Water Quality Framework for watersheds using Hydrological Modeling

Ph.D. Synopsis

For the Degree of Doctor of Philosophy
In Civil Engineering

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Submitted to

GUJARAT TECHNOLOGICAL UNIVERSITY AHMEDABAD

[Jan - 2023]

I. Title: "Water Quality Framework for Watersheds using Hydrological Modelling"

1. Abstract

Watershed management refers to the process of implementing land use and water management practices to protect and enhance the quality of the water 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 depleting nutrient water quality parameters from watersheds it is an immense and urgent requirement to have a policy framework at the national and regional level which mandates and counters the menace of pollution.

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. 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 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 nutrient 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.

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 that assumed a 1 km buffer of forested cover on either side of the Hathmati river 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 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.

2. State the art of the research topic

Nonpoint source pollution is defined as the runoff transport of constituents from diffuse sources on the land to streams [Browne, 1990]. Nonpoint source pollution occurs when rainfall, snowmelt, or irrigation flows over land or through the ground, picks up pollutants, and deposits them into rivers, lakes, and coastal waters or introduces them into ground water [EPA, 2002]. Sediments, nutrients, and pesticides are some of the constituents that contribute to nonpoint source pollutants.

Nutrients, mainly nitrogen, phosphorous, and potassium can threaten associated water resources. They create algae and aquatic weed conditions in water bodies and accelerate the eutrophication of lakes. Nitrate nitrogen is highly mobile and has a high potential to leach below the root zone into groundwater, volatilize into the atmosphere, or be carried overland to nearby surface waters [USDA, 1997]. Phosphate is mostly carried into water bodies as a result of erosion that takes place due to runoff. Soil type, tillage practices, and climatic conditions govern the potential of these chemical transports from land to water. Pollutants, nutrients, and pesticides t in the air is transported into the watershed area either by wet or dry deposition.

Arnold et al. (1995; 1996) used the SWAT model to understand the effect of land use management on the water, sediment, and agriculture chemical yield from the large watershed by changing the soils, land use, and management activity over a long period.

Srinivasan et al. (1998) described that the largescale hydrological modeling such as SWAT significantly plays a role in policy making and planning, land management issues, assessment of the impacts and risk of management alternatives on the availability and quality of water in large and complex systems. They also discussed the Hydrological Unit Model for the United States (HUMUS) which is used for making national and river basin resource analyses.

Spruill et al (2000) used the SWAT model for the simulation of daily and monthly discharge from small watersheds. Parameters like saturated hydraulic conductivity, alpha base flow factor, recharge, drainage area, channel length, and channel width were found to be the most sensitive use in Central Kentucky. The daily assessment gave low R^2 values both for the years 1995 and 1996 with -0.04 and 0.19 respectively. Monthly totals of the data showed better performance R^2 value of 0.58 for 1995 and 0.89 for 1996. Hence, the determination of accurate parameters was found to be significant for producing simulated stream flow data.

Karakoc et al. (2003) showed lakes Eymir and Mogan in Turkey to be seriously threatened by anthropogenic activities (domestic, agricultural, and industrial), which led to eutrophication. The rising worldwide occurrence of natural disasters and pollution are symptomatic of a larger and more basic problem of environmental imbalance. Since the incident problems exist and interact with one another, they cannot be solved individually. Measures that holistically consider the economic, environmental, social, and cultural factors are crucial to the mitigation of such problems.

Abbaspour et al. (2006) applied the SWAT model for the computation of the hydrological component like discharge, sediment, and water quality in the pre-alpine/ alpine Thur watershed. Based on the study SWAT model proved to be one of the reasonable models used for the water quantity and quality studies. They concluded that a large amount of observed data is necessary for proper calibration and that the "second Storm" effect has a huge role in subjecting large model uncertainties regarding the simulation of particulates like sediment and phosphorus.

Abraham et al. (2007) applied SWAT for the Hydrological Modeling of the Meki watershed in Ethiopia in which the surface runoff volume and evapotranspiration were computed using the SCS Curve Number and Hargreaves methods respectively. Model evaluation was done using statistical parameters like Nash-Sutcliffe Efficiency and Coefficient of Determination in which satisfying results were indicated. Sensitivity analysis indicated that CN2, SOL_AWC, and ESCO were the most dominant parameter for surface runoff generation. On the contrary, GWQMN, SOL_K, rchrg_dp, and GW_REVAP had the highest influence on the base flow.

Moriasi et al. (2007) mentioned that watershed models are one of the most powerful tools used for simulating various effects of hydrological processes including soil and water resources management. About their studies of the previously published recommendations, a combination of graphical techniques and dimensionless and error-index statistics is suggested to be used for model evaluation. For a better representation of the model, quantitative statistics like Nash-Sutcliffe Efficiency, PBIAS, and RSR were recommended.

Setegn et al. (2008) applied the SWAT2005 model for hydrological modeling in the Lake Tana Basin, Ethiopia in which the model was calibrated using SUFI2, GLUE, and Parasol algorithms. The sensitivity analysis indicated that the flow was more sensitive to the HRU definition thresholds than the sub-basin discretization effect. SUFI2 and GLUE showed good performance. Thus, the calibrated model could be used for further climate and land use change analysis, and other management scenarios on flow and soil erosion.

Birhanu B Z (2009) used SWAT for the study of the distributed and lumped hydrological modeling approaches for the Kihansi River watershed in South Central Tanzania. Model evaluation using unoptimized parameters indicated poor performance, whereas with the proper specification and optimization of the parameters resulted in better hydrological processes. In this study, a correction factor was introduced for optimized parameters to facilitate future land use land cover change studies.

Xie et al. (2010) used the SWAT model for the hydrological modeling in a large watershed in Nigeria. The evaluation was conducted on a daily and sub-daily basis. The study showed that the sub-daily model was better at simulating peak flows during the flood season, which is a critical factor in the formulation of precise strategies and planning for flood control and water security in river basins. The analysis indicated that 58% of stream flow was contributed by base flow using the sub-daily model whereas the daily model showed an estimate of 34%. Despite the differences in the two models, SWAT showed to be an important tool for conducting different hydrological assessments in similar watershed behavior.

Ajay et al. (2012) conducted monthly simulations for flows in which the simulated flow is in close agreement with the measured flow data. The SWAT model offers the most comprehensive representation of hydrological processes that can be of great help to take decisions on land use management alternatives impacting water quality. The findings of the result can be applied to simulate similar watersheds under the same agroecological zone in India.

Arnold et al. (2012) explained the SWAT history development and model adaptations, and the model calibration approaches show numerous parameters that are very much sensitive to various processes. They gave a look up into the importance of manual and automated calibration, and how to fine-tune daily and sub-daily statistics keeping in mind that many SWAT parameters are all physically based and must keep within realistic range in defining the parameter.

Dessau et al. (2012) mentioned that Mara River Basin was facing unprecedented threats due to anthropogenic activities and social development such as agriculture expansion, deforestation, human settlement, deforestation, flooding, and low flow. By understanding the human interventions and natural processes complexities, a reliable representation of the relevant hydrological processes could be studied using the SWAT model. The overall performance of the model was satisfactory and the parameters established in this study may be used significantly in hydrology and assessment of water resource challenges in the Mara River Basin.

Jajarmizadeh et al. (2012) described the use of the semi-distributed model such as SWAT for flow computation and sensitivity analysis of parameters for the Roodan watershed in Iran, which is an arid and semi-arid climate condition that could be developed as they have the potential to preserve surface waters despite a shortage of water availability. They used SUFI2 for the performance evaluation which gave satisfactory statistical values of R^2 and NSE both for calibration and validation.

Lin-jing et al. (2012) used SWAT to simulate daily runoff and sediment load in a small watershed, a part of the loessial hilly-gullied region of China. The quantitative evaluation showed that the model gave acceptable NSE and R^2. SWAT however underestimated runoff and sediment load for some high-flow events. They suggested that the reason for such cases was the dependence of the SWAT on the empirical and semi-empirical models, like SCS-CN and MUSLE, which caused the model to track specific runoff and sediment load less accurately.

Lirong et al. (2012) concluded that SWAT proved to be a useful tool for assessing the effects of environmental changes including land use change and climate variability in the Beijiang River Basin in South China.

Kushwaha et al. (2013) successfully tested the model suitability using SWAT in Dabka, North-west of Nainital, and Uttarakhand having a drainage area of 69.41 km^2. The study area was predominantly covered with forest but the model showed a good response with good acceptable NSE and R^2 values. CN2 followed by SOL_K and SOL_K are more sensitive toward flow generation. Parameters like SOL_AWC, SOL_Z, and GWQMN are more sensitive for base flow generation.

Sahoo S (2013) used SWAT for assessing the hydrological behavior of the Bandu River Basin in West Bengal. He successfully performed surface runoff generation in which surface runoff lag time showed a good impact on the temporal representation of the surface runoff.

Based on the sensitivity analysis performed the Curve number and the Evapotranspiration are the main key factor for predicting surface runoff.

Diwakar et al. (2014) successfully applied to the Middle Narmada basin for the hydrological modeling and surface runoff using SWAT2012. The model was calibrated and validated using SUFI2. The analysis indicated that the base flow was an important component that contributes more than the surface runoff. More than 46% of losses in the basin were through evapotranspiration. Hence, SWAT proves to be a useful tool for such studies on the effect of climate and land use change and other management scenarios on stream flow.

Haldar et al. (2014) used the SWAT model for simulating hydrological components like discharge in Gandak Basin. They used the gridded observation precipitation datasets which were obtained from Indian Meteorological Department and APHRODITE. The outputs showed that the latter gives relatively better results. Calibration was performed using SUFI2 and PARASOL methods. Nash-Sutcliffe Efficiency (NSE) and Root Mean Square Error were used for model evaluation. The results revealed that Temperature Lapse Rate (Tlaps) and CN2 were the major parameters that significantly affected the model output.

Jain et al. (2014) performed successfully the runoff generation and sediment outflow of the Vamsadhara River basin using Soil and Water Assessment Tool (SWAT). Model performance was evaluated using quantitative Statistic parameters such as NSE, PBIAS, and R^2 with good response. The analysis showed that the initial SCS curve number for moisture condition II (CN2) was the most sensitive parameter for both flow and sediment.

Khan et al. (2014) studied that the best utility of the GIS to create the necessary data setup combined with the SWAT model can be used in large mountainous watersheds and semi-arid regions like Upper Indus Basin and Deltaic Ecology. The evaluation showed better NSE and R^2 for calibration periods. The study also recommended considering the upstream conditions for the particular basin to get the best model response.

Manaswi et al. (2014) applied SWAT for Runoff modeling of the Karam river Basin in Madhya Pradesh in which SUFI2 was used for the model calibration. By using SUFI2 they could perform an uncertainty analysis and calibration successfully giving relatively good statistical results. As most of the river originates from an intense storm during the rainy season, SWAT can be a good tool in hydrological assessment for these kinds of watersheds.

Memarian et al. (2014) used the SWAT model for the hydrological assessment of the Tropical land use scenarios in the Halu Langat Basin in Malaysia. The optimized model was run using different land use maps over the periods 1997-2008 and 1997-2004 for water discharge and sediment load estimation respectively. The analysis showed that the SWAT simulation based on the future scenarios indicated a significant increase in monthly direct runoff, monthly sediment load, and groundwater recharge as compared to the SWAT simulation based on the past conservative scenarios.

Panhalkar S S (2014) applied the SWAT model for the hydrological modeling in the mountainous Satluj Basin to assess the runoff and sediment yield of the basin. The average annual prediction of stream flow was found to be 79.67 mm and the total sediment loading was predicted to be about 51.279 T/Ha. Having a reasonably accepted R^2 and RMSE value of 0.88 and 0.71 respectively, this model could be utilized as a potential tool for water resource management of the Satluj Basin.

Patil et al. (2014) performed the Hydrological modeling assessment for the Bhima River using the SWAT model. They used SUFI2 in SWAT-CUP for the performance evaluation of the model in which they achieved good statistical results both for calibration and validation. They got NSE of 0.81 and 0.77 for calibration and validation respectively. Hence, the study showed that if the model is properly validated, can be used effectively for testing management scenarios in watersheds and for making reliable water decision-making.

Taffese et al. (2014) used SWAT to study the hydrological response of the Upper Nile Basin of Ethiopia in which the model performance criteria were fulfilled. The sensitivity analysis was carried out which indicated that ESCO and CN2 were the most sensitive parameters for that watershed. Also, according to the HRU analysis agricultural lands were the most runoff-generating areas. Hence, training farmers about Rain Water Management (RWM) interventions could give better agricultural productivity.

Abbaspour et al. (2015) successfully studied the behavior of the integrated hydrological model of Europe using the SWAT model where they consider different components like discharge, crop yield, and water quality to calibrate and validate at the Hydrological Response Unit (HRU) level. Issues like data availability, calibration of large-scale distributed models, and the procedures regarding model calibration and uncertainty analysis were discussed. They mentioned that many applications can be done with the model like conducting climate and land use change studies, calculating cross-boundary water transfer, Nitrogen loads from upstream to downstream calculation, etc. With the advancement of technology and the free availability of the required data, modeling at the continental level can be achieved at high temporal and spatial resolution.

Malunjkar et al. (2015) assessed surface runoff for the Maheshgad watershed using the SWAT model 2005. Nash-Sutcliffe Efficiency and Coefficient of Determination were the two main statistical parameters used for analysis giving a reasonably good result both for calibration and validation. Thus, the study revealed that the SWAT model is a good model for assessing hydrological response from a small watershed.

3. Definition of the Problem

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. 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.

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”)

4. Objectives

The major research objectives that we address in the problem area are:

- To create a water quality monitoring framework at the watershed level.
- To study the impact of various interventions at the watershed level through modeling.
- To study the effect of climate change on water quality parameters.

5. Scope of the Work

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.

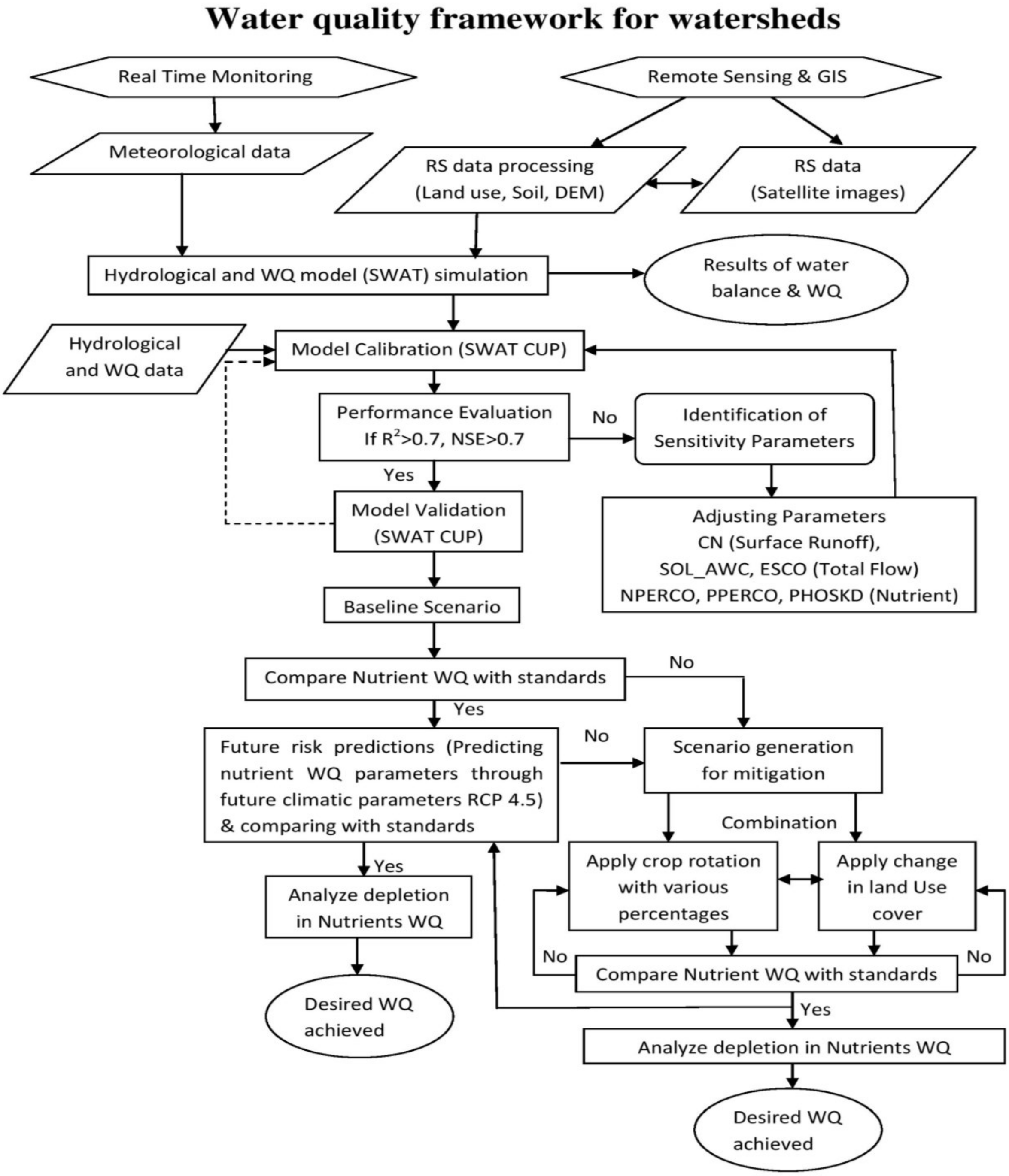
6. Original contribution of the thesis

The original contribution of the thesis is in terms of developing a water quality framework for watersheds after calibrating and validating the SWAT model for water quality analysis specifically for nutrient loads.

Water Quality Framework

A water quality framework is needed to generate information on the nature and extent of nonpoint pollution. The Water Quality Framework offers a fresh perspective on how water quality data and remote sensing data might be better integrated to support decision-makers more efficiently and better inform the public about water quality. The watershed's surface water quality management frameworks establish specific goals and take into account how all interventions in the watershed may affect the water quality. This study describes the need for and use of a water quality framework for urban and agricultural watersheds as a means to manage, protect, and restore water quality.

Watershed monitoring and water quality standards are commonly acknowledged as preventive management techniques for the protection of watersheds. Here, the framework for water quality is made up of the monitoring system and measures to stop rising nitrate concentrations in watersheds. To optimize water quality knowledge and enhance decision-making processes in support of Framework goals, SWAT modeling is being developed and maintained to support the impacts of management scenarios (crop rotation and Land use change). A crucial component of the water quality framework is monitoring nitrogen and phosphorus in the Hathmati watershed. To manage the effects of diffuse discharges from rural land use on water quality, a good water quality framework has to be implemented which has been shown below.



This may also be used to address other problems with water quality (e.g. urban stormwater and point source discharges). 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 original contribution is also observed in the research paper listed at the end.

7. Methodologies of Research and Results

A. Methodology

- Problem identification
- 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
- Simulation of the model to estimate values of hydrological parameters and nutrient parameters for different scenarios
- Results & Discussions
- Developing a water quality framework
- Conclusions & recommendation
- Literature review

B. Results

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

Precip mm	Surface runoff Q mm	Et mm	No3_surQ Kg/ha	N-org Kg/ha	P_sol Kg/ha	P_org Kg/ha	Min N kg/ha	Min P kg/ha	TN Kg/ha	TP Kg/ha
1009.14	85.52	472.28	0.042	16.49	2.046	0.005	6.010	1.32	20.24	3.17

8. Obtained results for the objectives

A. Forecasting Scenario - Prediction for 2021-2055

Precip mm	Surface runoff Q 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
959.32	141.54	315.86	0.017	16.141	1.981	0.01	2.88	0.42	19.49	5.08

B. Crop Rotation

Hydrological Parameters for different scenarios											PREDICTION FOR 2021-2055										
PRECIP MM	SURFACE RUNOFF Q MM	ET MM	NO3_SURQ KG/HA	ORGN KG/HA	SOLP KG/HA	ORGP KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA	PRECIP MM	SURFACE RUNOFF Q MM	ET MM	NO3_SURQ KG/HA	ORGN KG/HA	SOLP KG/HA	ORGP KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA
1008.952	200.043	528.910	0.016	17.933	2.213	0.008	3.250	0.440	12.71	2.90	959.32	141.18	318.613	0.023	16.312	1.989	0.01	3.25	0.44	19.99	5.12

C. Land Use change

Hydrological Parameters for different scenarios											PREDICTION FOR 2021-2055										
PRECIP MM	SURFACE RUNOFF Q MM	ET MM	NO3_SURQ KG/HA	ORGN KG/HA	SOLP KG/HA	ORGP KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA	PRECIP MM	SURFACE RUNOFF Q MM	ET MM	NO3_SURQ KG/HA	ORGN KG/HA	SOLP KG/HA	ORGP KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA
1008.401	62.260	468.066	0.009	8.589	1.068	0.003	1.060	0.320	11.48	2.63	959.32	107.57	302.224	0.004	13.443	1.641	0.006	1.46	0.21	19.03	4.75

D. Comparison with the baseline scenario

	% change (2002-2020)								% change (2021-2055)							
Scenarios	ORGN KG/HA	ORGP KG/HA	SOLP KG/HA	NO3_SURQ KG/HA	MINN KG/HA	MINP KG/HA	TN KG/HA	TP KG/HA	ORGN KG/HA	ORGP KG/HA	SOLP KG/HA	NO3_SURQ 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 of river)	-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

9. Conclusion

- Spatially, the decrease in nitrogen and phosphorus loads mainly occurred in the watershed where agricultural land was majorly replaced by dense forest.
- It is recommended that watershed conditions be continuously monitored for better

management of its hydrologic response in the present and future.

- The collective evaluation of dense forest change and climate changes predicted a noticeable decrease in surface runoff in the future climate.

- These study findings provide evidence that combined climate and dense forest changes pose a stronger impact on water quality in the future. Therefore, effective management of water requires the evaluation of the combined effects of various climate models and LULC scenarios on water quality.
- Future stream-flow predictions were modeled for RCP4.5 climatic scenarios and two intervention 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 baseline.

10. Publications

Papers:

- Mohdzuned M. Shaikh, Payal Vinit Shah, and Pradeep P. Lodha. (2020), " Climate Change Impact Assessment through Trend Analysis: A Case Study of Hathmati River, Western India ", InDACON conference, Indus University, Ahmedabad.

- Payal Shah and Dr. P. P. Lodha. (2021), "Integrated Watershed Monitoring Framework for Irrigation Water Quality: Targeting Critical Source Areas", International Journal of Engineering Research and Applications www.ijera.com ISSN: 2248-9622, Vol. 11, Issue 1, (Series-II) January 2021, pp. 17-25.

- Payal Shah and Dr. P. P. Lodha (2021), "A STATE-OF-THE-ART REVIEW OF SOIL AND WATER ASSESSMENT TOOL'S POLLUTANT LOAD AND ROUTING COMPONENTS", 1st Virtual International Conference on "Emerging Research and Innovations in Civil Engineering" ISBN No.: 978-93-54733-18-5.

11. References

1. Abbaspour K C, Johnson C A, Genuchten M T V. 2004. Estimating Uncertain Flow and Transport Parameters Using a Sequential Uncertainty Fitting Procedure. Vadose Zone Journal, pp 1341-1351.
2. Abbaspour, K. C., 2013. SWAT-CUP 2012: SWAT Calibration and Uncertainty Programs - A User Manual.
3. Abbaspour K C, Rouhalonejad E, Vaghefi S, Srinivasan R, Yang H, Kløve B. 2015. A

continental-scale hydrology and water quality model for Europe Calibration and uncertainty of a high-resolution large-scale SWAT model. Journal of Hydrology 524, pp. 733–752.

4. Abu-Ashour, J., Joy D.M., Lee H., Whiteley H.R. and Zelin S., 1998. Movement of bacteria in unsaturated soil columns with macropores. Transactions of the ASAE. 41:1043-1050

5. Agriculture and Agri-Food Canada, 2002. Assessed from: <http://sis.agr.gc.ca/cansis/soils/on/soils.html>. [6 March 2014]

6. An, Y.J., Kampbell, D. H. and Breidenbach, J. P., 2002. Escherichia coli and total coliforms in water and sediments at lake marinas. Environmental Pollution. 120: 771–778.

7. Anderson, K. L., Whitlock, J. E. and Harwood, V. J., 2005. Persistence and differential survival of fecal indicator bacteria in subtropical waters and sediments. Applied and Environmental Microbiology. 71: 3041–3048.

8. Aqua Resource, 2013. Water Budget Reference Manual. The Ontario Ministry of Natural Resources.

9. Arnold, J.G. and Fohrer, N., 2005. SWAT2000: Current capabilities and research opportunities in applied watershed modeling. Hydrological Processes. 19 (3): 563-572

10. Arnold, J. G., Kiniry, J. R., Srinivasan, R., Williams, J. R., Haney, E. B. and Neitsch, S. L., 2012. Soil and Water Assessment Tool Input/Output Documentation Version 2012. Texas Water Resource Institute, TR-4

11. Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., Santhi, C., Harmel, R. D., van Griensven, A., Van Liew, M. W., Kannan, N. and Jha, M. K., 2012. SWAT: Model Use, Calibration, and Validation. Transactions of the ASABE: 2012 American Society of Agricultural and Biological Engineers ISSN 2151-0032. 55(4): 1491-1508

12. Arnold, J.G., Srinivasan, R., Muttiah, R.S. and Williams, J.R., 1998. Large area hydrologic modeling and assessment part I: Model development. Journal of the American Water Resources Association. 34 (1): 73-89

13. Abraham L Z, Roehrigi J, Alamirew D A.2007. Calibration and Validation of Hydrologic Model for Meki Watershed, Ethiopia. University of Kassel-Witzenhausen and University of Göttingen.

14. Arnold, J.G., Neitsch, S.L., Kiniry, J.R., Williams, J.R., 2011. Soil and Water Assessment Tool Version. 2009. Texas water resources institute technical report No. 406.

15. Behrendt, H., Opitz, D. 2000. Retention of nutrients in river systems: dependence on specific runoff and hydraulic load, Hydrobiologia, 410: 111–122.

16. Birhanu Z. 2009. Hydrological modeling of the Kihansi river catchment in South Central Tanzania using SWAT model. International Journal of Water Resources and Environmental Engineering: Vol. 1 (1), pp. 001-010.

17. Bøggild, C.E., Knudby, C.J., Knudsen, M.B., Starzer, W. 1999. Snowmelt and runoff modeling of an Arctic hydrological basin in west Greenland, Hydrological Processes, 13: 1989–2002.

18. Cao W, Bowden BW, Davie T. (2006). Multi-variable and multi-site calibration and validation of SWAT in a large mountainous catchment with high spatial variability. Hydrol Process 20:1057–1073

19. Chew, C.Y., Moore, L.W., Smith, R.H. 1991. Hydrological simulation of Tennessee's North Reelfoot Creek watershed, Research Journal of the Water Pollution Control Federation, 63(1): 10–16.

20. Dessu S B, Melesse A M. 2012. Modeling the rainfall-runoff process of the Mara River basin using the Soil and Water Assessment Tool. Hydrological Process: 26, 4038–4049.

21. Diwakar S K, Kaur S, Patel N. 2014. Hydrologic Assessment in a Middle Narmada Basin, India using SWAT Model. International Journal of Engineering Technology and Computer Research (IJETCR), Volume 2 Issue 6; Page No. 10-25.

22. Haan, C. T., D. E. Storm, T. Al-Issa, S. Prabhu, G. J. Sabbagh, and D. R. Edwards. 1998. Effect of parameter distributions on uncertainty analysis of hydrologic models. Trans. ASAE 41(1): 65-70.

23. Haldar R, Singla S, Singla R, Khosa R. 2014. Hydrologic Modeling for the Gandak Basin Using SWAT with Sensitivity Considerations. International. International Journal of Earth sciences and Engineering: ISSN 0974-5904, Volume 07, No. 02.

24. Herbst, M., Fialkiewicz, W., Chen, T., Pütz, T., Thiéry, D., Mouvet, C., Vachaud, G., Vereecken, H. 2005a. "Intercomparison of Flow and Transport Models Applied to Vertical Drainage in Cropped Lysimeters", Vadose Zone Journal, 4(2): 240–254.

25. Ireson, A., Makropoulos, C., Maksimovic, C. 2006. Water Resources Modelling under Data Scarcity: Coupling MIKE BASIN and ASM Groundwater Model, Water Resources Management, 20: 567–590.

26. Jajarmizadeh M, Harun S, Abdullah R, Salarpour M. 2012. Using Soil and Water Assessment Tool for Flow Simulation and Assessment of Sensitive Parameters Applying SUFI-2 Algorithm. Caspian Journal of Applied Sciences Research, 2(1), pp. 37-44.

27. Jain M, Sharma S D. 2014. Hydrological Modeling of Vamsadhara River Basin, India

using SWAT. International Conference on Emerging Trends in Computer and Image Processing (ICETCIP'2014) Dec. 15-16, 2014 Pattaya (Thailand).
28. Keshta N, Elshorbagy A, Carey S. (2009). A generic system dynamics model for simulating and evaluating the hydrological performance of reconstructed watersheds. Hydrol Earth Syst Sci 13:865–881.
29. Kienzle, S.W., Schulze, R.E. 1992. A simulation model to assess the effect of afforestation on groundwater resources in deep sandy soils, Water SA, 18(4): 265–272.
30. Khan A D, Ghoraba S, Arnold J G, Luzio M D. 2014. Hydrological Modeling of Upper Indus Basin and Assessment of Deltaic Ecology. IJMER, ISSN: 2249–6645, Vol. 4, Iss.1.
31. Krysanova, V., Müller-Wohlfeil, D.-I., Becker, A. 1998. Development and test of a spatially distributed hydrological/water quality model for mesoscale watersheds, Ecological Modelling, 106 (2–3): 261–289.
32. Kushwaha, Akansha, and Jain M K. 2013. Hydrological Simulation in a Forest Dominated Watershed in Himalayan Region using SWAT Model. J. Water Resources Management, Springer, Vol. 27: 3005 – 3023. (DOI: 10.1007/s11269-013-0329-9) Rainfall-Runoff Modeling of a Watershed using SWAT Model
33. Luo P, Takara K, He B, Cao B, Yamashiki Y, Nover D. 2011. Calibration and Uncertainty analysis of SWAT Model in Japanese River Catchment. Journal of Hydraulic Engineering, JSCE, Vol.55.
34. Malunjkar V S, Shinde M G, Ghotekar S S, Atre A A. 2015. Estimation of Surface Runoff using SWAT Model. International Journal of Inventive Engineering and Sciences (IJIES): ISSN: 2319–9598, Volume-3 Issue-4.
35. Manaswi C.M., A.K Thawait. 2010. Application of Soil and Water Assessment Tool for Runoff Modeling of Karam River Basin in Madhya Pradesh. International Journal of Scientific Engineering and Technology (ISSN: 2277-1581) Volume No.3 Issue No.5, pp: 529-532.
36. Memarian H, Balasundram S K, Abbaspour KC, Talib J B, Sung C T B & Sood A M. 2014.SWAT-based hydrological modeling of tropical land-use Scenarios. Hydrological Sciences Journal – Journal des Sciences Hydrologiques, 59 (10).
37. Moriasi D N, Arnold J G, Liew M W V, Bingner R L, Harmel R D, Veith T L. 2007. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. Transactions of the ASABE; ISSN 0001−2351, Vol. 50(3): 885−900.
38. Panhalkar, S.S., (2014). Hydrological modeling using SWAT model and

geoinformatics techniques. The Egyptian Journal of Remote Sensing and Space Sciences (2014) 17, 197.

39. Patil N S, Raikar R V, Manoj S. 2014. Runoff Modeling for Bhima River using Swat Hydrological Model. International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 3 Issue 7.

40. Raju D B, Naidu M V S, Ramavatharam N, Rao K V G R, Reedy K S. 2005. Characterization, classification, and evaluation of soils in Chandragiri mandai of Chittoor district, Andhra Pradesh. Agropedology , 15 (1) 55-62.

41. Rosenthal, W.D., Srinivasan, R., Arnold, J.G. 1995. Alternative river management using a linked GIS-hydrology model, Transactions of the ASAE, 38(3): 783–790.

42. Rudra, R.P., Dickinson, W.T., Wall, G.J. 1985. Application of the CREAMS model in southern Ontario conditions, Transactions of the ASAE, 28(4): 1233–1240.

43. Sahoo S. 2013. Assessing Hydrological Modeling of Bandu River Basin, West Bengal (India). International Journal of Remote Sensing & Geoscience (IJRSG), ISSN No: 2319 3484, Volume 2, Issue 5.

44. Santhi, C., Arnold, J.G., Williams, J.R., Dugas, W.A. and Hauck, L. (2001) Validation of the SWAT model on a large river basin with point and nonpoint sources, J. American Water Resour. Assoc, 37(5), 1169–1188.

45. Schuol, J., and K. C. Abbaspour. 2007. Using monthly weather statistics to generate daily data in a SWAT model application in West Africa. Ecol. Model. 201(3-4): 301-311.

46. Setegn S G, Srinivasan R and Dargahi B. 2008. Hydrological Modeling in the Lake Tana Basin, Ethiopia Using SWAT Model. The Open Hydrology Journal, 2, 49-62.

47. Singh R, Kundu D K, Kumar A. 2009. Characterization of Dominant Soil Subgroups of Eastern India for Formulating Water Management Strategies. Water Technology for Eastern region (ICAR), Bhubaneshwar.

48. Singh V, Bankar N, Salunkhe S S, Bera A K, Sharma J R. 2013. Hydrological stream flow modeling on Tungabhadra catchment: parameterization and uncertainty analysis using SWAT CUP. Current Science: vol. 104, No. 9, pp 1187-1199.

49. Spruill C A, Workman S R, Taraba J L. 2000. Simulation of Daily and Monthly Stream Discharge from Small Watersheds using SWAT Model. Transactions of the American Society of Agricultural Engineers: pp 1431.

50. Srinivasan R, Arnold J G, Jones C A. 1998. Hydrologic Modeling of the United States with the Soil and Water Assessment Tool. Water Resources Development, Vol. 14, No. 3, 315± 325.

51. Taffese T and Zemadim B. 2014. Hydrological modeling of a catchment using SWAT model in the upper Blue Nile Basin of Ethiopia. E3 Journal of Environmental Research and Management: Vol. 5(5). pp. 087-091.

52. Thiéry, D., Amraoui, N. (2001), Hydrological Modelling of the Saone Basin Sensitivity to the Soil Model, Physics and Chemistry of the Earth (B), 26(5–6): 467–472.

53. Wu H, Chen B. 2015. Evaluating uncertainty estimates in distributed hydrological modeling for the Wenjing River watershed in China by GLUE, SUFI-2, and ParaSol methods. Ecological Engineering 76, pp 110–121.

54. Xie H, Nkonya E, Weilgosz B. 2010. Evaluation of the SWAT Model in Hydrologic Modeling of a Large Watershed in Nigeria. IASTED African Conference Water Resource Management.

55. Xu, Chong-yu, 2002. Textbook of Hydrologic Models (edition 2002). Uppsala University Department of Earth Sciences Hydrology.

56. Yarnal, B., Lakhtakia, M.N., Yu, Z., White, R.A., Pollard, D., Miller, D.A., Lapenta,

57. W.M. 2000. A linked meteorological and hydrological model system: the Susquehanna River Basin Experiment (SRBEX), Global and Planetary Change, 25(1–2): 149–161.