Monitoring, Modeling and Implementation of Best Management Practices to Reduce Nutrient Loadings in the Atwood and Tappan Lake Watersheds in Tuscarawas Basin, Ohio

by

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Submitted in Partial Fulfillment of the Requirements

for the Degree of

Master of Science in Engineering

in the

Civil and Environmental Engineering Program

YOUNGSTOWN STATE UNIVERSITY

August, 2023

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ABSTRACT

Water quality in lakes and reservoirs has been significantly degraded due to anthropogenic activities including point and non-point source pollution. Agricultural practices, particularly excessive fertilizer application, have been consistently identified as a major contributor to water contamination in the lakes and reservoirs. The escalation of nutrient loading into water bodies has raised serious concerns regarding eutrophication in lakes, as well as the potability of drinking water and other consumptive use of water. In order to address these problems, Best Management Practices (BMPs) have been implemented globally to reduce nutrient loadings and improve water quality in lakes and reservoirs.

This study aims to assess the effectiveness of BMPs in reducing nutrient levels in the Atwood and Tappan Lakes of the Tuscarawas basin in Ohio by monitoring the sites for water quality sampling and using the Soil and Water Assessment Tool (SWAT) for watershed modeling. Stream flow data from five USGS gauge stations were gathered for multi-site calibration and validation of the model, whereas water quality data from five representative stations within the watersheds were monitored to calibrate the model for nutrients. The performance of the model for streamflow calibration at various USGS gauging stations was satisfactory with Nash-Sutcliffe Efficiency (NSE) values ranging from 0.54 to 0.79 during calibration, and 0.50 to 0.89 during validation. However, due to limited availability of water quality data, the calibration of nutrient was not as good as hydrological calibration. Subsequently, a scenario analysis was carried out using the calibrated SWAT model to assess the effectiveness of different management practices in reducing nutrient levels from the sub-watersheds. The selection of management practices, such as filter strips, grass waterways, fertilizer reduction, crop rotation, and cover crops, were considered for analysis based on active consultation with local stakeholders involved in nutrient reduction initiatives in each watershed. The analysis encompassed 12 sub-watersheds of Atwood Lake and 10 sub-watersheds of Tappan Lake, evaluating the performance of these BMPs in both watersheds.

The analysis revealed a remarkable outcome, demonstrating that a synergistic implementation of cover crops (rye), grass waterways, and a 10% reduction in fertilizer usage caused the most substantial reduction in nutrient flow by 88%. On the contrary, only 10% reduction in fertilizer application without the incorporation of other BMPs resulted in a small reduction (9%) of nutrient levels. These results underscore the significance of implementing a comprehensive and integrated approach to effectively combat nutrient pollution while maintaining agricultural productions. The overall analysis suggested that notable reductions in total nitrogen and total phosphorus could be achieved, ranging from 8% to 53% for nitrogen, and from 7% to 88% for phosphorus, depending upon the specific combination of Best Management Practices (BMPs) implemented in the watersheds. The study emphasizes the efficacy of employing grass waterways with cover crop and fertilizer reduction to mitigate nutrient losses in both nitrogen and phosphorus.

Since the water quality model was not well calibrated, the comparison of calibrated and uncalibrated was accomplished to report the discrepancy in modeling outcome with less calibrated models. When comparing the efficacies of BMPs with the calibrated and uncalibrated water quality models, the calibrated model demonstrated a slightly higher reduction in nutrient load but not a significant difference in nutrient load reduction compared to the uncalibrated model. Furthermore, when the rankings of BMPs in terms of nutrient load reduction were compared, both the calibrated and uncalibrated models demonstrated a similar pattern and retained their relative effectiveness with a consistent order in terms of rankings despite the absolute changes in overall nutrient reduction levels between the two models. The same order of rankings from both calibrated and uncalibrated models affords credibility to the findings and imply that the relative efficacy of different BMPs in decreasing nutrient loads could be independent of model calibration. Also, the study explored on the significant impact of cattle grazing on nutrient loads within the watersheds. It was observed that allowing cattle to graze freely on pastureland resulted in a substantial increase in total nitrogen and total phosphorus. However, by reducing the grazing rate to 50% and 25%, the model predicted less increment in nutrient levels suggesting the sensitivity of cattle grazing in nutrient loadings from pastureland.

The research findings also suggested that the effectiveness of implemented BMPs could rely on the specific characteristics of each site, including the land cover, local land use pattern, and climatic conditions. This study emphasizes the selection and implementation of BMPs are site-specific and the BMP efficacy reported in this study are not simply transferable to other regions rather rely based on the unique land use and land cover characteristics of each area. By adopting the suggested BMPs in this study, significant improvement can be made in curbing nutrient runoff and its detrimental impacts on water quality in the study area. Also, this study underscored the challenges of monitoring and calibrating the SWAT model for nutrients at a small sub-watershed scale. Nonetheless, the findings provide valuable insights for stakeholders involved in the restoration of the Atwood and Tappan Lakes watersheds.

Keywords: SWAT Model, Calibration, Validation, Nutrient, Nitrogen, Phosphorus, Stakeholders

ACKNOWLEDGEMENTS

I am deeply grateful for the exceptional guidance and unwavering support provided by my esteemed advisor, Dr. Suresh Sharma, throughout my research journey. His dedication and mentorship have been invaluable, shaping the course of my study with insightful suggestions and vast experience.

I extend my heartfelt appreciation to Dr. Sahar Ehsani and Dr. Peter Kimosop, members of my thesis committee, for their valuable contributions and enriching feedback. I am thankful to Dr. Anawarul Islam, the Program Coordinator and Dr. Frank Li, the Department Chair, for fostering a conducive environment and providing consistent support and encouragement in my academic pursuits.

I would like to express immense gratitude to Youngstown State University for their funding support, enabling me to pursue my research aspirations. The university's commitment to an enriching learning experience and research environment has been truly remarkable. I am particularly grateful to Ms. Linda Adovasio for her exceptional assistance with various administrative matters, ensuring a smooth research journey.

To my esteemed colleagues, I sincerely appreciate their invaluable contributions and encouragement. Lastly, my cherished family deserves profound gratitude for their unwavering support throughout this period.

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BMP	Best Management Practices
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
GIS	Geographic Information System
HRU	Hydrologic Response Units
NCDC	National Climatic Data Center
NLCD	National Land Cover Dataset
NPDES	National Pollutant Discharge Elimination System
NSE	Nash-Sutcliffe's Efficiency
LOADEST	Load Estimator
PBIAS	Percentage Bias
RSR	RMSE Standard Deviation Ratio
STATSGO	State Soil Geographic
SSURGO	Soil Survey Geographic
SUFI-2	Sequential Uncertainty Fitting
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration and Uncertainty Procedures
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey

Chapter 1. Introduction

In recent decades, the degradation of water quality in lakes and reservoirs has intensified due to diverse human impacts. These bodies of water are essential resources for supplying drinking water, irrigating crops, providing opportunities for recreation, and maintaining aquatic ecosystems. But, they are facing substantial threat from both point and non-point sources of pollution (Plunge et al. 2022; Saravanan et al. 2023; Hashemi Aslani et al. 2023). Consequently, there have been significant problems with the quality of the water in lakes and ponds. (Burigato Costa et al. 2019; Jiang et al. 2021).

According to the findings of a number of previous studies, non-point sources of pollution from agricultural operations are an important factor contributing to the quality issues that exist in lakes and reservoirs (Risal & Parajuli 2022; Venishetty & Parajuli 2022; Zhang et al. 2022; US-EPA 2022), and one of the most important factors contributing to the contamination of water sources in the United States is, in particular, the excessive use of fertilizer in agricultural areas (Merriman et al. 2018; Rudra et al. 2020). The alarming rise in nutrient loading into water bodies has brought the problem of eutrophication in lakes, as well as the potability of drinking water and other consumptive use of water (Bhandari et al. 2017; Oliver et al. 2018; Lintern et al. 2020; Cheng et al. 2021; Venishetty & Parajuli 2022). In addition, the algal bloom alters the oxygen levels in the water bodies posing threats to water supplies, and toxicity to plant and animal life, including disturbances in fish populations. It is imperative to address and mitigate non-point pollution to preserve water resources and sustain aquatic ecosystems (Umuhire 2007).

Numerous recent studies have asserted that the implementation of conservation techniques, commonly referred to as Best Management Practices (BMPs), can effectively improve water quality issues. These practices encompass a range of strategies including Vegetative Filter Strips (VFS), Grass waterways (GWW), Fertilizer Reduction (FR), Crop Rotation (CR), and Cover Crop (CC). They have gained substantial recognition as practical measures to enhance water quality in impaired water bodies. (Liu et al. 2019; Lintern et al. 2020; Ahsan et al. 2023). The brief description of some of the well-known BMPs are discussed in the following section.

Best Management Practices in Agricultural Lands

Various conservation practices have been adopted to reduce nutrient and loadings in the lakes and reservoirs. Some of the commonly adopted BMPs are discussed in the following section.

Grass waterways

Grass waterways is one of the widely used management practices around the globe to control non-point pollution coming from its sources (Schaefer & Dogwiler 2020). The grass waterways can be natural or human made waterway whose effectiveness in controlling sediment and nutrients flow is comparatively higher among BMPs (Makarewicz et al. 2015; Leh et al. 2018; Abimbola et al. 2021). Moreover, Leh et al. (2018) argued that areas with pasture and agricultural land should be considered while implementing grassed waterways. Grass waterways helps to slow down flow velocity, thus, settle down nutrients in its bed (Luo & Zhang 2009); therefore, GWW helps to control non-point sources coming into the waterbodies (Makarewicz et al. 2015; Schaefer & Dogwiler, 2020; Abimbola et al. 2021; Hassen et al. 2022). Alongside nutrient reduction, grass waterways also play a beneficial role in enhancing infiltration, leading to the enrichment of groundwater tables and aquifers (Seka & Mohammed 2016) furthermore, they contribute to a reduction in peak flow rates within stream flows (Hyandye et al. 2018; Gashaw et al. 2021; Pandey et al. 2021).

Grass waterways are designed channels with a gentle slope and planted with grass or other appropriate vegetation (Figure 1.1). The presence of vegetation helps to reduce the speed of water flow, while the grassed waterway effectively carries the water to a stable outlet without causing erosion (United States Department of Agriculture 2012).

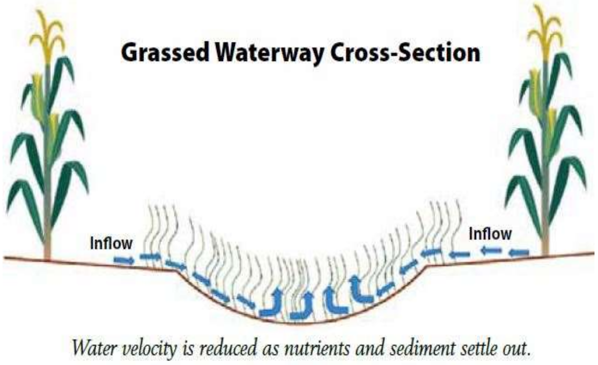

Figure1.1. A typical cross-section of grass waterways (Sanders 2016)

Vegetative Filter Strips

Vegetative filter strips (VFS) are commonly recognized as effective structural measures to mitigate non-point pollution from various sources that affect water bodies. Moreover, by incorporating biofuel plants as a filter medium, VFS can not only provide environmental benefits but also yield economic advantages through the potential for harvest (Zhang et al. 2010; Cibin et al. 2018). The concept underlying filter strips involves establishing vegetative zones along the perimeters of agricultural lands, grazing areas, forests, and other disturbed landscapes. This strategic placement of filters aims to reduce the transfer of nutrients from agricultural fields into water channels (Waidler et al. 2011).

Filter strips are strategically positioned at the lower boundaries of fields to act as protective buffers against sediment and pollutants that could harm sensitive areas like streams, lakes, and wetlands (Figure 1.2) (NRCS 2016).

Figure1.2. A vegetative filter strip between agricultural field and stream (NRCS 2016)

Cover Crops

Previous studies have consistently demonstrated the effectiveness of cover crops as a management practice in reducing nutrient runoff from agricultural lands into streams or creeks. (Sood & Ritter 2010; Yeo et al. 2014). However, Lee et al. (2016) contended that while cover crops play a crucial role in mitigating nutrient loads coming into water bodies, their performance is contingent upon several factors, including planting dates, crop rotation, and soil characteristics (Lee et al. 2016). Cover crops are typically sown following the harvest of the main crop and remain in place until the subsequent crop is ready to be planted (Bosch et al. 2013). The effectiveness of cover crops is particularly notable in watersheds with a significant agricultural presence, as these crops absorb residual nutrients following the harvest of the primary crop (Yeo et al. 2014).

Nutrient Management: Fertilizer Reduction

Nutrient management is applicable to any land area receiving plant nutrients and soil amendments such as agricultural lands. It aims to enhance crop productivity, improve soil organic matter, and minimize environmental effects. Nutrient sources encompass various inputs such as commercial fertilizers, animal manures, green manures, etc. (USDA

2019). The fertilizer reduction should be carefully employed to reduce nutrient flow while safeguarding the crop yield (Figure 1.3).

Figure1.3. Fertilizer application in agricultural lands (USDA 2019)

Crop Rotation

Crop rotation is a planned series of crops grown on the same land over a specific period. It serves multiple purposes, including preventing water quality degradation from excessive nutrients (NRCS & NHCP 2014). Crop rotations consist of alternating high-residue crops like corn or wheat with low-residue crops such as vegetables or soybeans. The specific crop choices, management of crop residues, and rotation patterns depend on factors like soil type, farming practices, and desired outcomes (USDA 2014).

Scope and Objective

The main objectives of this study are as follows:

1. To monitor and model Atwood & Tappan Lake watershed.
2. To evaluate the effectiveness of management practices in the watersheds in terms of nutrient reductions.

Methodology for Objective I

a) Prepare the SWAT simulation input data, including climatic data (precipitation and temperature), stream flow data at various USGS gauge stations, soil data, land use data, etc.

b) Set up SWAT 2012 model in ArcMap 10.7.1 with Arc-SWAT interface to delineate watersheds for model simulation.

c) Calibrate and validate the SWAT hydrologic model with SWAT-CUP.

d) Locate representative monitoring stations within the study area, then collect water samples, and perform water quality analysis in the laboratory.

e) Calibrate SWAT model for nutrient analysis with the help of observed water quality data obtained from previous step.

Methodology for Objective II

a) Experiment various management practices to evaluate their efficacy in terms of nutrient reduction within the study area by comparing with base line condition.

b) Evaluate the sensitivity of cattle grazing rate in nutrient load.

c) Compare the results of calibrated and uncalibrated model in terms of effectiveness of management practices in terms of nutrient reduction.

Thesis Structure

This thesis consists of two distinct chapters. Chapter 1 provides an overview of the context, scope, and objectives of the research, along with an outline of the overall organization of the thesis.

Chapter 2 focuses on the comprehensive process of developing the SWAT model for the watersheds that encompass Atwood and Tappan Lakes. This process includes various stages, starting from delineation of watershed area and extending to the preparation of input data, as well as model calibration and validation for both flow and nutrient parameters. Importantly, this section explores different management practices emphasizing their efficacies in nutrient reduction. Detailed results and conclusions regarding the efficacy of the management practices in reducing nutrient loads in both watersheds are also elaborated upon in this chapter. In addition, the second chapter takes the form of a journal paper, which could potentially be developed into a standalone publication in the future. Since a journal paper should be self-contained and accessible to independent readers, therefore, readers may encounter repetitions within this chapter.

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Chapter 2. Monitoring and Modeling Atwood and Tappan Lake Watershed by Engaging Stakeholders for the Implementation of Best Management Practices

Abstract

Various Best Management Practices (BMPs) have been implemented around the world in order to reduce the nutrient loadings in lakes and reservoirs. This study was conducted in the Atwood and Tappan Lakes watersheds of the Tuscarawas basin of Ohio. The flow and nutrient loadings were monitored for a few years at the various locations of the watershed to develop the Soil and Water Assessment Tool (SWAT). The multi-site SWAT model calibration and validation were accomplished with a reasonable model performance. In the next step, the scenario analysis was conducted in the SWAT model using various BMPs, including vegetative filter strips, grass waterways, fertilizer reduction, crop rotation, and cover crops to evaluate their performance in reducing nutrients from the watershed. These BMPs were selected based on active consultation with the local stakeholders, who were engaged in the reduction of nutrient loadings from the watersheds. Since the SWAT model calibration for nutrients was not as good as the hydrologic model calibration, various scenarios of nutrient reduction using BMPs were investigated for several years using both calibrated and uncalibrated SWAT models. We examined all the BMPs in 12 sub-watersheds of Atwood and 10 sub-watersheds of the Tappan Lake watershed. The analysis indicated that the management practices of cover crops (rye) in combination with grass waterways with a 10% fertilizer reduction could minimize the nutrient loading to as high as 88%, without significantly compromising the agricultural yield. However, a 10% fertilizer reduction without any BMPs could reduce nutrients just by 9%. The cover crop (rye), 10% fertilizer reduction with grass waterways seems to be the most effective in reducing nutrients, whereas the implementation of a filter strip could be the next effective BMPs to reduce nutrient loadings. In general, Total Nitrogen (TN) losses were reduced by 8% to 53%, while Total Phosphorus (TP) losses were reduced by 7% to 88%, depending on the BMPs used. By and large, the nutrient reduction achieved through the calibrated model was not significantly different from the uncalibrated model even though the nutrient reduction using the calibrated model was slightly higher for all scenarios than that of the uncalibrated model. Our investigation revealed that monitoring the watershed at a small sub-watershed scale and calibrating the SWAT model for nutrients is a delicate job. This analysis is expected to be helpful for the stakeholders working on the restoration of both watersheds.

Keywords: SWAT model, BMPs, Calibration, Validation, Nutrient, Monitoring

Introduction

The most significant reserves of freshwater resources are the earth's surface lakes, reservoirs, rivers, and springs (Vasistha & Ganguly 2020). Water quality problems in lakes and reservoirs have become increasingly critical over the past few decades as a result of anthropogenic influences including point and non-point sources (Iavorivska et al. 2021; Han et al. 2021; Chang et al. 2021; Plunge et al. 2022; Saravanan et al. 2023; Hashemi Aslani et al. 2023) resulting in serious water quality issues in lakes and ponds (Burigato Costa et al. 2019; Jiang et al. 2021).

Several past studies reported that non-point sources from the agricultural activities (Risal & Parajuli 2022; Venishetty & Parajuli 2022; Zhang et al. 2022; US-EPA 2022), especially due to the nutrient loading from the agricultural field, is one of the major contributor of the water contamination in the United States (Peacher et al. 2018; Merriman et al. 2018; Rudra et al. 2020). Since the farmers generally tend to increase fertilizer input in the field for the high agricultural production (Qi & Altinakar 2011; Zhu et al. 2012; Zuo et al. 2022), excessive use of fertilizers enriched with nitrogen (N) and phosphorus (P) has increased the amount of nutrients discharged into the water bodies thus degrading the quality of lakes and ponds (Carpenter 2008; Shen et al. 2013; Bonab 2019; Risal & Parajuli 2019; Alam & Dutta 2021; Roland et al. 2022; Homayounfar et al. 2023).

The alarming rate of nutrient loading entering water bodies has posed critical challenges, notably the escalating issue of eutrophication in lakes, compromising the quality of drinking water, and impacting various water-related activities (Merriman et al. 2009; Dash et al. 2015; Andersen et al. 2016; Bhandari et al. 2017; Oliver et al. 2018; Lintern et al. 2020; Cheng et al. 2021; Venishetty & Parajuli 2022).

To minimize the adverse effects of nutrient pollution in water bodies, many researchers in recent studies claimed conservation methods, also known as Best Management Practices (BMPs) including Vegetative Filter Strips (VFS), Grass Waterways (GWW), Fertilizer Reduction (FR), Crop Rotation (CR), and Cover Crop (CC) have been widely recommended as viable mitigation measures to improve water quality in impaired waterbodies (Chen et al. 2015; Sith et al. 2019; Briak et al. 2019; Liu et al. 2019; Lintern et al. 2020; Ahsan et al. 2023). However, the efficacy of BMPs which are being used to reduce the non-point pollution is case by case and mostly limited to individual site locations. Therefore, there has not been any standardized or widely approved BMPs coherent for all type of case studies (Merriman et al. 2009; Tasdighi et al. 2018; Hubbart 2021).

Even though the field experiments are ideal for assessing the effectiveness of these BMPs for a particular site, field experiments especially in a small scale are challenging because of their high cost and lengthy duration (Guo et al. 2020). One of the typical approaches to address this issue is to use simulation model and evaluate the appropriate BMPs for the specific study. Numerous studies conducted in recent decades have utilized the Soil and Water Assessment Tool (SWAT) model to investigate the effectiveness of BMPs in water quality analysis (Uribe et al. 2018; Merriman et al. 2019; Olaoye et al. 2021; Gu et al. 2022; Nepal & Parajuli 2022). For example, several studies reported that VFS could potentially reduce the nutrient level from 31% to 90% (Cibin et al. 2018; Himanshu et al. 2019 ; and Risal & Parajuli 2022). Similarly, several investigations have demonstrated that crop rotation can lead to a significant decrease in nutrient load, with reductions ranging from 15% to 32% (Himanshu et al. 2019; Jiang et al. 2021; Ahsan et al.

2023). Additionally, the application of cover crops has been shown to effectively decrease nutrient loads by 20% to 38%S, as observed in various studies (Singer et al. 2011; Hively et al. 2020). Furthermore, research by various scientists reported that GWW has found to be effective (Hassen et al. 2022), and could reduce the nutrient concentration by 17% (Hanief & Laursen 2019).

However, in order to develop scenario analysis, long term flow, water quality data and other watershed information are needed to appropriately calibrate and validate the models. Many researchers pointed out that addressing nutrient pollution by employing BMPs is still complex and have an immense challenge (Ongley et al. 2010; Duncan, 2014; Yeboah, Lupi, & Kaplowitz, 2015; Tasdighi et al. 2018; Han et al. 2021; Chen et al. 2022) due to poor design such as undersize of proposed structure and lack of adequate maintenance of the structure (Li, 2015; Lintern et al. 2020). Most importantly, many BMPs are not either simply sustainable due to site conditions or the farmers and local stakeholders have a strong reservation about the implementation and the maintenance of such BMPs in the long run. In this context, the consultation with watershed stakeholders, for instance watershed specialist and engagement of local farmers of the related study area, is crucial for the sustainable BMPs application in the field incorporating the field data and information (Taylor, He, & Hiscock 2016; Hubbart, Kellner, & Zeiger 2019; Neumann et al. 2021; Martin et al. 2021; Basso et al. 2022; Parsinejad et al. 2022). Such models developed using the data from field monitoring along with the direct involvement of stakeholders (Kreiling, Thoms, & Richardson 2018) can be helpful to better understand the water and nutrient transport processes (Kalcic et al. 2016; Ricci et al. 2022). Besides modeling, active stakeholder engagement from the onset of project design is equally important for sustainable water quality management to integrate the stakeholder's perceptions of water quality problems, indigenous knowledge, expertise, and rights in the decision-making process. Though several scientific tools and approaches for BMPs have been developed, very few of them are sustainable for the benefit of the community. Therefore, this study will involve coordination with various stakeholders, including agencies engaged in water quality monitoring, to obtain their potential suggestions for model development.

Since the selection of a watershed model plays a crucial role in analyzing BMPs (Shrestha et al. 2019), the widely used SWAT model was selected as the primary modeling tool for this study. In summary, the major objectives of this study are: i) to monitor the watershed at selected stations, collect the sample and analyze the nutrient for SWAT model development; ii) calibrate the model for flow and nutrient to analyze the BMPs for the potential reduction of nutrient loads into Atwood & Tappan Lake from the sub watersheds.

Materials and Methods

Study Area

The study was conducted in Atwood and Tappan Lake watersheds located within the Tuscarawas basin, which is geographically positioned in the northeast part of Ohio (Figure 2.1). The Atwood Lake watershed encompasses 181 km^2, whereas the Tappan Lake watershed covers 183 km^2. Both watersheds, with elevations ranging from 256 to 415 m, drain into their respective lakes and receive 1085 mm of precipitation per year. In general, each watershed is dominated by forest accounting for more than 50% of the entire watershed area. Atwood and Tappan share the similar watershed characteristics in terms of land use and landcover. For example, the Atwood and Tappan watersheds are distinguished by their distinct land-use patterns, with approximately 30% and 20% of agricultural land including pasture, respectively (Figure 2.2). These land uses are considered major sources of non-point source pollution. Though the portion of agricultural/hay area is relatively less, both lakes experience water quality impairment, including eutrophication and algal bloom. Tappan Lake provides drinking water to the town of Cadiz, while Atwood Lake serves only a small portion of Carroll County.

Soil and Water Assessment Tool (SWAT)

SWAT model is a process-based, semi-distributed watershed model that operates in real-time (Arnold et al. 1998). Globally, SWAT is one of the most used watershed models to assess the impact of management practices on analyzing water quantity and quality (Almeida, Pereira, & Pinto 2018; Merriman et al. 2018; Venishetty & Parajuli 2022; Risal & Parajuli 2022; López-Ballesteros et al. 2023). The model is popularly used for the simulation of hydrologic analysis, erosion, nutrient cycle, and pesticide transport (Neitsch et al. 2005; Bonab 2019) in small to very large complex watersheds with varied soil and land use characteristics across the world (Arnold et al. 2012; Shrestha 2014; Almeida et al. 2018).

There are typically two phases of the hydrological cycle represented in the SWAT model, including the land phase and the routing of runoff through the reaches. When simulating the land phase of a river's flow, researchers divide the basin into smaller sections called "sub-basins," each of which has its own unique set of land use/land cover, soil type, and slope. The water balance is then determined for additional Hydrologic Response Units (HRUs) in each sub-basin. During routing phase, control points decide how water will flow through the stream network and discharges from the basin outlet, connecting the many sub-basin outlets (Shrestha 2017; Folle 2010).

SWAT Model Input

The simulation of stream flows involves inputs including digital elevation model (DEM), land use, soil, and weather etc. (Table 2.1). The stream networks were delineated in ArcGIS using a digital elevation model (DEM) of 30 m resolution, which was downloaded from the USGS National Elevation Dataset. This resulted in the creation of 46 subbasins following the demarcation of the watershed boundary. Moreover, most recent land use data with a resolution of 30 meters was obtained from the National Land Cover Database (NLCD 2016) to appropriately represent the existing land use characteristics of the watershed. The high-resolution soil data from Soil Survey Geographic Database (SSURGO) was used as the input for the SWAT model. Since a large number of HRUS are extremely helpful for streamflow prediction (Sharma 2016), 761 HRUs were created after excluding the minor land uses, soils and slopes using a threshold of 10%, 10% and 5%, respectively.

In order to capture the spatial and temporal variability of the precipitation, and temperatures, the climate data over the past 20 years were utilized from the National Climatic Data Center (NCDC). Altogether, four precipitation and temperature stations were incorporated in the model and the remaining climatic datasets were simulated using the SWAT built-in weather generator. Additionally, five USGS locations were used to obtain the daily flow data to accomplish multi-site calibration and validation of the stream flow.

Model Calibration & Validation

The application of distributed watershed models as decision-making tools in the fields of water management is increasing (Yang et al. 2008) . Therefore, it is essential that these models pass a comprehensive process of calibration and validation. For this, the model was set up to calibrate and validate at multiple sites by using SUFI-2 algorithm in SWAT Calibration and Uncertainty Program (SWAT-CUP) (Abbaspour 2015; Sharma 2016; Asl-Rousta et al. 2018; Tejaswini & Sathian 2018).

The SWAT Model was set up for the period of 2000-2020 and run in monthly time steps after an initial 3-year warm up period (2000-2002). Thirteen years of observed streamflow data from 2003 to 2015 at three USGS sites within the Tuscarawas watershed were used for model calibration. The SWAT-CUP was utilized to conduct the sensitivity analysis to identify the most sensitive model parameters for hydrologic simulation. Additionally, manual calibration was also undertaken following the automated calibration to fine tune the model parameters. Twenty distinct parameters were selected for hydrological calibration (Table 2.2) based on the previous studies (Sharma, 2016; Almeida et al. 2018). In the next step, the optimized model parameters were tested against the observed streamflow data from 2016 to 2020 at each site for validation using various statistical measures to evaluate the performance of the model including Coefficient of Determination (R^2), Nash-Sutcliffe Efficiency (NSE) (Moriasi et al. 2007; Asl-Rousta et al. 2018; Almeida et al. 2018), Percent of Bias (PBIAS) and Root Mean Square Error (RSR).

Hydrologic and Water Quality Monitoring

Since the long term and spatially distributed hydrologic and water quality data are essential for simulation studies, the monitoring sites were established at various locations on Atwood and Tappan Lake sub-watersheds. The five stations (Figure 2.2) were identified by consulting with the stakeholders of Carroll and Harrison Counties, which generally represent the upstream sub watersheds. The water samples were collected by grab sampling method at the five stations and sent to water quality laboratory for the analysis of total nitrogen and total phosphorus concentrations. Meanwhile, stream flow data was also recorded on those stations with the help of Flow Tracker 2, which was specifically used to log the flow data at small shallow creeks.

The water quality monitoring plan (Josh 2019) was adopted during the collection and analysis of water samples, whereas the EPA protocol was followed for water sample collection and delivery to the laboratory. For example, a sample bottle was rinsed three times before collecting water sample and then preserved the sample with 2 ml Sulphuric acid (H_2SO_4). Then the samples were stored in ice box to maintain the temperature below 6 degree for laboratory analysis of total nitrogen & total phosphorus.

Since, the water quality data was sporadically available from 2015 to 2022, in an average, 15 observed data were recorded for each designated monitoring stations. Particularly for nutrient simulation, we chose a manual calibration in SWAT model with manual calibration helper using available observed nutrient data. The most sensitive parameters (Table 2.3) which were identified through similar studies conducted in different regions were considered in the SWAT model (Venishetty & Parajuli 2022; Ahsan et al. 2023). Since it is a general practice to use a regression-based Load Estimator (LOADEST), a software developed by USGS to generate continuous data from sporadic sets of data (Leh et al. 2018; Abimbola et al. 2021; Nepal & Parajuli 2022), this study utilized LOADEST to interpolate observed nutrient data Sat the five monitoring stations to generate continuous data in daily and monthly scale.

Best Management Practices Scenarios

In order to analyze the effectiveness of the BMPs on reducing nutrient pollution, such as vegetative filter strip (VFS), grass water ways (GWW), crop rotation (CR), cover crop (CC), fertilizer reduction (FR), these BMPS were employed in the agricultural areas of both watersheds in the SWAT model to simulate nutrient loadings. The efficacy of all BMPs was evaluated in the Atwood and Tappan Lake sub-basins by computing the reduction in nutrient yield at the outlets of respective lakes and comparing with the baseline scenario (i.e., no BMPs). Besides, this study evaluates the sensitivity of cattle grazing pattern in the pasture lands of both watersheds, resulting in nutrient yields.

In this study, VFS of 1 m width was applied only for agricultural and pasture land use, which were identified in both watersheds in the ArcGIS. We also experimented with 7 m width VFS but the agricultural area in both watersheds is relatively small; therefore, we adopted VFS of 1 m width as reasonable selection. Similarly, the average width (GWATW) of 3 m and depth (GWATD) of 0.5 m GWW with other default values of parameters GWATN, GWATL & GWATS was considered while simulating GWW in the model. The winter cover crop rye is simulated in this study which has demonstrated reasonable effectiveness in lowering the nitrogen load from the agricultural fields (Malone et al. 2020) as we discussed with the producers and stakeholders for the feasible cover crops that could potentially be used in the watersheds. The cover crop rye was simulated after completing harvest and kill operation of the major crop.

Next, crop rotation is a common farming method that lets different crops be grown in the same area at different times (Ni & Parajuli 2018). The water quality can be improved by changing the order of cultivation of different crops (Almendinger & Ulrich 2017; Risal & Parajuli 2019; Jiang et al. 2021), hence, by consulting with stakeholders corn-soyabean rotation was simulated in alternate years to assess nutrient yields.

Likewise, in order to simulate the impact of nutrient management, the fertilizer application rate was reduced by 10%; as one of the BMPs to evaluate the nutrient reduction and crop yield. The greater amount of nutrient flow is one of the consequences of over exploitation of pasture fields by cattle grazing (Chaubey et al. 2010; Sheshukov et al. 2016; Park, Ale, & Teague 2017). In order to analyze the impact of cattle grazing in nutrient yields from pasture lands, the population of cattle, grass consumption and manure deposition was roughly estimated based on the various reports (Turner & Morris 2021; James et al. 2006). Since it was not easy to exactly determine the number cattle grazing in the field in the given month, the sensitivity analysis was done in nutrient yield using percentage cattle (25%, 50% and 100%) engaged in grazing.

In order to better understand the effects of climate variability on the implementation of best management practices (BMPs), simulations were carried out over a span of several years, from 2000 to 2022. These simulations were conducted at intervals of every seven years, which included a warm-up period of two years. This approach of short and equal interval of running the model was taken to ensure that the model could produce coherent and consistent analysis on BMP implementation.

Result and Discussions

Model Calibration

The graphical representation and statistical criteria exhibited satisfactory SWAT model performance during calibration and validation (Figure 2.3). The statistical parameters NSE, R^2, PBIAS & RSR that measure the monthly performance of the model are tabulated in Table 2.4. The NSE values ranged from 0.54 to 0.79 for monthly streamflow calibration, and from 0.50 to 0.89 for monthly streamflow validation at USGS gauge stations. The sub watershed response in terms of flow was consistent with the overall flow from the final outlet of the entire basin. The performance of the model for the sub basins representing the Atwood Lake (lake outlet) and Tappan Lake (lake outlet) watersheds show satisfactory result and not as good as other three stations, which were used in model calibration because the observed time series discharge of those lake outlets was limited (Figure 2.4). However, we experimented with various precipitation data from the stations located within the watershed boundaries and beyond to ensure that the precipitation data was more or less consistent with the observed streamflow. Our analysis suggested that the precipitation data utilized in our model analysis appropriately represented the corresponding observed streamflow of respective locations (lake outlets).

Water Quality Calibration

The graphical representation of simulation of water quality analysis for base line was compared with the monitored nutrient data (Figure 2.5) for 5 different stations. However, a single station is presented in figure 2.6 for general understanding. The nutrient calibration in the present study was relatively less satisfactory as compared to the hydrological model calibration. This can be attributed to the fact that the available sporadic data pertaining to nutrient concentrations were limited in number, and only a few of these data sets were encompassed by the simulated datasets. The correlation between observed concentrations and simulated concentrations for five monitoring stations were compared to see the performance of the calibrated model in predicting nutrient flow.

Among them the outlet of Atwood and Tappan lakes showed negative correlation. It could be because of possible internal loading of the lakes due to resuspension of the sediment from the lakes. This part is easily ignored by the SWAT model because SWAT treats the lake as a simple waterbody and does not include lake water quality modeling. It is noteworthy to report that the calibration of the model for nutrient were accomplished in the upstream of the lake as SWAT model does not simulate the lake nutrient processes and the calibration of the nutrient at the outlet is not justified unless we couple with hydrodynamic and water quality models.

In addition, continuous daily total nitrogen & total phosphorus load (kg/d) from 2015 to 2022 was estimated by the LOADEST. In the next step, after converting the daily load to average monthly, the estimated monthly average load was compared with the load simulated by the SWAT model. The graphical representation of the comparison is depicted in Figure 2.6 (Station ATW 10). The load distribution pattern appears to be comparable to the LOADEST and SWAT models, despite significant differences in peak load estimations. Specifically, the peak load estimations produced by LOADEST are significantly lower than those produced by the SWAT model. This disparity could be due to a number of variables, including a lack of sufficient observed data. One of the reasons for underestimation by the LOADEST regression could be due to the sample primarily being taken during the low and medium flows. The water quality sampling during extremely high flows was not physically possible due to the size of the streams. The LOADEST primarily relies on 10 available regression equations and can decide the best fitting of the observed data with simulated output based on the data pattern. While we experimented with all regression equations in the LOADEST, the regression equation automatically selected by the LOADEST was used for the analysis.

The water quality calibration analyses' results along with the hazard map of nutrient loading in base scenario for both watersheds are presented in the appendices.

BMPs Analysis

This study used the existing practice of corn cultivation and fertilizer input as base line scenario to evaluate operation management strategies. Since the water quality calibration was not as good as the hydrologic calibration, the BMPs were simulated in both calibrated and uncalibrated SWAT model and the results were compared in terms of nutrient reduction. The analysis conducted in Atwood watershed showed that each BMPs showed a wide range of variations in total nitrogen and total phosphorus concentrations in various years in both watersheds (Figure 2.7). The study found that the modeled BMPs generally have small variability in total phosphorus reduction, except for a scenario in which the cover crop was implemented with a 10% fertilizer reduction (Figure 2.8). It is worthwhile to report that the yield was significantly reduced while the fertilizer reduction was lowered by more than 10%. Therefore, fertilizer reduction was limited up to 10% with a negligible change in crop yield. However, there was some variation among BMPs in terms of their efficacy to reduce total nitrogen and total phosphorus. The average reduction in total nitrogen and total phosphorus by application of BMPs and their combinations at the outlet of both lakes is presented in the Figure 2.9. The reduction in nutrients was experimented individually in both watersheds.

The simulation study conducted in the Atwood watershed using GWW suggested that the reduction of total nitrogen and total phosphorus sought to be 40% and 81%, respectively, at the outlet of the lake. The reduction indicated that the effectiveness of GWW is comparatively higher, and similar type of findings was also asserted by previous study (Makarewicz et al. 2015). Likewise, VFS exhibited reductions of 32% for both total nitrogen and total phosphorus which is similar with previous studies having such range of reductions (Pongpetch et al. 2015; Jang, Ahn, and Kim 2017). The total nitrogen and total phosphorus were reduced by 8% and 7%, respectively, with a minor decrease in agricultural yield (1%) while applying 10% fertilizer reduction. Since, Rye was predominately used cover crop, we experimented with the combination of Rye, GWW and

10% fertilizer reduction. It further reduced the total nitrogen and total phosphorus by 48% & 85%, respectively.

Since both watersheds shared the similar land use/land cover characteristics, and climatic features, the nutrient reduction in Tappan watersheds showed similar nature of nutrient reduction by BMPs at the outlet of the lake while comparing with baseline for the entire simulation period of 2000 to 2022 (Figure 2.10). The analysis conducted in the Tappan watershed suggested that the effectiveness of GWW was significant. The average reduction of total nitrogen was observed by 46%, whereas total phosphorus was reduced by 86% (Figure 2.10). In fact, the reduction of total nitrogen by GWW was as low as 22% in 2012, whereas it was as high as 54% in 2004. This is not surprising because the year 2012 was a dry year with annual precipitation of 892 mm, whereas year 2004 was considered a wet year with annual precipitation of 1370 mm, and the nutrient simulation in SWAT model was primarily driven by the climate as we did not vary the fertilizer application and land use/land cover each year (Figure 2.11). However, variation in total phosphorus reduction was less sensitive to climatic patterns. Next, standalone BMP as a fertilizer reduction of 10% was experimented which lowered the total nitrogen & total phosphorus by 9% & 7%, respectively in the same simulation period. However, the removal efficiency was not significantly varied in both years, which suggested that BMP is less sensitive to climatic variability. Likewise, the implementation of VFS in an average reduced total nitrogen & total phosphorus by 34% & 68%, respectively for the entire simulation period. This finding of efficacy of VFS for nutrient reduction was consistent with the many previous studies (Risal and Parajuli 2022). In addition, it is interesting to report that the performance of VFS was similar to GWW for total nitrogen reduction, which was as high as 38% in wet year, and as low as of 17% in dry year of 2004 and 2012, respectively However, the removal efficiency was not significantly varied in both years, which suggested that BMP is less sensitive to climatic variability. The scenario analysis with the combination of Rye, GWW & 10% fertilizer reduction was experimented in the model, which showed the reduction of total nitrogen & total phosphorus by 53% & 88% respectively (Figure 2.12). In addition, the overall analysis of both watersheds demonstrated similar phenomena in nutrient reduction while simulating the model for entire simulation period of 2000-2022.

In general, while comparing the individual effect of BMPs in both watersheds, GWW showed highest average reduction in total nitrogen ranges from 20% to 53%, while VFS decreased average total nitrogen load ranges from 16% to 40%. The results indicated that percentage reductions in total nitrogen were sensitive to climatic conditions, as the watershed experienced comparatively low precipitation in 2012 and comparatively high flow in 2004. The effectiveness of GWW in the reduction of average total phosphorus varied from 82% to 87%, while VFS reduced average total phosphorus load from 67% to 72% during the simulation period. Moreover, the analysis revealed that fertilizer reduction of 10% reduced the total nitrogen and total phosphorus by 9% and 7%, respectively throughout the simulation period with small variability in reduction from year to year. It is crucial to report here that the higher reduction of nutrient in GWW is not only because of its efficacy but also due to its application in relatively larger areas as the GWW was implemented all in agricultural and pasture areas, which covered almost 25 to 30% of the total watersheds for both Atwood and Tappan. Therefore, the efficacy of each BMPs is location specific and true only for this particular research and these findings are not simply transferrable to the other locations as the fertilizer reduction could be more effective in the watershed where agricultural land is significant.

On the other hand, BMPs such as fertilizer reduction, cover crop and crop rotation were not effective for reducing nutrient as those were limited to agricultural lands, which account for a small percentage of the overall watershed area (approximately 3% for both watersheds) suggesting that the nutrient reduction by cover crops, fertilizer reduction and crop rotation might be significant in agriculture dominant areas. It is important to note that the effectiveness of these practices vary on a case-by-case basis and also depends on various factors including soil type, climate, slope, etc.

Moreover, the study tried to investigate the sensitivity of cattle grazing effect on nutrient loading in the watersheds (Figure 2.13). The research found that the nutrient load dramatically increased in both watersheds when all of the cattle were allowed to graze freely in the pasture areas. Atwood Lake watershed demonstrated an increase in total nitrogen by 100% and total phosphorus by 250%, whereas Tappan Lake watershed demonstrated an increase in total nitrogen and total phosphorus of respectively by 135% and 350%. When just 50 percent of the cattle were permitted to graze, the model predicted that there would be a 40% increase in total nitrogen and a 70% increase in total phosphorus in both watersheds. Likewise, when 25% of the cattle were allowed to graze, in average, there was an increase of 19% and 36% of total nitrogen and total phosphorus in both watersheds, respectively. This study suggests that controlling cattle grazing in the pasture area is essential to minimize nutrient load in both watersheds as noted by previous studies (Chaubey et al. 2010; Park et al. 2017).

While conducting BMPs analysis, it is worthwhile to report that the results in terms of nutrient reduction with uncalibrated model was not considerably different from the calibrated model even though the nutrient reduction using the calibrated model was slightly higher than that of the uncalibrated model (Figure 2.14). The findings of the comparison between the calibrated and uncalibrated SWAT model revealed that the calibration of the model had minimal effect on the nutrient loadings and would not have substantial effect on BMPs analysis while ranking their effectiveness as long as watershed area and other characteristics remains same. This findings is in line with the previous studies reporting the identification of the critical sources of the area would not be considerably different based on the calibrated and uncalibrated model (Niroula et al. 2011; Liu et al. 2016; Imani, Delavar, and Niksokhan 2019; Chen et al. 2023) and the uncalibrated SWAT can perform reasonably well (Srinivasan, Zhang, and Arnold 2010).

Moreover, while we compared the rank of BMPs in the reduction of nutrient loads, both calibrated and uncalibrated model depicted similar ranking pattern. For instance, combination of GWW-cover crop- fertilizer reduction of 10% exhibited highest reduction of total nitrogen & total phosphorus for both in calibrated and uncalibrated model. Among the BMPs that we had experimented, fertilizer reduction by 10% showed (Niraula et al. 2011) lowest reduction of total nitrogen & total phosphorus both by calibrated and un-calibrated models.

For this study, we engaged stakeholders for data collection and tried to calibrate and validate the model using the data collected by stakeholders especially for Nitrogen and Phosphorus. This result will be finally shared to the stakeholders. Since watershed models are the approximations of the natural processes and their representation in terms of mathematical equations, the watershed models may or may not capture all the underlying real-world phenomenon. More importantly, the uncertainties exist even the outcome of the well calibrated model. We truly acknowledge that nutrient calibration was not as good as hydrologic calibration. Perhaps, the model could be improved by collecting more data in the existing locations and the improved model could be more reliable for scenario analysis. However, how much improvement we can make in the model, and with that improvement what would be the differences in our scenario analysis would still remain a big question mark. In the first hand, all models are approximations and none of them can predict 100%. On the other hand, it is very less likely to get the significant different in our analysis even after the further improvement of the model especially in the context that our calibrated and uncalibrated results are pretty much the same. We started this research with the consultation of the stakeholder, and we will end this research by sharing the outcome to our collaborators along with the open question of whether further improvement of the model by collecting more data and spending resources, time and efforts will be meaningful if the results remain almost same. Regardless, our findings especially percentage reduction in nutrient by implementing various BMPS would be a great resource for the decision making and the restoration planning of both watersheds.

Conclusion

This study was conducted in Atwood and Tappan Lake watersheds, located in Tuscarawas basin, Ohio. The purpose of this study was to examine the effectiveness of best management practices (BMPs) in reducing nutrient loads in both watersheds, in order to recommend management practices for the Carroll and Harrison Counties. Various sites were monitored in the watersheds for recording flow and nutrient levels for a number of years. The sites were selected based on the extensive communication with stakeholders and their active participation for data collection and their feedback on the existing land use practices, agricultural patterns, and fertilizer inputs in the fields. The stream flow calibration and validation were accomplished in various USGS gauging stations. Similarly, nutrient data were collected, analyzed and the model calibrated for TN and TP at various locations. The nutrient calibration in the present study was relatively poor as compared to the hydrological model calibration due to limited datasets. Once the model was calibrated and validated, we experimented with various BMPs and their combinations to evaluate their effectiveness in reducing nutrients.

The study simulated various BMPs including GWW, VFS, cover crop & fertilizer reduction of 10% and their combinations and assessed their efficacy in the period of 2000 to 2022 for both watersheds. The results showed that, depending on the BMP used, total nitrogen loads could be reduced from 9% to 51% and total phosphorus loads could be reduced from 7% to 87%. Individual efficacy of GWW in lowering total phosphorus was as high as 84%, and fertilizer reduction of 10% accounted for as little as 7%. Meanwhile, GWW's efficacy in lowering total nitrogen was as high as 43%, with a 10% fertilizer reduction accounting for as little as 9%. The model was tested with combinations of the cover crop rye, GWW, and a 10% reduction in the amount of fertilizer used, and the results showed a reduction in the amount of total nitrogen and total phosphorus by 51% and 87%, respectively. In the meantime, the study noted that there were variations in the efficacies of BMPs in reducing total nitrogen loads, indicating the effect of climatic conditions while simulating for entire period of 2000-2022. Moreover, the analysis revealed that fertilizer reduction by 10% reduced the total nitrogen and total phosphorus by 9% and 7%, respectively throughout the simulation period with approximately decrement of 1% agricultural yield. The observed outcomes can be attributed to the prevalence of a particular type of land use, like extensive hay fields or agricultural areas.

The effect of rate of cattle grazing was also assessed in this study. It is noteworthy to report that nutrient loads were significantly affected by the grazing rate. The significant increase of total nitrogen and total phosphorus was detected in both watersheds when the cattle grazing in the pasture were considered in the model simulation, suggesting the nutrient loading is sensitive to the cattle grazing.

As the nutrient model was not adequately calibrated due to lack of sufficient data especially during the high flows, this study compared the result simulated from calibrated and uncalibrated models to evaluate the difference in the outcome. The results showed that nutrient reduction using uncalibrated model was not significantly different from the calibrated model even though the calibrated model reported a slightly higher average nutrient reduction, suggesting the potential use of uncalibrated models in a watershed with limited data.

The collection of nutrient data for various seasons for additional few years especially in the high flow period could improve the model. Regardless, the BMPs application for nutrient reduction should be carefully evaluated with due economic considerations in terms of its potential reduction verses the cost incurred for particular BMPs before implementing them on a larger scale.

Further research can be conducted to assess the economic viability and practicality of BMPs, while considering farmers’ preference and identifying other implementation constraints. Regardless, the research contributes valuable insights into the efficiency of BMPs in reducing nutrient loads, and these findings will be helpful in promoting sustainable watershed management practices in the Carrol and Harrison Counties.

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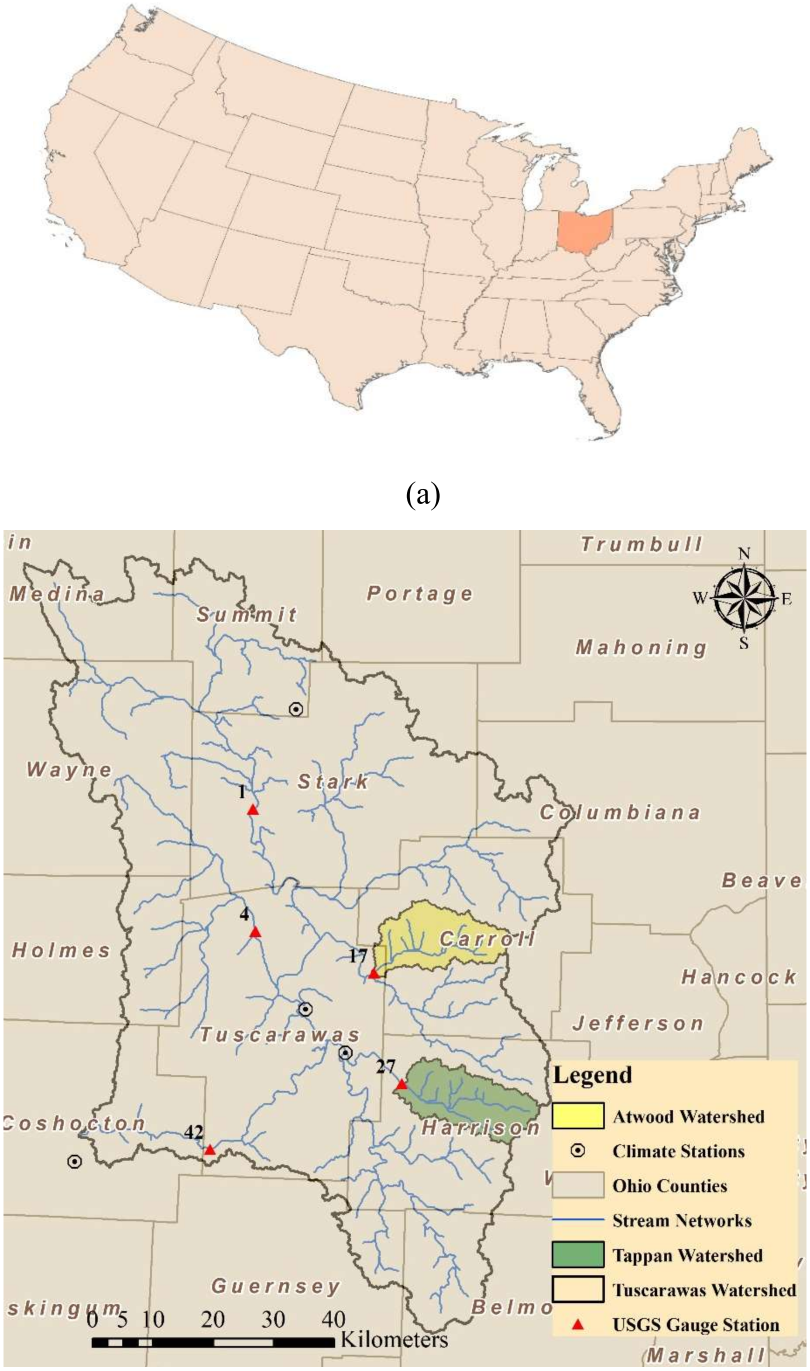

(a)

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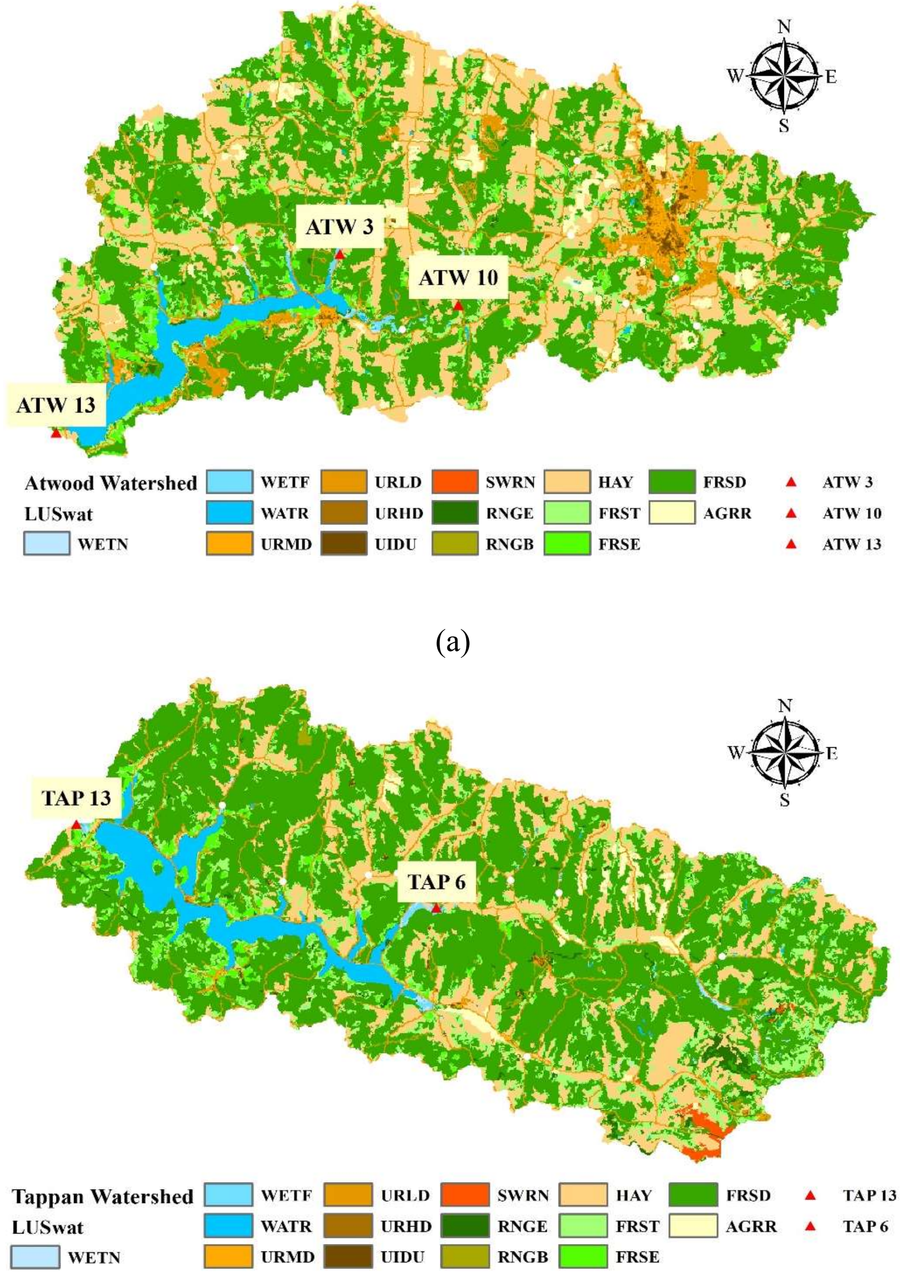
Figure 2.1. Location of study area (a) map of Ohio (b) map of Tuscarawas watershed, Atwood and Tappan Lake watersheds consisting of climatic stations and USGS gauge stations for SWAT model development.



(a)

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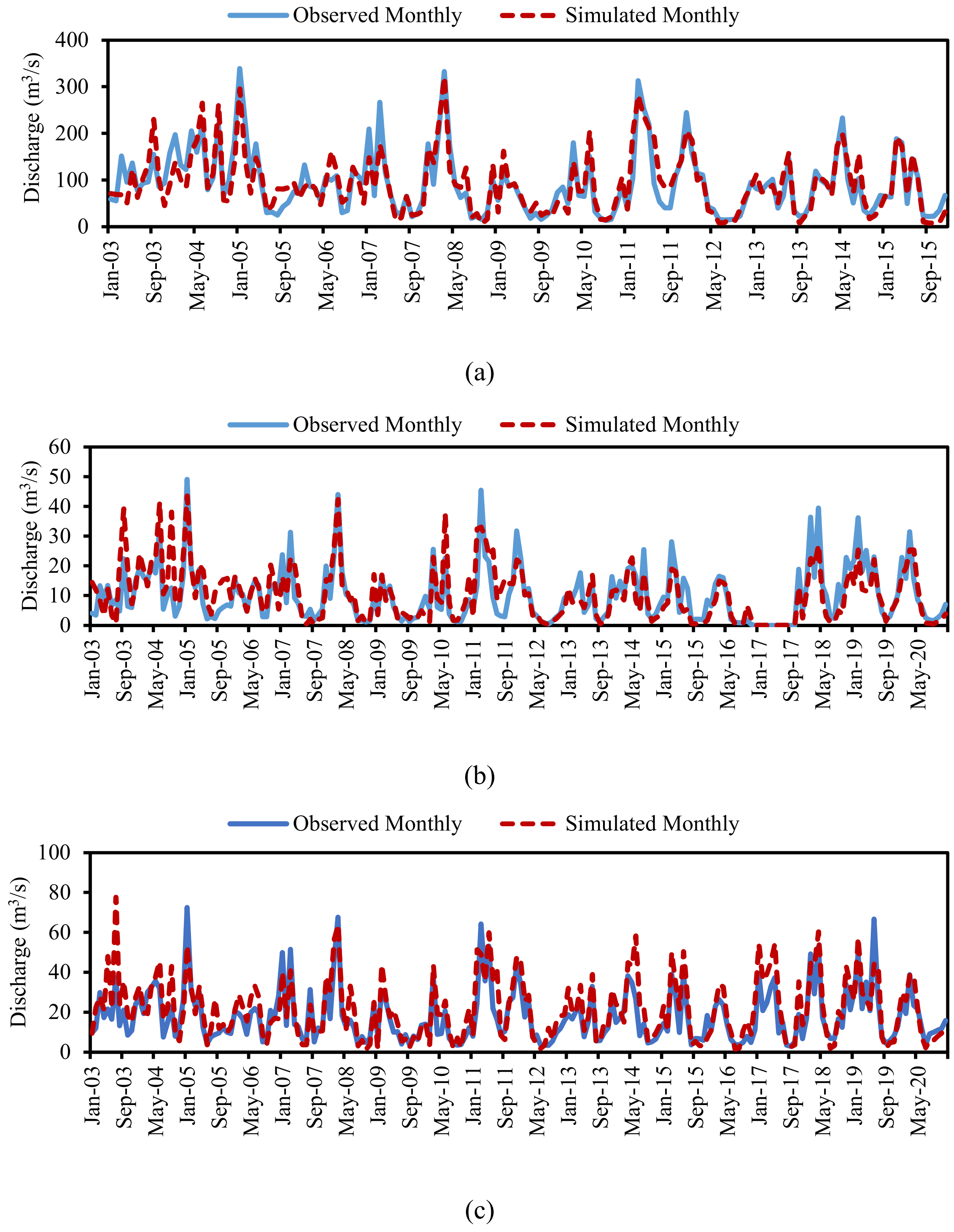
Figure 2.2. Landuse map of (a) Atwood Lake watershed and nutrient monitoring stations (b) Tappan Lake watershed and nutrient monitoring stations. WATR: open water; WETN: emergent herbaceous wetlands; WETF: woody wetlands; URMD: developed low intensity; URLD: developed open space; URHD: developed medium intensity; UIDU: developed high intensity; SWRN: barren land; RNGE: herbaceous; RNGB: shrub/scrub; HAY: hay/pasture; FRST: mixed forest; FRSE: evergreen forest; FRSD: deciduous forest; AGRR: cultivated crops



(a)

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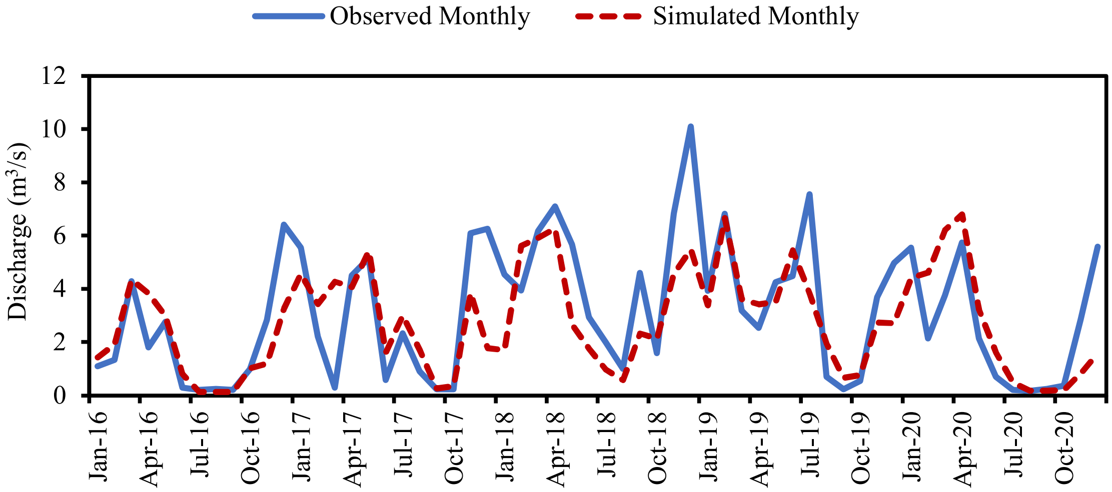
(c)

Figure 2.3. SWAT model streamflow calibration (2003-2015) and validation (2016-2020) at 3 USGS gauge stations (a) USGS Gauge 3129000 (Outlet 42) (b) USGS Gauge 3124500 (Outlet 4) & (c) USGS Gauge 3117000 (Outlet 1).



(a)

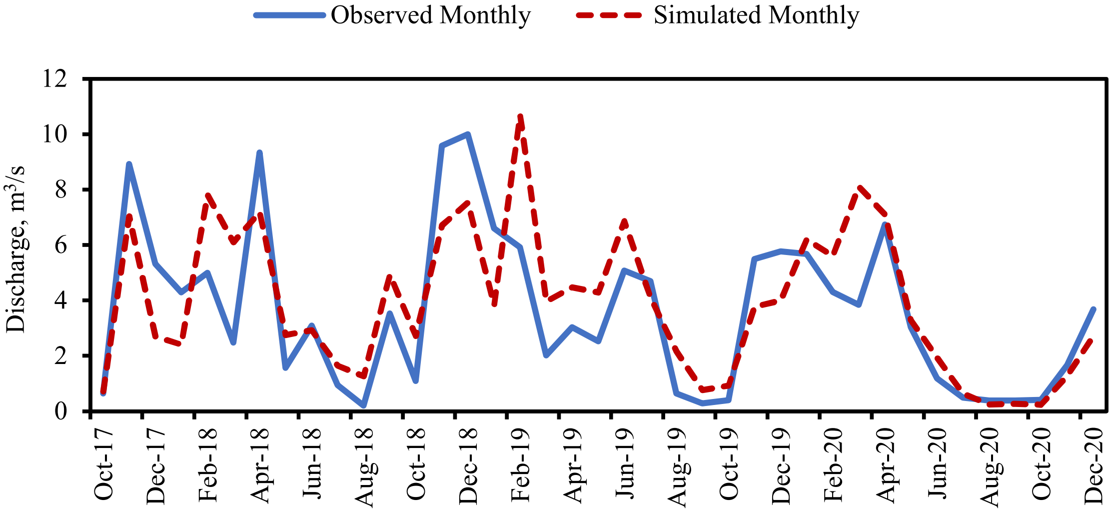


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Figure 2.4. Streamflow validation at outlets of (a) Atwood Lake watershed (2016-2020) USGS gauge 3121500 & (b) Tappan Lake watershed (2017-2020) USGS gauge 3128500.

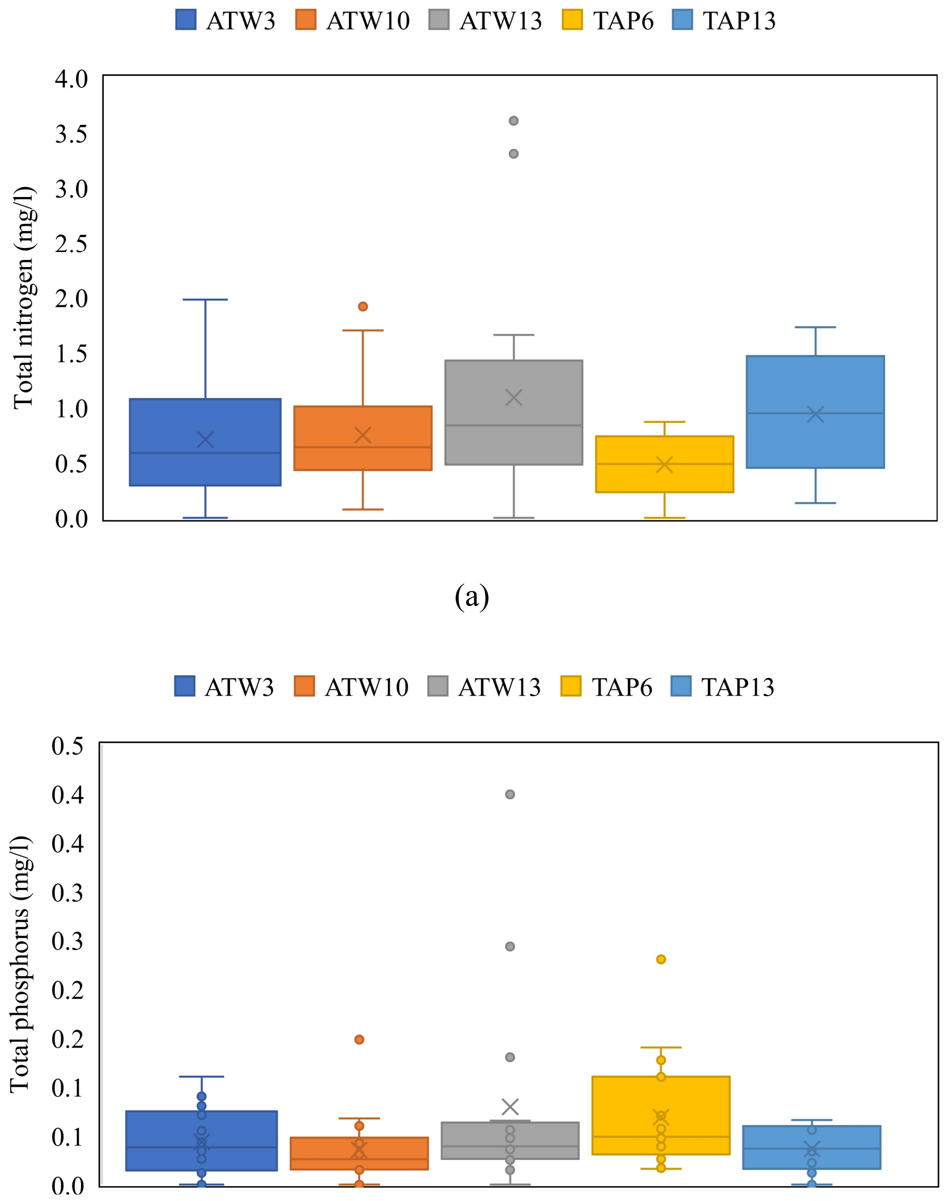

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Figure 2.5. Observed nutrient concentrations at 5 monitoring stations during (2015-2022) (a) total nitrogen concentrations and (b) total phosphorus concentrations.

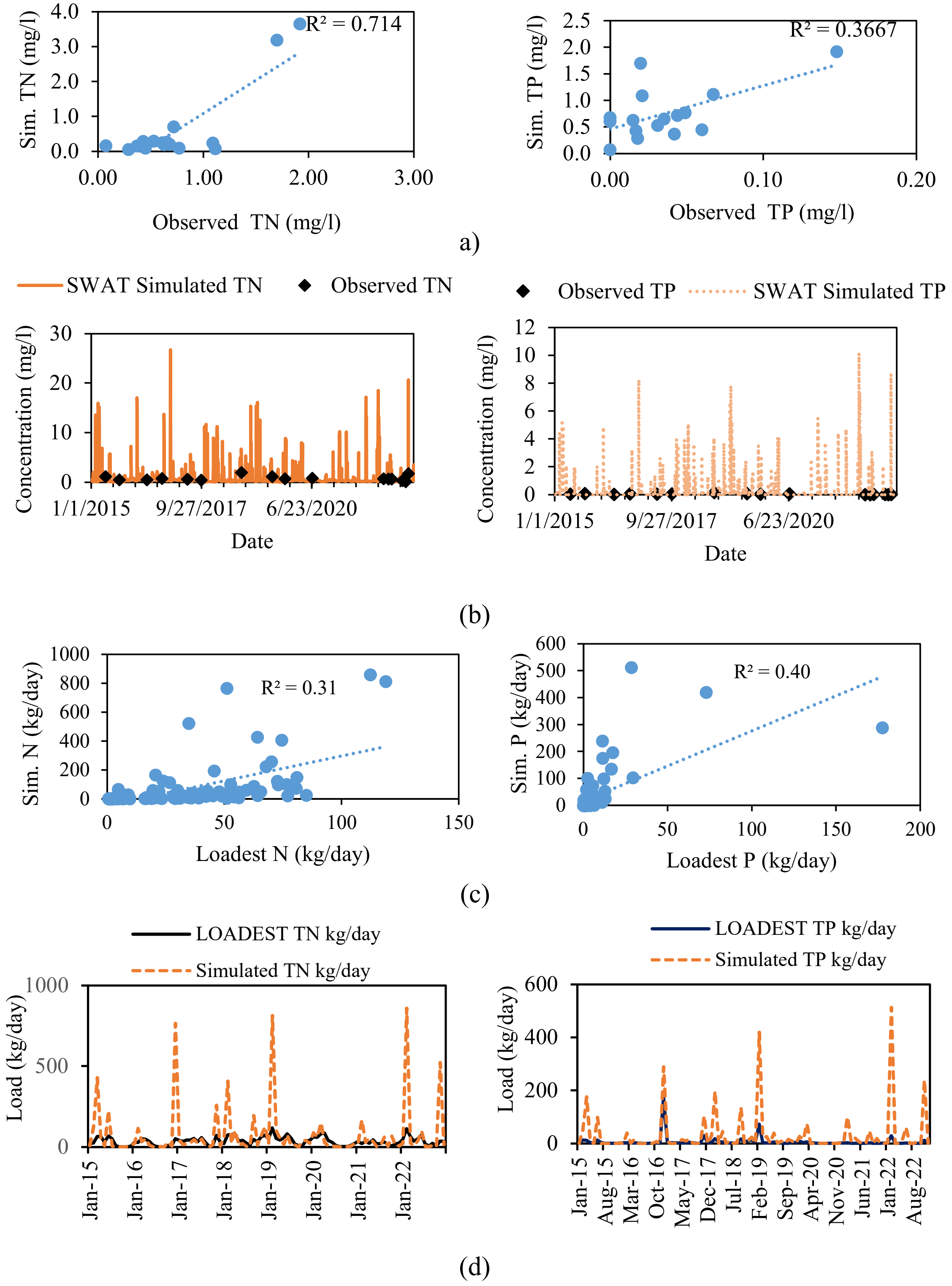
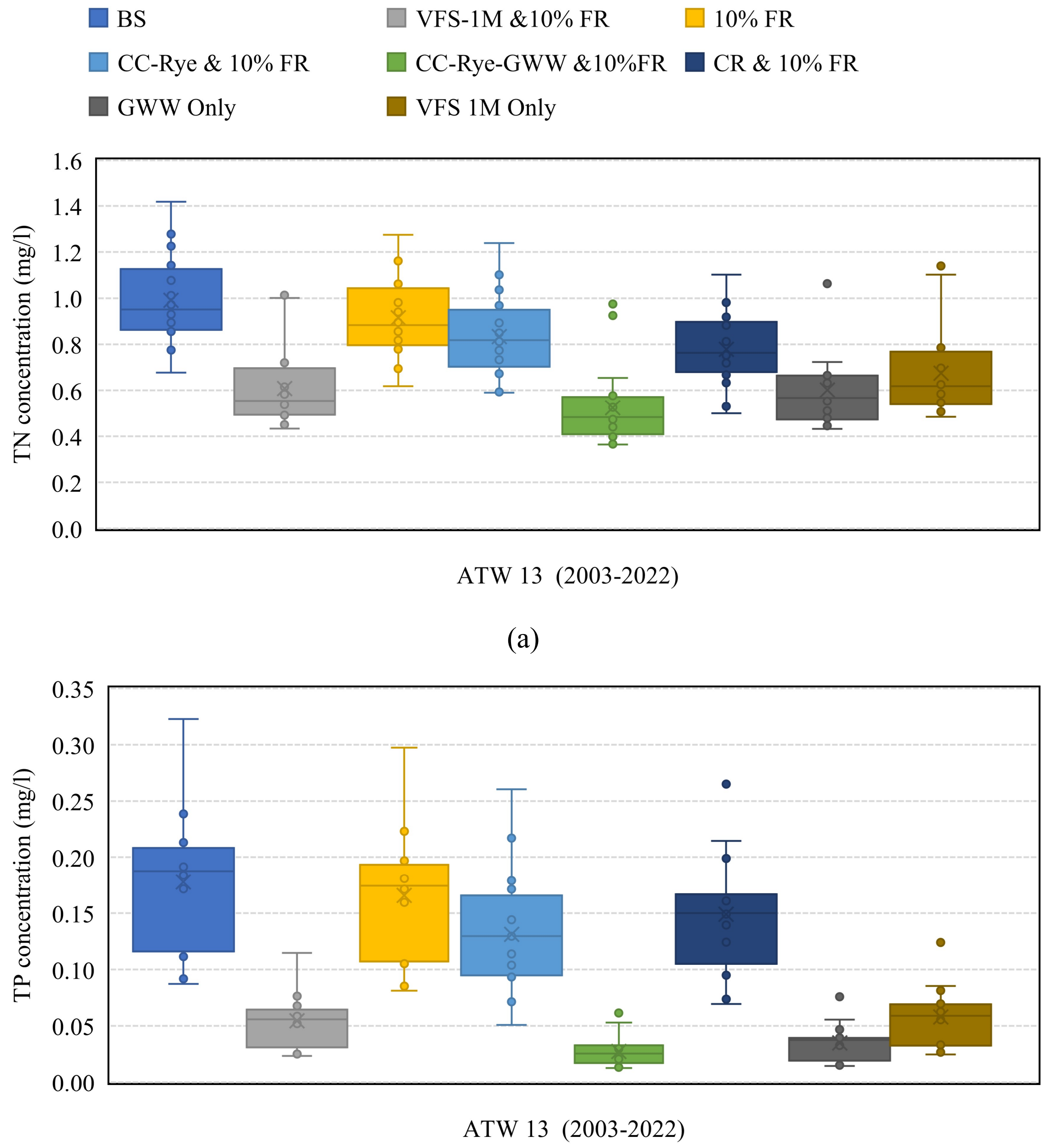


Figure 2.6. ATW 10 (Sub-Basin 11) (a) Scatter plot of simulated and observed concentrations at observed dates (b) Comparison between the simulated and observed concentrations (c) Scatter plot of simulated load and estimated load by LOADEST (d) Load comparison between simulated and LOADEST estimation.



(a)

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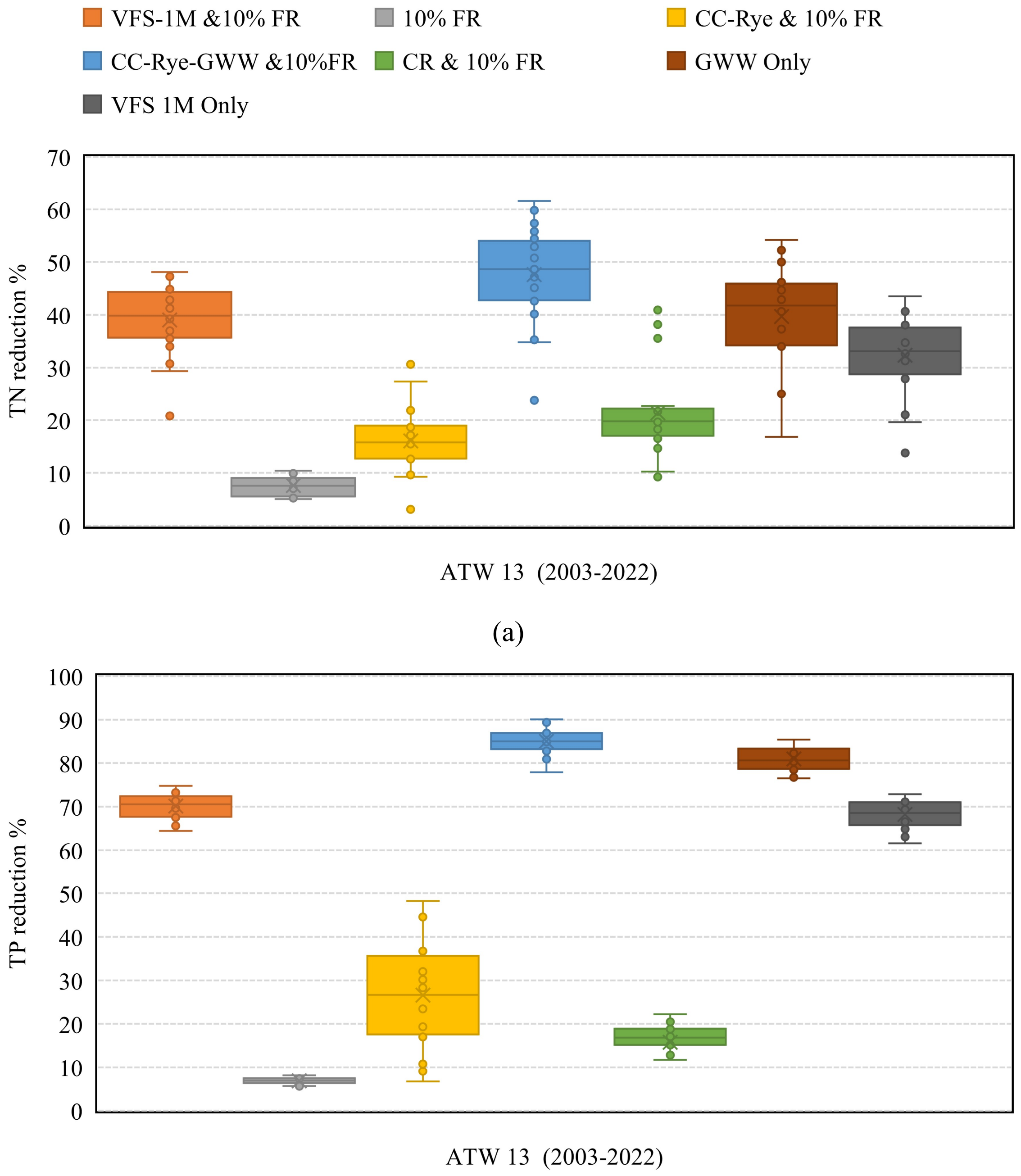
Figure 2.7. Box plot for (a) total nitrogen concentrations and (b) total phosphorus concentration at outlet of Atwood Lake in various BMPs (2003-2022); BS (base scenario), CC (cover crop), CR (crop rotation), FR (fertilizer reduction), GWW (grass waterways), VFS (vegetative filter strip).



(a)

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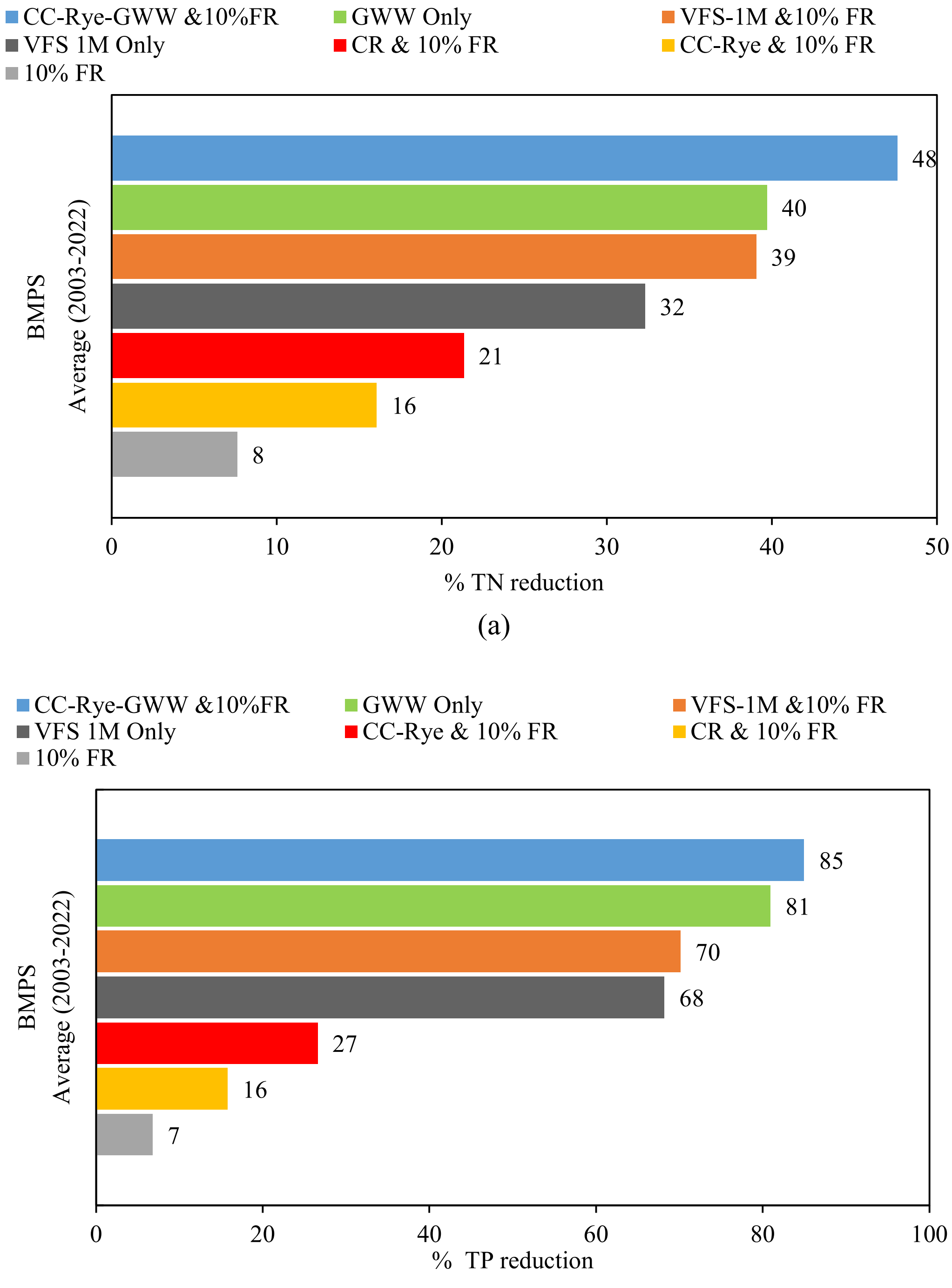
Figure: 2.8. Box plot for (a) total nitrogen concentrations and (b) total phosphorus concentrations reduction at outlet of Atwood Lake in various BMPs during 2003 to 2022; BS (base scenario), CC (cover crop), CR (crop rotation), FR (fertilizer reduction), GWW (grass waterways), VFS (vegetative filter strip).



(a)

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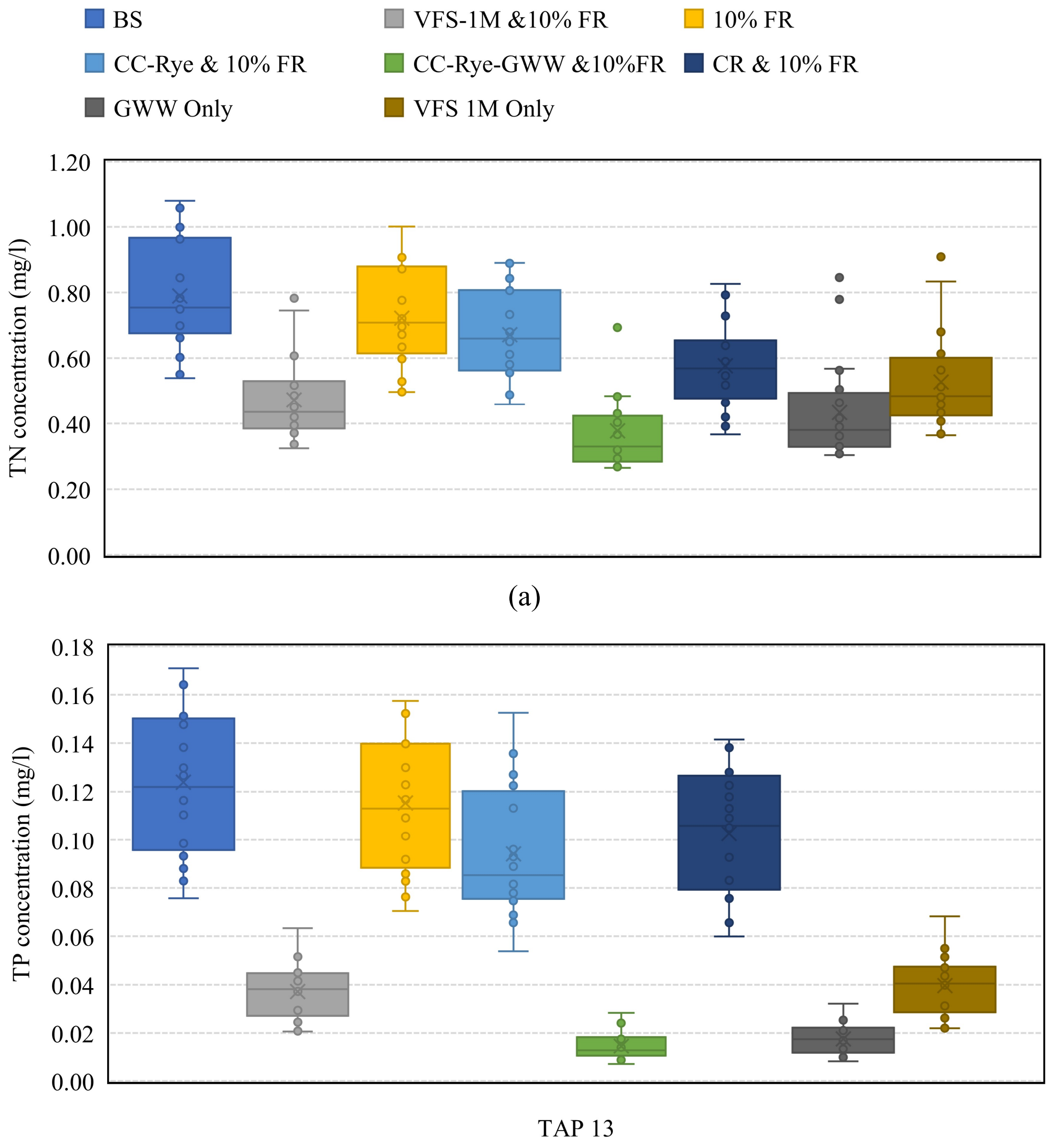
Figure 2.9. Average reduction in (a) total nitrogen concentrations and (b) total phosphorus concentrations at outlet of Atwood Lake in various BMPs during 2003 to 2022; BS (base scenario), CC (cover crop), CR (crop rotation), FR (fertilizer reduction), GWW (grass waterways), VFS (vegetative filter strip).



(a)

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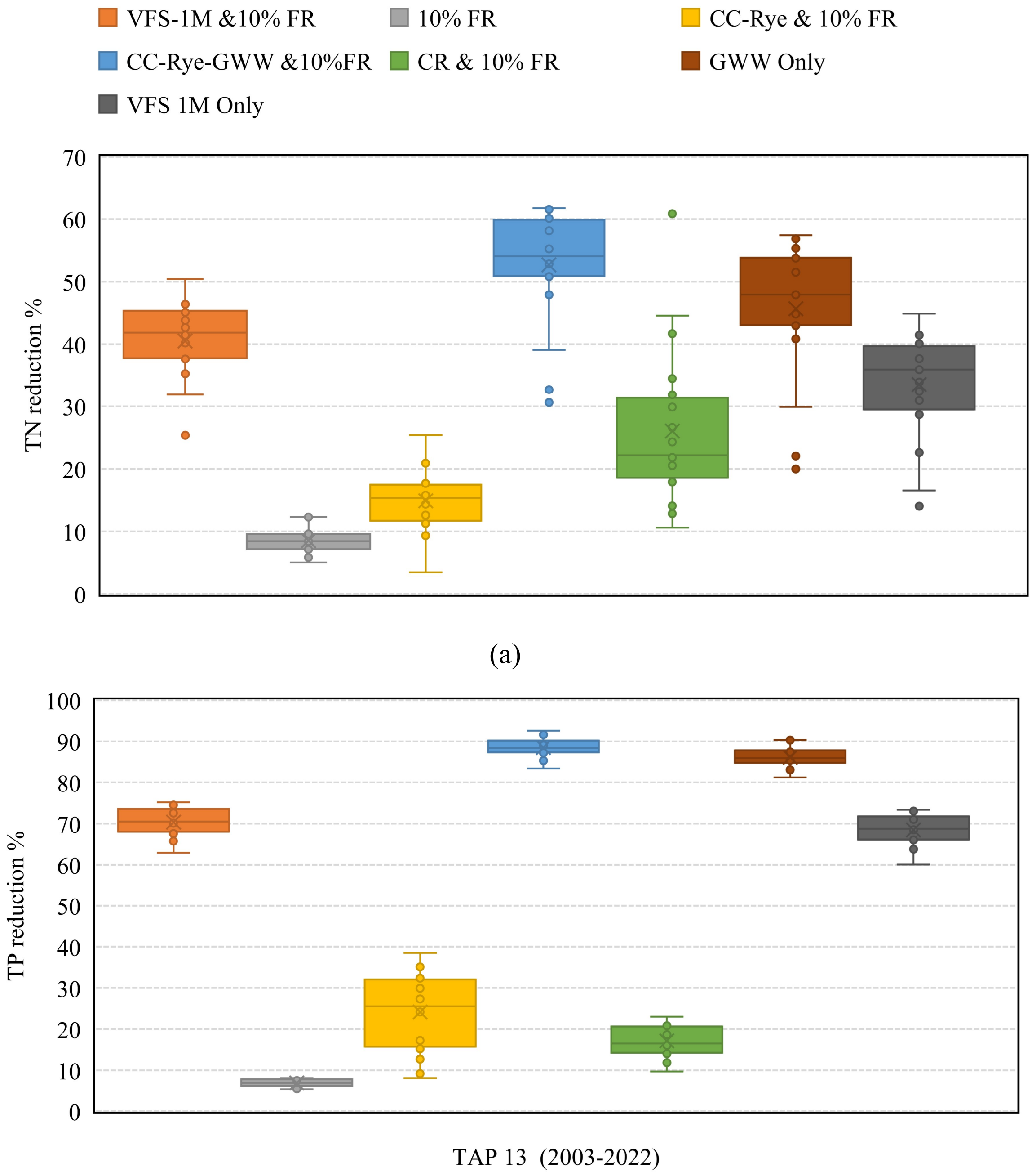
Figure 2.10. Box plot for (a) total nitrogen concentrations and (b) total phosphorus concentrations at outlet of Tappan Lake in various BMPs (2003-2022); BS (base scenario), CC (cover crop), CR (crop rotation), FR (fertilizer reduction), GWW (grass waterways), VFS (vegetative filter strip).



(a)

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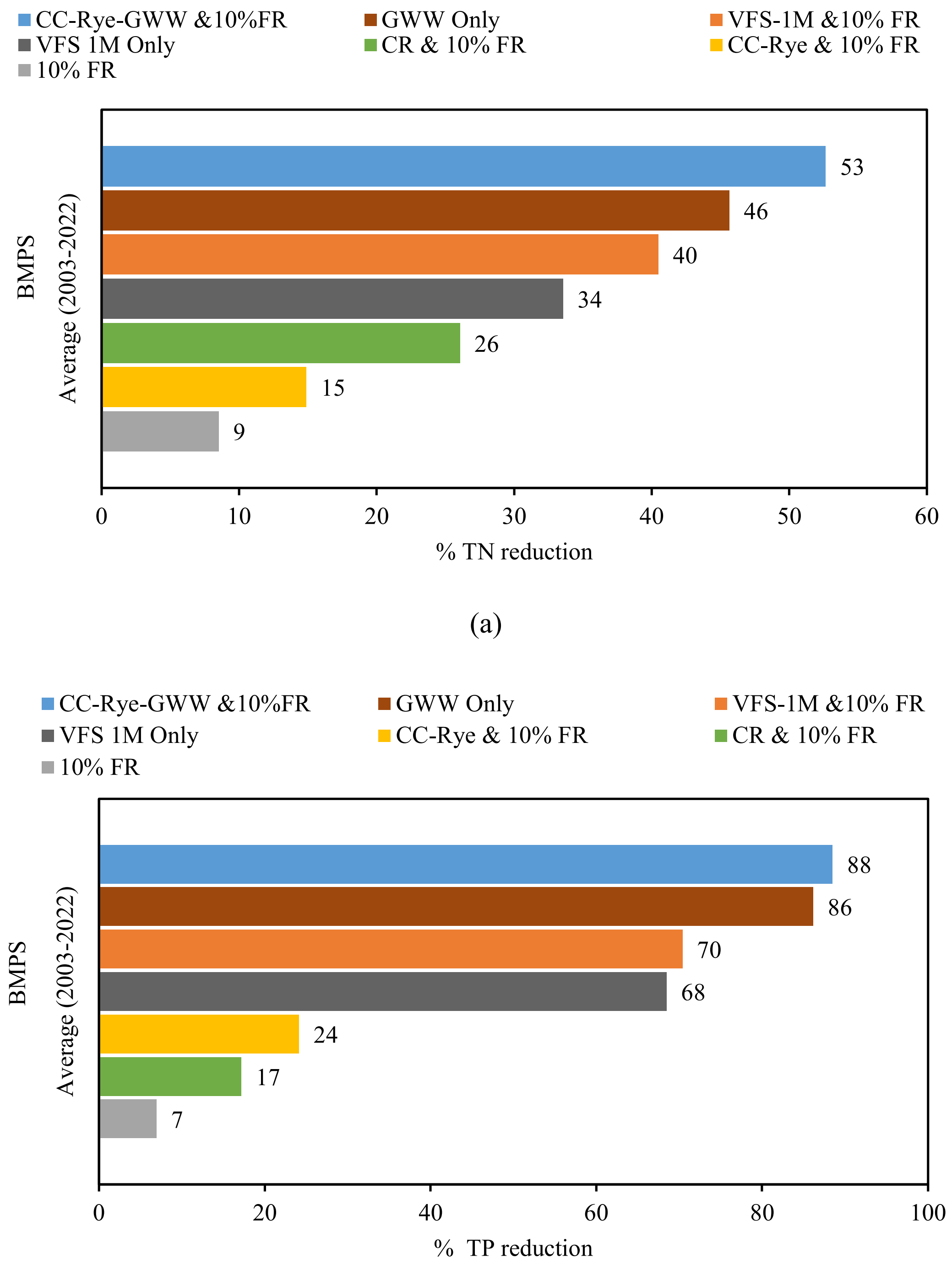
Figure 2.11. Box plot for (a) total nitrogen concentrations & (b) total phosphorus concentrations reduction at outlet of Tappan Lake in various BMPs during 2003 to 2022; BS (base scenario), CC (cover crop), CR (crop rotation), FR (fertilizer reduction), GWW (grass waterways), VFS (vegetative filter strip).



(a)

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Figure 2.12. Average reduction in (a) total nitrogen concentrations and (b) total phosphorus concentrations at outlet of Tappan Lake in various BMPs during 2003 to 2022; BS (base scenario), CC (cover crop), CR (crop rotation), FR (fertilizer reduction), GWW (grass waterways), VFS (vegetative filter strip).

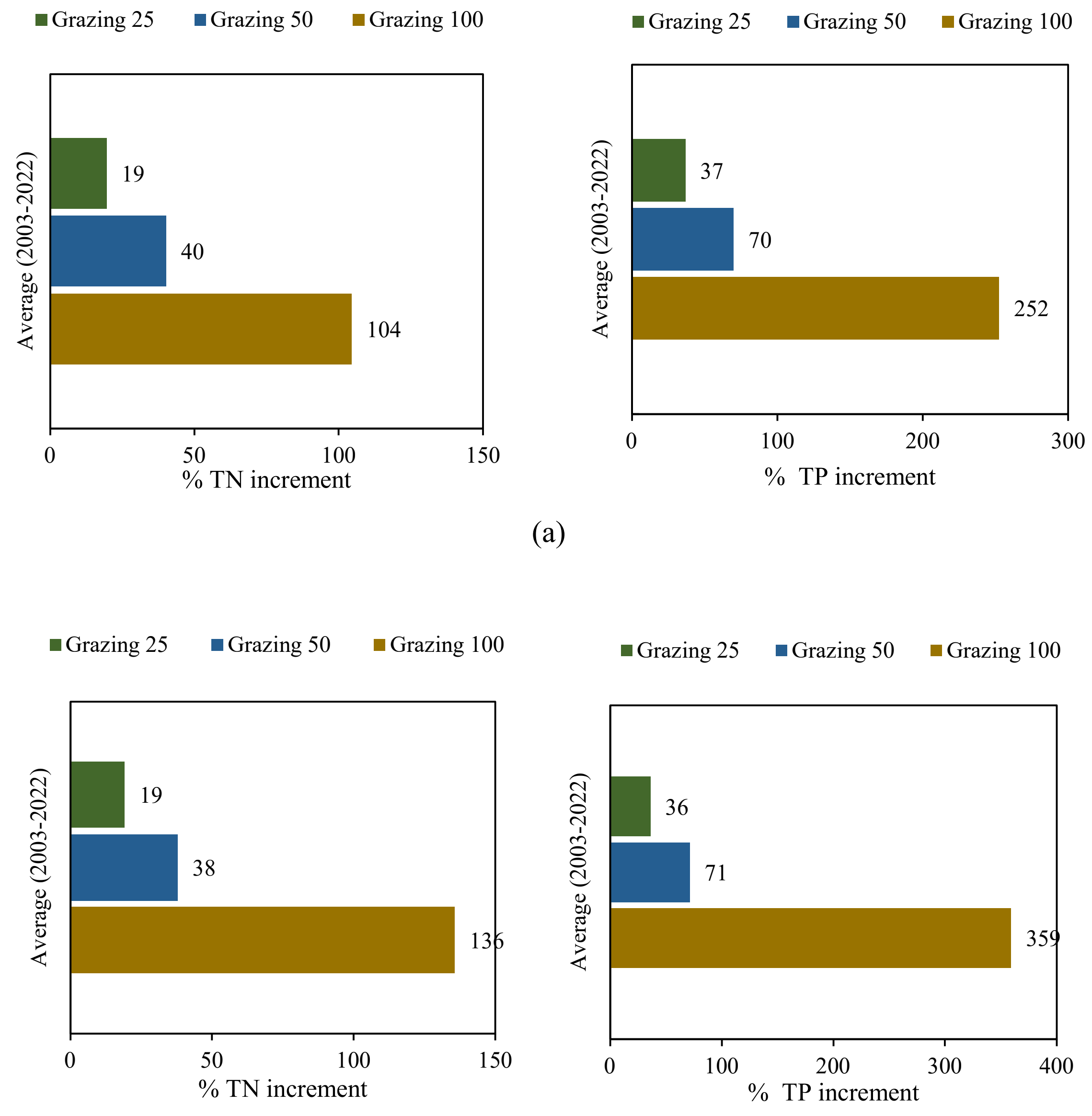

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Figure 2.13. Average increment in total nitrogen concentrations and total phosphorus concentrations in various rate of cattle grazing (a) outlet of Atwood Lake watershed (b) outlet of Tappan Lake watershed.

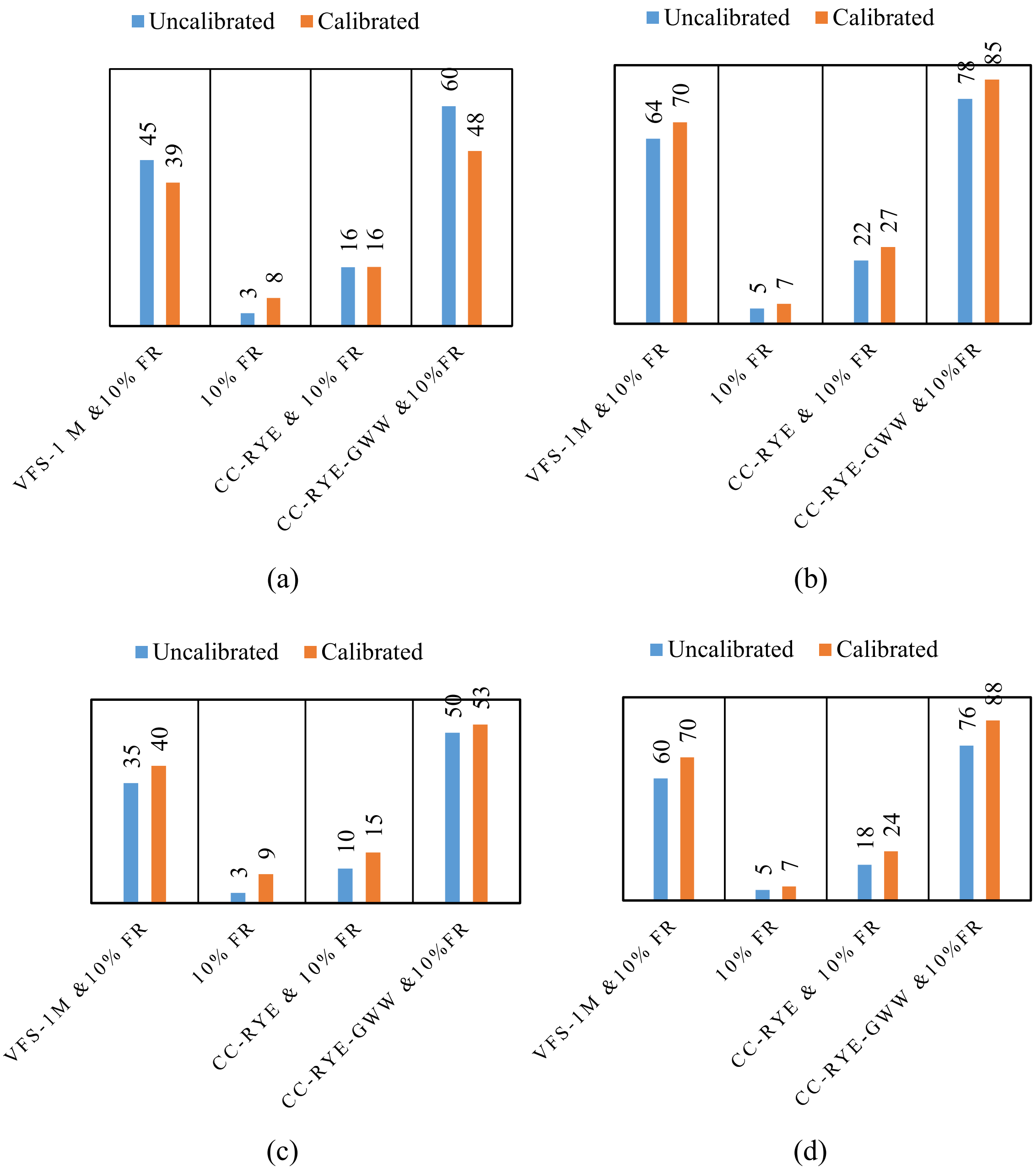


Figure 2.14. Comparison of calibrated and uncalibrated model (a) average total nitrogen concentrations reductions, Atwood Lake outlet (b) average total phosphorus concentrations reductions, Atwood Lake outlet (c) average total nitrogen concentrations reductions, Tappan Lake outlet (d) average total phosphorus concentrations reductions, Tappan Lake outlet.

Table 2.1. Data and sources

Data Type	**Data**	**Source**
GIS	Digital Elevation Model	USGS, National Elevation Dataset
	Landuse Data	USGS, National Land Cover Dataset
	Soil Data	SWAT US SSURGO Soils Database
Climate	Rainfall and Temperature	NOAA National Climatic Data Center
Hydrology	Stream flow	USGS, National Water Information System

Table 2.2. Hydrological calibration parameters in SWAT watershed model

SN	Parameter	Descriptions	Method	Value	Range	
1	SURLAG.bsn	Surface runoff lag time	Replace	8.809	0.5	10
2	SMTMP.bsn	Snowmelt base temperature	Replace	1.888	0	10
3	SMFMX.bsn	Maximum melt rate for snow during year (occurs on summer solstice)	Replace	8.529	0	10
4	SMFMN.bsn	Minimum melt rate for snow during the year (occurs on winter solstice)	Replace	9.421	0	10
5	TIMP.bsn	Snowpack temperature lag factor	Replace	0.319	0	1
6	SNO50COV.bsn	Snow water equivalent that corresponds to 50% snow cover	Replace	0.153	0	0.918
7	SNOCOVMX.bsn	Minimum snow water content that corresponds to 100% snow cover	Replace	2.292	0	500
8	ALPHA_BF.gw	Base flow alpha factor	Replace	0.314	0	1
9	REVAPMN.gw	Threshold depth of water in the shallow aquifer for 'revap' to occur	Replace	44.792	0	500
10	GW_DELAY.gw	Groundwater delay time	Replace	16.042	0	500
11	GW_REVAP.gw	Groundwater revap. coefficient	Replace	0.009	-0.2	0.2
12	GWQMN.gw	Threshold depth of water in the shallow aquifer for 'revap' to occur flow to occur	Replace	1153.750	0	3000
13	CH_N2.rte	Manning's n value for main channel	Replace	0.081	0	0.15
14	CH_K2.rte	Effective hydraulic conductivity in the main channel	Replace	435.425	-500.01	500.01
15	ESCO.hru	Soil evaporation compensation factor	Replace	1.000	0	1
16	EPCO.hru	Plant uptake compensation factor	Replace	0.100	0.01	1
17	SOL_AWC(..).sol	Soil available water storage capacity	Relative	0.082	-0.1	0.1
18	SOL_K(..).sol	Soil conductivity	Relative	-0.056	-0.1	0.1
19	SOL_BD(..).sol	Soil bulk density	Relative	0.090	-0.1	0.1
20	CN2.mgt	SCS runoff curve number for moisture condition II	Relative	-0.088	-0.1	0.1

Table 2.3. Nutrient calibration parameters in SWAT watershed model

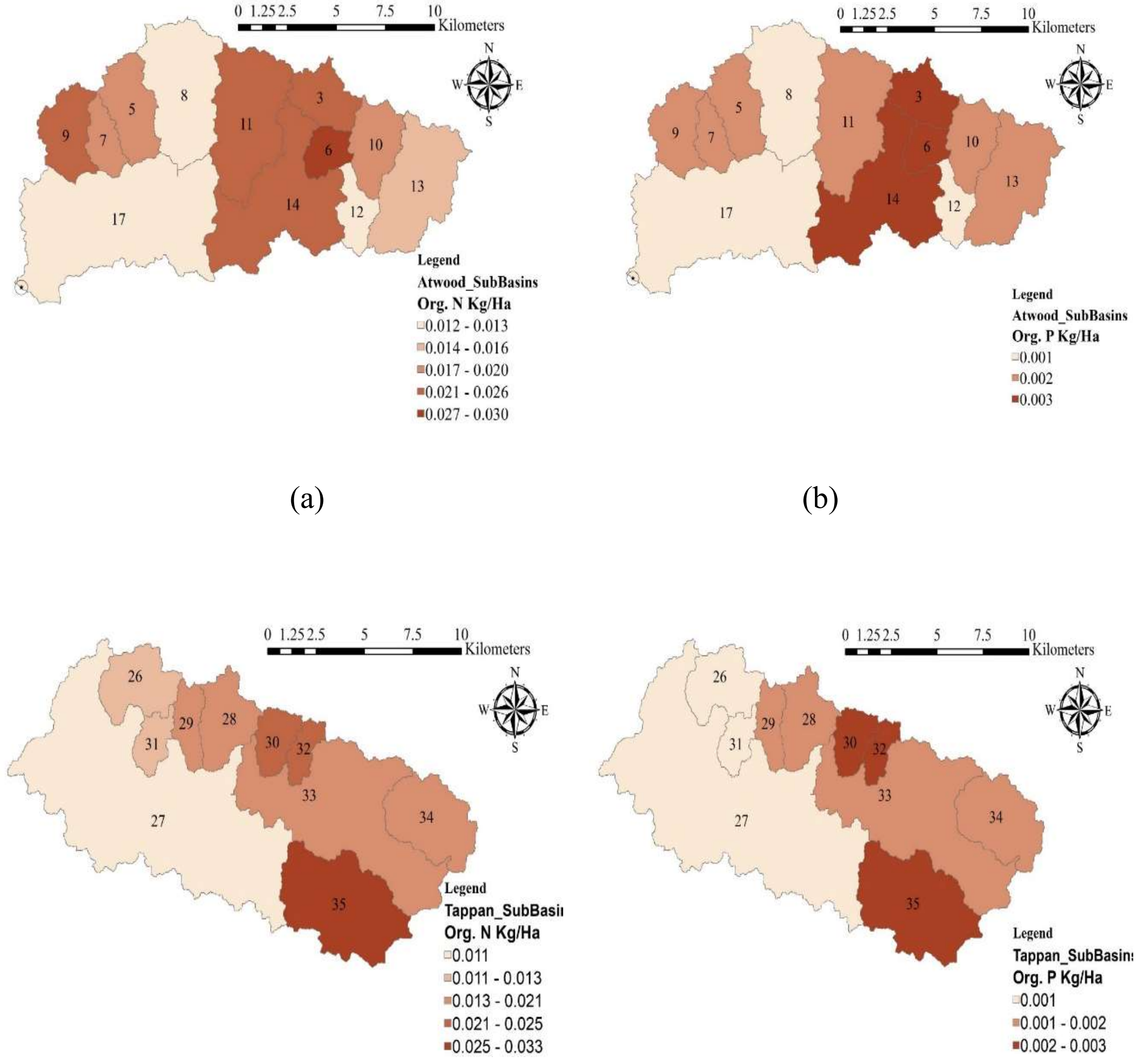
SN	Parameter	Descriptions	Method	Value
1	CDN.bsn	Denitrification Exponential Rate Coefficient	Replace	0
2	CMN.bsn	Rate Factor for Humus Mineralization of Active Organic Nitrogen	Replace	0.003
3	N_UPDIS.bsn	Nitrogen Uptake Distribution Parameter	Replace	20
4	NPERCO.bsn	Nitrate Percolation Coefficient	Replace	2
5	P_UPDIS.bsn	Phosphorus Uptake Distribution Parameter	Replace	100
6	PHOSKD.bsn	Phosphorus Soil Partitioning Coefficient	Replace	200
7	PPERCO.bsn	Phosphorus Percolation Coefficient	Replace	10
8	PRF.bsn	Peak Rate Adjustment Factor For Sediment Routing	Replace	1
9	PSP.bsn	Phosphorus Availability Index	Replace	0.7
10	RCN.bsn	Concentration of Nitrogen in Rainfall	Replace	1
11	RSDCO.bsn	Residue Decomposition Coefficient	Replace	0.1
12	SDNCO.bsn	Denitrification Threshold Water Content	Replace	0
13	SPCON.bsn	Linear Parameter for Calculating the maximum Amount of Sediment	Replace	0.01
14	SPEXP.bsn	Exponent Parameter For calculating Sediment Re-entrained	Replace	1.5
15	USLE_P.mgt	USLE Equation Support Practice Factor	Replace	1

Table 2.4. Monthly flow performance of the watershed SWAT model

Model Outlet	USGS Gage Station	Calibration (2003-2015)				Validation (2016-2020)			
		NSE	R2	PBIAS	RSR	NSE	R2	PBIAS	RSR
1	3117000	0.54	0.72	-20.87	0.67	0.63	0.78	-18.56	0.60
4	3124500	0.55	0.64	-10.79	0.67	0.78	0.83	19.52	0.47
42	3129000	0.79	0.80	-0.09	0.45	0.89	0.92	-5.11	0.33
17*	3121500					0.50	0.52	11.29	0.71
27**	3128500					0.56	0.60	-8.40	0.66

*Atwood Lake Dam Outlet ** Tappan Lake Dam Outlet

APPENDICES



(a) (b)

(c) (d)

Figure 3.1. Sub-watershed wise organic nutrient loading in base scenario (a) nitrogen loading from Atwood Lake sub-watersheds (b) phosphorus loading from Atwood Lake sub-watersheds (c) nitrogen loading from Tappan Lake sub-watersheds (d) phosphorus loading from Tappan Lake sub-watersheds.

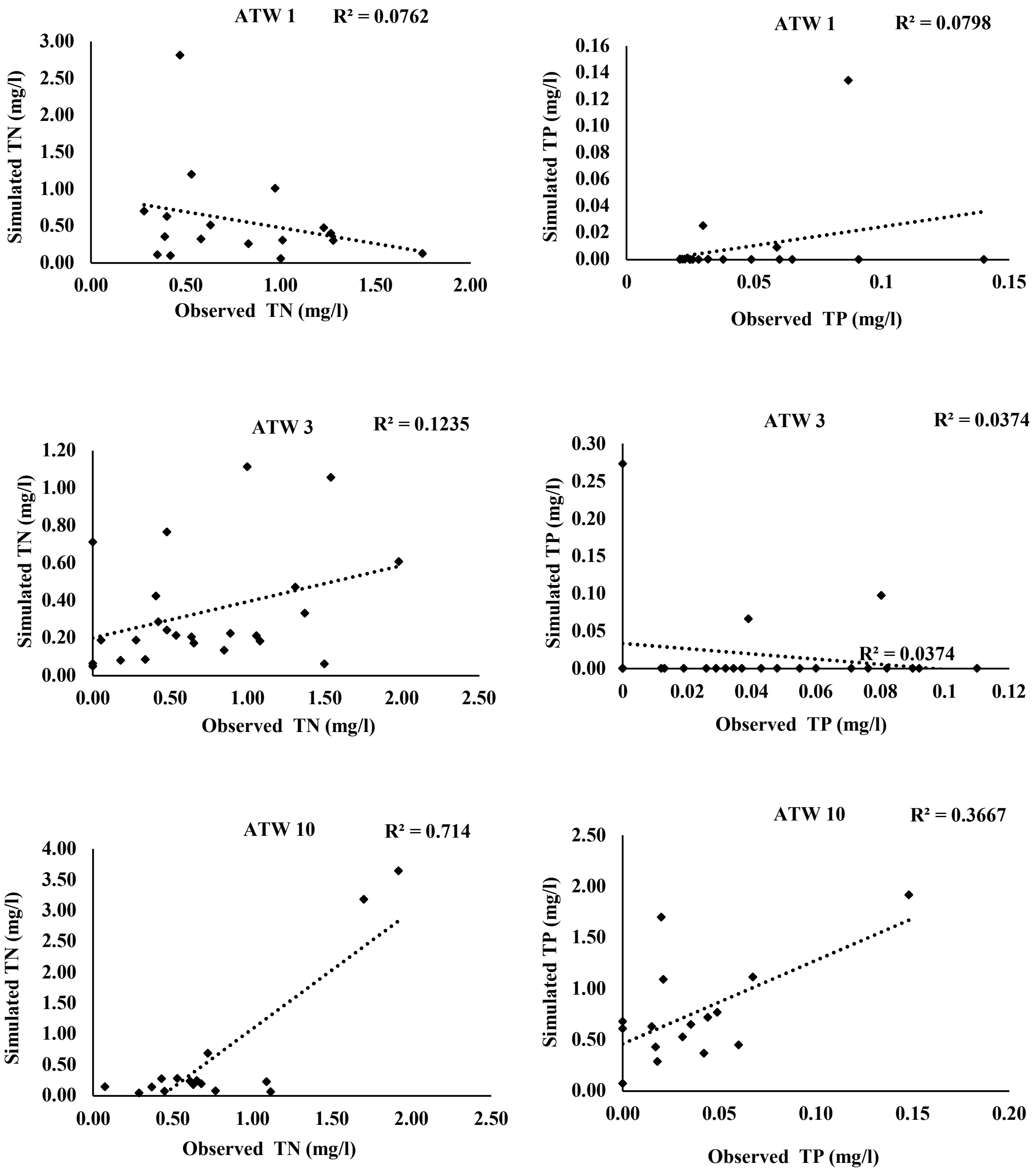


Figure 3.2. Scatter plot of simulated and observed total nitrogen (TN) and total phosphorus (TP) concentrations at various monitoring locations during 2015 to 2022.

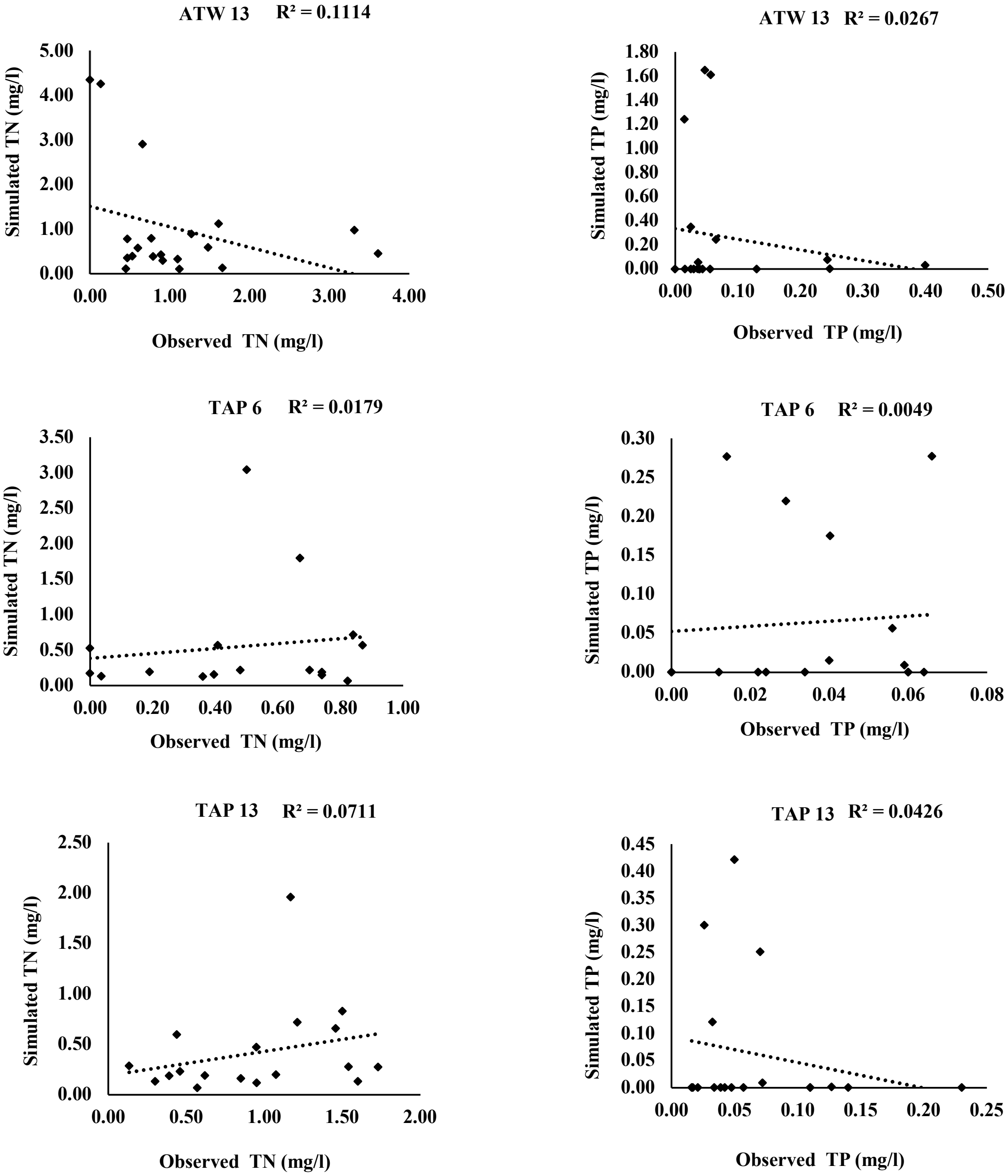


Figure 3.3. Scatter plot of simulated and observed total nitrogen (TN) and total phosphorus (TP) concentrations at various monitoring locations during 2015 to 2022.

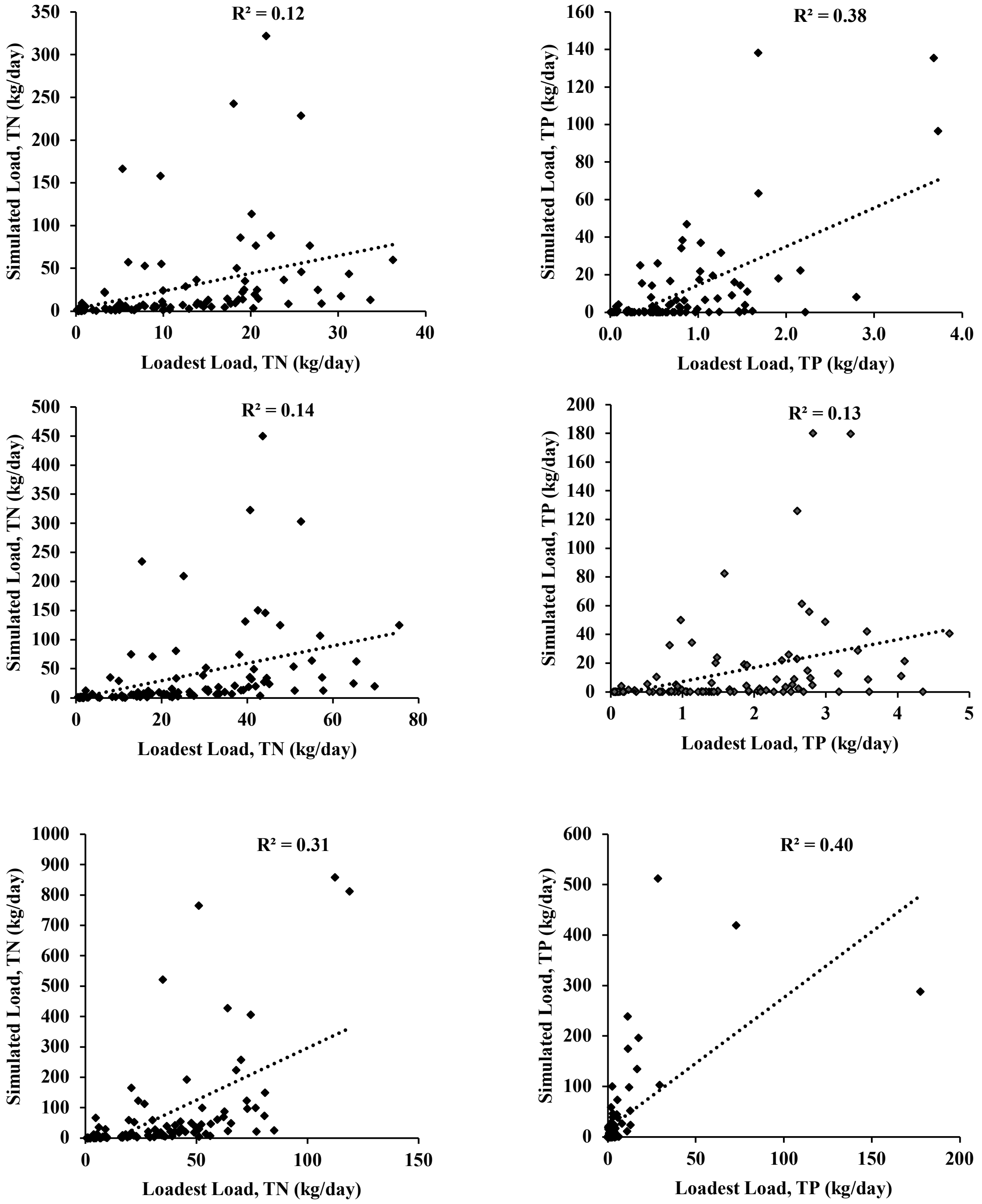


Figure 3.4. Scatter plot of simulated and estimated (LOADEST) total nitrogen (TN) and total phosphorus (TP) load at various monitoring locations during 2015 to 2022.

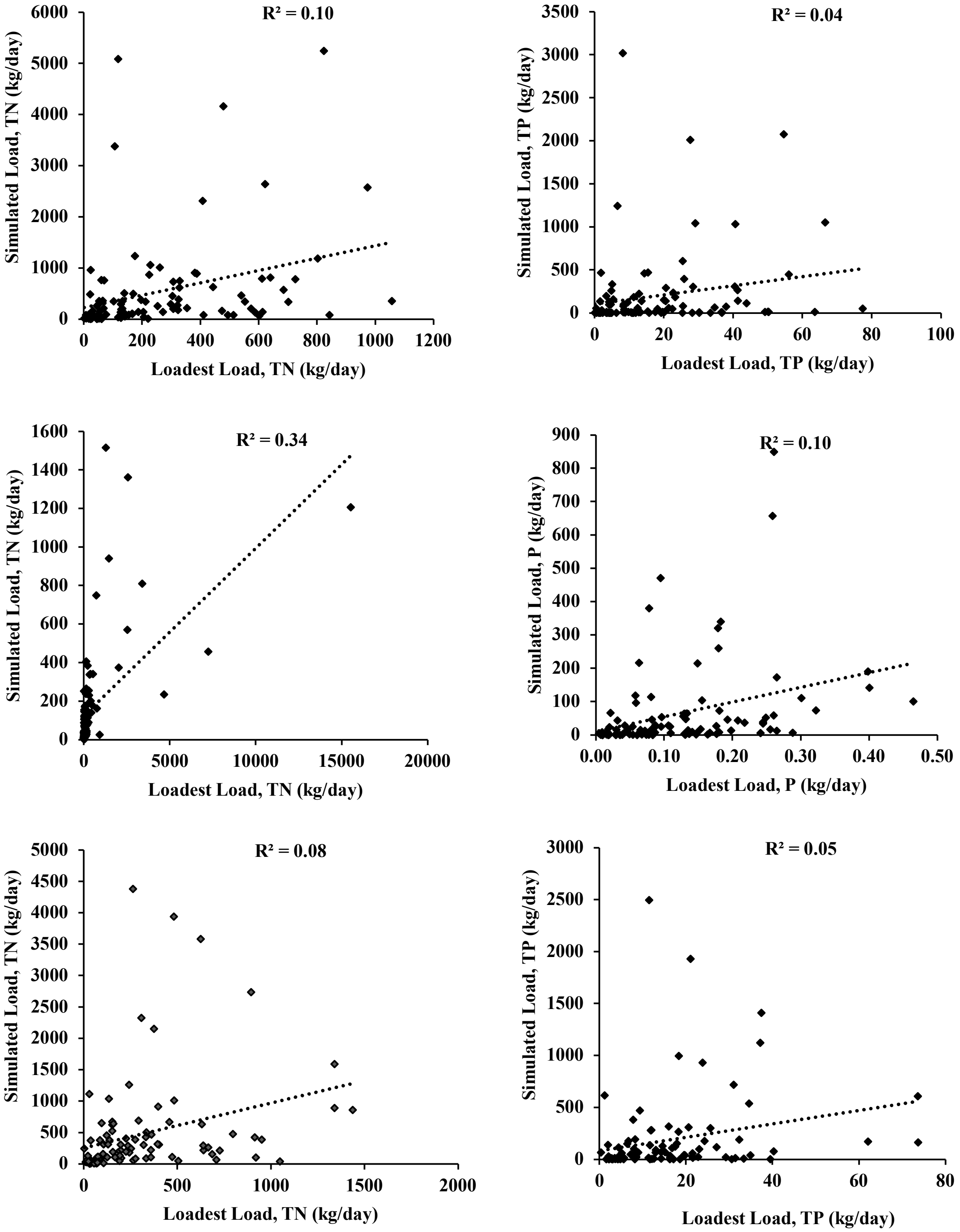


Figure 3.5. Scatter plot of simulated and estimated (LOADEST) total nitrogen (TN) and total phosphorus (TP) load at various monitoring locations during 2015 to 2022.