept can be implemented for other watersheds and to other sectors also. A defined technical sustainability means reliable and correct functioning of the technology and water of an acceptable quality is used to analyze the current water quality. Requirements for technical sustainability includes technically good planning which is adhered to in choosing suitable scenario. Two scenarios are suggested once the issues with the current nutrient water quality have been identified for the current situation. One is based on various watershed-level interventions, such as crop rotation and change in land use land cover. The second one includes proposing a scenario involving climate change predictions for the future. A combination of above two scenarios has been also involved in this study.

6.2 Scenario I: Baseline Scenario

The baseline scenario (do-nothing-scenario) describes the watershed's status. It's primary goal is to pinpoint the current issues with the watershed's nutrient water quality. To evaluate the technical sustainability identified, the suggested technical sustainability assessment approach is applied to a water quality framework utilizing the present nutrient water quality. When the values for nutrient water quality are compared with the standards, if the parameters come within the range of the criteria, it is considered a good situation; otherwise, different scenarios are suggested to improve the sustainability circumstances in this zone.

6.3 Scenario II: Various Interventions at watershed level

Once the model has been calibrated and validated, it can be rated as being able to simulate the results under various scenarios. In this study, crop rotation and changes in land use and land cover were chosen as interventions to assess their effects on streamflow and water quality at watershed sizes. Our aim of applying various interventions at watershed level includes reducing the amount of fertilizer used by applying only the amount a crop requires as a part of nutrient management. It entails controlling the quantity, type, application techniques, and timing of nutrients (whether they come from animal waste, synthetic fertilizers, or other sources). As nutrient loss is kept to a minimum, nutrient management is economical. Additionally, it is among the greatest methods for lowering nonpoint source nutrient contamination.

6.3.1 Crop Rotation

Farmers have been using crop rotation as a farming technique since the first century BC. Crop rotation is the deliberate planting of various crop varieties in various fields and at various seasons successively. It also involves deciding not to plant anything at all during a specific season and letting the ground rest until the next one. Contrary to monocropping or random succession, crop rotation entails planting a variety of plants on the same piece of ground in a specific order. In basic rotations, there may be two or three plants, while in complex ones, there may be twelve or more than it.

Crop rotation cycles can last up to eight years on an average. Crop rotation is the best incorporated after careful preparation of land and water requirement. It is essential to keep plants separated by family since it is not advisable to cultivate the same or closely related plants in close succession. It may also be useful to classify plants into subgroups according to their physical qualities, growth patterns, harvest seasons, and other factors, as well as their cultural and management requirements. When possible, modifications to a short-rotation system should be undertaken, such as moving to a different plant or adding green manure. The most well-known methods you can currently employ to successfully perform crop rotation are as follows:

- By plant family, revolving: This method, which is most frequently used, entails planting various plant families in a field in a seasonal, orderly pattern, frequently over the period of four years.
- Rotate based on gathered plant parts: During this cycle, it is customary to alternate between gathering roots, fruits, leaves, and legumes. The method incorporates several essential ideas even if it just uses harvested plant pieces. Legumes are frequently planted as restorative plants, together with plants from a variety of families and rooting depths.
- Rotate according to plant compatibility: Planning a rotation cycle requires considering which plants work best together. Sweet corn is strongly advised as a pre-potato plant due to its significantly good impact on potato productivity, as demonstrated by this crop rotation example.
- Rotate based on nutrient needs: This strategy often involves planting legumes first, followed the following year by heavy feeders like tomatoes or maize.
- Rotate according to roots depth and kind: With this method, you must alternately cultivate crops with shallow and deep roots on the same plot, such beets and cauliflower.
- Cover plants: Unused nitrogen from the maize or soybeans that came before will be utilized by a grass or little grain planted in the autumn.

The type of rotation will depend on how many different plants you decide to grow. You can either divide the field into zones or cultivate various plants in each zone, or you can grow a new plant in the same field every season. Let's think about the most common 1 to 3 year time intervals.

Change the current crop patterns season wise and run SWAT model on seasonal basis. (Cotton, castor, maize, groundnut, and pigeon pea are the main kharif crops and wheat, maize, mustard, and vegetables are the main Rabi crops). Crop rotation has been done by having yearly rotation of corn and winter wheat and outputs have been compared with base line scenario. It has been taken as an example based only. We can apply any other recommended crop rotation in the SWAT model for simulation and check the results in the form of nutrient losses from it before applied at watershed level. For applying crop rotation in baseline scenario operations management menu in .mgt file was used as per below shown table 6.1. Corn and winter crop (wheat) have been chosen hypothetically and same management (on 1st June, Harvesting and land preparation has been done, on 15th June corn seed germinated then applied water and fertilizers successively on 30th June and 15th July then finally crop has been harvested, again on 15th October winter crop has been germinated, on 30th October fertilizer applied) to enter just 1 year. It will continue throughout simulation period automatically.

Table 6. 1 Applying Crop Rotation

Year	Month	Day	Operation	Crop
1	6	1	Harvest and kill	
1	6	15	Plant/ Begin	Corn
1	6	30	Irrigation	
1	7	15	Fertilization	
1	9	30	Harvest and kill	
1	10	15	Plant/ Begin	Winter
1	10	30	Fertilization	

6.3.2 Change in Land use Land cover

Trees aid in the infiltration of rainwater into the soil by generating a network of interconnected, minute channels in the soil through the action of their living and decaying roots. Rainwater penetrates the soil with these conduits hundreds of times more quickly than it does the soil without them. Rainwater can be absorbed better on ground with vegetation. This lessens the amount of water that flows over the surface following a rain event, which lessens the amount of water that enters rivers and streams. After 25 years of forest growth, computational models indicate that reforestation in 20–35% of the river's watershed will result in a 10-15% reduction in flood peak heights (N. R. Gangadharappa et al.). Because most of the rainwater enters streams and rivers in a very brief period when trees are removed, floods frequently get worse. Such high-intensity flow is frequently unusable by people and typically flows into the ocean, along with causing soil erosion and nutrient loss in the soil. The removal of trees is what causes vast tracts of formerly fertile land where annual precipitation is relatively high to turn into desert. According to the study's goals, the analysis of hydrological parameters must take land cover into account. Even if the forest contributes the majority of the land cover, increasing the amount of vegetation could change the situations favorably. For Land use cover change in this study, 1 km buffer of dense forest land use has been considered on both the sides of Hathmati river and compared all the results with baseline scenario. LULC map has been changed by having buffer zone of 1 km dense forest to both the sides of Hathmati river having length of nearly 78 km and model has been simulated. Fig. 6.1 shows a new Land use Land cover map (year 2021) with 1 km of buffer zone of dense forest at both sides of Hathmati river.

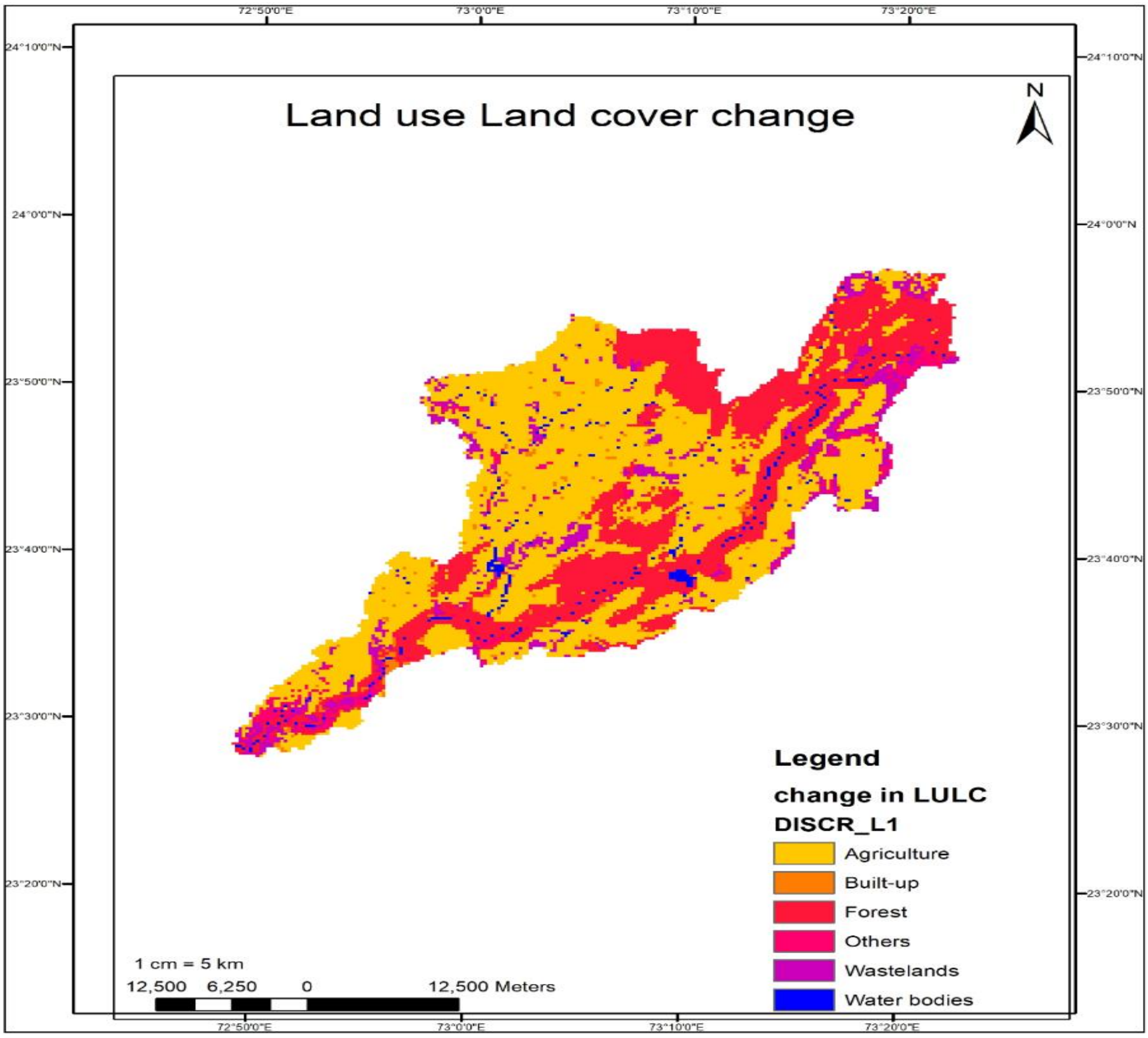

Fig. 6. 1 A new Land use Land cover map

For scenario 2, change in Land use Land cover map, dense forest has been increased by 12.3% and agricultural land has been decreased by 12.3% approximately. Table 6.2 shows comparison of new Land use classes with original one.

Table 6. 2 Comparison of Land use classes

	With Forest cover change %	**Original %**
Forest	30.51	18.22
Water bodies	2.09	2.09
Wastelands	7.59	7.59
Agriculture	55.01	67.30
Built-up	1.45	1.45
Others	3.35	3.35

6.4 Scenario III: Impact Assessment and Future Trends

As climate change will interact with future changes in local agricultural and urban land use to influence future nutrient loading to waterbodies (Tong et al. 2012; Ficklin et al. 2013). The model can be used to forecast outputs in the form of hydrological parameters for various meteorological conditions soon.

The scenarios outlined by the IPCC are included in this analysis, and they call for significant adjustments to be made to the weather data and 2055 estimates. The model's future projections are used as input data for hydrological and nutrient water quality analysis. Watershed models are often used to simulate the impact of future climate conditions on hydrologic processes. However, Teutschbein and Seibert (2012) state that simulations of temperature and precipitation often show significant biases due to systematic model errors or discretization and spatial averaging within grid cells, which hampers the use of simulated climate data as direct input data for hydrological models.

Bias correction procedures are used to minimize the discrepancy between observed and simulated climate variables on a daily time step so that hydrological simulations driven by corrected simulated climate data match simulations using observed climate data reasonably well. In this study the coupled model interpretation program (CMIP-5) has been used for generating forecasting scenarios (Dibesh Khadka, Mukand S. Babel, Abayomi A. Abatan, Matthew Collins).

The program utilized for this assignment is called CMhyd (Climate Model data for hydrologic modelling), and it is open source. A tool called CMhyd is available for extracting and bias-correcting (downscaling) data from regional and global climate models. The selection of model is done as per the recommendations of (j. atmosres.2019). The model is chosen in accordance with the suggestions made by (Jena P. et al. 2015).

Daily maximum temperatures from the CMIP5 climate model historical simulations and projections based on the Representative Concentration Pathways (RCP 4.5) scenario (Taylor et al. 2012) were used to evaluate the current and future climate change scenarios. Under RCP 4.5 the world's average temperature would rise by 2˚ -3˚ Celsius by 2100. Data has been obtained from Climate Data Store, Copernicus which is the European Union's Earth observation program. https://cds.climate.copernicus.eu. Future projections based on this model using Representative Concentration Pathways (RCP 4.5) scenario for nearly 47 years (2009-2055) has been set. Incorporated the data of temperature and rainfall in the model and extract the outputs for hydrological as well as water quality parameters.

This simulation's entire process can be summed up as;

1. Find the existing anomalies between observed data and modelled data (CMIP5).
2. Do bias correction using CMhyd tool to minimize anomalies for selected models.
3. Select the model showing the best fit or minimum anomalies.
4. Do the future projections based on this model using Representative Concentration Pathways (RCP4.5) scenario.
5. Incorporate the data of temperature and rainfall in the model and extract the outputs for runoff and evapotranspiration.

A thorough literature review is conducted before choosing the models. Two models, CCSM4 latitude and longitude (1.25 × 0.9424) from National Center for Atmospheric Research, U.S.A and CESM1-CAM5 latitude and longitude (1.25 × 0.9424), Community Earth System Model Contributors, NCAR USA, are chosen from the wide literature review on the CMIP5 models to process the bias correction. CCSM4 model is chosen as its RMSE is coming as 0.74. Precipitation and temperature projections up to 2055 were made using the RCP 4.5 project. These data are incorporated into SWAT (which has already been calibrated), and the results are obtained as hydrological and nutritional water quality. After getting considerable results for baseline scenario, data for precipitation and temperature has been used for predictions for other scenarios. So, ultimately in this study, baseline scenario, crop rotation, and land use land cover scenarios were generated and their combinations with climate change future prediction scenarios has been successfully carried out. Fig. 6.2 demonstrates future prediction of precipitation which was taken for the duration 2009-2055 and for the initial years of 2002-2020 observed data of precipitation has been shown for validating the precipitation data.

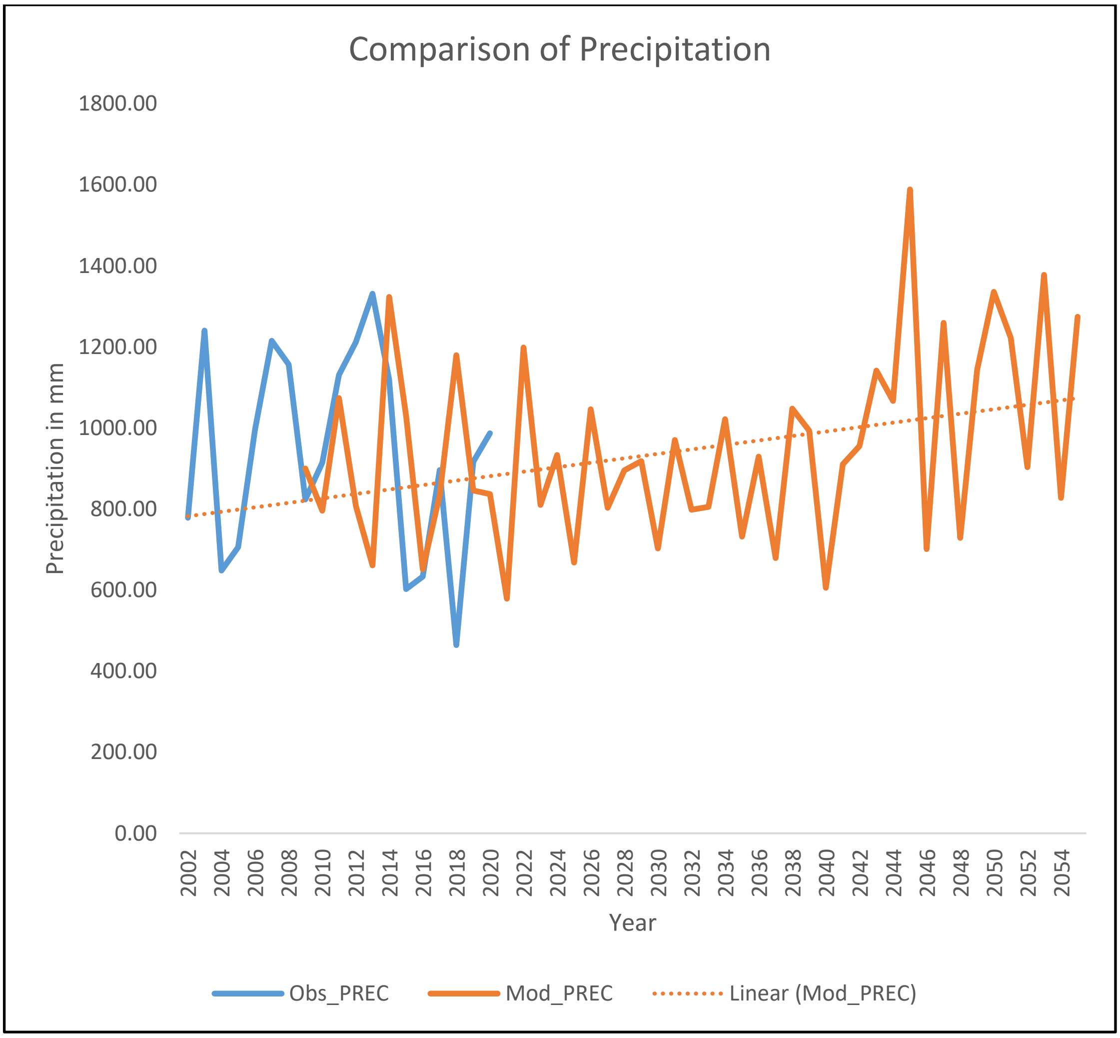

Fig. 6. 2 Projected values of precipitation

Fig. 6.3 demonstrates future prediction of maximum temperature which was taken for the duration 2009-2055 and for the initial years of 2002-2020 observed data of maximum temperature has been shown for validating the data.

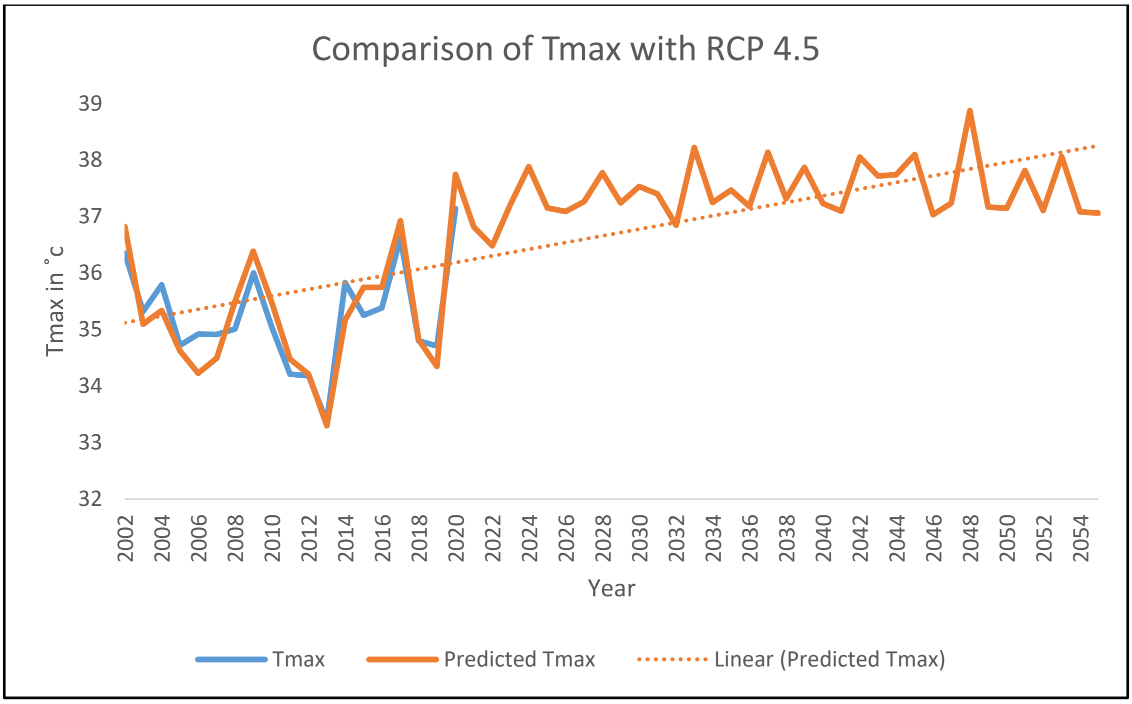

Fig. 6. 3 Projected values of maximum temperature

Fig. 6.4 demonstrates future prediction of minimum temperature which was taken for the duration 2009-2055 and for the initial years of 2002-2020 observed data of minimum temperature has been shown for validating the data.

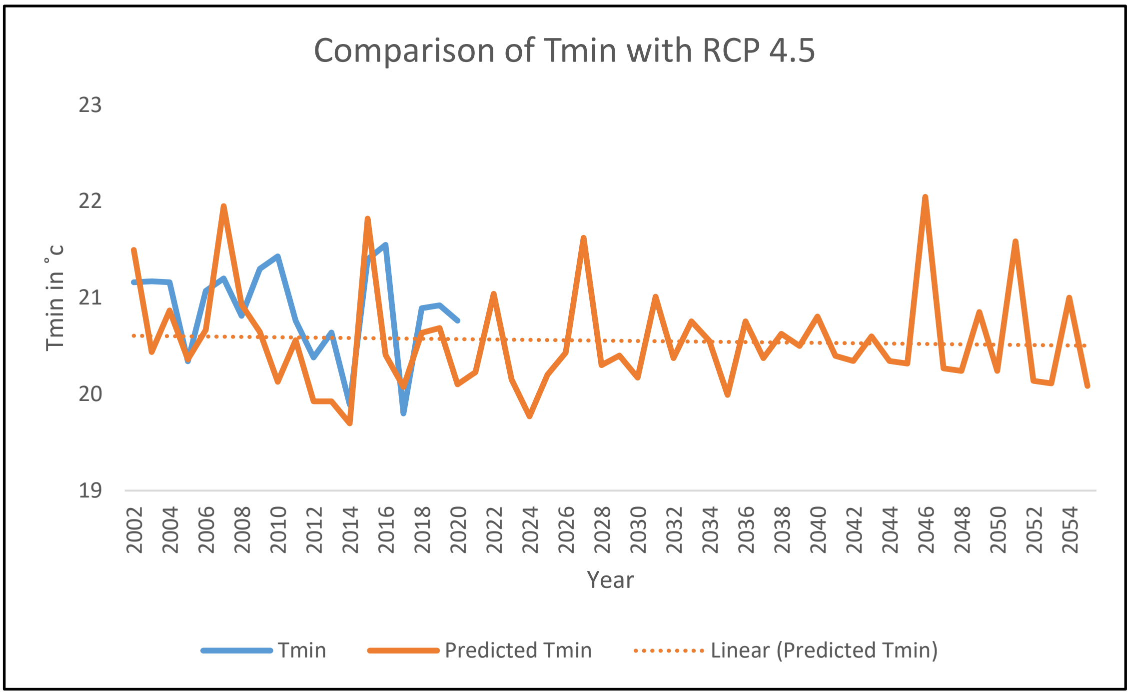

Fig. 6. 4 Projected values of minimum temperature

6.5 Operational Water Quality Framework

Developing effective means of managing water quality operationally is now both desirable and necessary, particularly for water resource systems that are used intensively. The Water Quality Framework is a new way of thinking about how water quality data and information systems can be better integrated to more effectively support water quality decision makers and better inform the public. The Framework will streamline water quality assessment and reporting, eliminate paper reporting and provide a more complete picture of the nation's water quality. A water quality framework is needed to generate information on the nature and extent of the nonpoint pollution. The Water Quality Framework offers a fresh perspective on how the water quality data and remote sensing data might be better integrated to support decision-makers more efficiently and better to inform the public about the water quality. Developing effective means of managing water quality operationally is now both desirable and necessary, particularly for water resource systems that are used intensively. This framework provides a preventive, approach to managing water quality.

The watershed's surface water quality management frameworks establish specific goals and take into account how all the interventions in the watershed may affect the water quality. Here, the framework for the water quality is made up of the monitoring system and the measures to stop the rising nutrient concentrations in watersheds.

To optimize the water quality knowledge and enhance decision-making processes in support of the framework goals, SWAT modeling is being developed and maintained to support the impacts of management scenarios (crop rotation and land cover change). The study used rainfall variability, crop rotation, and land use analyses to examine the effects of climate change on the water quality because both climatic and non-climatic elements affect the watershed system.

Future climate change forecasts indicate an intensification of annual rainfall events, which will lead to an increase in water contamination and additional declines in water quality. The simulation of the generated scenarios demonstrates the significant outcomes in relation to the impact of climate change on hydrological and nutrient water quality parameters. The framework for assessing and mitigating the effects of various interventions and climate change is provided by the current work. Figure 6.2, Water Quality Framework is divided mainly into eight stages, which are described below;

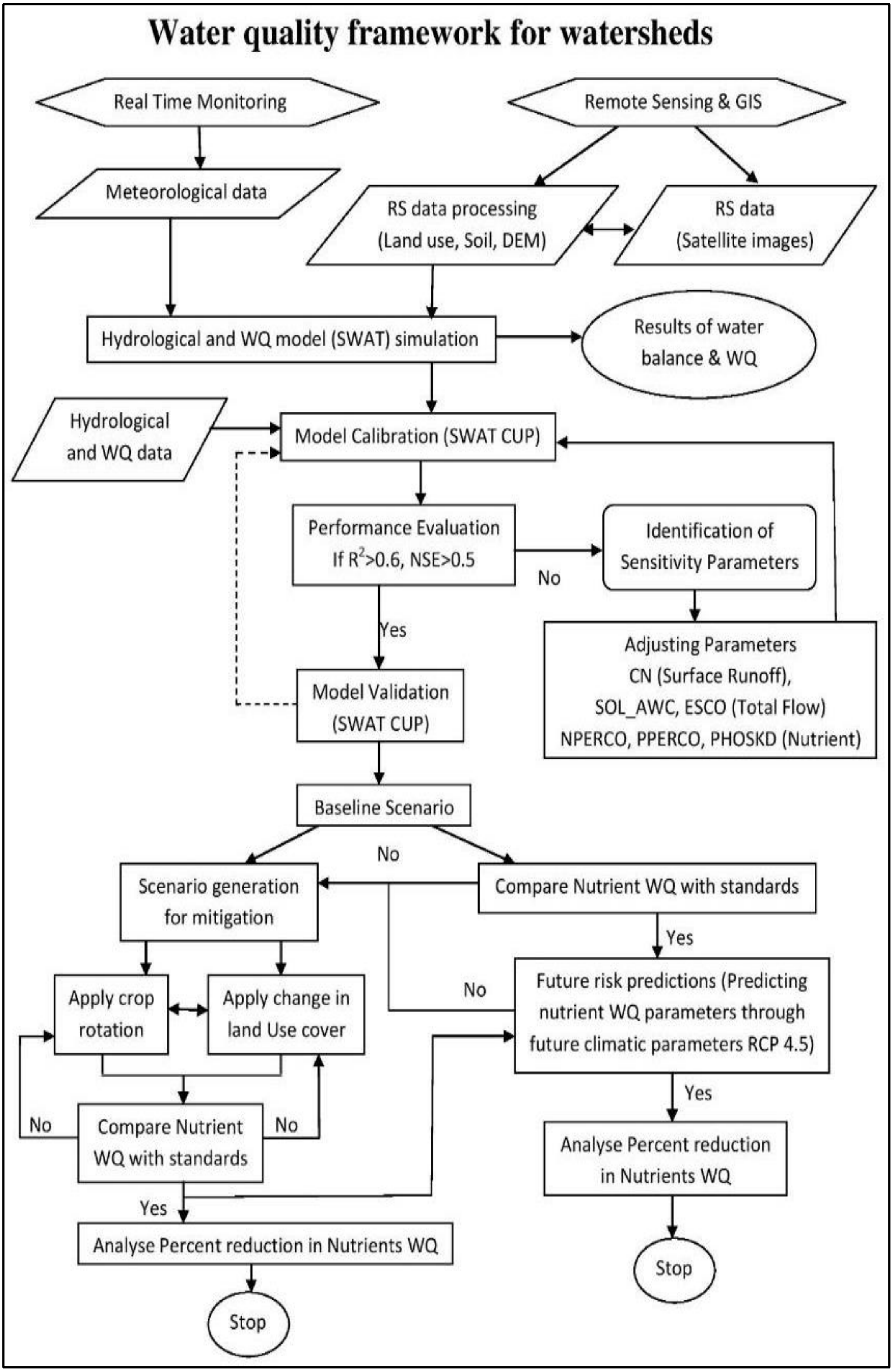

Fig. 6. 5 Water Quality Framework

1. **Watershed Selection with datasets:** The research process begins with the choice of the study area (case study) to serve the goals and illustrate the framework (strategy). based on previous studies and problems influence on the watershed, the study region that appears to be more susceptible can be identified, followed by collecting and analysis of relevant information. Maps and statistical formats would be used to represent the spatial and temporal data in the dataset. Governmental agencies like data centers and space organizations can help with this. To be more precise, the spatial data needed for the study would include a digital elevation model (DEM) of the tributaries, a land use/landcover map, a soil map, a map of weather stations, etc., while the temporal data would include weather information like rainfall, temperature, humidity, solar radiation, and wind speed. Through analysis, these data are then used to gain a better understanding of the watershed's susceptibility.

2. **Verification of vulnerability through data analysis:** In this section of the framework, the temporal data gathered/compiled from stage 1 is examined. This is accomplished by doing analysis on the climatic data, specifically the rainfall, temperature, and water quality data, specifically the parameters related to nutrient water quality. According to IPCC, the two most crucial climatic variables to consider when determining how climate change may affect water quality and hydrological parameters are temperature and rainfall.

3. **Simulation modelling:** After the statistical analysis, the hydrological model is built using spatial data such as maps and collaterals to calculate the values of the watershed's hydrological parameters. There are a variety of hydrological models that can be used for this; however, it is advised to choose distributed or semi-distributed models that can vary in space and/or time. The model employed in this study is SWAT (soil and water assessment tool), which is a semi-distributed model that permits spatial variation in the data. The choice of model is also influenced by a review of prior studies in the relevant subject, which have demonstrated that the model produces outcomes that are essentially positive. The model serves as a GIS interface for the study, which uses ArcGIS. Prior to running the simulation, the model is first calibrated and validated by comparing the findings with the actual value of the outputs.

4. **Watershed hydrological outputs for an existing watershed:** The goal of modelling is to ascertain the watershed's hydrological characteristics using a calibrated (and

validated) model. In the same manner as in stages 2 and 3, analysis is carried out on the hydrological outputs, such as evapotranspiration and runoff, and water quality outputs, such as Nitrate, Organic Nitrogen, and Organic Phosphorous etc. for all years. The importance of hydrological characteristics plays a role in determining the near-term effects of climate change. This study can be used to predict what might happen if the current trend continues in the near future.

5. **Applying various scenarios to the tested model during simulation:** The model can be graded as being able to mimic the outcomes under various scenarios once it has been calibrated and validated. To be more precise, the model can be used to predict future hydrological and nutritional water quality parameters under a variety of climatic conditions. This analysis incorporates the IPCC's proposed scenarios, which call for significant adjustments to meteorological data and projections out to 2050.

6. **Results of scenarios' hydrological outputs:** A summary of the model's outputs, which take the form of hydrological parameters and water quality parameters, is done together. The anticipated value of hydrological and nutrient water quality parameters, are two major outputs provided by this module. These findings facilitate a comparison of the actual and projected values.

7. **Comparing results with standards:** All the results coming for nutrient water quality parameters are compared with standards and if they are coming within the limits its ok otherwise need to change the scenario at this stage.

8. **Mitigation:** After comparing all the results with the standards, we can compare all the results with all different scenarios also. Through each and individual scenario we can find out the percentage reduction in the nutrient water quality parameters. Parallelly, we can also check the best scenario among all through which we can get the maximum reduction in the nutrient water quality parameters.

CHAPTER - 7

RESULTS AND DISCUSSIONS

7.1 Summary and Results

The data that was used for the research and the conclusions are summarized in this chapter. The results are displayed in tables and graphs that were taken from the data analysis and software like SWAT and SWAT-Cup. The first specific objective of research is to create a water quality monitoring framework at watershed level. Input data and information for Hathmati watershed was collected from State Water Data Centre, Gandhinagar and analyzed for input of SWAT modeling.

7.2 Assessment of hydrological parameters

Hydrological and climatic parameters for Hathmati watershed have been collected and analyzed on yearly basis for entering it into SWAT model as an input data. Fig. 7.1, 7.2, 7.3, 7.4 and 7.5 shows average annual data of Precipitation, surface runoff, evapotranspiration, maximum Temperature and minimum temperature successively.

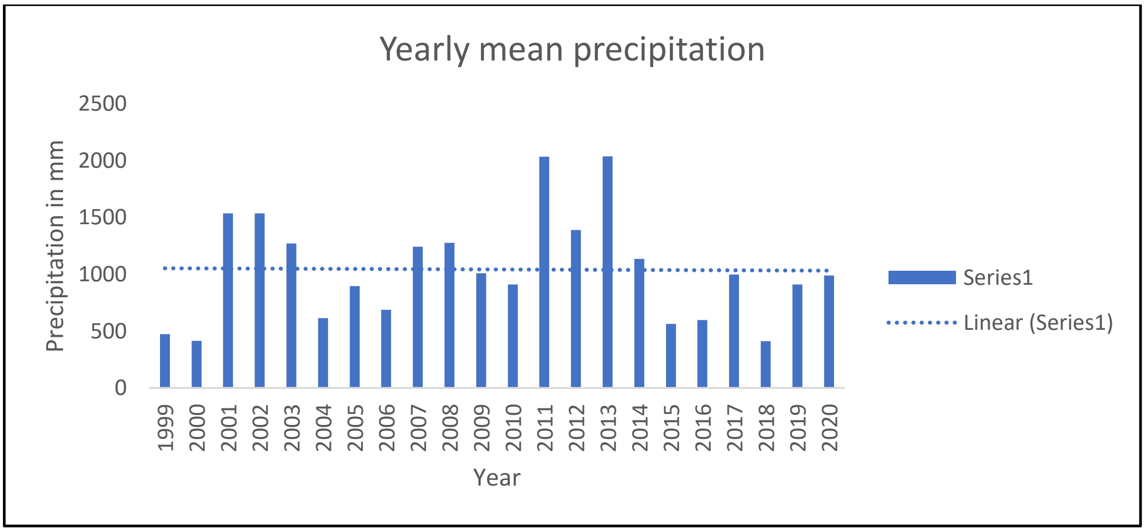

Fig. 7. 1 Average Annual Precipitation in mm

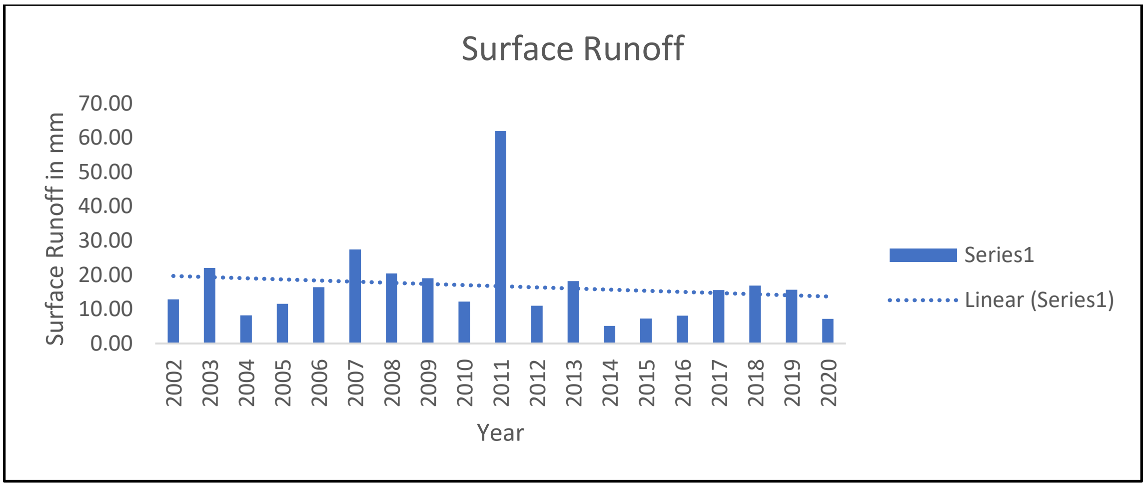

Fig. 7. 2 Average Annual Surface runoff in mm

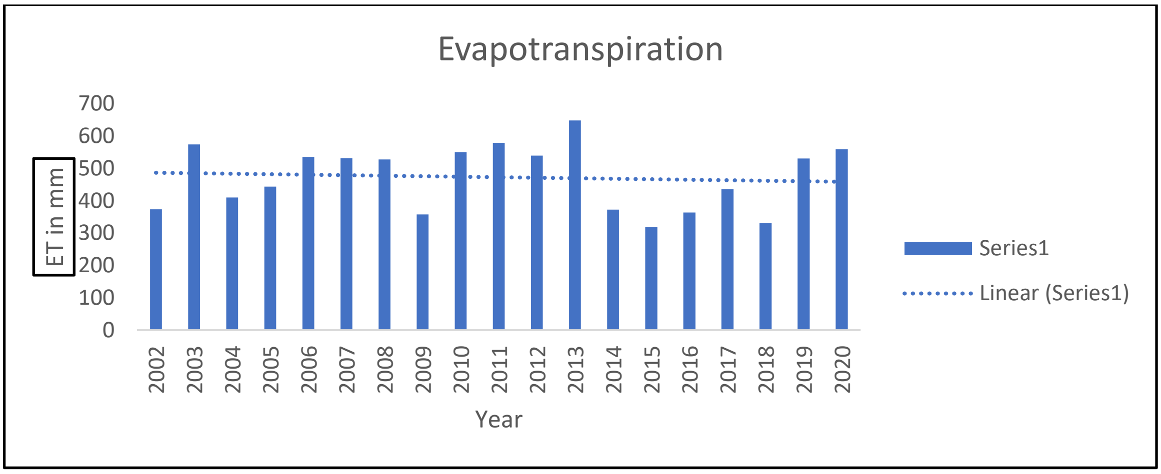

Fig. 7. 3 Average Annual Evapotranspiration in mm

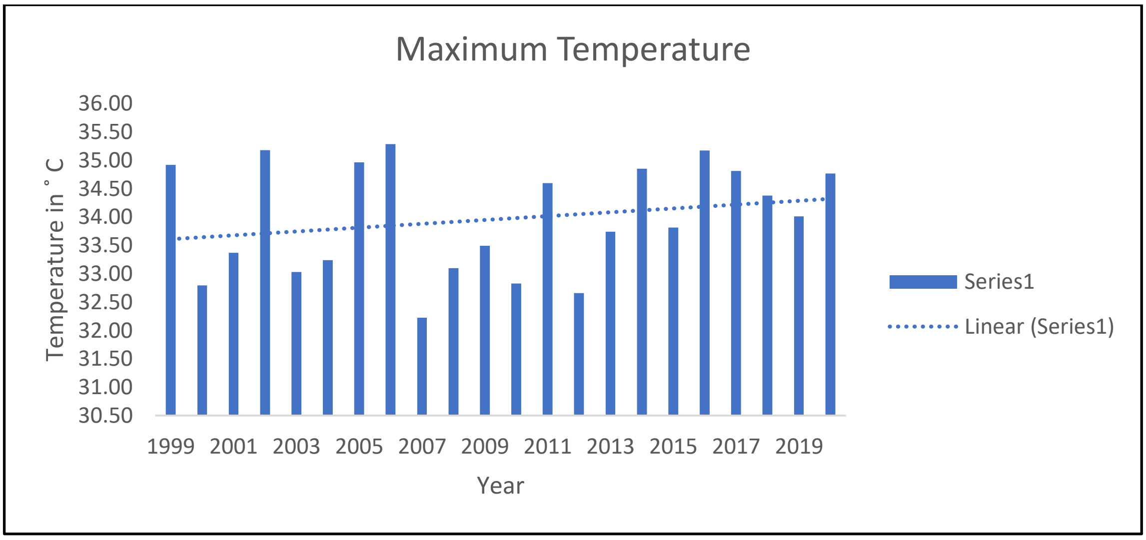

Fig. 7. 4 Average Annual Maximum temperature in ˚C

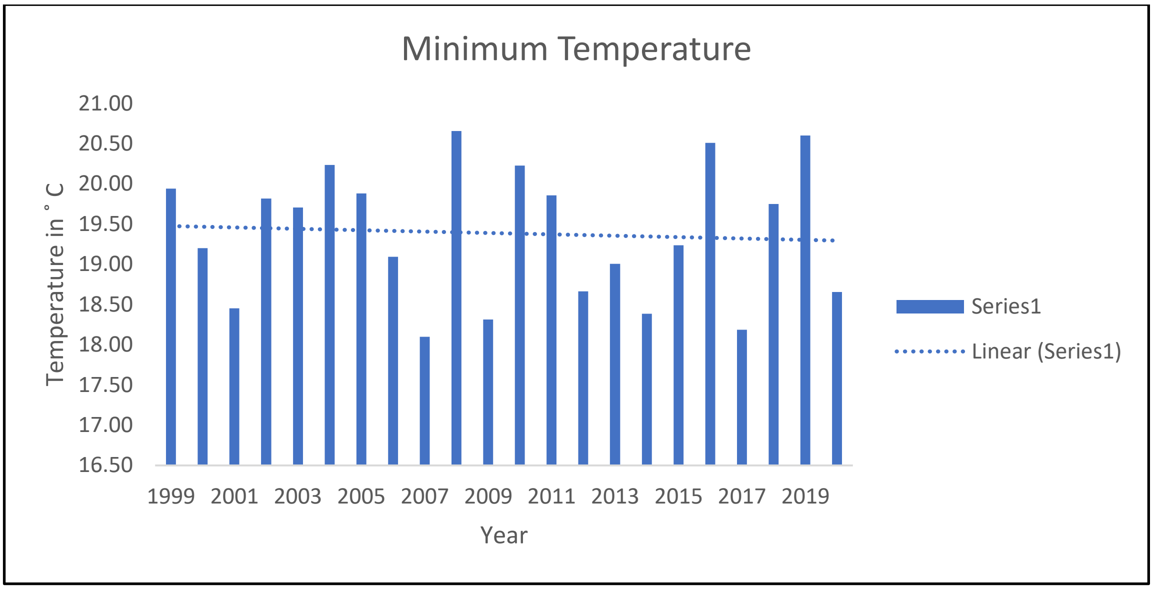

Fig. 7. 5 Average Annual Miniimum temperature in ˚C

7.3 Assessment of Nutrient water quality parameters

Nutrient water quality parameters for Hathmati watershed have been collected from SWDC, Gandhinagar for three locations on daily basis and it has been calculated for yearly basis for SWAT input. These data have been used for calibration and validation for SWAT model also. Fig. 7.6, 7.7, 7.8, 7.9, 7.10 and 7.11 gives brief idea about Average Annual Nitrate, organic nitrogen, organic phosphorous, soluble phosphorous, total nitrogen and total phosphorous for Hathmati watershed.

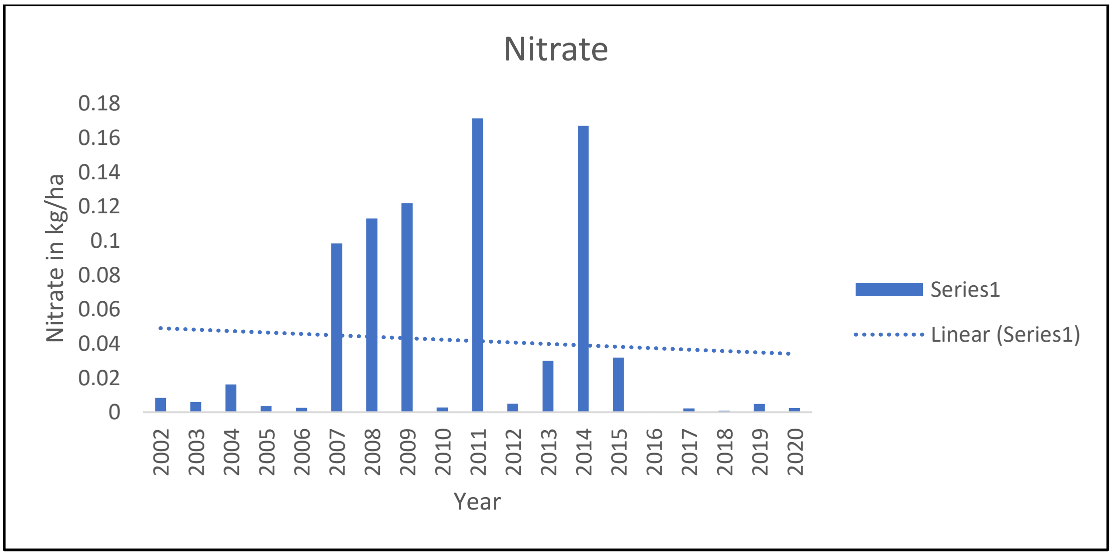

Fig. 7. 6 Average Annual Nitrate

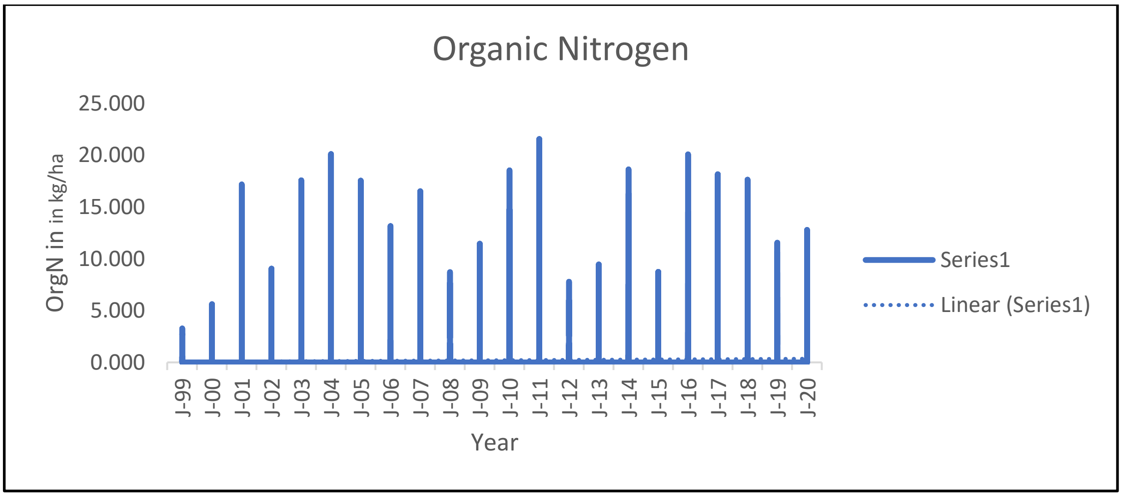

Fig. 7. 7 Average Annual Organic Nitrogen

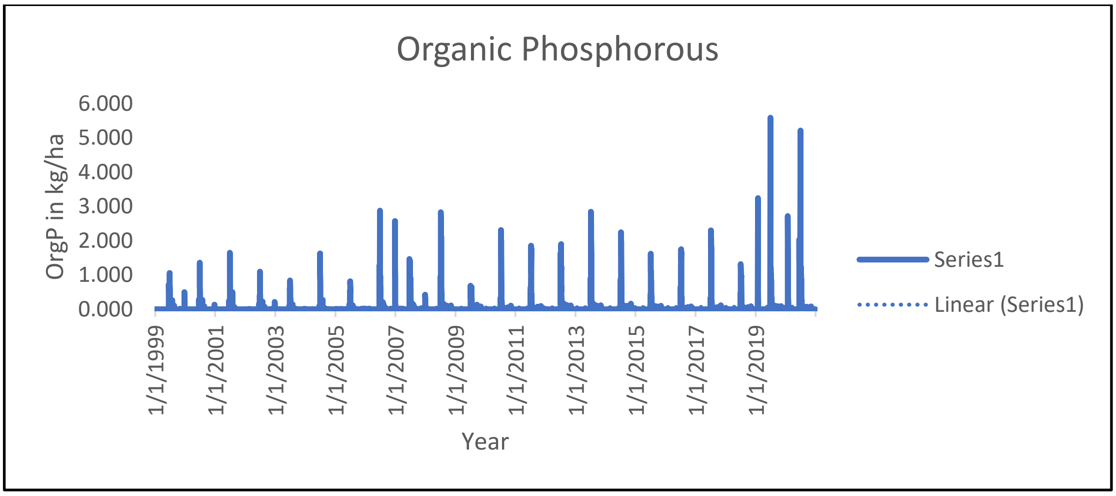

Fig. 7. 8 Average Annual Organic Phosphorous

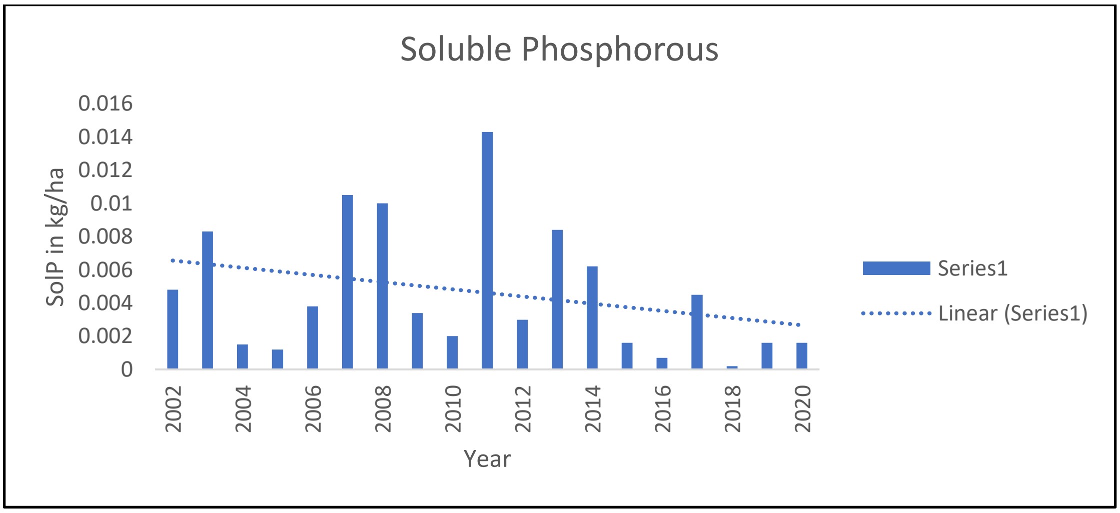

Fig. 7. 9 Average Annual Soluble Phosphorous

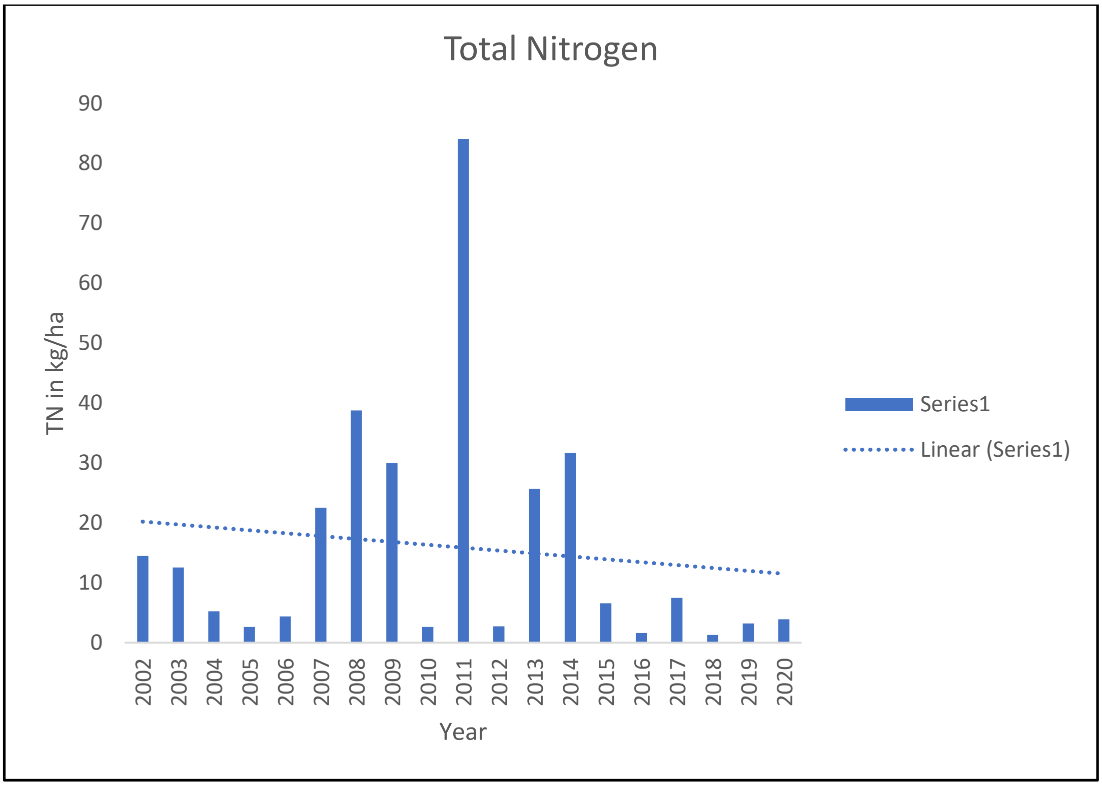

Fig. 7. 10 Average Annual Total Nitrogen

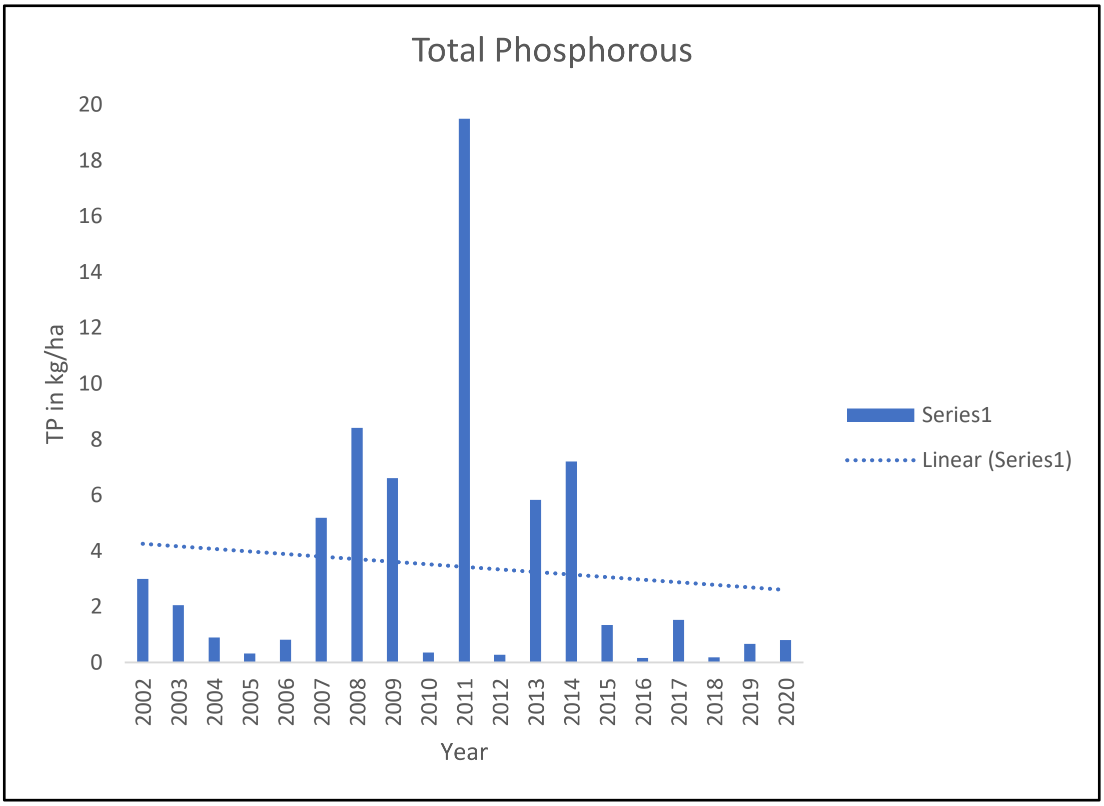

Fig. 7. 11 Average Annual Total Phosphorous

7.4 Summary of Hydrological Modeling Output

Model has been run for total 22 years (1999-2020) in which 3 years (1999-2001) has been taken as Warm-up period. Model has been calibrated for 11 years (2002-2011) and validated for 9 years (2012-2020). After successfully completing the model run, the results are summarized as;

- SURQ contributes about 18-20% of total flow.
- Model shows the approximate value of rainfall, evapotranspiration, surface runoff, lateral flow, base-flow and infiltration in mm as 1009, 469, 86, 132, 321 and 454 respectively.
- Nutrient losses are critical aspect of watershed.
- The results coming here are the losses from the surface area of watershed which is delivered to reach.
- Total Nitrogen losses are greater than 40 % of applied Nitrogen.
- Nitrate losses, and soluble phosphorous losses, in surface runoff is coming as low.
- Solubility ratio for phosphorous in runoff is coming as low, which may indicate a problem
- Nitrate leaching is greater which is more than 38 % of applied fertilizer may also indicate a problem.

Table 7.1 gives a brief about water balance ratios coming as an outlet of SWAT modeling of baseline scenario.

Table 7. 1 Water Balance Ratios

Ratio	Value
Stream flow/Precipitation	0.47
Base flow/Total flow	0.82
Surface runoff/Total flow	0.18
Percolation/Precipitation	0.32
Deep recharge/Precipitation	0.02
ET/Precipitation	0.46

Surface runoff was one of the dominant liquid pathways in N loss, whereas most of P loss (introduced from fertilizers) was fixed in the soil. The primary sources of N and P losses were fertilizers rather than N and P in the soil. The current results suggest controlled management relating to fertilization, irrigation, and other strategies are effective measures for reducing N and P losses, thereby controlling agricultural non-point source pollution. Table 7.2 gives a brief about total nitrogen losses and total phosphorous losses coming as an outlet of modeling. Most cropping systems received more N than P application, and N losses by both runoff and leaching were higher than P losses. Almost twice as much N and P fertilizer was applied. Nitrogen and Phosphorus losses through leaching during the whole season is affected by different water and nitrogen management strategies.

Table 7. 2 Nitrogen and Phosphorous losses

Nitrogen losses in kg/ha	Total Nitrogen losses	33.463
	Organic Nitrogen	16.814
	Nitrate surface runoff	0.035
	Nitrate leached	14.4
	Nitrate lateral flow	2.006
	Nitrate ground water yield	0.208
	Solubility ratio in runoff	0.002
Phosphorous losses in kg/ha	Total Phosphorous loss	2.087
	Organic Phosphorous	2.083
	Soluble P Surface runoff	0.004
	Solubility ratio in runoff	0.002

As per the analysis carried out for individual sub basin, below mentioned table 7.3 indicates the sub basin which attains maximum values of Nutrient water quality parameters in a particular year to identify the non-point pollution source.

Table 7. 3 Sub basin with maximum value

Parameter	**OrgN Kg/ha**	**OrgP Kg/ha**	**NO3 Kg/ha**	**SolP Kg/ha**	**TN Kg/ha**	**TP Kg/ha**
Sub watershed	7	7	5	9	1	7
Year	2011	2011	2014	2003	2011	2011

Figure 7.12 and fig. 7.13 shows the hydrological and nutrient water quality parameters outputs which has been analyzed through SWAT Output viewer successfully.

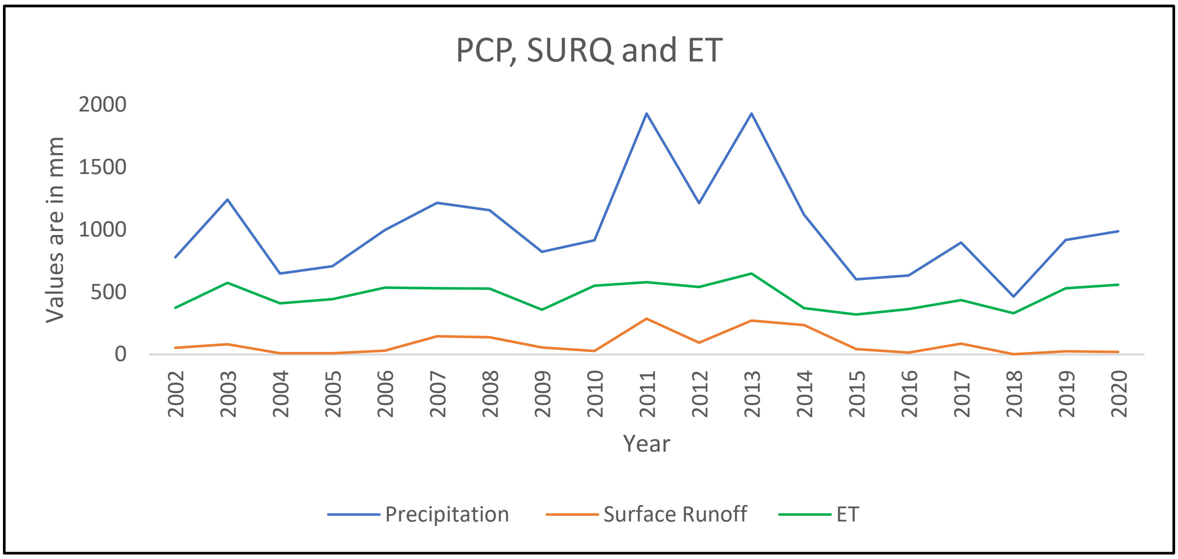

Fig. 7. 12 Hydrological parametrs from SWAT-Cup

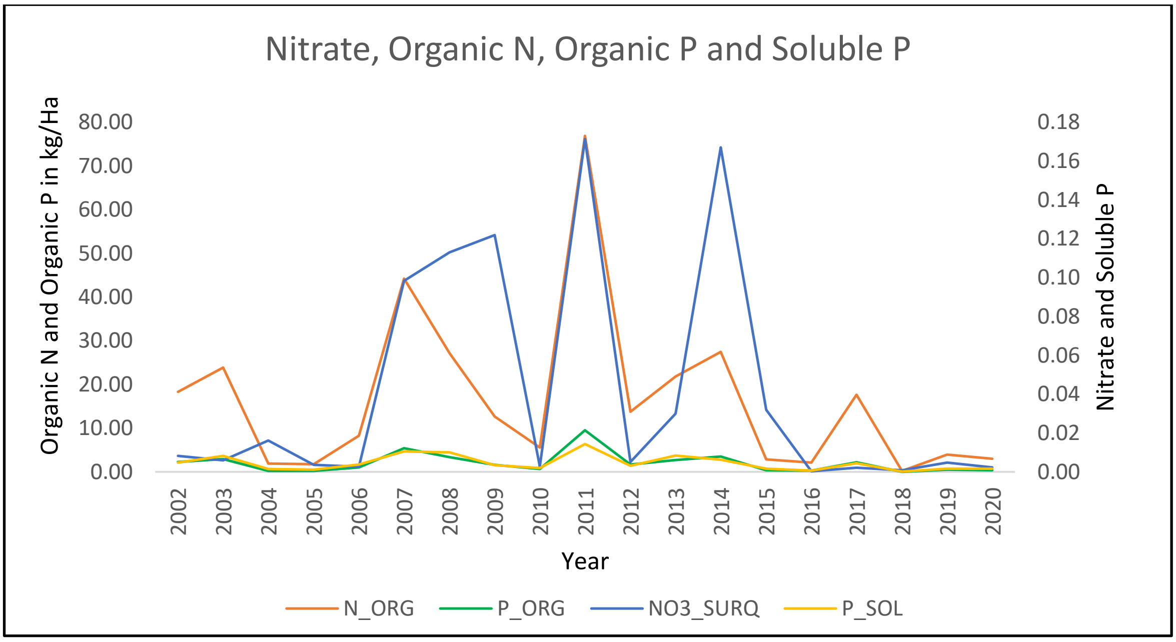

Fig. 7. 13 Nutrient water quality parametrs from SWAT-Cup

Fig. 7.14 and fig. 7.15 shows comparison of monthly observed and simulated values through model run for surface runoff and nitrates which is available from SWAT Output Viewer. R^2 and NSE values for surface runoff are coming as 0.93 and 0.87 and same for nitrates are coming as 0.90 and 0.89.

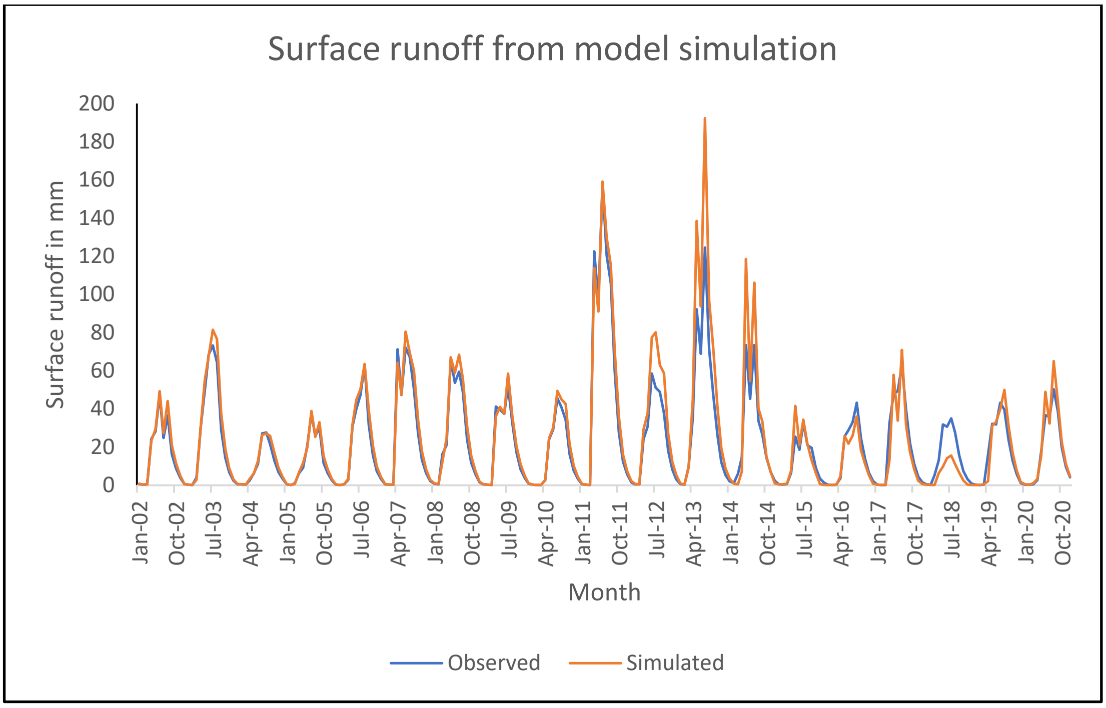

Fig. 7. 14 Comparison of monthly observed and simulated values for surface runoff

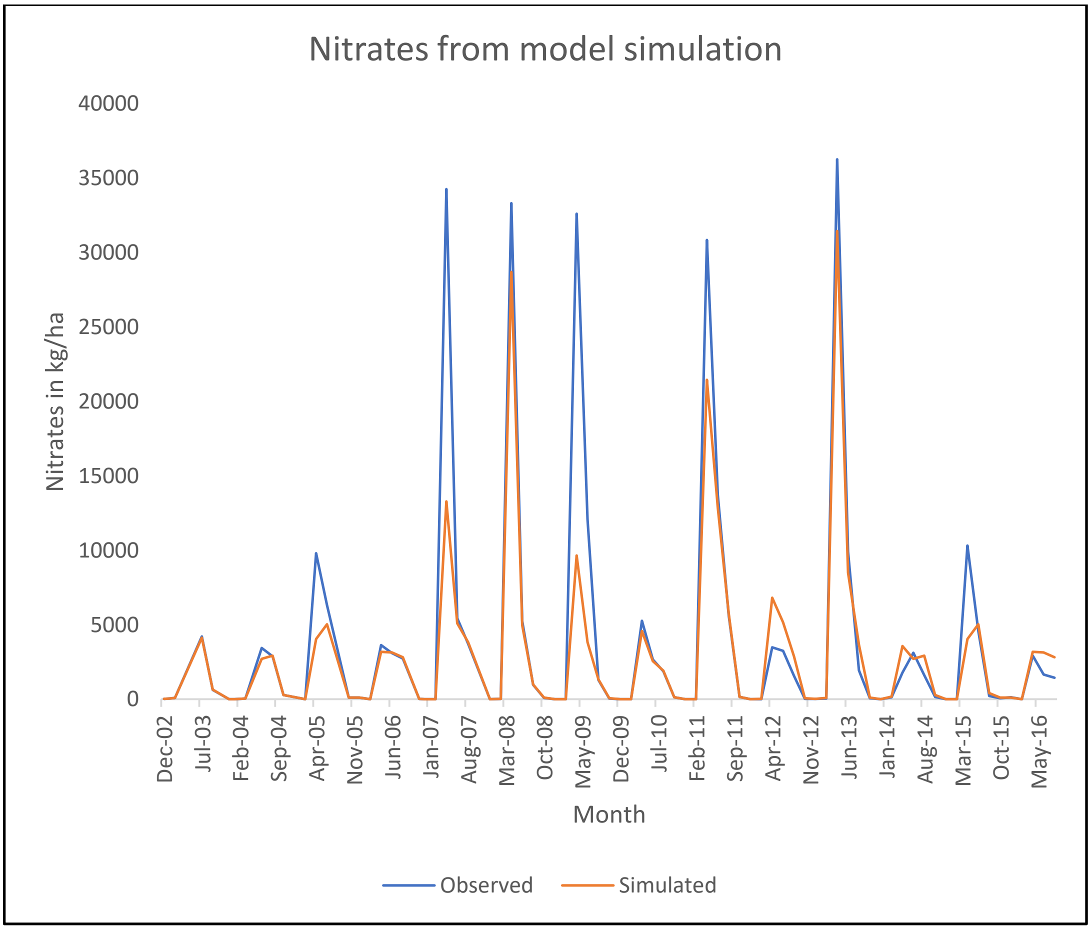

Fig. 7. 15 Comparison of monthly observed and simulated values for nitrate

7.5 Calibration Results

After model simulation in Arc SWAT, model has been calibrated monthly for surface runoff and nitrates in SWAT CUP for 2002-2011. Soils contain a large amount of organic nitrogen in the form of organic matter. Large changes in initial and final nitrogen contents (in particular organic N) may indicate under or over fertilization during the simulation. Crop is consuming less than half the amount of applied N. Large increases in mineral phosphorus content during simulation often result from overfertilization with either commercial or manure phosphorus sources. This means that phosphorus concentrations in runoff also increased during the simulation period. The model is calibrated by “Sequential Uncertainty Fitting” (SUFI-2) algorithm where surface runoff and Nitrate over the reach is taken as a variable and 12 sensitive parameters are chosen as per (Gupta 2019). Table 7.4 denotes sensitive parameters values for different iterations.

Table 7. 4 Sensitive parameters values for different iterations

Sr. No.	Parameter_Name	Iter1	Iter2	Iter3	Iter4	Iter5	Iter6
1	CN2.mgt	57.05	75.95	69.65	50.75	88.55	44.45
2	ALPHA_BF.gw	0.05	0.35	0.45	0.95	0.75	0.25
3	GW_DELAY.gw	375	175	75	475	275	125
4	GWQMN.gw	3250	3750	250	2250	2750	4250
5	SOL_AWC(..).sol	0.85	0.75	0.95	0.05	0.25	0.35
6	ESCO.bsn	0.75	0.45	0.95	0.55	0.35	0.15
7	SURLAG.bsn	18.01	22.80	10.82	15.61	1.24	20.40
8	NPERCO.bsn	0.25	0.55	0.65	0.95	0.45	0.75
9	PPERCO.bsn	11.87	17.12	11.12	14.87	10.37	14.12
10	PHOSKD.bsn	135	145	165	155	115	125
11	GWSOLP.gw	350	50	550	750	850	950
12	EPCO.bsn	0.05	0.45	0.75	0.65	0.25	0.95

Fig. 7.16, and 7.17 gives brief about monthly calibration output and its comparison with observed values for surface runoff & same for nitrates. R^2 and NSE values for surface runoff are coming as 0.95 and 0.92 and same for nitrates are coming as 0.81 and 0.70.

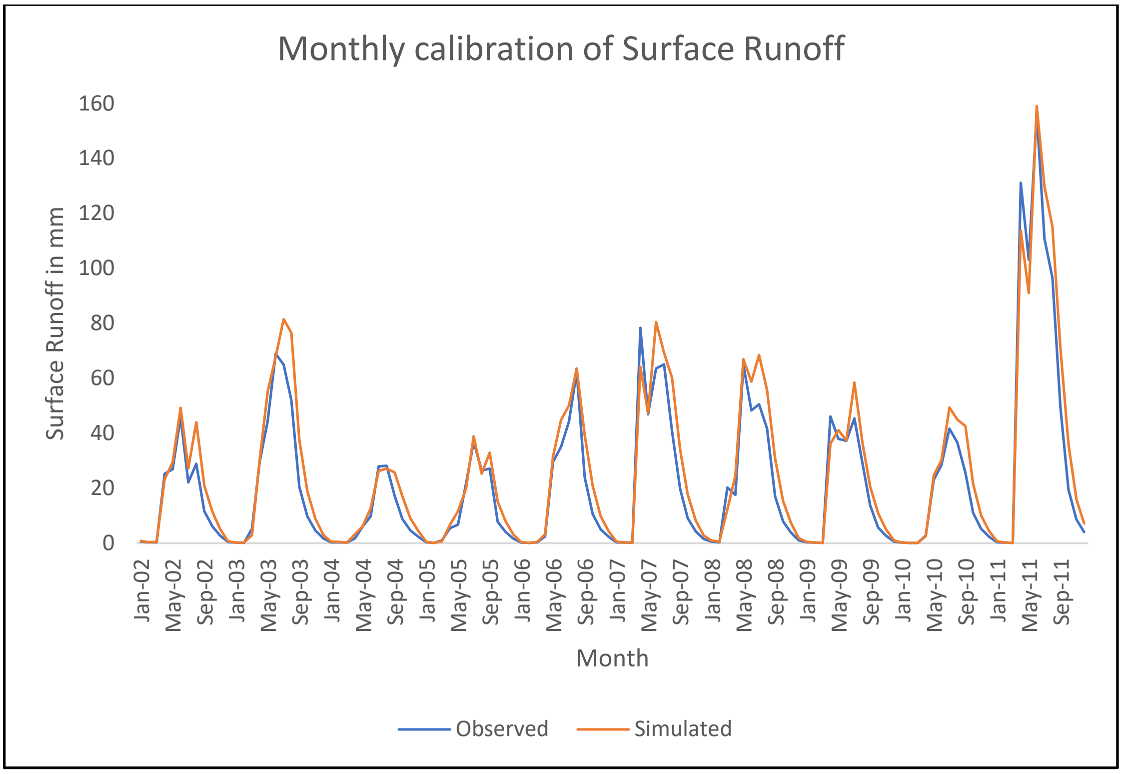

Fig. 7. 16 Monthly calibration of surface runoff comparing with observed values

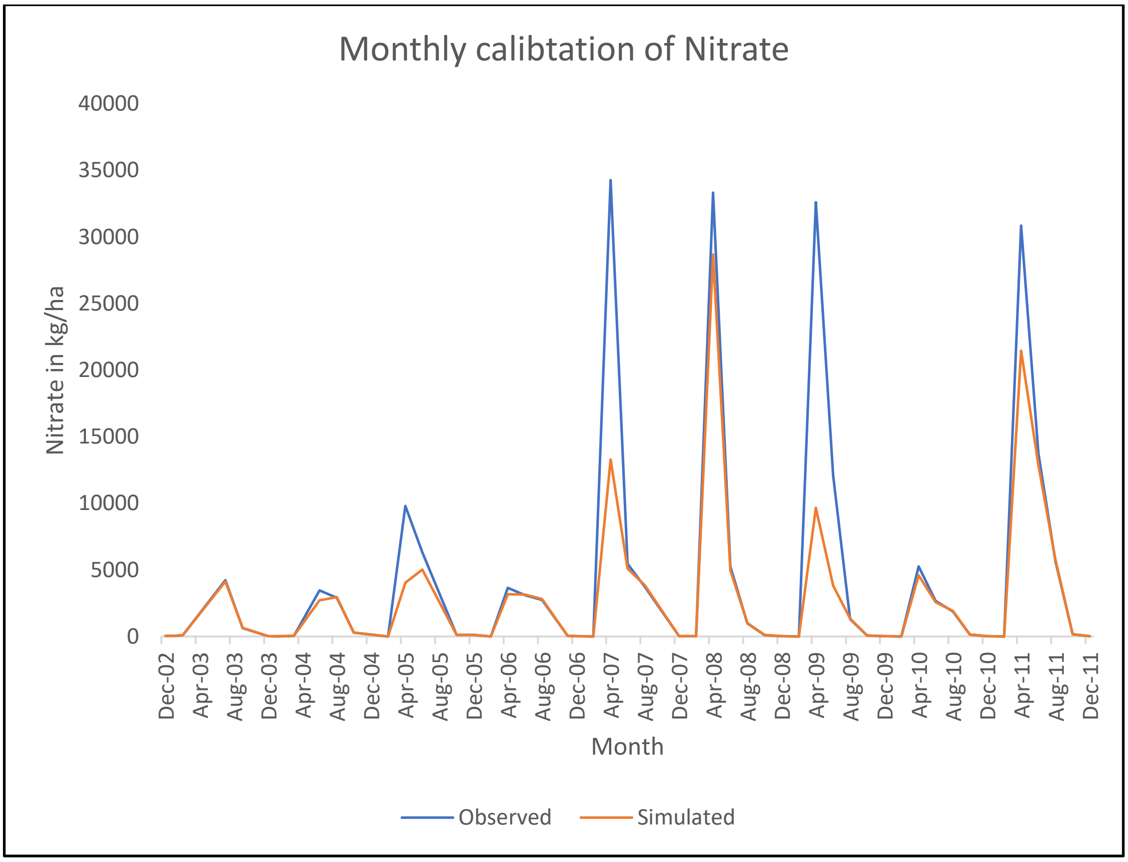

Fig. 7. 17 Monthly calibration of nitrate comparing with observed values

Table 7.5 gives summary of average annual values of hydrological and nutrient water quality parameters after calibration of the model. For calibration for duration of 2002-2011, value of R^2 and NSE for discharge comes as 0.95 and 0.92 successively and for Nitrate it comes as 0.81 and 0.70.

Table 7. 5 Summary of hydrological and nutrient water quality parameters

PRECIP MM	SURFACE RUNOFF Q MM	ET MM	NO3 KG/HA	N-ORG KG/HA	P_SOL KG/HA	P_ORG KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA
1009.140	85.521	472.286	0.042	16.493	2.046	0.005	6.010	1.320	20.24	3.17

7.6 Validation Results

After successful calibration, model has been validated monthly for surface runoff and nitrates in SWAT CUP for 2012-2020. Fig. 7.18, and 7.19 gives brief about monthly validation output and its comparison with observed and simulated values for surface runoff & same for nitrates. R^2 and NSE values for surface runoff are coming as 0.92 and 0.77 and same for nitrates are coming as 0.94 and 0.93. Table 7.6 gives the values of R^2 and NSE for all segments after successfully calibration and validation of the model and these values are coming as satisfactorily so this calibrated model can be used for any other watershed also.

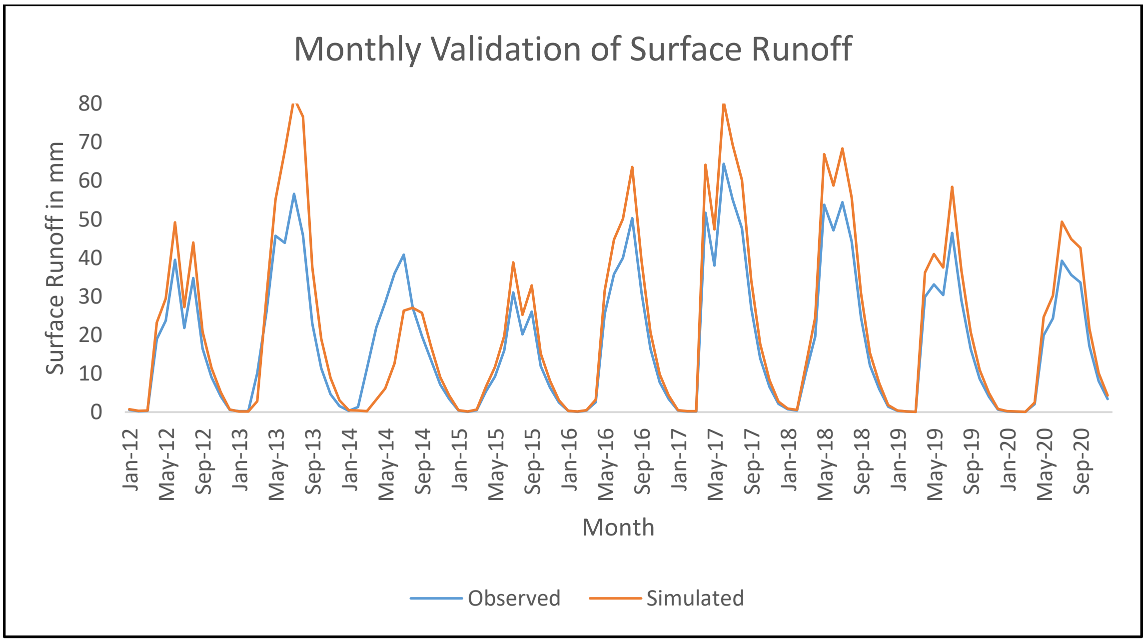

Fig. 7. 18 Monthly validation output for surface runoff

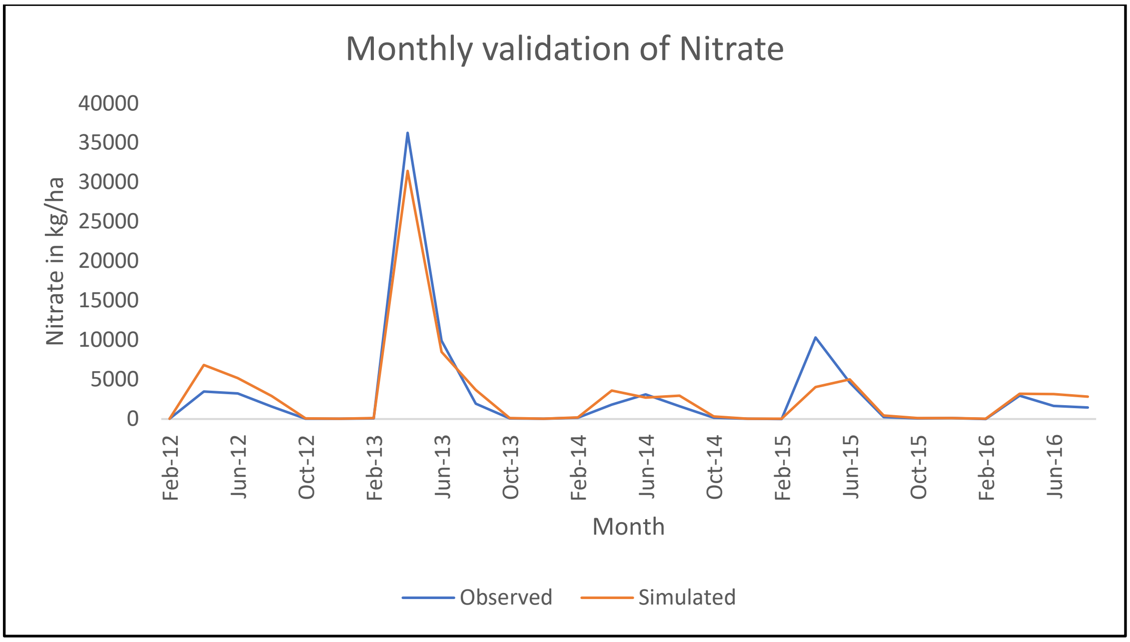

Fig. 7. 19 Monthly validation output for nitrates

Table 7. 6 Values of R^2 and NSE

Period	Discharge		Nitrate	
	R^2	NSE	R^2	NSE
Warm up (1999-2001)	0.91	0.74	0.91	0.79
Calibration (2002-2011)	0.95	0.92	0.81	0.70
Validation (2012-2020)	0.92	0.77	0.94	0.93
Overall (2002-2020)	0.93	0.87	0.90	0.89

7.7 Scenario Results

In this section results have been shown in the form of tables and graphs for all the scenarios like baseline (model simulation), crop rotation and change in land use land cover and for all the scenarios its predictions for years 2021-2050 have also been added.

7.7.1 Baseline Scenario

Base line scenario is considered as a model simulation means comprehensive model results after validation of a model without implementing any interventions and future prediction due to climate change scenario. It was estimated that 47% of the precipitation (P) was lost through evapotranspiration (ET) and 32% as percolation in deep aquifer and 22% was discharged in stream. Surface Runoff is 18% of total flow. Table 7.7 shows results from model simulation for baseline scenario.

Table 7. 7 Baseline scenario results

PRECIP MM	SURFACE RUNOFF Q MM	ET MM	NO3 KG/HA	N-ORG KG/HA	P_SOL KG/HA	P_ORG KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA
1009.14	85.521	472.286	0.042	16.493	2.046	0.005	6.010	1.320	20.24	3.17

7.7.2 Crop rotation Scenario

The results of the crop rotation had a lower Nitrogen loss compared to the baseline scenario. Simulation results from the crop rotation exhibited a decreased nutrient loss relative to our baseline scenario. Table 7.8 gives idea about hydrological and nutrient water quality parameters used in this study.

Table 7. 8 Crop rotation scenario results

PRECIP MM	SURFACE RUNOFF Q MM	ET MM	NO3 KG/HA	N-ORG KG/HA	P_SOL KG/HA	P_ORG KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA
1008.95	200.043	528.910	0.016	17.933	2.213	0.008	3.250	0.440	12.71	2.90

7.7.3 Change in land use land cover Scenario

Compared to the present climate, reductions in surface runoff were significantly high for the future climate. This indicates the noticeable impact caused by LULC changes. The relative decrease in nitrogen loads in future climate with the changed land use land cover of dense forest is one of the hydrologic effects of the lesser surface runoff predicted in future climate model. The relative increase in phosphorous loads in future climate with the changed land use land cover of dense forest is one of the indications that further regulation of phosphorus and nitrogen is needed to improve water quality. This is supplemented by the rapid increases predicted in TP loads in the future climate model, which is the overall temporal trend for the average annual phosphorus loads in the basin. Nutrients such as phosphorus and nitrogen are vital elements to life, but can be undesirable when present at high concentrations (Woltersdorf et al., 2018; Oviatt et al., 2017; Malago et al., 2017; Stoner and Arrington, 2017; Vanhoutte et al., 2017). Hence good management practices to control indirect effects of nutrients on water quality should be implemented. Table 7.9 gives brief idea about result of hydrological as well as nutrient water quality parameters after implementing this scenario.

Table 7. 9 Change in land use land cover scenario results

PRECIP MM	SURFACE RUNOFF Q MM	ET MM	NO3 KG/HA	N-ORG KG/HA	P_SOL KG/HA	P_ORG KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA
1008.40	62.260	468.066	0.009	8.589	1.068	0.003	1.060	0.320	11.48	2.63

7.7.4 Future prediction Scenario

Future predictions for all the above three scenarios have been done for years 2021-2055. For this reason, precipitation, maximum and minimum temperature files have been resulted and also compared with observed data for initial duration. Compared to the present climate, increase in surface runoff is significantly high for the future climate. Fig. 7.20 shows the predicted values using RCP 4.5 for precipitation, it has been validated with observed data for initial duration of 2009-2020 and its trend has been shown by dotted line. It has been seen that average annual precipitation in future shows increasing trend.

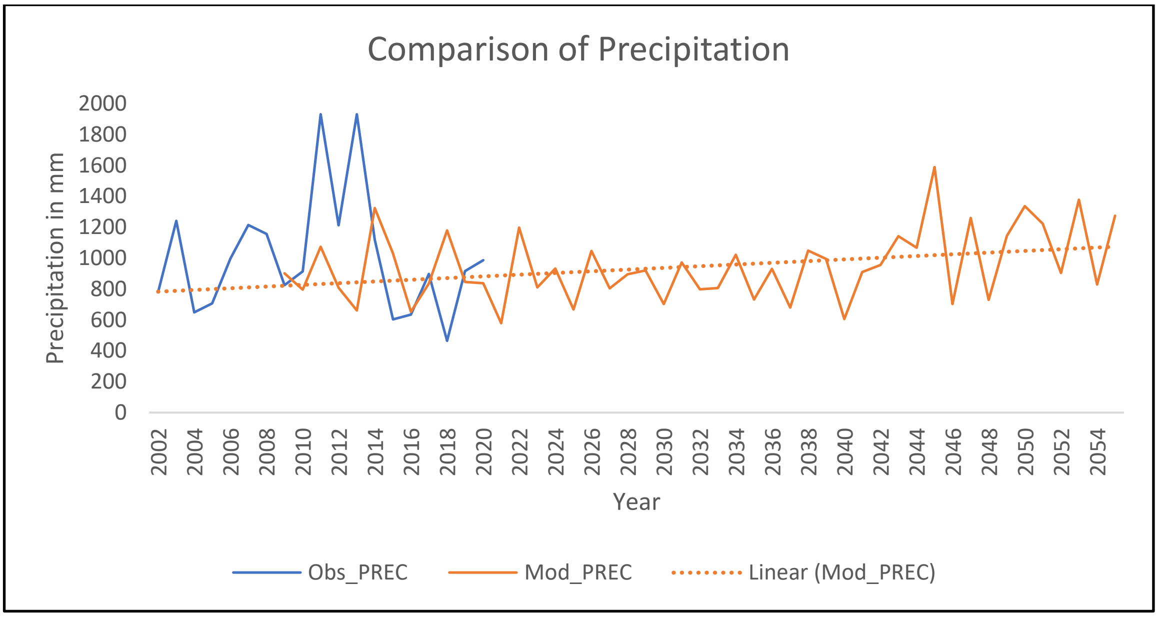

Fig. 7. 20 Comparison of Observed and predicted values of precipitation

Fig. 7.21 shows the predicted values using RCP 4.5 for surface runoff, it has been validated with observed data for initial duration of 2009-2020 and its trend has been shown by dotted line. It has been seen that average annual surface runoff will highly increase in future.

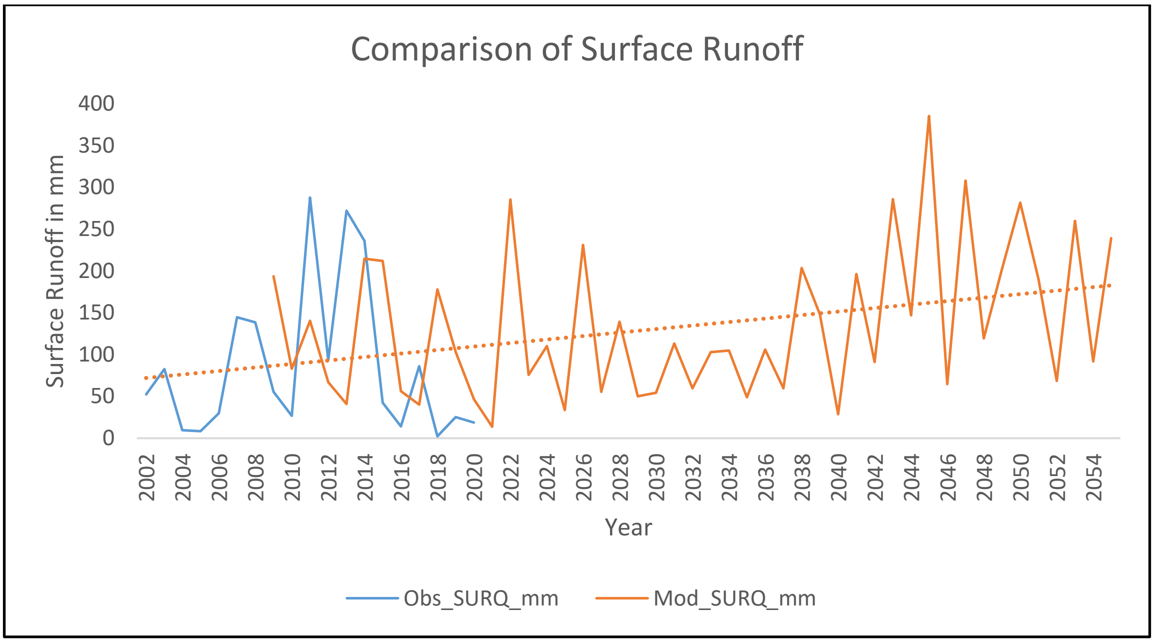

Fig. 7. 21 Comparison of Observed and predicted values of surface runoff

Fig. 7.22 shows the predicted values using RCP 4.5 for Evapotranspiration, it has been validated with observed data for initial duration of 2009-2020 and its trend has been shown by dotted line. It has been seen that average annual value of Evapotranspiration in future will remain almost constant but it is in decreasing trend with observed value.

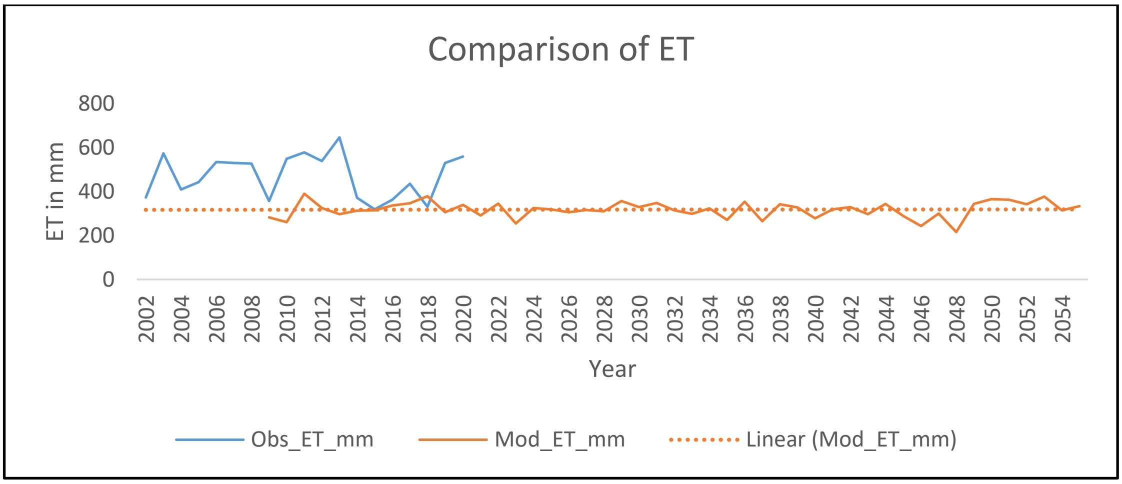

Fig. 7. 22 Comparison of Observed and predicted values of Evapotranspiration

Fig. 7.23 shows the predicted values using RCP 4.5 for surface nitrate for the duration of 2009-2055, it has been validated with observed data for initial duration of 2002-2020 and its trend has been shown by dotted line. It has been seen that average annual value of surface nitrate in future will remain almost constant but it is in decreasing trend with observed value.

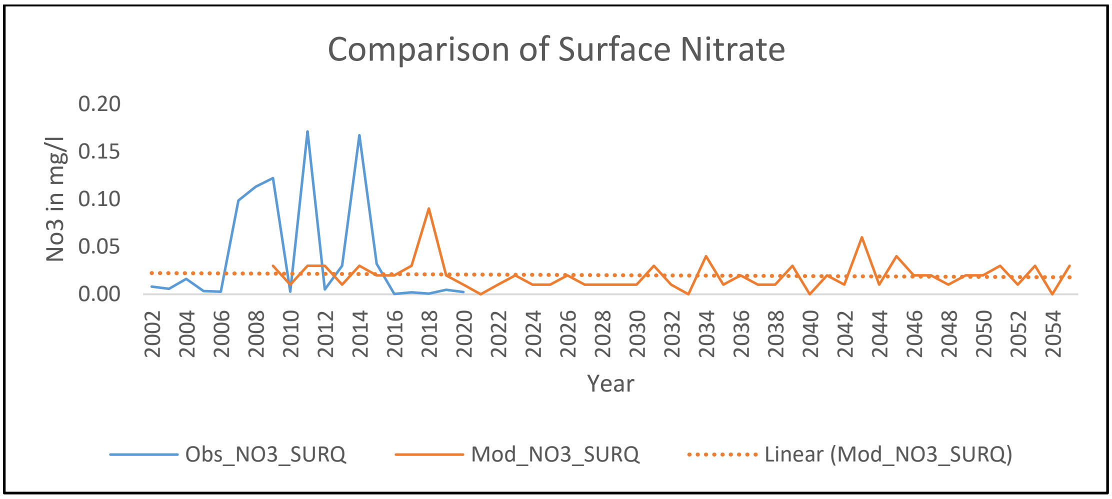

Fig. 7. 23 Comparison of Observed and predicted values of Nitrate

Fig. 7.24 shows the predicted values using RCP 4.5 for organic nitrogen for the duration of 2009-2055, it has been validated with observed data for initial duration of 2002-2020 and its trend has been shown by dotted line. It has been seen that average annual value of organic nitrogen in future will be in decreasing trend with observed value.

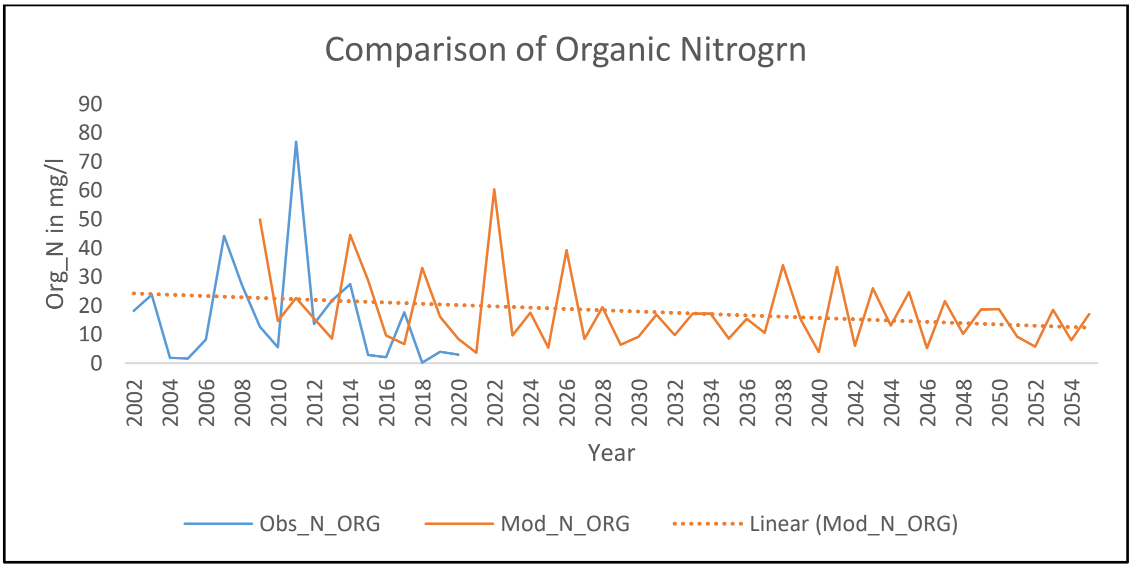

Fig. 7. 24 Comparison of Observed and predicted values of Organic Nitrogen

Fig. 7.25 shows the predicted values using RCP 4.5 for organic phosphorous for the duration of 2009-2055, it has been validated with observed data for initial duration of 2002-2020 and its trend has been shown by dotted line. It has been seen that average annual value of organic phosphorous in future will be in decreasing trend with observed value.

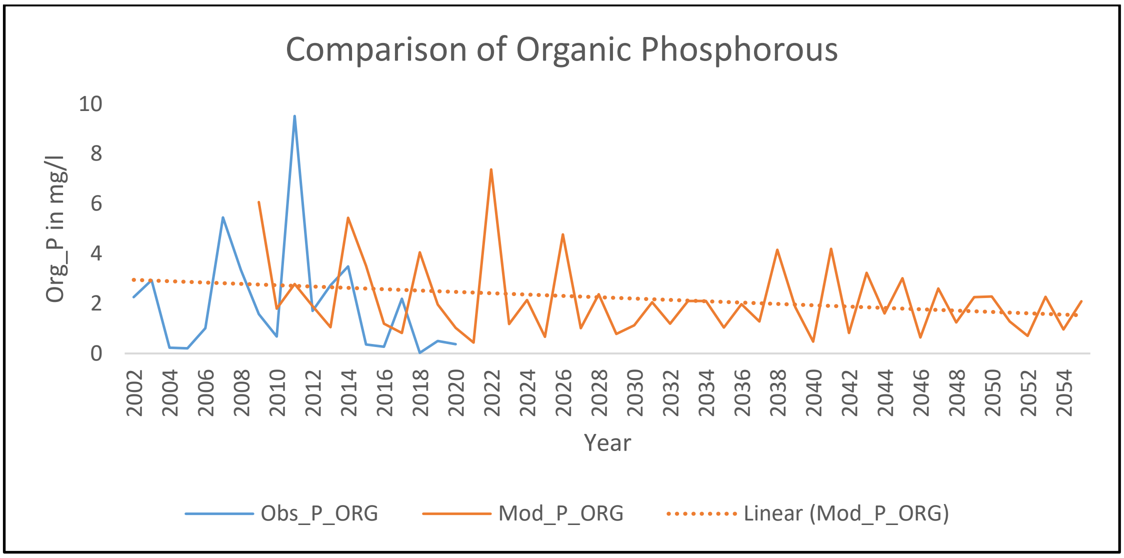

Fig. 7. 25 Comparison of Observed and predicted values of Organic Phosphorous

Fig. 7.26 shows the predicted values using RCP 4.5 for soluble phosphate for the duration of 2009-2055, it has been validated with observed data for initial duration of 2002-2020 and its trend has been shown by dotted line. It has been seen that average annual value of soluble phosphate in future will be in increasing trend with observed value.

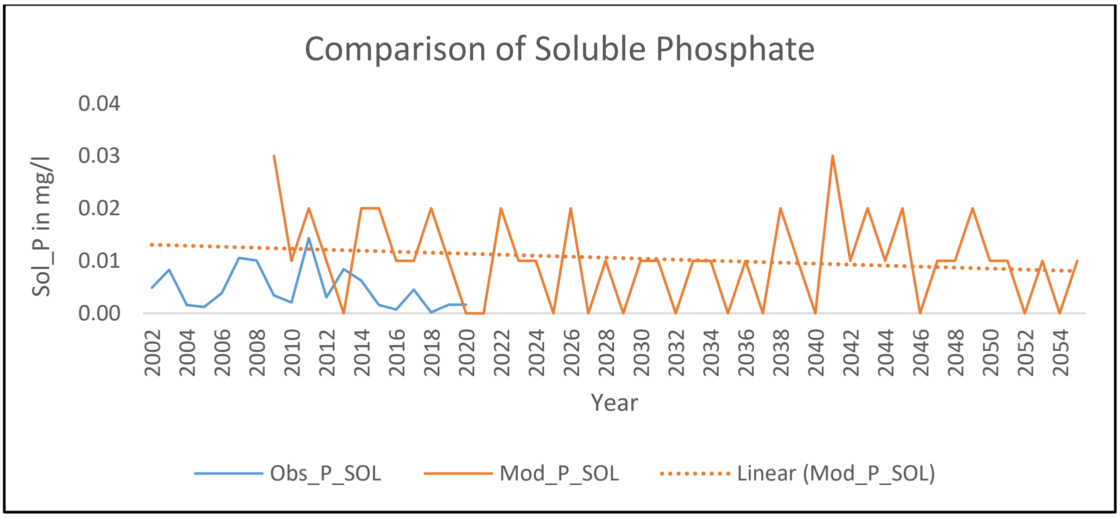

Fig. 7. 26 Comparison of Observed and predicted values of Soluble Phosphate

Fig. 7.27 shows the predicted values using RCP 4.5 for total nitrogen for the duration of 2009-2055, it has been validated with observed data for initial duration of 2002-2020 and its trend has been shown by dotted line. It has been seen that average annual value of total nitrogen in future will be in increasing trend with observed value. For some years, it will be higher than average value but for some years it will be lower than the peak value.

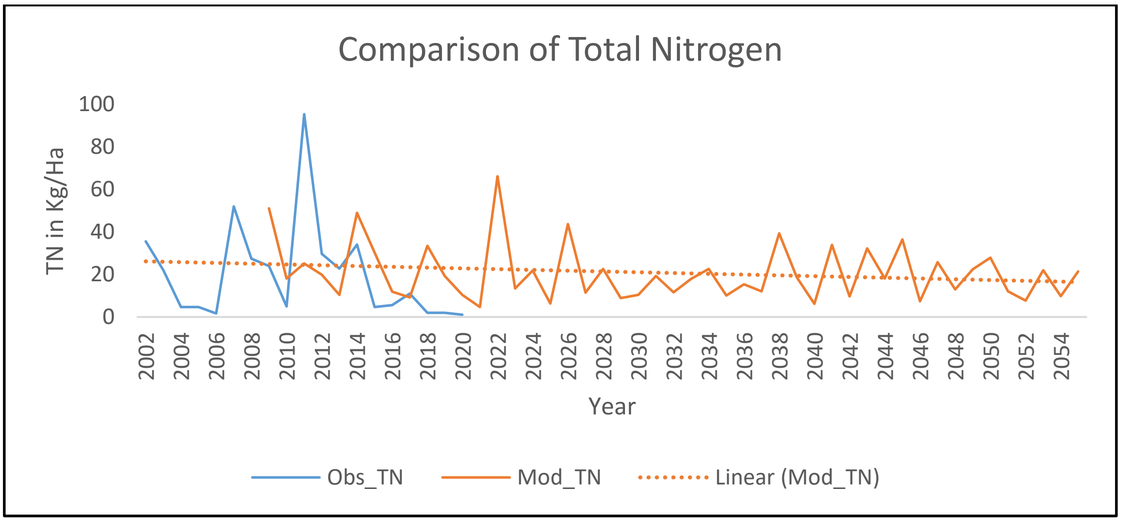

Fig. 7. 27 Comparison of Observed and predicted values of Total Nitrogen

Fig. 7.28 shows the predicted values using RCP 4.5 for total phosphorous for the duration of 2009-2055, it has been validated with observed data for initial duration of 2002-2020 and its trend has been shown by dotted line. It has been seen that average annual value of total phosphorous in future will be in increasing trend with observed value.

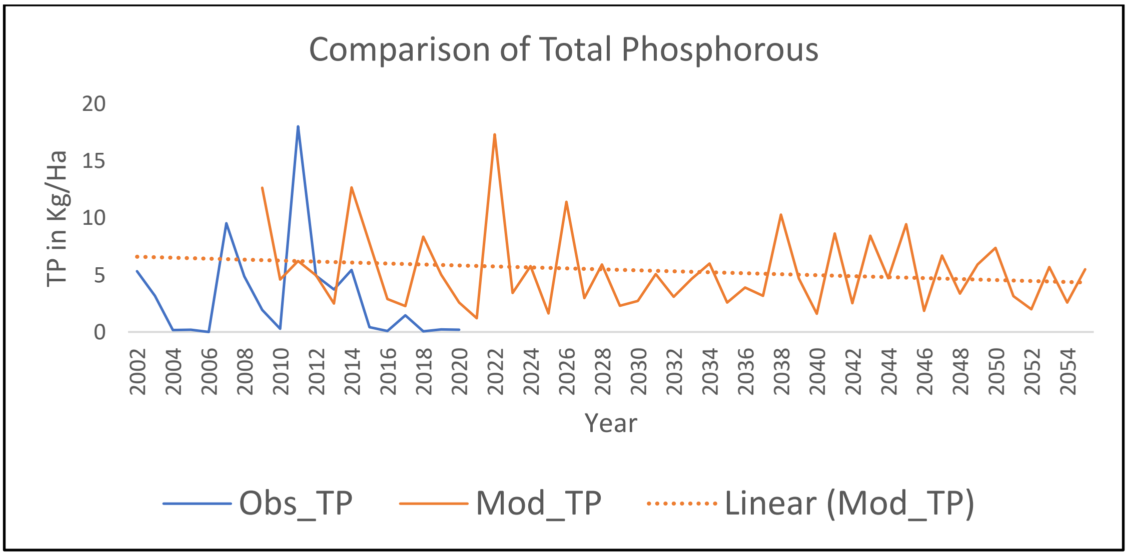

Fig. 7. 28 Comparison of Observed and predicted values of Total Phosphorous

Table 7.10 shows future prediction results for different scenarios.

Table 7. 10 Future predictions for baseline scenario

	(2021-2055)							
Scenarios	**ORGN**	**ORGP**	**SOLP**	**NO3**	**MINN**	**MINP**	**TN**	**TP**
Base line scenario	16.141	0.01	1.981	0.017	2.88	0.42	19.49	5.08
Crop Rotation	16.312	0.01	1.989	0.023	3.25	0.44	19.99	5.12
Dense forest	13.443	0.006	1.641	0.004	1.46	0.21	19.03	4.75

7.8 Discussion of Scenario Results

After receiving results through model and its different scenarios and its future predictions we can take out some facts in the discussion.

7.8.1 Baseline Scenario

After the simulation of calibrated and validated model, following conclusions were noted through SWAT model output.

- Regarding TN, the inputs were estimated at about 86 kg/ha, in which fertilizers application contributed 41.2 kg/ha, nitrogen from atmospheric deposition is13 kg/ha and the nitrogen fixed by plant is 31.8 kg/ha. Point sources amounted to 2.6 kg/ha.
- The nitrogen removed by crop yield and lost in soils had the most significant impact on sources with a reduction of 60% (48.2 kg/ha) and 37% (30 kg/ha), respectively.
- Ammonia is less than 0.01% of applied fertilizer amount so it has no consideration.
- 74.4% Nitrate has been removed from the soil.
- Crop is consuming half the amount of fertilizer applied and the remaining part of fertilizers is coming with return flow in river.
- Total Nitrogen losses are greater than 40% of applied Nitrogen.
- Nitrate, Soluble Phosphorous losses, solubility ratio for Nitrogen, solubility ratio for Phosphorous in surface runoff may be low which indicates problem.
- Nitrate leaching is more than 38% of the applied fertilizer may also indicate problem.
- Initial Mineral Phosphorous in soil is 452 kg/ha and final Mineral Phosphorous in soil is 376 kg/ha which is a large quantity results from over fertilization. This also means Phosphorous content in runoff may also increase.

7.8.2 Crop rotation Scenario

In the baseline scenario, crop rotation scenario has been generated and following conclusions have been made for nutrient water quality parameters.

- Simulated nutrient loss from the corn-winter wheat rotation, was 17.78 kg/ha for organic nitrogen and 2.18 kg/ha for particulate phosphorus (mineral and organic), respectively. Simulated average annual agricultural TN loss is about 17.65 kg/ha.
- TN loss from crop rotation was reduced by about 37.20%; TP loss dropped by about 8.52%.
- The average dissolved phosphorus losses from agricultural areas in the watershed was increased by 8.16%.

7.8.3 Change in land use land cover Scenario

In the baseline scenario, change in land use land cover change scenario by converting agricultural land of 1 km both the sides of river into dense forest has been generated and following conclusions have been made for nutrient water quality parameters.

- The annual rate of decrease of TN from baseline scenario to dense forest scenario were 2443.38 tons from present climate and 2376.50 tons from future climate respectively.
- Annual reduction of 43.28% nitrogen loads and annual reduction of 6.5% phosphorus loads were predicted in the watershed.

7.8.4 Future prediction Scenario

Future prediction scenario has been generated by simulating the calibrated and validated model till 2055 and following observations have been made.

- Trends in mean projection rainfall shows a decrease as compared to the baseline rainfall. The 19-year averages of mean of rainfall showed percentage decrease of approximately (959 mm) i.e., 4.94% for RCP 4.5 as against baseline average (1009.14 mm).

- The years of extreme rainfall under RCP 4.5 mean exhibited a near-decadal trend with increments observed from 2045, 2047, 2051, 2053 and 2055.
- The average total Nitrogen concentrations during simulation period were 1151.01 mg/l in observation datasets and 1110.97 mg/l in simulation.
- Compared to the present climate, increase in surface runoff is significantly high for the future climate.

7.9 Summary of Scenario Results

The application of various interventions at watershed level showed that after implementing above mentioned two scenarios Nitrogen content in Hathmati river return flow can be decreased. Table 7.11 shows summary of all the results with its predictions.

Table 7. 11 Summary of all the results with its predictions

	(2002-2020)								(2021-2055)							
Scenarios	ORGN KG/HA	ORGP KG/HA	SOLP KG/HA	NO3 KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA	ORGN KG/HA	ORGP KG/HA	SOLP KG/HA	NO3 KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA
Base line	16.493	0.005	2.046	0.042	6.010	1.320	20.24	3.17	16.141	0.01	1.981	0.017	2.88	0.42	19.49	5.08
Crop Rotation (C-WW)	17.933	0.008	2.213	0.016	3.250	0.440	12.71	2.90	16.312	0.01	1.989	0.023	3.25	0.44	19.99	5.12
Dense forest (1 km buffer on both side)	8.589	0.003	1.068	0.009	1.060	0.320	11.48	2.63	13.443	0.006	1.641	0.004	1.46	0.21	19.03	4.75

Table 7.12 shows the percentage reduction in nutrient water quality comparing with baseline scenario so that it can be chosen and implemented by beneficiaries. Negative sign indicated decrease in value compared with base line scenario.

Table 7. 12 percentage reduction in nutrient water quality parameters

	% change (2002-2020)								% change (2021-2055)							
Scenarios	ORGN KG/HA	ORGP KG/HA	SOLP KG/HA	NO3 KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA	ORGN KG/HA	ORGP KG/HA	SOLP KG/HA	NO3 KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA
Crop Rotation (C-WW)	8.73	60.00	8.16	-61.90	-45.92	-66.67	-37.20	-8.52	1.06	0.00	0.40	35.29	12.85	4.76	2.57	0.79
Dense forest (1 km buffer on both side)	-47.923	-40.000	-47.801	-78.571	-82.363	-75.758	-43.281	-17.035	-16.715	-40.000	-17.163	-76.471	-49.306	-50.000	-2.360	-6.496

- The decrease in nitrogen loads, and phosphorus loads mainly occurred in the

- watershed where agricultural lands was majorly replaced by dense forest.
- The collective evaluation of dense forest change and climate changes predicted a noticeable decrease in surface runoff in the future climate.
- Future stream-flow predictions were modelled for RCP4.5 climatic scenarios and two interventions scenarios, crop rotation and dense forest. The downscaled rainfall trends showed decreases in rainfall totals between 2021 and 2050 in the RCPs as compared to the base-line.
- These findings of the study provide evidence that combined changes in climate and dense forest pose a stronger impact on water quality in future. Therefore, effective management of water requires the evaluation of combined effects of various climate models and LULC scenarios on water quality.

CHAPTER - 8

CONCLUSION AND RECOMMENDATION

8.1 Conclusion

For this Ph.D. thesis, three main objectives have been developed. The first aim was to conceptualize the framework for maintaining water quality and to offer a tool to assist in decision-making. The second aim was to see the effects of climate change on water quality parameters. The third aim was to observe the results of different interventions at the watershed level. For this final object, two methods were implemented: crop rotation and changing the land use land cover.

Specific conclusions are summarized below related to the results of the different parts of this study:

i) The SWAT model was performed to conceptualize water quality framework in Hathmati watershed. The model can give good results after streamflow and nitrate calibration. The hydrograph comparisons between the observed and modeled flow showed similarities, a good fit for the regression curve, and demonstrated the potential of adopting model scenarios. With some seasonal variation, modelled NO_3- was similar in terms of magnitude and distribution.

ii) Applying a hydrological model under conditions of limited data availability is a tremendous challenge for hydrologists and modelers, especially when a hydrological model such as SWAT was used, which requires a large number of input data. This process has been done by using the SWAT model at Hathmati watershed, which has shown a good model performance during the calibration and validation phases with a NSE of 0.92 and 0.70 for discharge and 0.77 and 0.93 for nitrate and with R^2 of 0.95 and 0.92 for discharge and 0.81 and 0.94 for nitrate for calibration and validation, respectively. After this, the fitted values for all sensitive parameters have been used to generate the flow and estimate nitrate at the Hathmati watershed.

iii) Applying this validated model for different scenarios and if we check the scenario of various interventions, total nitrogen and total phosphorous has been decreased compared to model simulation. Being specific for two scenarios of various interventions at watershed level as crop rotation and land use land cover change, total nitrogen and total phosphorous has been decreased for land use land cover change scenario compared to crop rotation scenario. However, there is a chance that the total simulated NO_3- (kg/ha) export into streams and lakes will be reduced due to increased NO_3- and other nutrient export from crop land.

iv) While comparing all the above scenario with future predictions for RCP 4.5 till 2055, for baseline scenario total nitrogen is decreasing and total phosphorous is increasing. The major interventions for crop rotation and change in land use land cover were assessed, for crop rotation scenario, total nitrogen and total phosphorous is increasing compared to baseline future prediction scenario and for change in land use land cover change scenario total nitrogen and total phosphorous is decreasing compared to baseline future prediction scenario. By comparing above two interventions, change in land use land cover scenario seems better for decreasing total nitrogen and total phosphorous. The SWAT model will give policy makers a practical tool that will assist best practices in agriculture and the environment while also validating watershed studies and acting as a forecasting tool for decision-making.

The findings of modelling various interventions at the watershed level show that the amount of NO_3- exported fluctuates seasonally and is also dependent on flow volume, which is affected by timing and amount of fertilizer applied. This thesis has demonstrated that SWAT model can be a useful tool for agricultural watershed management with proper incorporation of long-term measured flow and NO_3^- data.

Using these data, recommendations for a better monitoring system can be developed. Additionally, they can be used to estimate the nitrate content of times and locations which aren't really observed. The SWAT model that was used to analyze the effects of irrigated agriculture - by far the biggest source of nitrate contamination in the river - is well adapted for forecasting nitrate concentrations. It is suitable for a circumstance where there is little data availability and no significant environmental monitoring history. On the other side, there are a few issues with the selected strategy as well. We don't know if the nitrate is exported as a result of certain irrigation management techniques, if it is related to the soil, or if it is caused by other environmental factors. It only offers an empirical estimate of how much nitrate is exported when base flow and overland flow are combined, and it makes the assumption that all irrigation perimeters would behave in the same way. For the Hathmati watershed, the modelling results' validation was satisfactory. But the study's availability of scant validation data was another crucial flaw. With only few observations, it is challenging to determine the usefulness of the suggested model. If we assume that the model accurately represents the spatiotemporal behavior of nitrate concentration, it can be used to generate monitoring recommendations.

8.2 Recommendations

Applying some of these techniques to the study area yields the following recommendations: Priorities could be established among many places for monitoring water quality, providing the decision-maker with a foundation for including or excluding a monitoring station based on the available resources. The strategy was used in the instance of the Hathmati river, but it can be simply applied to other areas. The presence of measured or trustworthily modelled discharge data and an accurate estimation of the main nitrate emitting water uses are essential conditions for using the approach. Data on point sources as well as information on the dynamics of land and fertilizer use are required. As demonstrated in this work, the interpretation of satellite images and/or agricultural or demographic censuses can enable the investigation of their regional and temporal distribution. The major soil properties, hydrological pattern, irrigation systems, and farmed crops of the other watersheds are comparable to those of the Hathmati. In other regions, specialized empirical investigations would be required to confirm the nitrate export.

The presence of a good representation of the hydrological components of the watershed is a requirement for modelling concentrations and the resulting variability of any water quality parameter, as the spatiotemporal dynamics of water quantity greatly influence water quality. It makes perfect sense to incorporate the proposed model into the national monitoring system. It is sufficient for both supporting the design of monitoring and the analysis of monitoring outcomes. The model allows determinations of nitrate concentrations to be generated even for instances and locations when no observations were made. The model's quality could be raised and revalidated over time as new monitoring data is produced. Since the model will be able to accurately estimate nitrate concentrations, which might replace direct measurements, if the model's reliability rises, it may even help to lower monitoring frequencies in the future. The model may also assess if it is likely that critical nitrate concentrations will be achieved at a specific time during the year. With the method outlined in this thesis, it is possible to optimize water quality monitoring systems in terms of the choice of sampling locations and frequency, even in regions with a poor overall data availability. Without needing to construct water quality time series across several years with high temporal precision, it might be helpful to make quick decisions regarding monitoring system design. As a result, it may help to distribute funds more effectively for managing water quality. In theory, every watershed can use the described method to identify constituent variability in water quality. Although they are frequently found in the literature, the export coefficients that best reflect the export of nitrate from a particular land use must occasionally be established empirically for each case study.

The recommendations are offered for upcoming simulation projects. In order to improve the weather generator, ground water, routing, and NO_3 algorithms, more attention should be paid to develop new SWAT model methods, interfaces, and software tools. There is a requirement for ongoing discharge and chemical data collecting at the subbasin and watershed outlets since data gaps can provide serious challenges for any modelling study and cause progress to stagnate, costing significant time. The model's accuracy should be improved by taking into account point source pollution. If the simulation lasted at least five years and there were more monitoring data stations at the Hathmati watershed, a more intricate watershed model could be created. The generation of trends would benefit with accurate long-term monitoring data for observed stream flow and pollutant concentration data. According to the time frame, it is also advised to include the type of crops grown, pesticide application, fertilizer application, and conservation tillage in the management choice.

For future research, it is advised to use 10-meter resolution GIS data themes for land use, soil themes, and the digital elevation model. Monitoring work would include continuous sampling at key locations to provide additional data for input as well as calibration and validation. Management scenarios like urbanization, deforestation, and, crop changes can be incorporated into the model and studied using a different software model. To link loads generated to in-stream conditions, future studies should include thorough in-stream water quality modelling. In order to estimate the pollutant load and concentration, it should also incorporate atmospheric deposition of any air pollutant into a watershed model that accounts for the deposition effects and takes point and non-point source pollution from air into consideration. It is necessary to create a more adaptable modelling framework that can offer solutions to a variety of hydrological issues of varying degrees of complexity. Surface, subsurface, and groundwater flow should all be integrated into the model, which should be adaptable, physically based, and fully dispersed.

Future research is advised to (i) collect more field data, (ii) install more weather stations to monitor climatic parameters (rainfall, temperature, wind speed, solar radiation, and evapotranspiration), (iii) monitor sediment rate in each watershed to be able to calibrate and validate the model with suspended matter, and (iv) try to reduce the rate of erosion in the area.

This framework is expected to be applied to other watersheds to balance economic and environmental benefits. Especially in the context of climate change, an area which is suitable for a certain crop production can become unsuitable over time, or vice versa. Also, future work should incorporate adoption of effective means to represent the physical processes of hydrological model, use of land use land cover transitions and incorporation of multiple climate scenarios could significantly improve the outcomes of this study.

APPENDICES

APPENDIX – A: HRU Analysis

Hydrological response unit (HRU) is the fundamental spatial unit, which is the combination of unique land use, soil, and slope characteristics. Following data shows the HRU report of Hathmati watershed.

```
SWAT   model   simulation   Date: 12/2/2022 12:00:00 AM   Time: 00:00:00
MULTIPLE HRUs  LandUse/Soil/Slope OPTION           THRESHOLDS : 0 / 0
/ 0 [%]
Number of HRUs: 30
Number of Subbasins: 13

_________________________________________________________________________
Area [ha]                                                    Area[acres]

Watershed                                                    131741.4530
325539.7174

                                                               Area [ha]
Area[acres] %Wat.Area
LANDUSE:
                                Forest-Mixed --> FRST         36261.2590
89603.3840     27.52
                    Agricultural Land-Generic --> AGRL         95480.1940
235936.3334     72.48

SOILS:
                                             FINE             112699.1341
278485.1952     85.55
                                   LOAMY SKELETON              7191.7523
17771.1795      5.46
                                     COARSE LOAMY              2865.9598
7081.9300      2.18
                                       FINE LOAMY              8984.6068
22201.4126      6.82

SLOPE:
                                              3-8             73678.2166
182062.5571     55.93
                                          15-9999              7191.7523
17771.1795      5.46
                                              1-3             50871.4841
125705.9808     38.61

                                                               Area [ha]
Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                      1             10623.4847
26251.1618      8.06

LANDUSE:
                                Forest-Mixed --> FRST         10623.4847
26251.1618      8.06    100.00

SOILS:
                                             FINE             10623.4847
26251.1618      8.06    100.00

SLOPE:
```

3-8 10623.4847
26251.1618 8.06 100.00
HRUs
1 Forest-Mixed --> FRST/FINE/3-8 10623.4847
26251.1618 8.06 100.00 1
Area [ha]
Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 2 4531.6506
11197.9351 3.44

LANDUSE:
Forest-Mixed --> FRST 4531.6506
11197.9351 3.44 100.00

SOILS:
LOAMY SKELETON 4531.6506
11197.9351 3.44 100.00

SLOPE:
15-9999 4531.6506
11197.9351 3.44 100.00
HRUs
2 Forest-Mixed --> FRST/LOAMY SKELETON/15-9999 4531.6506
11197.9351 3.44 100.00 1
Area [ha]
Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 3 5025.8952
12419.2384 3.81

LANDUSE:
Agricultural Land-Generic --> AGRL 5025.8952
12419.2384 3.81 100.00

SOILS:
FINE 5025.8952
12419.2384 3.81 100.00

SLOPE:
1-3 2719.1789
6719.2270 2.06 54.10
3-8 2306.7163
5700.0114 1.75 45.90
HRUs
3 Agricultural Land-Generic --> AGRL/FINE/1-3 2719.1789
6719.2270 2.06 54.10 1
4 Agricultural Land-Generic --> AGRL/FINE/3-8 2306.7163
5700.0114 1.75 45.90 2
Area [ha]
Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 4 17585.4401
43454.5018 13.35

LANDUSE:

Agricultural Land-Generic --> AGRL 14925.3384
36881.2574 11.33 84.87
Forest-Mixed --> FRST 2660.1017
6573.2444 2.02 15.13

SOILS:

FINE 14925.3384
36881.2574 11.33 84.87
LOAMY SKELETON 2660.1017
6573.2444 2.02 15.13

SLOPE:

1-3 8105.6258
20029.4067 6.15 46.09
3-8 6819.7125
16851.8507 5.18 38.78
15-9999 2660.1017
6573.2444 2.02 15.13
HRUs
5 Agricultural Land-Generic --> AGRL/FINE/1-3 8105.6258
20029.4067 6.15 46.09 1
6 Agricultural Land-Generic --> AGRL/FINE/3-8 6819.7125
16851.8507 5.18 38.78 2
7 Forest-Mixed --> FRST/LOAMY SKELETON/15-9999 2660.1017
6573.2444 2.02 15.13 3
Area [ha]

Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 5 7739.1373
19123.7952 5.87

LANDUSE:

Forest-Mixed --> FRST 7739.1373
19123.7952 5.87 100.00

SOILS:

FINE 7739.1373
19123.7952 5.87 100.00

SLOPE:

3-8 7739.1373
19123.7952 5.87 100.00
HRUs
8 Forest-Mixed --> FRST/FINE/3-8 7739.1373
19123.7952 5.87 100.00 1
Area [ha]

Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 6 6549.5477
16184.2597 4.97

LANDUSE:

Agricultural Land-Generic --> AGRL 6549.5477
16184.2597 4.97 100.00

SOILS:
FINE 6549.5477
16184.2597 4.97 100.00

SLOPE:
1-3 3107.7700
7679.4551 2.36 47.45
3-8 3441.7776
8504.8046 2.61 52.55
HRUs
9 Agricultural Land-Generic --> AGRL/FINE/1-3 3107.7700
7679.4551 2.36 47.45 1
10 Agricultural Land-Generic --> AGRL/FINE/3-8 3441.7776
8504.8046 2.61 52.55 2
Area [ha]
Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 7 10210.9874
25231.8603 7.75

LANDUSE:
Agricultural Land-Generic --> AGRL 10210.9874
25231.8603 7.75 100.00

SOILS:
FINE 10210.9874
25231.8603 7.75 100.00

SLOPE:
1-3 4727.9774
11683.0687 3.59 46.30
3-8 5483.0099
13548.7916 4.16 53.70
HRUs
11 Agricultural Land-Generic --> AGRL/FINE/1-3 4727.9774
11683.0687 3.59 46.30 1
12 Agricultural Land-Generic --> AGRL/FINE/3-8 5483.0099
13548.7916 4.16 53.70 2
Area [ha]
Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 8 9478.8427
23422.6942 7.20

LANDUSE:
Agricultural Land-Generic --> AGRL 7173.2474
17725.4529 5.44 75.68
Forest-Mixed --> FRST 2305.5953
5697.2413 1.75 24.32

SOILS:

```
                                                            FINE           9478.8427
23422.6942      7.20    100.00

SLOPE:
                                                             1-3           3184.7943
7869.7859      2.42      33.60
                                                             3-8           6294.0484
15552.9083      4.78     66.40
HRUs
 13        Agricultural Land-Generic --> AGRL/FINE/1-3              3184.7943
7869.7859      2.42      33.60     1
 14        Agricultural Land-Generic --> AGRL/FINE/3-8              3988.4531
9855.6670      3.03      42.08     2
 15                    Forest-Mixed --> FRST/FINE/3-8               2305.5953
5697.2413      1.75      24.32     3
                                                                    Area [ha]
Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                                     9           5273.3757
13030.7750      4.00

LANDUSE:
                   Agricultural Land-Generic --> AGRL              5273.3757
13030.7750      4.00    100.00

SOILS:
                                                            FINE           5273.3757
13030.7750      4.00    100.00

SLOPE:
                                                             1-3           2938.9244
7262.2292      2.23      55.73
                                                             3-8           2334.4513
5768.5458      1.77      44.27
HRUs
 16        Agricultural Land-Generic --> AGRL/FINE/1-3              2938.9244
7262.2292      2.23      55.73     1
 17        Agricultural Land-Generic --> AGRL/FINE/3-8              2334.4513
5768.5458      1.77      44.27     2
                                                                    Area [ha]
Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                                    10          12594.2853
31121.1086      9.56

LANDUSE:
                   Agricultural Land-Generic --> AGRL             12594.2853
31121.1086      9.56    100.00

SOILS:
                                                            FINE          12594.2853
31121.1086      9.56    100.00

SLOPE:
```

```
                                                        1-3          6634.3446
16393.7973      5.04     52.68
                                                        3-8          5959.9407
14727.3114      4.52     47.32
HRUs
 18       Agricultural Land-Generic --> AGRL/FINE/1-3          6634.3446
16393.7973      5.04     52.68     1
 19       Agricultural Land-Generic --> AGRL/FINE/3-8          5959.9407
14727.3114      4.52     47.32     2
                                                               Area [ha]
Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                              11           9267.1770
22899.6577      7.03

LANDUSE:
                   Agricultural Land-Generic --> AGRL          9267.1770
22899.6577      7.03    100.00

SOILS:
                                               COARSE LOAMY          2865.9598
7081.9300      2.18     30.93
                                                       FINE          6401.2172
15817.7277      4.86     69.07

SLOPE:
                                                        3-8          6000.7359
14828.1184      4.55     64.75
                                                        1-3          3266.4411
8071.5393      2.48     35.25
HRUs
 20 Agricultural Land-Generic --> AGRL/COARSE LOAMY/3-8
2865.9598           7081.9300      2.18      30.93     1
 21       Agricultural Land-Generic --> AGRL/FINE/1-3          3266.4411
8071.5393      2.48     35.25     2
 22       Agricultural Land-Generic --> AGRL/FINE/3-8          3134.7760
7746.1883      2.38     33.83     3
                                                               Area [ha]
Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                              12          15489.9144
38276.3529     11.76

LANDUSE:
                   Agricultural Land-Generic --> AGRL          7088.6249
17516.3466      5.38     45.76
                                Forest-Mixed --> FRST          8401.2894
20760.0063      6.38     54.24

SOILS:
                                                       FINE         15489.9144
38276.3529     11.76    100.00

SLOPE:
```

```
                                                         1-3         7023.2579
17354.8215      5.33    45.34
                                                         3-8         8466.6565
20921.5314      6.43    54.66
HRUs
 23      Agricultural Land-Generic --> AGRL/FINE/1-3                 3461.4945
8553.5260      2.63    22.35   1
 24      Agricultural Land-Generic --> AGRL/FINE/3-8                 3627.1304
8962.8206      2.75    23.42   2
 25                   Forest-Mixed --> FRST/FINE/1-3                 3561.7634
8801.2954      2.70    22.99   3
 26                   Forest-Mixed --> FRST/FINE/3-8                 4839.5260
11958.7108      3.67    31.24   4
                                                                     Area [ha]
Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                                13         17371.7151
42926.3766     13.19

LANDUSE:
                  Agricultural Land-Generic --> AGRL                 17371.7151
42926.3766     13.19   100.00

SOILS:
                                                        FINE         8387.1083
20724.9640      6.37    48.28
                                                  FINE LOAMY         8984.6068
22201.4126      6.82    51.72

SLOPE:
                                                         1-3         9163.1696
22642.6502      6.96    52.75
                                                         3-8         8208.5456
20283.7265      6.23    47.25
HRUs
 27      Agricultural Land-Generic --> AGRL/FINE/1-3                 4341.2118
10727.3515      3.30    24.99   1
 28      Agricultural Land-Generic --> AGRL/FINE/3-8                 4045.8965
9997.6125      3.07    23.29   2
 29 Agricultural Land-Generic --> AGRL/FINE LOAMY/1-3                4821.9577
11915.2987      3.66    27.76   3
 30 Agricultural Land-Generic --> AGRL/FINE LOAMY/3-8                4162.6491
10286.1140      3.16    23.96   4
```

APPENDIX – B: Landuse / Soil / Slope distribution

Following data shows the land use, soil and slope distribution for whole watershed area as well as for each sub basins which its area, land use classes, soil classes and slope classes.

Detailed LANDUSE/SOIL/SLOPE distribution SWAT model class Date: 12/2/2022 12:00:00 AM Time: 19:43:38.7218831

Area [ha] Area[acres]

Watershed 131741.4530 325539.7174

Number of Subbasins: 13

Area [ha] Area[acres] %Wat.Area

LANDUSE:

Forest-Mixed --> FRST 40198.1578 99331.6579 30.51

Water --> WATR 2748.5384 6791.7758 2.09

Wetlands-Non-Forested --> WETN 9994.1557 24696.0585 7.59

Agricultural Land-Generic --> AGRL 72474.8062 179088.8698 55.01

Residential --> URBN 1907.9060 4714.5310 1.45

Barren --> BARR 4417.8889 10916.8244 3.35

SOILS:

COARSE 10727.4696 26508.1136 8.14

COARSE LOAMY 23434.7790 57908.5106 17.79

FINE 76179.4475 188243.2238 57.82

FINE LOAMY 5415.1993 13381.2283 4.11

LOAMY 1236.8512 3056.3212 0.94

LOAMY SKELETON 14747.7064 36442.3198 11.19

SLOPE:

0-1 8413.9387 20791.2633 6.39

1-3 39664.7898 98013.6788 30.11

15-9999 18227.3191 45040.6168 13.84

3-8 50666.1099 125198.4908 38.46

8-15 14769.2955 36495.6677 11.21

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 1 10623.4847 26251.1618 8.06

LANDUSE:

Forest-Mixed --> FRST 6576.9813 16252.0496 4.99 61.91

Water --> WATR 150.1385 370.9998 0.11 1.41

Wetlands-Non-Forested --> WETN 1398.6354 3456.0979 1.06 13.17

Agricultural Land-Generic --> AGRL 1680.1003 4151.6119 1.28 15.81

Residential --> URBN 40.3117 99.6121 0.03 0.38

Barren --> BARR 766.3694 1893.7371 0.58 7.21

SOILS:

COARSE LOAMY 11.9143 29.4409 0.01 0.11

FINE 5957.1672 14720.4579 4.52 56.08

LOAMY SKELETON 4643.4550 11474.2096 3.52 43.71

SLOPE:

0-1 281.7337 696.1780 0.21 2.65

1-3 1625.7244 4017.2462 1.23 15.30

15-9999 2761.7069 6824.3158 2.10 26.00

3-8 3835.3407 9477.3186 2.91 36.10

8-15 2108.0309 5209.0499 1.60 19.84

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 2 4531.6506 11197.9351 3.44

LANDUSE:

Forest-Mixed --> FRST 2527.4513 6245.4586 1.92 55.77

Water --> WATR 84.5649 208.9641 0.06 1.87

Wetlands-Non-Forested --> WETN 563.5570 1392.5775 0.43 12.44

Agricultural Land-Generic --> AGRL 1331.8972 3291.1845 1.01 29.39

Residential --> URBN 16.2142 40.0662 0.01 0.36

SOILS:

COARSE LOAMY 565.7965 1398.1115 0.43 12.49

FINE 674.1901 1665.9574 0.51 14.88

LOAMY SKELETON 3283.6980 8114.1820 2.49 72.46

SLOPE:

0-1 56.4363 139.4570 0.04 1.25

1-3 383.5878 947.8647 0.29 8.46

15-9999 1218.5766 3011.1637 0.92 26.89

3-8 1536.4116 3796.5500 1.17 33.90

8-15 1328.6722 3283.2155 1.01 29.32

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 3 5025.8952 12419.2384 3.81

LANDUSE:

Water --> WATR 109.5581 270.7236 0.08 2.18

Wetlands-Non-Forested --> WETN 576.8150 1425.3388 0.44 11.48

Agricultural Land-Generic --> AGRL 4175.8398 10318.7090 3.17 83.09

Residential --> URBN 61.5425 152.0745 0.05 1.22

Barren --> BARR 98.6292 243.7177 0.07 1.96

SOILS:

COARSE LOAMY 5.6436 13.9457 0.00 0.11

FINE 5016.7410 12396.6178 3.81 99.82

SLOPE:

0-1 486.2482 1201.5435 0.37 9.67

1-3 2181.3086 5390.1226 1.66 43.40

15-9999 187.3148 462.8643 0.14 3.73

3-8 1996.3229 4933.0136 1.52 39.72

8-15 171.1902 423.0195 0.13 3.41

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 4 17585.4401 43454.5018 13.35

LANDUSE:

Forest-Mixed --> FRST 4776.6627 11803.3723 3.63 27.16

Water --> WATR 248.9469 615.1602 0.19 1.42

Wetlands-Non-Forested --> WETN 656.8113 1623.0135 0.50 3.73

Agricultural Land-Generic --> AGRL 11662.4313 28818.4508 8.85 66.32

Residential --> URBN 214.8163 530.8219 0.16 1.22

Barren --> BARR 28.5765 70.6139 0.02 0.16

SOILS:

COARSE LOAMY 2920.6244 7217.0089 2.22 16.61

FINE 10701.2222 26443.2551 8.12 60.85

LOAMY 1236.8512 3056.3212 0.94 7.03

LOAMY SKELETON 2729.5471 6744.8474 2.07 15.52

SLOPE:

0-1 1299.6478 3211.4948 0.99 7.39

1-3 6086.1645 15039.2167 4.62 34.61

15-9999 2509.4455 6200.9652 1.90 14.27

3-8 6541.1487 16163.5055 4.97 37.20

8-15 1151.8384 2846.2503 0.87 6.55

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 5 7739.1373 19123.7952 5.87

LANDUSE:

Forest-Mixed --> FRST 4569.0128 11290.2592 3.47 59.04

Water --> WATR 251.1864 620.6942 0.19 3.25

Wetlands-Non-Forested --> WETN 518.2288 1280.5692 0.39 6.70

Agricultural Land-Generic --> AGRL 2292.4792 5664.8307 1.74 29.62

Barren --> BARR 108.6623 268.5100 0.08 1.40

SOILS:

COARSE LOAMY 1724.8015 4262.0706 1.31 22.29

FINE 5349.0882 13217.8644 4.06 69.12

LOAMY SKELETON 665.6798 1644.9282 0.51 8.60

SLOPE:

0-1 313.8039 775.4250 0.24 4.05

1-3 1602.5228 3959.9139 1.22 20.71

15-9999 2247.4197 5553.4864 1.71 29.04

3-8 2610.3142 6450.2169 1.98 33.73

8-15 965.5090 2385.8210 0.73 12.48

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 6 6549.5477 16184.2597 4.97

LANDUSE:

Forest-Mixed --> FRST 82.3254 203.4301 0.06 1.26

Water --> WATR 56.6155 139.8997 0.04 0.86

Wetlands-Non-Forested --> WETN 1107.1373 2735.7916 0.84 16.90

Agricultural Land-Generic --> AGRL 4434.4615 10957.7761 3.37 67.71

Residential --> URBN 26.9640 66.6294 0.02 0.41

Barren --> BARR 841.3491 2079.0157 0.64 12.85

SOILS:

COARSE LOAMY 580.8462 1435.3000 0.44 8.87

FINE 5809.8952 14356.5416 4.41 88.71

LOAMY SKELETON 158.1113 390.7009 0.12 2.41

SLOPE:

0-1 375.7942 928.6063 0.29 5.74

1-3 1725.0702 4262.7347 1.31 26.34

15-9999 1578.0670 3899.4825 1.20 24.09

3-8 2206.1226 5451.4394 1.67 33.68

8-15 663.7986 1640.2796 0.50 10.14

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 7 10210.9874 25231.8603 7.75

LANDUSE:

Forest-Mixed --> FRST 2514.4620 6213.3614 1.91 24.63

Water --> WATR 95.9417 237.0768 0.07 0.94

Wetlands-Non-Forested --> WETN 563.4674 1392.3561 0.43 5.52

Agricultural Land-Generic --> AGRL 6769.6710 16728.1956 5.14 66.30

Residential --> URBN 67.1861 166.0202 0.05 0.66

Barren --> BARR 204.7832 506.0296 0.16 2.01

SOILS:

COARSE LOAMY 4046.6633 9999.5075 3.07 39.63

FINE 4669.0753 11537.5186 3.54 45.73

LOAMY SKELETON 1499.7728 3706.0136 1.14 14.69

SLOPE:

0-1 535.3388 1322.8490 0.41 5.24

1-3 2563.2839 6334.0028 1.95 25.10

15-9999 2216.5141 5477.1172 1.68 21.71

3-8 3595.1728 8883.8517 2.73 35.21

8-15 1305.2019 3225.2191 0.99 12.78

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 8 9478.8427 23422.6942 7.20

LANDUSE:

Forest-Mixed --> FRST 2927.7013 7234.4963 2.22 30.89

Water --> WATR 442.8907 1094.4052 0.34 4.67

Wetlands-Non-Forested --> WETN 407.7748 1007.6319 0.31 4.30

Agricultural Land-Generic --> AGRL 5394.5956 13330.3154 4.09 56.91

Residential --> URBN 193.4960 478.1382 0.15 2.04

Barren --> BARR 111.7977 276.2576 0.08 1.18

SOILS:

COARSE 43.2678 106.9170 0.03 0.46

COARSE LOAMY 1010.2101 2496.2798 0.77 10.66

FINE 8173.2334 20196.4683 6.20 86.23

LOAMY SKELETON 251.5447 621.5796 0.19 2.65

SLOPE:

0-1 624.5619 1543.3238 0.47 6.59

1-3 3145.9218 7773.7299 2.39 33.19

15-9999 722.2057 1784.6065 0.55 7.62

3-8 4208.4475 10399.2841 3.19 44.40

8-15 777.1192 1920.3003 0.59 8.20

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 9 5273.3757 13030.7750 4.00

LANDUSE:

Forest-Mixed --> FRST 116.8142 288.6538 0.09 2.22

Water --> WATR 83.5795 206.5291 0.06 1.58

Wetlands-Non-Forested --> WETN 425.2432 1050.7972 0.32 8.06

Agricultural Land-Generic --> AGRL 4331.2636 10702.7690 3.29 82.13

Residential --> URBN 105.5270 260.7624 0.08 2.00

Barren --> BARR 209.2623 517.0976 0.16 3.97

SOILS:

COARSE LOAMY 362.5362 895.8450 0.28 6.87

FINE 4909.1537 12130.7641 3.73 93.09

SLOPE:

0-1 506.5832 1251.7923 0.38 9.61

1-3 2212.4829 5467.1559 1.68 41.96

15-9999 170.2944 420.8059 0.13 3.23

3-8 2067.4505 5108.7737 1.57 39.21

8-15 314.8788 778.0813 0.24 5.97

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 10 12594.2853 31121.1086 9.56

LANDUSE:

Forest-Mixed --> FRST 1316.3100 3252.6678 1.00 10.45

Water --> WATR 147.4511 364.3590 0.11 1.17

Wetlands-Non-Forested --> WETN 527.8140 1304.2547 0.40 4.19

Agricultural Land-Generic --> AGRL 10255.9127 25342.8732 7.78 81.43

Residential --> URBN 243.0345 600.5504 0.18 1.93

Barren --> BARR 109.9165 271.6091 0.08 0.87

SOILS:

COARSE LOAMY 2533.0950 6259.4043 1.92 20.11

FINE 9697.4619 23962.9133 7.36 77.00

LOAMY SKELETON 369.8819 913.9966 0.28 2.94

SLOPE:

0-1 1070.0506 2644.1484 0.81 8.50

1-3 4792.5186 11842.5531 3.64 38.05

15-9999 826.2098 2041.6058 0.63 6.56

3-8 5000.7955 12357.2157 3.80 39.71

8-15 910.8643 2250.7912 0.69 7.23

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 11 9267.1770 22899.6577 7.03

LANDUSE:

Forest-Mixed --> FRST 2655.8216 6562.6679 2.02 28.66

Water --> WATR 383.5878 947.8647 0.29 4.14

Wetlands-Non-Forested --> WETN 1014.5100 2506.9051 0.77 10.95

Agricultural Land-Generic --> AGRL 4953.6756 12240.7802 3.76 53.45

Residential --> URBN 114.9330 284.0052 0.09 1.24

Barren --> BARR 149.2427 368.7862 0.11 1.61

SOILS:

COARSE LOAMY 5300.8038 13098.5512 4.02 57.20

FINE 3970.9670 9812.4580 3.01 42.85

SLOPE:

0-1 527.3661 1303.1479 0.40 5.69

1-3 2504.3393 6188.3477 1.90 27.02

15-9999 980.5587 2423.0095 0.74 10.58

3-8 3720.1389 9192.6493 2.82 40.14

8-15 1539.3678 3803.8549 1.17 16.61

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 12 15489.9144 38276.3529 11.76

LANDUSE:

Forest-Mixed --> FRST 8814.7262 21781.6292 6.69 56.91

Water --> WATR 334.3180 826.1165 0.25 2.16

Wetlands-Non-Forested --> WETN 398.1000 983.7250 0.30 2.57

Agricultural Land-Generic --> AGRL 5410.8098 13370.3816 4.11 34.93

Residential --> URBN 162.7695 402.2116 0.12 1.05

Barren --> BARR 370.0610 914.4393 0.28 2.39

SOILS:

COARSE 4699.9809 11613.8879 3.57 30.34

COARSE LOAMY 2931.2846 7243.3507 2.23 18.92

FINE 6714.1305 16590.9522 5.10 43.35

LOAMY SKELETON 1145.3886 2830.3124 0.87 7.39

SLOPE:

0-1 959.6862 2371.4326 0.73 6.20

1-3 4358.3172 10769.6198 3.31 28.14

15-9999 2360.4715 5832.8431 1.79 15.24

3-8 5762.7754 14240.1061 4.37 37.20

8-15 2049.5343 5064.5016 1.56 13.23

Area [ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 13 17371.7151 42926.3766 13.19

LANDUSE:

Forest-Mixed --> FRST 3319.8890 8203.6116 2.52 19.11

Water --> WATR 359.7591 888.9828 0.27 2.07

Wetlands-Non-Forested --> WETN 1836.0616 4537.0001 1.39 10.57

Agricultural Land-Generic --> AGRL 9781.6685 24170.9919 7.42 56.31

Residential --> URBN 661.1112 1633.6388 0.50 3.81

Barren --> BARR 1419.2391 3507.0108 1.08 8.17

SOILS:

COARSE 5984.2208 14787.3087 4.54 34.45

COARSE LOAMY 1440.5595 3559.6945 1.09 8.29

FINE 4537.1218 11211.4549 3.44 26.12

FINE LOAMY 5415.1993 13381.2283 4.11 31.17

LOAMY SKELETON 0.6271 1.5495 0.00 0.00

SLOPE:

0-1 1376.6879 3401.8646 1.04 7.92

1-3 6483.5478 16021.1709 4.92 37.32

15-9999	448.5344	1108.3509	0.34	2.58
3-8	7585.6686	18744.5663	5.76	43.67
8-15	1483.2898	3665.2833	1.13	8.54

APPENDIX – C: SWAT Run files

Following data shows Output of SWAT Run files for baseline scenario. It gives data of observed flow and data of the best available simulation.

FLOW_OUT_13

observed	L95PPU	U95PPU	Best_Sim	M95PPU
0.029000	0.028880	0.028880	0.028900	0.028880
0.022000	0.022350	0.022350	0.022400	0.022350
0.021000	0.020550	0.020550	0.020500	0.020550
2.806000	2.806000	2.806000	2.806000	2.806000
2.497000	2.497001	2.497001	2.497000	2.497001
3.407000	3.406999	3.406999	3.407000	3.406999
1.718000	1.718000	1.718000	1.718000	1.718000
0.363000	0.363400	0.363400	0.363400	0.363400
0.071000	0.071200	0.071200	0.071200	0.071200
0.035000	0.034890	0.034890	0.034900	0.034890
0.028000	0.027760	0.027760	0.027800	0.027760
0.020000	0.019740	0.019740	0.019700	0.019740
0.014000	0.014380	0.014380	0.014400	0.014380
0.011000	0.011120	0.011120	0.011100	0.011120
0.774000	0.774000	0.774000	0.774000	0.774000
2.982000	2.982000	2.982000	2.982000	2.982000
3.473000	3.473002	3.473002	3.473000	3.473002
7.326000	6.825999	6.825999	6.826000	6.825999
2.449000	2.448999	2.448999	2.449000	2.448999
0.902000	0.901500	0.901500	0.901500	0.901500
0.159000	0.158600	0.158600	0.158600	0.158600
0.049000	0.048840	0.048840	0.048800	0.048840
0.037000	0.036660	0.036660	0.036700	0.036660
0.027000	0.027280	0.027280	0.027300	0.027280
0.020000	0.020100	0.020100	0.020100	0.020100
0.018000	0.018300	0.018300	0.018300	0.018300

0.014000	0.013910	0.013910	0.013900	0.013910
0.017000	0.016520	0.016520	0.016500	0.016520
0.604000	0.604300	0.604300	0.604300	0.604300
0.349000	0.349000	0.349000	0.349000	0.349000
2.196000	2.195999	2.195999	2.196000	2.195999
1.064000	1.064000	1.064000	1.064000	1.064000
0.709000	0.708500	0.708500	0.708500	0.708500
0.060000	0.059470	0.059470	0.059500	0.059470
0.024000	0.024400	0.024400	0.024400	0.024400
0.019000	0.018460	0.018460	0.018500	0.018460
0.014000	0.013710	0.013710	0.013700	0.013710
0.011000	0.010650	0.010650	0.010600	0.010650
0.155000	0.155300	0.155300	0.155300	0.155300
0.448000	0.448300	0.448300	0.448300	0.448300
0.184000	0.184400	0.184400	0.184400	0.184400
1.877000	1.876999	1.876999	1.877000	1.876999
1.797000	1.797000	1.797000	1.797000	1.797000
1.186000	1.186001	1.186001	1.186000	1.186001
0.485000	0.484900	0.484900	0.484900	0.484900
0.038000	0.037970	0.037970	0.038000	0.037970
0.024000	0.023480	0.023480	0.023500	0.023480
0.019000	0.018640	0.018640	0.018600	0.018640
0.013000	0.013080	0.013080	0.013100	0.013080
0.010000	0.010140	0.010140	0.010100	0.010140
0.012000	0.011920	0.011920	0.011900	0.011920
0.165000	0.165400	0.165400	0.165400	0.165400
2.841000	2.841002	2.841002	2.841000	2.841002
2.046000	2.046000	2.046000	2.046000	2.046000
1.960000	1.959999	1.959999	1.960000	1.959999
0.849000	0.848999	0.848999	0.849000	0.848999
0.111000	0.111200	0.111200	0.111200	0.111200
0.032000	0.031660	0.031660	0.031700	0.031660
0.024000	0.023890	0.023890	0.023900	0.023890

0.018000	0.017820	0.017820	0.017800	0.017820
0.013000	0.013150	0.013150	0.013200	0.013150
0.010000	0.010180	0.010180	0.010200	0.010180
0.011000	0.011130	0.011130	0.011100	0.011130
5.055000	9.554996	9.554996	9.555000	9.554996
2.790000	4.789997	4.789997	4.790000	4.789997
4.549000	4.548997	4.548997	4.549000	4.548997
2.250000	2.250000	2.250000	2.250000	2.250000
0.614000	0.613700	0.613700	0.613700	0.613700
0.128000	0.128100	0.128100	0.128100	0.128100
0.051000	0.050740	0.050740	0.050700	0.050740
0.038000	0.037940	0.037940	0.037900	0.037940
0.028000	0.028180	0.028180	0.028200	0.028180
0.022000	0.021900	0.021900	0.021900	0.021900
0.015000	0.015390	0.015390	0.015400	0.015390
2.909000	2.908998	2.908998	2.909000	2.908998
1.104000	1.104000	1.104000	1.104000	1.104000
4.474000	6.474000	6.474000	6.474000	6.474000
3.463000	3.462999	3.462999	3.463000	3.462999
2.105000	2.105001	2.105001	2.105000	2.105001
1.547000	0.547400	0.547400	0.547400	0.547400
1.129000	0.127100	0.127100	0.127100	0.127100
0.045000	0.044760	0.044760	0.044800	0.044760
0.034000	0.033590	0.033590	0.033600	0.033590
0.025000	0.025000	0.025000	0.025000	0.025000
0.018000	0.018420	0.018420	0.018400	0.018420
0.014000	0.014240	0.014240	0.014200	0.014240
0.010000	0.010250	0.010250	0.010300	0.010250
6.284000	5.783998	5.783998	5.784000	5.783998
3.601000	3.600999	3.600999	3.601000	3.600999
3.650000	3.649999	3.649999	3.650000	3.649999
1.682000	1.681999	1.681999	1.682000	1.681999
0.286000	0.285800	0.285800	0.285800	0.285800

0.077000	0.076480	0.076480	0.076500	0.076480
0.041000	0.041240	0.041240	0.041200	0.041240
0.031000	0.030800	0.030800	0.030800	0.030800
0.023000	0.022860	0.022860	0.022900	0.022860
0.017000	0.016830	0.016830	0.016800	0.016830
0.013000	0.013010	0.013010	0.013000	0.013010
0.011000	0.010640	0.010640	0.010600	0.010640
0.294000	0.294300	0.294300	0.294300	0.294300
2.205000	2.205001	2.205001	2.205000	2.205001
2.426000	2.426001	2.426001	2.426000	2.426001
1.454000	1.454000	1.454000	1.454000	1.454000
0.623000	0.622700	0.622700	0.622700	0.622700
0.095000	0.094790	0.094790	0.094800	0.094790
0.029000	0.028910	0.028910	0.028900	0.028910
0.022000	0.021770	0.021770	0.021800	0.021770
0.016000	0.016240	0.016240	0.016200	0.016240

p-factor= 0.95

r-factor= 0.00

R2= 0.91

Nash_Sutclif= 0.87

NO3_OUT_13

observed	L95PPU	U95PPU	Best_Sim	M95PPU
4.090000	0.000175	0.000175	0.000200	0.000175
133.899994	141.399948	141.399948	141.399994	141.399948
1326.000000	1401.000000	1401.000000	1401.000000	1401.000000
268.799988	34.300014	34.300014	34.299999	34.300014
0.720000	0.000194	0.000194	0.000200	0.000194
7.000000	3.199998	3.199998	3.200000	3.199998
5.370000	0.000175	0.000175	0.000200	0.000175
41060.000000	68560.000000	68560.000000	68560.000000	68560.000000
11340.000000	12090.000000	12090.000000	12090.000000	12090.000000
223.899994	131.399948	131.399948	131.399994	131.399948
15.370000	0.000194	0.000194	0.000200	0.000194

4.000000	0.000194	0.000194	0.000200	0.000194
92.459999	30.959993	30.959993	30.959999	30.959993
7.150000	7.154000	7.154000	7.154000	7.154000
3520.500000	3497.000000	3497.000000	3497.000000	3497.000000
293.399994	178.399979	178.399979	178.399994	178.399979
5.970000	0.966400	0.966400	0.966400	0.966400
0.000000	0.000194	0.000194	0.000200	0.000194
0.000000	0.000175	0.000175	0.000200	0.000175
16620.000000	25120.000000	25120.000000	25120.000000	25120.000000
4152.500000	6195.000000	6195.000000	6195.000000	6195.000000
25.020000	97.169960	97.169960	97.169998	97.169960
0.760000	0.125600	0.125600	0.125600	0.125600
132.110001	35.560024	35.560024	35.560001	35.560024
0.090000	0.000175	0.000175	0.000200	0.000175
2690.000000	2404.000000	2404.000000	2404.000000	2404.000000
193.630005	239.299881	239.299881	239.300003	239.299881
51.680000	33.829990	33.829990	33.830002	33.829990

p-factor= 0.18

r-factor= 0.00

R2= 0.99

Nash_Sutclif= 0.56

FLOW_OUT_13

observed	L95PPU	U95PPU	Best_Sim	M95PPU
0.029000	0.028880	0.028880	0.028900	0.028880
0.022000	0.022350	0.022350	0.022400	0.022350
0.021000	0.020550	0.020550	0.020500	0.020550
2.806000	2.806000	2.806000	2.806000	2.806000
2.497000	2.497001	2.497001	2.497000	2.497001
3.407000	3.406999	3.406999	3.407000	3.406999
1.718000	1.718000	1.718000	1.718000	1.718000
0.363000	0.363400	0.363400	0.363400	0.363400
0.071000	0.071200	0.071200	0.071200	0.071200
0.035000	0.034890	0.034890	0.034900	0.034890

0.028000	0.027760	0.027760	0.027800	0.027760
0.020000	0.019740	0.019740	0.019700	0.019740
0.014000	0.014380	0.014380	0.014400	0.014380
0.011000	0.011120	0.011120	0.011100	0.011120
0.774000	0.774000	0.774000	0.774000	0.774000
2.982000	2.982000	2.982000	2.982000	2.982000
3.473000	3.473002	3.473002	3.473000	3.473002
7.326000	6.825999	6.825999	6.826000	6.825999
2.449000	2.448999	2.448999	2.449000	2.448999
0.902000	0.901500	0.901500	0.901500	0.901500
0.159000	0.158600	0.158600	0.158600	0.158600
0.049000	0.048840	0.048840	0.048800	0.048840
0.037000	0.036660	0.036660	0.036700	0.036660
0.027000	0.027280	0.027280	0.027300	0.027280
0.020000	0.020100	0.020100	0.020100	0.020100
0.018000	0.018300	0.018300	0.018300	0.018300
0.014000	0.013910	0.013910	0.013900	0.013910
0.017000	0.016520	0.016520	0.016500	0.016520
0.604000	0.604300	0.604300	0.604300	0.604300
0.349000	0.349000	0.349000	0.349000	0.349000
2.196000	2.195999	2.195999	2.196000	2.195999
1.064000	1.064000	1.064000	1.064000	1.064000
0.709000	0.708500	0.708500	0.708500	0.708500
0.060000	0.059470	0.059470	0.059500	0.059470
0.024000	0.024400	0.024400	0.024400	0.024400
0.019000	0.018460	0.018460	0.018500	0.018460
0.014000	0.013710	0.013710	0.013700	0.013710
0.011000	0.010650	0.010650	0.010600	0.010650
0.155000	0.155300	0.155300	0.155300	0.155300
0.448000	0.448300	0.448300	0.448300	0.448300
0.184000	0.184400	0.184400	0.184400	0.184400
1.877000	1.876999	1.876999	1.877000	1.876999
1.797000	1.797000	1.797000	1.797000	1.797000

1.186000	1.186001	1.186001	1.186000	1.186001
0.485000	0.484900	0.484900	0.484900	0.484900
0.038000	0.037970	0.037970	0.038000	0.037970
0.024000	0.023480	0.023480	0.023500	0.023480
0.019000	0.018640	0.018640	0.018600	0.018640
0.013000	0.013080	0.013080	0.013100	0.013080
0.010000	0.010140	0.010140	0.010100	0.010140
0.012000	0.011920	0.011920	0.011900	0.011920
0.165000	0.165400	0.165400	0.165400	0.165400
2.841000	2.841002	2.841002	2.841000	2.841002
2.046000	2.046000	2.046000	2.046000	2.046000
1.960000	1.959999	1.959999	1.960000	1.959999
0.849000	0.848999	0.848999	0.849000	0.848999
0.111000	0.111200	0.111200	0.111200	0.111200
0.032000	0.031660	0.031660	0.031700	0.031660
0.024000	0.023890	0.023890	0.023900	0.023890
0.018000	0.017820	0.017820	0.017800	0.017820
0.013000	0.013150	0.013150	0.013200	0.013150
0.010000	0.010180	0.010180	0.010200	0.010180
0.011000	0.011130	0.011130	0.011100	0.011130
5.055000	9.554996	9.554996	9.555000	9.554996
2.790000	4.789997	4.789997	4.790000	4.789997
4.549000	4.548997	4.548997	4.549000	4.548997
2.250000	2.250000	2.250000	2.250000	2.250000
0.614000	0.613700	0.613700	0.613700	0.613700
0.128000	0.128100	0.128100	0.128100	0.128100
0.051000	0.050740	0.050740	0.050700	0.050740
0.038000	0.037940	0.037940	0.037900	0.037940
0.028000	0.028180	0.028180	0.028200	0.028180
0.022000	0.021900	0.021900	0.021900	0.021900
0.015000	0.015390	0.015390	0.015400	0.015390
2.909000	2.908998	2.908998	2.909000	2.908998
1.104000	1.104000	1.104000	1.104000	1.104000

4.474000	6.474000	6.474000	6.474000	6.474000
3.463000	3.462999	3.462999	3.463000	3.462999
2.105000	2.105001	2.105001	2.105000	2.105001
1.547000	0.547400	0.547400	0.547400	0.547400
1.129000	0.127100	0.127100	0.127100	0.127100
0.045000	0.044760	0.044760	0.044800	0.044760
0.034000	0.033590	0.033590	0.033600	0.033590
0.025000	0.025000	0.025000	0.025000	0.025000
0.018000	0.018420	0.018420	0.018400	0.018420
0.014000	0.014240	0.014240	0.014200	0.014240
0.010000	0.010250	0.010250	0.010300	0.010250
6.284000	5.783998	5.783998	5.784000	5.783998
3.601000	3.600999	3.600999	3.601000	3.600999
3.650000	3.649999	3.649999	3.650000	3.649999
1.682000	1.681999	1.681999	1.682000	1.681999
0.286000	0.285800	0.285800	0.285800	0.285800
0.077000	0.076480	0.076480	0.076500	0.076480
0.041000	0.041240	0.041240	0.041200	0.041240
0.031000	0.030800	0.030800	0.030800	0.030800
0.023000	0.022860	0.022860	0.022900	0.022860
0.017000	0.016830	0.016830	0.016800	0.016830
0.013000	0.013010	0.013010	0.013000	0.013010
0.011000	0.010640	0.010640	0.010600	0.010640
0.294000	0.294300	0.294300	0.294300	0.294300
2.205000	2.205001	2.205001	2.205000	2.205001
2.426000	2.426001	2.426001	2.426000	2.426001
1.454000	1.454000	1.454000	1.454000	1.454000
0.623000	0.622700	0.622700	0.622700	0.622700
0.095000	0.094790	0.094790	0.094800	0.094790
0.029000	0.028910	0.028910	0.028900	0.028910
0.022000	0.021770	0.021770	0.021800	0.021770
0.016000	0.016240	0.016240	0.016200	0.016240

p-factor= 0.95

d_factor= 0.00

R2= 0.91

Nash_Sutclif= 0.87

NO3_OUT_13

observed	L95PPU	U95PPU	Best_Sim	M95PPU
4.090000	0.000175	0.000175	0.000200	0.000175
133.899994	141.399948	141.399948	141.399994	141.399948
1326.000000	1401.000000	1401.000000	1401.000000	1401.000000
268.799988	34.300014	34.300014	34.299999	34.300014
0.720000	0.000194	0.000194	0.000200	0.000194
7.000000	3.199998	3.199998	3.200000	3.199998
5.370000	0.000175	0.000175	0.000200	0.000175
41060.000000	68560.000000	68560.000000	68560.000000	68560.000000
11340.000000	12090.000000	12090.000000	12090.000000	12090.000000
223.899994	131.399948	131.399948	131.399994	131.399948
15.370000	0.000194	0.000194	0.000200	0.000194
4.000000	0.000194	0.000194	0.000200	0.000194
92.459999	30.959993	30.959993	30.959999	30.959993
7.150000	7.154000	7.154000	7.154000	7.154000
3520.500000	3497.000000	3497.000000	3497.000000	3497.000000
293.399994	178.399979	178.399979	178.399994	178.399979
5.970000	0.966400	0.966400	0.966400	0.966400
0.000000	0.000194	0.000194	0.000200	0.000194
0.000000	0.000175	0.000175	0.000200	0.000175
16620.000000	25120.000000	25120.000000	25120.000000	25120.000000
4152.500000	6195.000000	6195.000000	6195.000000	6195.000000
25.020000	97.169960	97.169960	97.169998	97.169960
0.760000	0.125600	0.125600	0.125600	0.125600
132.110001	35.560024	35.560024	35.560001	35.560024
0.090000	0.000175	0.000175	0.000200	0.000175
2690.000000	2404.000000	2404.000000	2404.000000	2404.000000
193.630005	239.299881	239.299881	239.300003	239.299881
51.680000	33.829990	33.829990	33.830002	33.829990

p-factor= 0.18

d_factor= 0.00

R2= 0.99

Nash_Sutclif= 0.56

Goal_type= Nash_Sutcliff No_sims= 50 Best_sim_no= 50 Best_goal = 7.137982e-001

Variable p-factor r-factor R2 NS bR2 MSE SSQR PBIAS KGE RSR MNS VOL_FR --- Mean_sim(Mean_obs) StdDev_sim(StdDev_obs)

FLOW_OUT_13 0.95 0.00 0.91 0.87 0.8291 2.8e-001 9.5e-002 -5.3 0.83 0.36 0.91 0.95 1.01(0.96) 1.69(1.47)

NO3_OUT_13 0.18 0.00 0.99 0.56 0.6102 3.0e+007 3.0e+007 -46.3 0.22 0.66 0.68 0.68 4292.88(2934.80) 13389.95(8212.58)

---- Results for behavioral parameters ---

Behavioral threshold= 0.500000

Number of behavioral simulations = 50

Variable p-factor r-factor R2 NS bR2 MSE SSQR PBIAS KGE RSR MNS VOL_FR --- Mean_sim(Mean_obs) StdDev_sim(StdDev_obs)

FLOW_OUT_13 0.95 0.00 0.91 0.87 0.8291 2.8e-001 9.5e-002 -5.3 0.83 0.36 0.00 0.95 1.01(0.96) 1.69(1.47)

NO3_OUT_13 0.18 0.00 0.99 0.56 0.6102 3.0e+007 3.0e+007 -46.3 0.22 0.66 0.00 0.68 4292.88(2934.80) 13389.95(8212.58)

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List of Publications

1. "Assessing hydrological and water quality parameters in the Hathmati Watershed using the SWAT (Soil and Water Assessment Tool)" by Payal Vinitkumar Shah, Mohd Zuned M. Shaikh and Pradeep P. Lodha in Water Practice & Technology Vol 18 No 11, 2483 doi: 10.2166/wpt.2023.151.
2. "Pollutant Load And Routing Components of Soil and Water Assessment Tool: State-of-the art Review" by Ms. Payal Shah and Dr. P. P. Lodha in Gradiva Review Journal, Volume 9, Issue 4, 2023 PAGE NO: 568-575. DOI: 10.37897.GRJ. 2022. V9I4.23.51032.
3. "A State-of-the-art review of Soil and Water Assessment Tool's Pollutant Load and Routing Components" by Ms. Payal Shah and Dr. P. P. Lodha in 1st International Conference on "Emerging Research and Innovations in Civil Engineering". May 2021, Dr. S. S. Gandhy Government Engineering College, Surat.
4. "Integrated Watershed Monitoring Framework for Irrigation Water Quality: Targeting Critical Source Areas" by Ms. Payal Shah and Dr. P. P. Lodha in International Journal of Engineering Research and Applications (IJERA), ISSN: 2248-9622, Vol. 11, Issue 1, (Series-II) January 2021, pp. 17-25. DOI: 10.9790/9622-1101021725.
5. "Climate Change Impact Assessment through Trend Analysis: A Case Study of Hathmati River, Western India" by Payal Vinit Shah and Mohdzuned M. Shaikh in International Conference on "Sustainable Technologies for Desalination & National Water Mission & Annual Congress of InDA (InDACON-2020)", February, 2020, Indus University, Ahmedabad.

Gujarat Technological University

PhD *Viva Voce* Report

TITLE OF THE THESIS:

"Water Quality Framework for Watersheds using Hydrological Modelling"

Name of the Scholar	Enrollment No.	Day & Date of Public Viva Voce	Discipline/ Branch	Venue
Shah Payal Vinitkumar	**179999912016**	**Monday 19/02/2024**	**Civil Engineering**	**Block 5, GTU, Ahmedabad**

Based on the thesis defense of above mentioned PhD Thesis, the overall recommendation on the thesis is as follows (Please tick any one of the following option):

- [x] The performance of the candidate was satisfactory. We recommend that ~~he~~/she be awarded the PhD Degree.
- [ ] Any further modifications in research work recommend by the panel after 3 months from the date of first *viva-voce* upon request of the Supervisor or request of Independent Research Scholar after which *viva-voce* can be re-conducted by the same panel again. The suggestions for improving the thesis based on the discussions during the oral examination is detailed in a separate sheet to be incorporated in the thesis.
- [ ] The performance of the candidate was unsatisfactory. We recommend that he/she should not be awarded the PhD Degree. A separate sheet is enclosed describing unsatisfactory performance.

Further, it is certified that the examiner who participated in the thesis defense through electronic medium (if any), have confirmed the above recommendation after the *viva-voce* (through email as attached; if any) and the same may be considered sufficient record for acceptance.

BOARD OF EXAMINERS:

Sl No	Name	Designation	Institute	Signature
1.	Dr. Pradeep P. Lodha	Supervisor/ Co-Supervisor*	GEC Bharuch	
2.	Dr. S. M. Yadav	External Examiner 1	SVNIT Surat	19/02/2024
3.		External Examiner 2		
4.		External Examiner 3		
5.	Dr. Nagraj S. Patil	External Examiner who participated through e-medium (if any)	VTU, Belagavi, Karnataka	

*The Co-Supervisor may sign in place of Supervisor if he/she has been assigned with the academic and administrative affairs/ responsibilities of the above mentioned scholar.

Encl.:

1) Separate sheet for suggestions / comments on the thesis (if any) endorsed by the Supervisor/ Co-Supervisor and the external examiners. The same to be provided to the scholar for revision/ modification in the thesis.
2) Email of external examiner (if any) who participated in the thesis defense through electronic medium.
3) Undertaking for final submission of hard copy of Ph.D. thesis & CD.

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Honorable Vice Chancellor