PROJECT REPORT

"Development of a SWAT Model to Investigate the Impact of Hydroclimate and Land Uses on Water Quantity and Quality in the 'Atrai' River, Bangladesh."

By

Jobair Ahmed Tasrif (2017-2-22-012)

Faria Sobhan (2018-1-22-029)

Ruddra Kumar Das (2018-2-22-012)

Md. Washif Iqbal Fayek (2018-3-22-043)

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Approved by

Thesis Advisor
Dr. Shakil Ahmed
Assistant Professor
Department of Civil Engineering

Department Chairperson
Dr. Md. Naimul Haque
Chairperson & Associate Professor
Department of Civil Engineering

Dedication

ACKNOWLEDGMENTS

It has been a pleasure for us to work on this project report. ArcGIS-ArcSWAT program was introduced to us, and we actually used it. It is currently one of the most modern IT talents that will aid in our ability to find employment in the future. Additionally, it will make us indispensable to any organization.

We are grateful to Allah for endowing us with the perseverance, wisdom, and knowledge needed to complete each task effectively throughout the entire process. Allah has given us a little help with our project so that we can leave our free time at home and finish it.

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All contributors—both those who have been acknowledged and those who have not—have our gratitude.

AUTHORIZATION

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______________________________ Md. Washif Iqbal Fayek

______________________________ Ruddra Kumar Das

______________________________ Jobair Ahmed Tasrif

______________________________ Faria Sobhan

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List of Abbreviation

- **ArcGIS** (Aeronautical Reconnaissance Coverage Geographic Information System)
- **ArcSWAT** (Aeronautical Reconnaissance Coverage Soil & Water Assessment Tool)
- **CN** (Curve Number)
- **DEM** (Digital Elevation Model)
- **GCM** (Global climate models)
- **HRU** (Hydrologic Response Units)
- **IPCC** (Intergovernmental Panel on Climate Change)
- **LARS-WG** (Long Ashton Research Station Weather Generator)
- **MS** (Microsoft)
- **NASA** (National Aeronautics and Space Administration)
- **NEX-GDDP** (NASA Earth Exchange Global Daily Downscaled Climate Projections)
- **USA** (United States of America)
- **RCP** (Representative Concentration Pathway)
- **SDSM** (Statistical Downscaling Model)
- **SWAT** (Soil and Water Assessment Tool)
- **SRTM** (Suttle Rader Topography Mission)
- **USA** (United States of America)
- **USGS** (United States Geological Survey)
- **VFS** (Vegetative Filter Strips)

EXECUTIVE SUMMARY

A project on the Atrai River was studied to calculate the surface-overflow runoff and nitrogen load of the selected watershed area. To get the data on present and future surface-overflow load and nitrogen load of the selected watershed area of the project, we used ArcGIS and ArcSWAT modeling software. The spatiotemporal data were processed in ArcGIS-ArcSWAT. The comparison of observed and simulated data from software and graph plotting was done by using MS Excel. Manual calibration was performed by changing the curve number. Good calibration (R2 = 0.654) was found by comparing 2020 simulated surface overflow data with 2020 observed surface overflow data. The validation (R2 = 0.67) was done by comparing observed data for 2021-2022 and model simulated data for 2021-2022. A comparison chart was created comparing 2021 observed surface overflow with 2052 simulated surface overflow data. We applied a vegetative strip as a nature-based solution to reduce nitrogen load for the year 2021. After applying the vegetative filter strip, we were able to reduce nitrogen load by almost 25% in the peak farming month of June. The forecast of future surface overflow data also showed that in the future there will be a drastic decrease in surface overflow load after 30 years.

Chapter 1 Project Concept and Description

To determine the nitrogen load and surface-overflow runoff of the chosen watershed area, a project on the Atrai River was investigated. We used ArcGIS and ArcSWAT modeling software to obtain information on the nitrogen load and current and projected surface-overflow load for the project's chosen watershed area. ArcGIS-ArcSWAT was used to process the spatiotemporal data.

1.1 Project Introduction

The quantity and quality of surface waters can be significantly impacted by changes in the climate, including variations in temperature, precipitation, and land use. It is crucial to look into how climate change and land use affect water bodies. By choosing the Atrai River in the Naogaon area as our study region, the following objectives were attained:

1) developing a water quality and hydrologic model to investigate the effect of climate change and land uses on water quantity and water quality (nitrogen load) in a watershed near the Atrai River.

2) designing a nature-based solution (NBS) to reduce nitrogen load from the watersheds.

According to data gathered from long-term ecosystem monitoring and research stations located all around the world, changes in climate, such as precipitation and temperature, can have a major impact on surface water quantity and quality. During storms, snowmelt, hot spells, or droughts, water quality may deteriorate. It could result in water quality issues that the environment is unable to handle. Climate change can affect an ecosystem's water quality components. The Earth's temperature is rising daily as a result of the greenhouse effect. Because of this, the world's typical climate is changing, and prolonged climatic stress will increase the frequency of ecosystem thresholds being surpassed. This will cause a negative impact on water bodies. We can see the example of this even in the present. Droughts are becoming longer and more extreme worldwide. Tropical Storms becoming more severe due to the rise of the temperature of ocean water. Changes in land use affect the chemical, physical, and biological components of watersheds. The quality of the neighboring surface waters alters as a result. Human-caused changes like the use of chemical fertilizers and pesticides in agriculture, the dumping of rubbish, etc., can either be mitigated or made worse by climate change. These modifications may make it challenging to detect alterations in water quality brought on by climate change. We require a technique to predict future events in order to examine these consequences and find ways to lessen the harm that climate change and land development do to water systems. We developed a hydrology and water quality model to accurately predict various future scenarios. We need to know the amount of surface overflow data and chemical outputs in order to predict the future effects of climate change and land development on water bodies. SWAT is the most recent program used to collect data for these activities, including chemical yield and surface overflow.

A simulation model for long-term water quality called SWAT forecasts the effects of management choices on the water, sediment, and agricultural chemicals in watersheds. The model specifically mentions a certain watershed. SWAT further defines HRUs, which are specific combinations of land cover and soils within each subbasin. A network of streams connects the subbasins that make up a watershed. The model predicts that HRUs do not interact. Additionally, one of these HRUs is present in practically every subbasin. HRU delineation lowers the cost of computing for simulation by combining similar soil and land use areas into a single unit. SWAT can mimic surface and subsurface flow, movement over the terrain, nutrient fate, sediment creation and deposition, and movement over the landscape. It accepts straightforward inputs and enables users to consider long-term impacts because it is a physically-based distribution model. SWAT needs a variety of factors, such as topography, soil, land usage, weather, etc., in order to be effective.

1.2 Literature review

To simulate runoff, sediment, and nutrients from catchments, the United States Department of Agriculture (USDA) developed the hydrologic model known as Soil Water and Assessment Tool (SWAT), which is semi-distributed and in the public domain. The catchment scale continuous-time landscape dynamics are simulated by the physical process-based SWAT model. There are various distinct hydrological response components in the basin (HRUs). Some of the key model elements are hydrology, meteorology, soil erosion, nutrients, temperature, crop development, pesticides, agricultural management, and stream routing. The model estimates the hydrology for each HRU using the water balance equation, which has components for daily precipitation, runoff, evapotranspiration, percolation, and returns flow. The model uses two approaches to forecast surface runoff: the Natural Resources Conservation Service Curve Number (CN) methodology and the Green and Ampt method, both released in 1972 by the USDA-SCS (Green and Ampt, 1911). The expected percolation across each soil layer is predicted using storage routing algorithms and a crack-flow model. SWAT calculates evapotranspiration using the Priestley-Taylor, Penman-Monteith, and Hargreaves techniques. The variable storage coefficient methodology sometimes referred to as the Muskingum method, is used to determine the flow path in river channels.

The definition of watersheds requires a digital stream network. The USGS Hydro-SHEDS website provides access to data from the digital stream network. The Hydro-SHEDS data are available in a wide range of regional extents, kinds, and resolutions. The investigation made use of data with a 15-second resolution. The DEM, a digital stream network, and the SWAT watershed delineation tool are used to delineate the watershed. Based on slope classes, soil types, and land uses, the Meghna River is divided into 29 sub-basins and 90 hydrological response units (HRU), allowing simulations with a high level of geographic knowledge.

One of the most crucial components of a SWAT model configuration is the soil. For each of the several soil layers, the SWAT model incorporates specific soil characteristics, such as soil textures, hydraulic conductivity, accessible water content, bulk density, etc. The soil data is gathered from the UNESCO-FAO World Soil Map and entered as a shape file. The digital soil map is 1:5 scale. After the soil shape file has been entered, a lookup table is used to find the SNUM, a sequential code number that is specific to each soil mapping and spans from 1 to 6,997. There is a lot of meteorological data needed for the SWAT model to work. The WATCH Forcing Data method and the ERA-Interim reanalysis data were used to collect temperature and precipitation data (WFDEI). The meteorological data are produced for SWAT model input after taking into consideration the geographic location of the research area and the location of the meteorological station. The SWAT model simply needs temperature and precipitation records as inputs; all other variables are optional. Using SWAT modeling, it is possible to forecast changes in precipitation and the northern part of the Thenpennar sub-temperature basin from 2020 to 2050. The simulation findings are validated using data from the base period of 1980 to 2000, which shows the distribution of temperature and rainfall over 38 watersheds. According to the analysis's findings, the amount of rainfall in December will only decrease by 20% between 2020 and 2050.

SWAT is used to evaluate how potential climate change may impact the hydrology and water resources in the Upper Blue Nile River Basin (UBNRB). After the weather data inputs were verified using the two well-known downscaling models SDSM and LARSWG, the final decisions were made. After being filtered by a substantial output from one or more GCMs, these inputs were chosen. The expected effects of various scenarios are compared to model output for the 1970–2000 reference period for the years 2046–2065 and 2081–20100, respectively. The SWAT model is calibrated and validated using the streamflow data collected at the Eldiem gauging station (on the border of Ethiopia and Sudan) during the baseline period. The effectiveness of the model is evaluated using standard performance metrics. All of these statistical measures demonstrate that throughout both the calibration period and the validation period, the projected streamflow was appropriately adjusted to the observed streamflow. The Blue Nile River's streamflow dropped in the 2050s and 2090s compared to the baseline era for the 20th century, according to SWAT's future estimates of flow and other hydrological processes in the UBNRB. The main factors causing these losses, which range from 10% to 61%, are higher temperatures and less precipitation, both of which the GCMs expected.

Based on certain soil, slope, and land use properties, a watershed in SWAT is divided into a number of sub-basins, which are further divided into hydrologic response units (HRUs). The model can take into consideration changes in evapotranspiration for different vegetation and soil types thanks to hydraulic response units (HRUs). The weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, agricultural growth and irrigation, groundwater flow, reach routing, fertilizer and pesticide loading, and water transfer are all included in the public domain hydrology model SWAT.

The two most crucial natural resources are land and water because all life depends on them. Therefore, it must function efficiently for the best utilization. The behavior of the hydrologic systems in watersheds can be managed through the use of hydrological modeling. A physically based stochastic model with operational agricultural watersheds under various management scenarios is called the Soil and Water Assessment Tool, and it is used in conjunction with Arc GIS (SWAT). In the current study, runoff for the upper Godavari sub-basin was estimated using SWAT (Soil and Water Assess GIS data). The digital elevation model has been used to determine the catchment area (DEM). Using IRS DEM, the Land Use Land Cover (LULC) map was produced. Modeling was done using hydrometeorological data from 1994 to 2014. Using a flow accumulation threshold of 500 hectares, the upper sub-basin were separated into 2468 sub-basins. Additionally, it is divided into 10,594 HRUs. By considering the land utilized to cover each sub-area catchment, together with the soil type, slope parameter, and 20% of each sub-area catchment as land, numerous hydrologic response unit possibilities are studied using hydro and the SWAT model. The coefficient of determination for the upper Godavari basin was 0.81 during the calibration period and 0.84 throughout that same period. As a result of the calibration and validation phases in the upper Godavari basin, the model demonstrated excellent runoff replication. The findings demonstrate that a SWAT model may be utilized to evaluate various watershed management scenarios with the proper validation. It is proven that including hydrological modeling considerably enhances the SWAT model in a GIS system.

- Several hydrologic and environmental simulations have made use of the well-known hydrological modeling program SWAT (Soil and Water Assessment Tool). Multiple peer-reviewed scientific articles found on the SWAT online database, which is supported by the Centre for Agricultural and Rural Development, revealed 206 studies for 15 years (2005-2019). (CARD). These studies were divided into five categories: contexts related to climate change, land-use management, applications considering water resources and streamflow, erosion, and sedimentation, applications considering erosion and sedimentation, and model parameterization and dataset inputs. To understand the hydrological actions and reactions in different river basins, studies of water resources were used. Researchers' insights for more efficient environmental management came from studies on the effects of land use and agriculture on the environment and how to offset such effects. Studies on erosion and sedimentation based on the SWAT model were carried out to determine sediment yield and evaluate soil conservation methods. The majority of climate change studies have demonstrated how responsive streamflow is to weather variations. The main emphasis was on the model calibrations, parameter choices, and streamflow analysis model parameterization study. The majority of the dataset's inputs compared expected rainfall totals to actual measurements made using rain gauges and other global rainfall data sources. The SWAT paradigm's applications and advantages as well as some of its disadvantages are examined. The model's flexibility in different applications, the data's accessibility, and the forecast's ambiguities are only a few examples. It is commonly brought up when talking about aspects of upcoming simulations, like data sharing and the potential for deeper study. Future simulations ought to utilize a multidimensional approach and concentrate on the importance of local data.

- On a worldwide scale, a variety of problems involving water resources have been resolved using hydrological and associated water assessment models. The bulk of evaluations has been completed using computer models, which has the advantage of allowing cost reductions because they can accurately depict operations that happen in the actual world in terms of place and time. They also help us understand a variety of physical processes by offering quantitative estimates of the distribution of water in diverse environmental conditions. The development of hydrologic models and recent developments in the use of geographic information systems have made it possible to evaluate water resources and the environment in a remarkable new way (GIS). Their use in assessing water resources has increased recently as a result. One of the best hydrological models for addressing major environmental and hydrologic issues is the soil and water assessment tool (SWAT). A physically based, semi-distributed, and continuous-time hydrological model is the SWAT model. The model was created to evaluate the available water resources and predict the effects of non-point source pollution, alterations in the usage or cover of the land, and land management techniques on watersheds or significant river basins.

1.3 Standards and codes of practices

For developing the model we have followed the R^2 value as a standard. Based on this standard we have done the calibration and validation. The calibration and validation are also followed to develop this model.

1.4 Stakeholders' expectations/requirements

Stakeholders are farmers, govt, agricultural people, policymakers, etc. Their reviews about this project are different which are given below.
As a result of filter stripping;

* Fisheries health will be good
* Aquatic environment will be good
* Will have a positive impact on the economy
* Environmental health will be good
* There will be no pollution

* People's health will be protected
* Stripping the filter will improve the water quality.

1.5 Project requirements

The project team shall meet, but is not limited to, the following requirements of model development and design:

1) The model calibration and validation should achieve minimum Nash–Sutcliffe Efficiency (NSE), respectively, of 0.65 and 0.55.
2) The model must incorporate important weather data consisting of rainfall (mm), maximum and minimum temperature (ºC), wind speed (km/hr), relative humidity (%), and solar radiation (cal/cm^2).
3) The effect of various land uses, such as urban, agricultural, water, forest, and pasture must be incorporated into the model.
4) The hydrologic response unit (HRU) should integrate soil classes, land cover, and slope classes.
5) The future projection of water quantity and quality should be at least 30 years.
6) The vegetative filter strip should be able to reduce nitrogen load by 25% in the peak farming month. Further, the vegetative filter strip must maintain the nitrogen load within the standard limit of Bangladesh Standard for inland discharge.

1.6 Project Management

Project management is the process of carrying out specific project goals within set parameters while applying procedures, techniques, skills, knowledge, and experience. Financial and scheduling constraints may affect the ultimate project management outputs.

In our project, we used the Arc SWAT model to investigate the effects of farming on the Naoga Atrai river watershed as a whole as well as on particular portions of the river. We needed a sizable amount of data, which we had to purchase from various for-profit websites in order to finish the project. Furthermore, we finished the assignment on schedule.

1.6.1 Project Plan

The discipline of project planning focuses on how to complete a project within a predetermined timeframe, often with predetermined stages and resources.

Who, what, where, why, how, and when the project will be done are all included in the planning process, also known as the project management plan. There are more than just activities and due dates on a Gantt chart. Organization and administration of the project's execution and control phases are the primary responsibilities of a project plan.

The following documents make up a project plan, as was already mentioned:

- **Project Charter:** In general, it gives the project a broad overview. The project's aims, objectives, and stakeholders are only a few of the many topics it covers.
- **Statement of Work:** In a statement of work (SOW), the project's goals, deadlines, deliverables, milestones, and tasks are specified.
- **Work Breakdown Structure:** Split the project's scope into the deliverables, phases, and subprojects that will lead to your end product.
- **Project Plan:** The project plan document is organized into numerous sections, each of which contains plans for scope management, quality management, risk assessment, resource management, stakeholder management, schedule management, and change management.

Our supervisor Dr. Shakil Ahmed sir made a perfect plan to complete our project on time, due to which we were able to complete the project within the stipulated time.

1.6.2 Risk management

Risk management is the act of identifying, evaluating, and addressing any potential risks in order to keep a project on track and meet its goals. In order to detect potential risks to the project and make management decisions should they materialize; risk management shouldn't only be an afterthought; it should also be a part of the planning process.

Soil erosion is one of the main causes of land degradation and a major environmental problem in Mediterranean regions. Estimating soil erosion loss in these areas is frequently difficult due to the complex interactions between a number of elements, including climate, land uses, geography, and human activities. This study uses the Soil and Water Assessment Tool (SWAT) model to analyze surface runoff generation patterns and soil erosion issues with the aim of identifying the most deteriorated sub-catchments and implementing the required management intervention.

1.6.3 Required resources and budget

Assigning administrative and departmental funds necessary to provide a financial foundation for delivering the stated project deliverables is a step in the process of developing the project budget. When we discuss a project's budget and financial resources, we are referring to the reliable structure that enables project managers to handle the "on budget" phase of the project execution process. This framework comprises cost management and planning.

1.7 Impacts of the project

The phrase "Project Impact" describes the effect that the project will have on technology once it is complete. Both positive and negative influences that occur inside the Project Assessment Boundary must be taken into account when assessing the Project's Impact. The term "Impact of Project" refers to a competitive scoring category that identifies and evaluates the possible social, economic, and financial benefits that a certain project would give to its community in order to select the Projects with the highest advantages for Reservations. When attempting to reduce expenses while enhancing project outcomes, project management is an effective strategy. The benefits might reduce unnecessary risks and increase success rates when taken together. When the economic crisis drove them to make cost-effective decisions, several corporate managers found that employing project management approaches was crucial to the organization's continuing profitability, despite declines in global commerce. Effective project management can benefit a company by boosting organizational prosperity. Businesses that can anticipate problems, change responsibilities, and improve departmental communication are in a better position overall.

1.7.1 Impacts on society

The impact that a project, program, activity, or policy has on individuals and communities as a result of its implementation or non-implementation is known as social impact. Climate change and land use can hugely affect society. Example: Chaco canyon is situated almost 150 miles away in the northeast direction from Albuquerque, New Mexico. Here, civilization was formed 1000 years ago. The civilized race was very developed in technology. They were the first to build two-story buildings. The civilization was built by the river. They were a hunter-gatherer race. At present, the race no longer exists. This is because of climate change's effect on the water body. There was no rain for about 50 years when the race existed. So, lack of water and drinking water caused the migration of animals. Crops were not growing also, due to the lack of water. Thus, causing the extinction of the civilized race. Changes in land use can also affect society. Example: In 2015, the thousand years flood event in South Carolina, USA happened. This was because of the construction of roads at a high rate which reduces the permeability and the percolation rate of water and leads to floods. The other reasons are there is less open space than before and more population. Urbanization was planned for a limited amount of people but then, the population increased which also increased the construction of the home. The draining system was also inadequate for the larger population. So, the flood happened which caused many difficulties in the urban life of South Carolina USA. the lesson that we learn here is that it will develop into various disasters when one changes land use without any effective plan. The same thing can happen if farmers of a community start to use chemical fertilizer instead of organic fertilizer without any treatment plan. It can lead to excessive nitrogen load in waterbodies which can hamper one’s health and also biodiversity. Thus, it will lead to the extinction of the community due to a lack of water for using and drinking. The nature-based solution vegetative filter strip from our project can mitigate the load of chemical yields in these situations, it can also trap nutrition and moisture thus helping to protect the environment and biodiversity without causing any chemical yields from the solution itself.

1.7.2 Effects on environment and sustainability

The way our communities use their water resources depends on how environmentally sustainable we are. Rapid action is unquestionably necessary due to the fact that temperature increases hasten other changes in the climate system, such as changes in precipitation patterns, increased evaporation, and high temperatures. It is overwhelmingly clear that greenhouse gas emissions cause climate change because they have an effect on several parts of the water cycle. In general, the models that are used to predict changes in oceanic precipitation are accurate; nevertheless, the rates at which dry areas become dryer and moist areas become wetter differ. High-resolution climate models show that the intensity of sub-daily severe rainfall is expected to increase in the future, making them theoretically estimated decadence most likely in many regions. Model-based estimates are now more trustworthy and represent extreme precipitation more accurately. Sustainability in combating climate change shouldn't be an all-encompassing strategy that shapes people's obligations and behaviors. The good news about climate change is that we are aware of its causes and know how to avoid it, but we also need to be aware of other, more significant environmental sustainability challenges that require action. We must learn more about some forms of environmental degradation if we are to put a stop to them. Every region of the world will undoubtedly be impacted by even minor climatic changes, which are nearly guaranteed to have devastating effects. To decrease the detrimental consequences of climate change on human health and the ecosystem, we must face its inevitable implications. Governmental organizations, decision-makers, and leaders will be assisted by these forecasts in developing policies and implementing adaptation plans in response to changing climatic circumstances.

1.7.3 Health and safety issues

Climate change will affect the farming season drastically as there can be both drought and flood in any season. Thus, it will reduce crop yields due to this unpredicted climate change. It will compel the farmers to use chemical fertilizer to increase crop yields. However, excess nitrogen can also hamper plants by decreasing the growth of crop yields. It can also harm the soils and waterways. Thus, it can create a shortage of food and drinking water which will affect our health and safety eventually.

Compounds including chlorine and nitrogen may evaporate into the atmosphere, and surface runoff from watersheds brought on by rainfall may get into waterbodies, altering how the land works. Pollutants like ozone and ammonia, which are created when there is too much nitrogen in the atmosphere, can affect our ability to see and breathe. If there is too much nitrogen in the water, algae may grow faster than the ecology can support them. Aquatic species' ability to live will be impacted by declining oxygen levels, habitat quality, food availability, and water quality, among other factors. Thus, it can create a shortage of aquatic food and potable water which will also affect our health and safety. Moreover, inducing nitrogen-polluted water, or breathing in nitrogen-polluted air, can cause liver-kidney damage and skin rashes.

Nitrogen can displace oxygen from the enclosed place which can cause oxygen deprivation Thus, hampering our health and safety. So, it must be handled in a well-ventilated area.

The nature-based solution vegetative filter strip from our project can mitigate a load of chemical yields in waterbodies, which will also save our health and ensure safety from the adverse effect of excess nitrogen load in water bodies.

Chapter 2 Project Design

We might utilize the SWAT program to forecast future flow discharge and other components utilizing the Arc Swat project model, which is based on the current circumstances. The setup, running, calibration and validation of the SWAT model is shown in the first of our project design's two sections. The main focuses of this SWAT model are simulations of climate change and water flow. In order to study how climate change might affect water resources and to set the proper parameters to reduce nutrient loads and vegetative loads, the objective of this project is to develop a hydrologic model or water quality, model. In the second part of this inquiry, nutrient loads will be predicted in light of population growth and urbanization.

2.1 Functional design

The geographic, numerical, and textual input and output of SWAT operations are organized and stored using the geographic databases that make up the ArcGIS-SWAT data model. As a result, it is suggested that a SWAT simulation be maintained in a single, comprehensive geodatabase. The functional design must be finished after numerous stages, including Swat Project Setup, Watershed Delineation, HRU Analysis, Write Input Tables, Edit Swat Input, and Swat Simulation. SWAT may simulate a single watershed or a network of many interconnected watersheds. Each watershed is divided into subbasins and subsequently hydrologic response units (HRUs) according to the distribution of soil and land use.

2.1.1 **Data sources and variables used in the Swat model**

S. No.	Variables	Data Sources
1	Remote sensing data, DEM	https://search.earthdata.nasa.gov/search
2	Soil Data	https://swat.tamu.edu/data/india-dataset/
3	Daily Weather Data	https://power.larc.nasa.gov/data-access-viewer/
4	Land use Data	Provided by the supervisor.
5	Country Shapefile	https://www.diva-gis.org/gdata
6	Digital Soil Map	https://data.apps.fao.org/map/catalog/srv/eng/catalog.search#/metadata/446ed430-8383-11db-b9b2-000d939bc5d8

2.1.2 Overview of SWAT Model

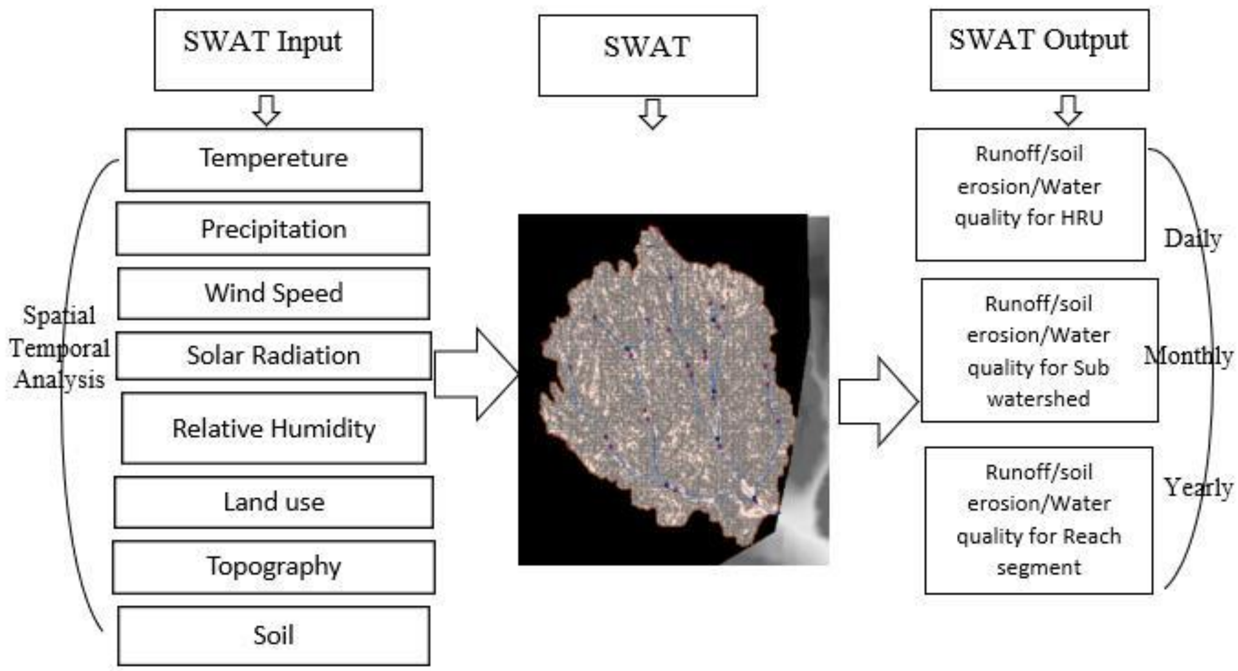

Fig. 2.1 Overview of SWAT Model

For hydrologic modeling there need two kinds of data.

(1) **Special Data:** Land use, Soil, Slop Topography or Digital Elevation Model (DEM), etc.

(2) **Temporal Data:** Temperature, Rainfall, Weather data, Wind speed, Relative humidity, Solar radiation, Discharge data, etc.

We have to set these special and temporal data as SWAT input files to create a SWAT model. By simulating the SWAT run we will get different output data such as Runoff data, Water quality for HRU, etc. Which are used as SWAT output.

2.1.3 Preparing DEM raster file

DEMs are files that contain pixels (raster), with an elevation value assigned to each point or pixel. They are available in a variety of file formats, ranging from CSV to dem to txt, and can extract a wide range of data. We have downloaded the raster DEM file from the NASA website along with the temporal data (Temperature, Rainfall, Weather data, Relative humidity, Wind speed, and Solar radiation) of the location where we have the latitude and longitude information.

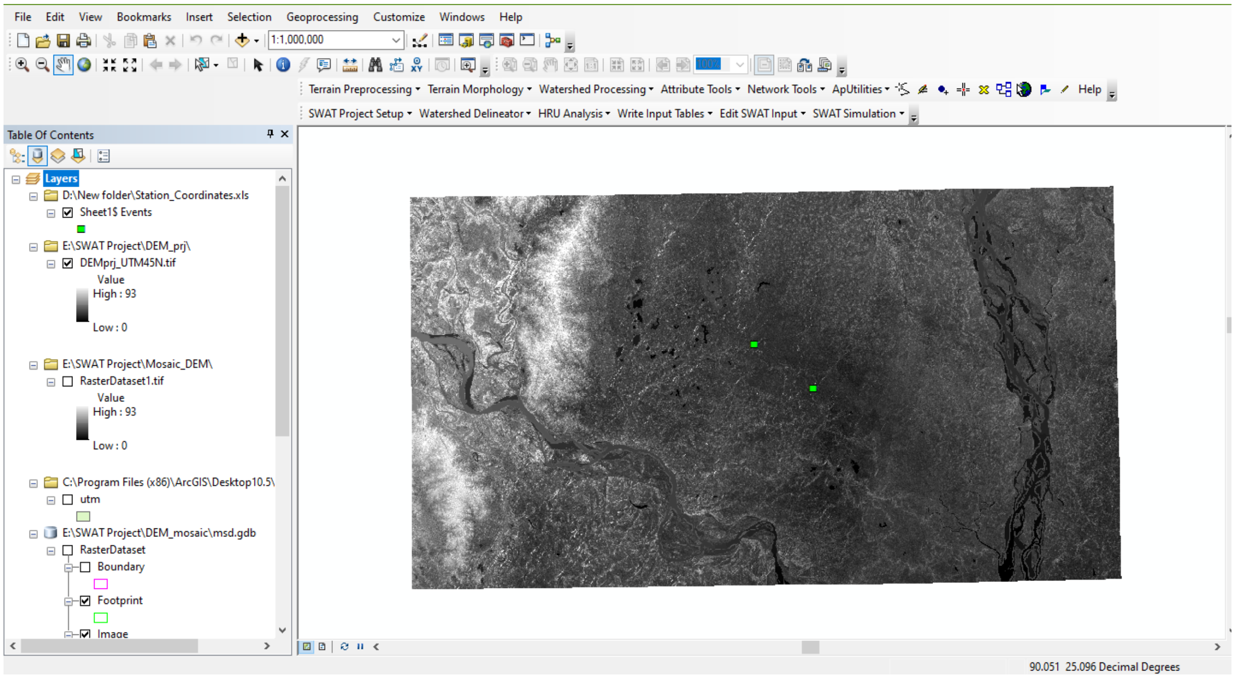

Fig. 2.2 Projected DEM coordinated at UTM45N

After that, we merged the separated DEM. Next, we created the mosaic dataset and add a raster to the mosaic dataset by using data management tools. After exporting the mosaic dataset, we identify the coordinate which is UTM zone 45° North then we reprojected and exported the DEM. With this DEM we have set up the swat project in ArcGIS.

2.1.4 Watershed Delineation

Drawing a circle around a water body or runoff outlet to represent the area that contributes to the analysis of a certain control point or water outlet is called watershed delineation. Arc SWAT used the DEM information as an input to automatically draw the watershed. For the provided DEM, stream outline metrics like flow direction were calculated. A total of 1000 Ha was covered by the concept of streams. The stream outline was followed by the stream network route. By manually adding a point to the sub-basin, the watershed outflow and the point source discharge were defined. The watershed outflow was then chosen in order to define the sub-basin. where the land use and soil distributions are used to first split the watershed into subbasins and then into hydrologic response units. The watershed of the Atrai River was separated into 25 sub-basins for this study. according to Fig. 2.3. The sub-basin parameters were calculated to estimate each sub-individual basin's area covered, length, reach, width, depth, and other characteristics.

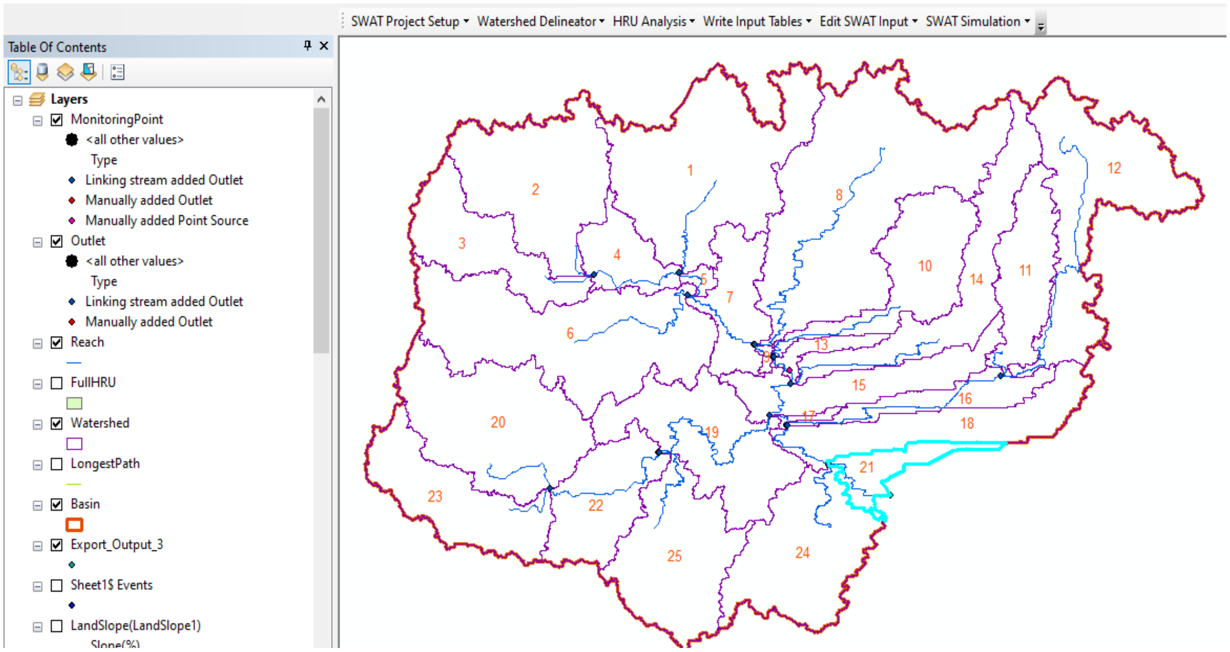

Fig. 2.3 Watershed delineation

2.1.5 Land Use/ Soil/ Slope

i. Land Use/ Landcover, mainly refers to the characterization of human actions and natural factors on the landscape over time using established scientific and statistical methods with adequate source materials. By importing Land Use and Land Cover data, the physical land type of the study region was determined. The area was then extracted using the sub-basin border.

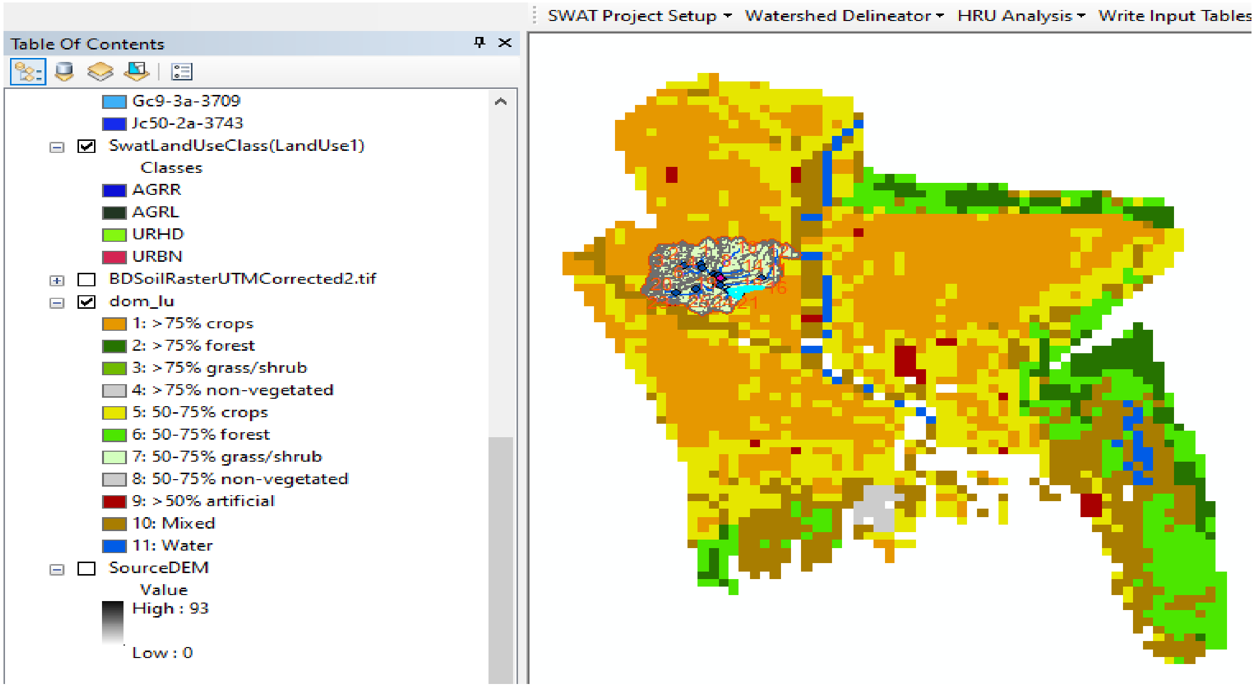

Fig. 2.4 Land Use/Landcover Classes

ii. In order to give information for calculating the soil cover, the soil type was first received as a layer file. It was then transformed to raster format and classified based on user-defined FAO soil types (SWAT- Soil Class).

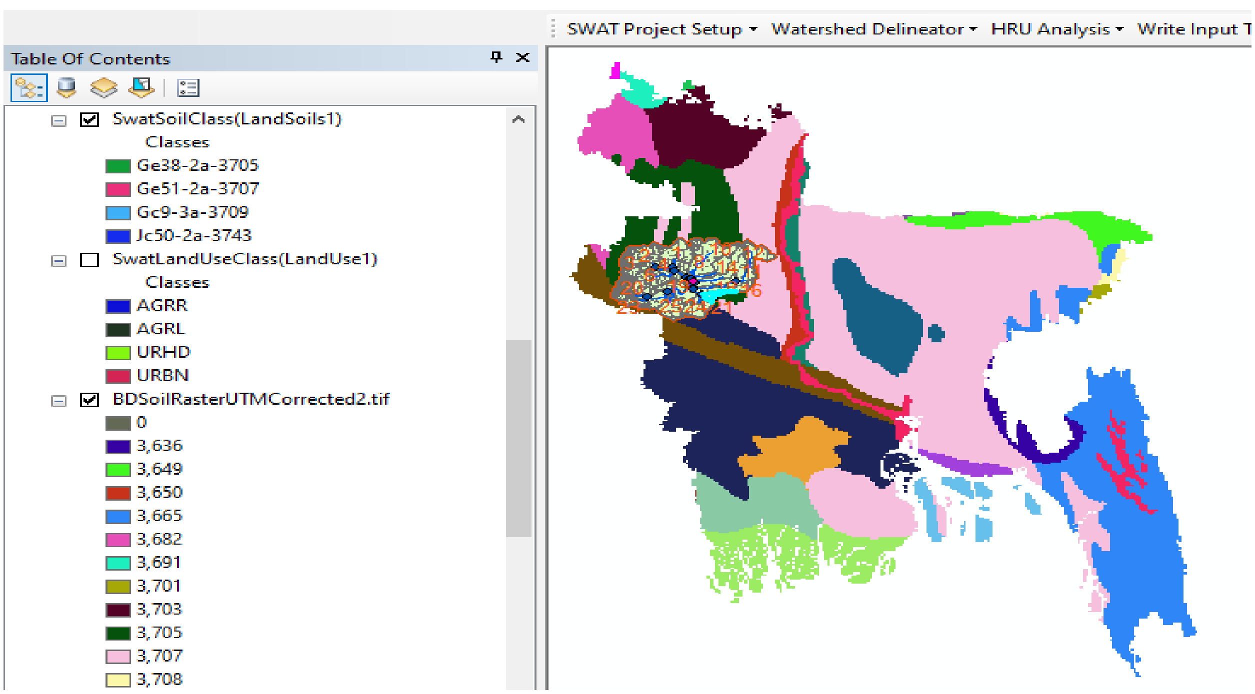

Fig. 2.5 BD Soil Classes

iii. The slope is a crucial metric that governs the movement of water, nutrients, and sediment. With a range of 0 to 15 as the lower limit and 15 to 9999 as the upper, there are a total of 2 slope classes.

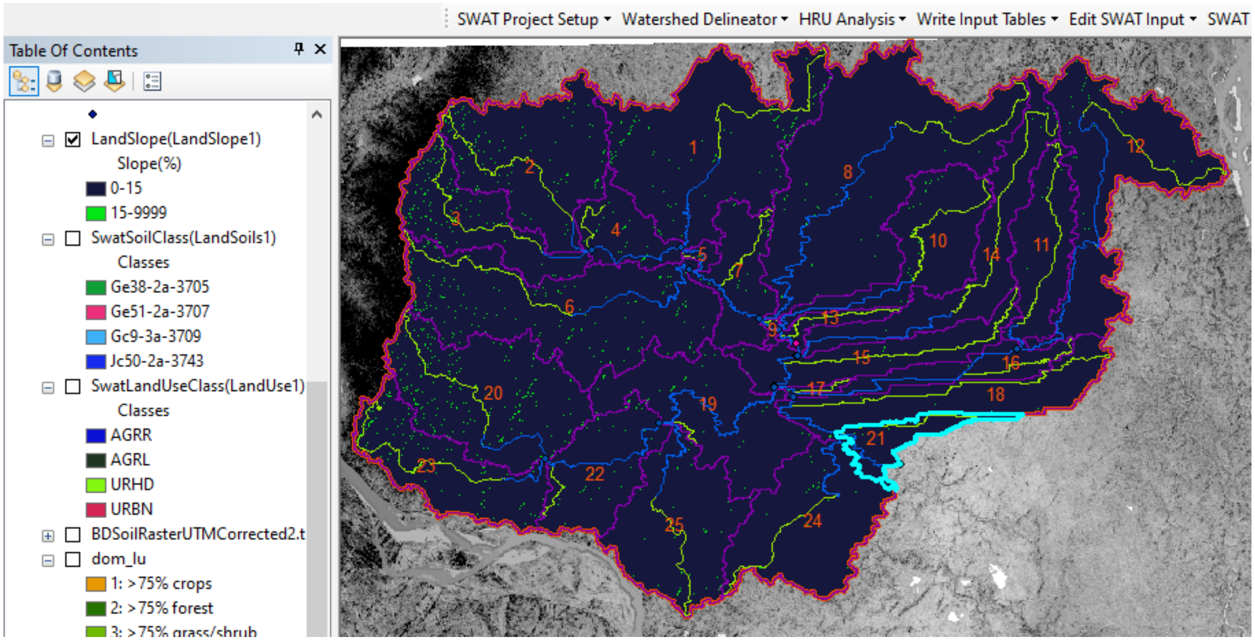

Fig. 2.6 SWAT Slope Classes

2.1.6 HRU Analysis

It can be characterized as the integration of numerous soil, cover, and slope classes. The HRU feature classes were made by overlaying the input parameters. A layer displays the HRU for sub-basins for each land use, type of soil, and slope. In conjunction with the weather database, land use/soil/slope defined HRUs were the primary source for obtaining the climate factors. The database imports results in a report that groups each HRU according to the current soil type and land use pattern. The presence of HRU in the Arc SWAT interface enables the creation of twenty-five sub-basins in the Atrai River watershed by superimposing soil maps, land use maps, and correspondingly delineated watersheds and slope classes. Since measurements are made for every watershed in the sub-basin, it can be said that climate change is influenced by land use, soil, and slope.

2.1.7 Weather Database

The latitude, longitude, and elevation of the study area were utilized to obtain weather data from the NASA website, including rainfall (mm), maximum and minimum temperatures (oC), wind speed (km/h), relative humidity (%), and solar radiation (cal/cm2). Then they are imported into the Arc SWAT weather database. After that, the software examined these values.

2.1.8 SWAT Simulation

The point source discharge was added in the edit swat input tab, after that, all files were re-written in the arc swat model. Now it was prepared for the swat simulation. the dates were set up from 1 January 2017 to 31 December 2021 in the swat run. Where the first three years were for NYSKIP. The user can utilize NYSKIP to remove data created during the equilibration period from the output summaries. Annual averages are not computed for the missing years in addition to no data being written to the output files. Additionally, data from the years that were skipped will not be included in averages for the whole simulation period. After setting up the swat run, the swat run started. Finally, it showed a dialogue box with the text which is, "The SWAT run is successful.

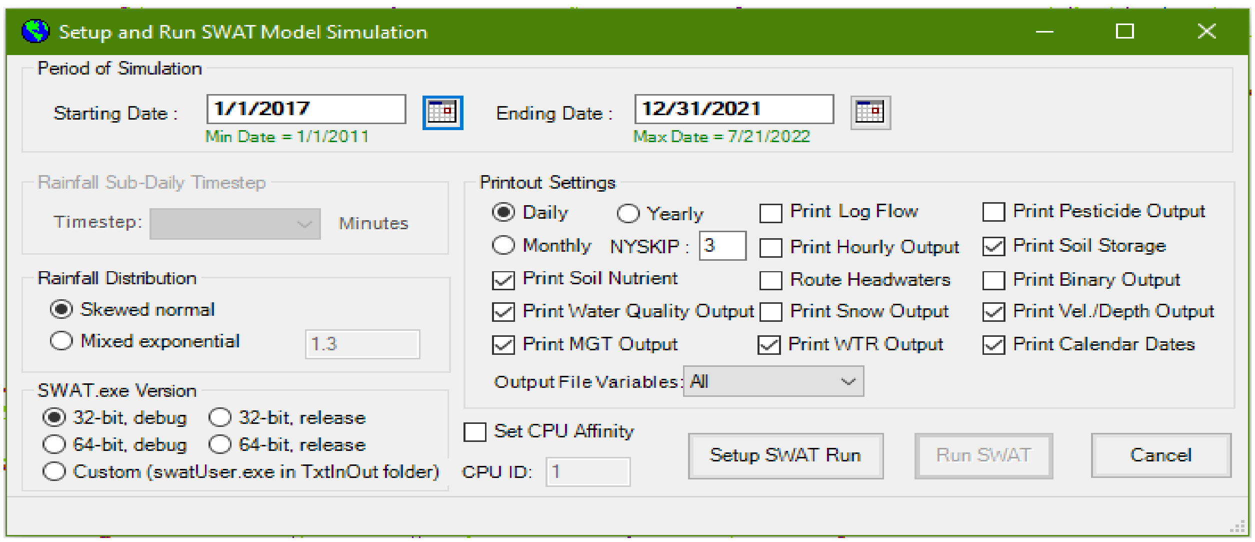

Fig. 2.7 Running SWAT simulation

2.2 Analysis of alternate solutions

An examination of alternatives is a comparison of the operational effectiveness of several suggested material solutions to operational capability gaps and deficiencies. Here, we've examined or quantitatively evaluated several options in relation to the project's design, and we've backed the choice of which option is best for our design and implementation.

2.2.1 Model Calibration

Model calibration is a crucial step in the first round of testing. To make sure that the parameters are used to portray the study region, calibration and validation are generally performed. The model was calibrated for the evaluation of the curve number and precipitation using the observed data. Calibration was completed to improve the model's precision and efficacy as well as to get favorable coefficient values that would improve the model's performance. After the NYSKIP or a warm-up period of three years (2017, 2018, and 2019) the calibration was done with the data from the year 2020 (2020 observed vs. 2020 simulated). We have done a total of four calibrations for our analysis. For each calibration, the multiplication factor of the slope was fixed which was 0.9 then we changed the curve number with different multiplication factors. High surface runoff is represented by a larger curve number, and soil permeability is shown by a lower curve number. R squared measures how well our data matches the regression model. In the first calibration, the curve number (cn2) was reduced by 10% by multiplying 0.9 with it and the R^2 value we got was 0.39. In the second calibration, the curve number was reduced by 20% and the value of R^2 was 0.37 which was smaller than before. Then the curve number was increased by 10% in the third calibration and the R^2 value we got was 0.654 which is larger than before. After that, in the fourth calibration, the curve number was increased by 20% and the value of R^2 was 0.653 which was smaller than the value in the third calibration.

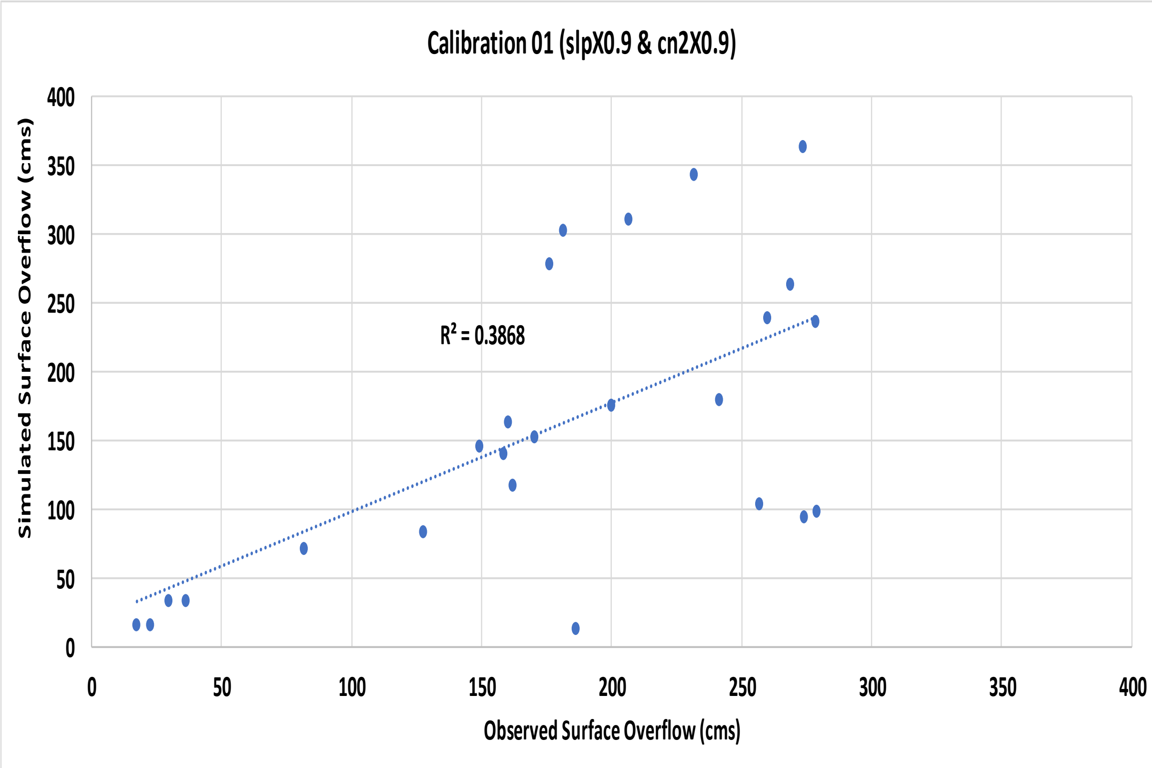

Fig. 2.8 Calibration 01

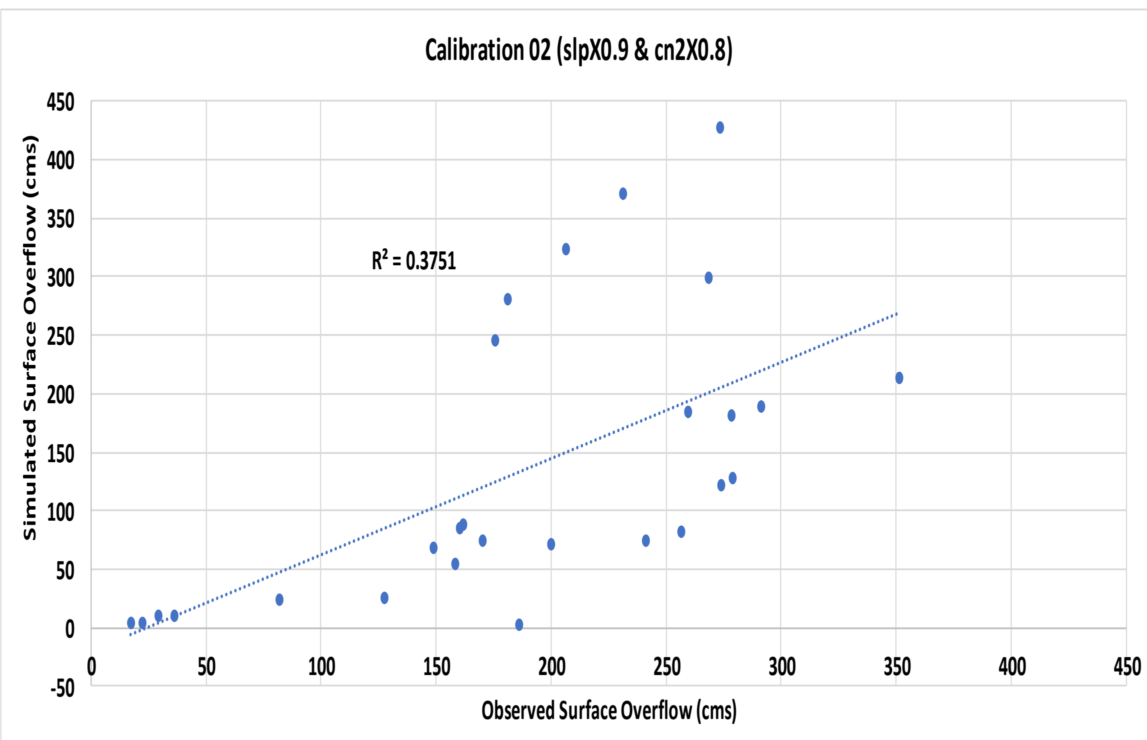

Fig. 2.9 Calibration 02

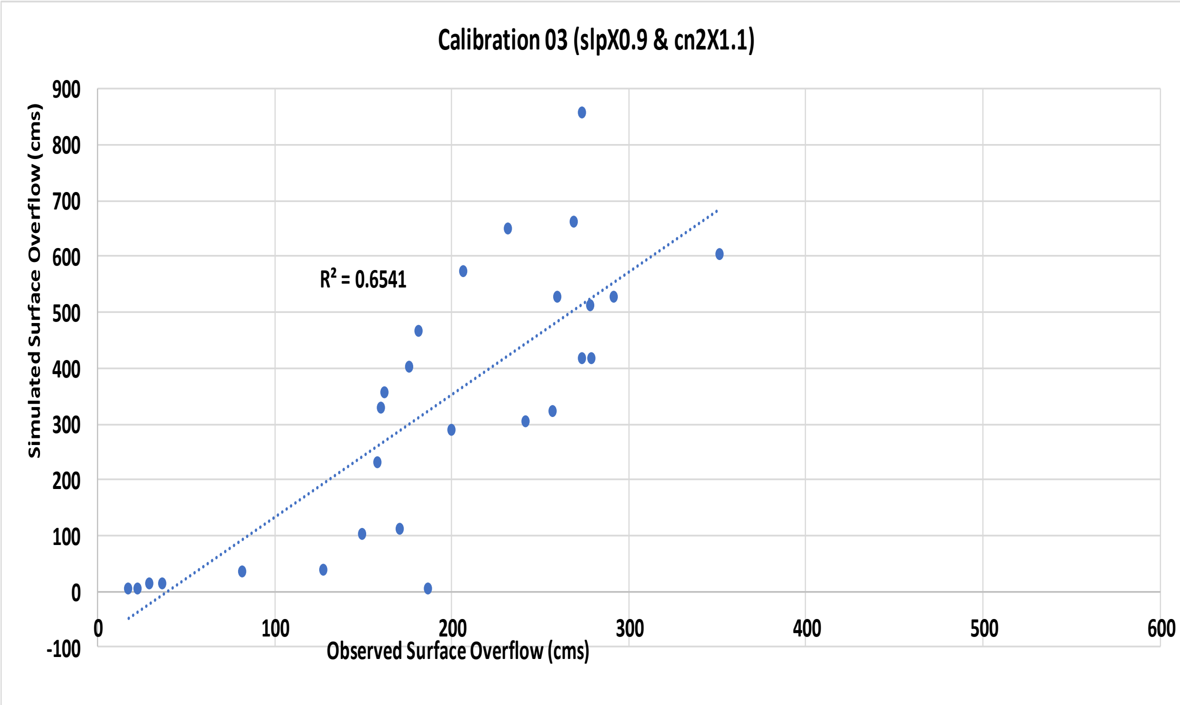

Fig. 2.10 Calibration 03

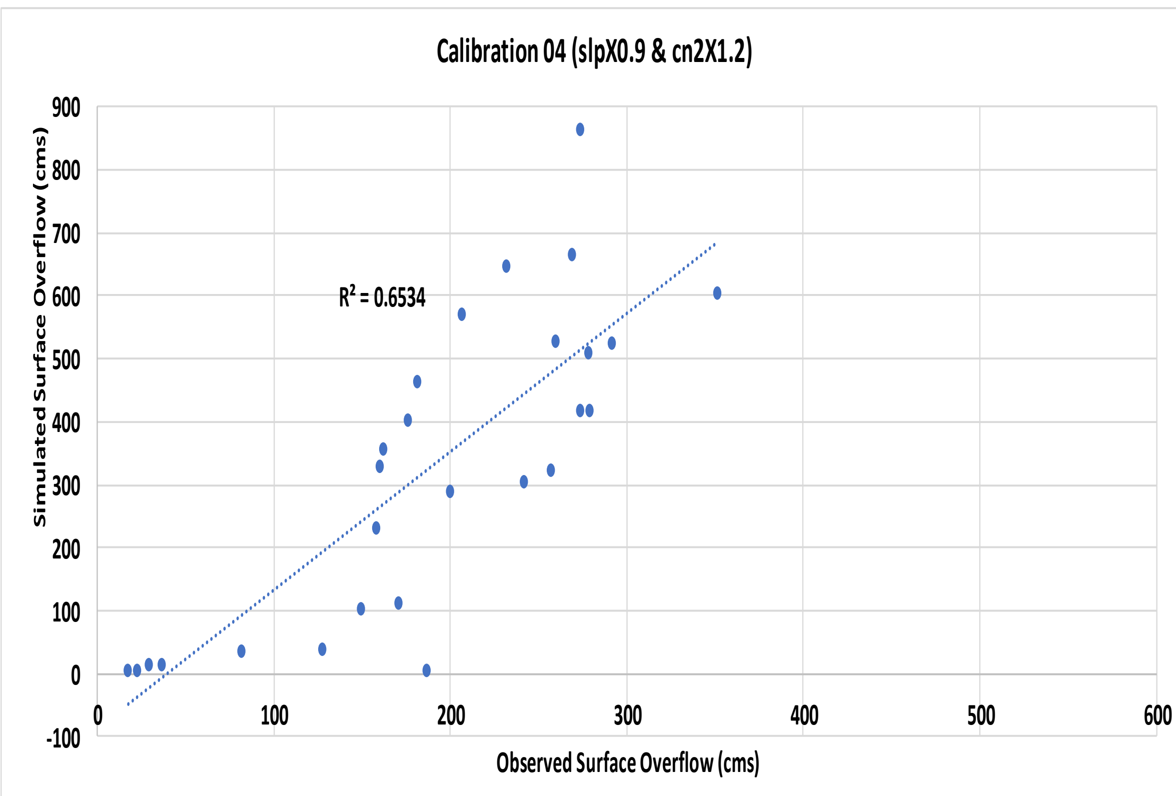

Fig. 2.11 Calibration 04

By doing this analysis we got 2 values that were upper than 0.65 as per the requirement but we had to take just one value as a best. So, by comparing the third and fourth calibrations the best value we had taken was 0.654 from the third calibration. It was noticeable from fig. 2.12 that, the maximum time in calibration 03 there was an over-prediction in the simulated data. It may be because the observed data was not measured properly.

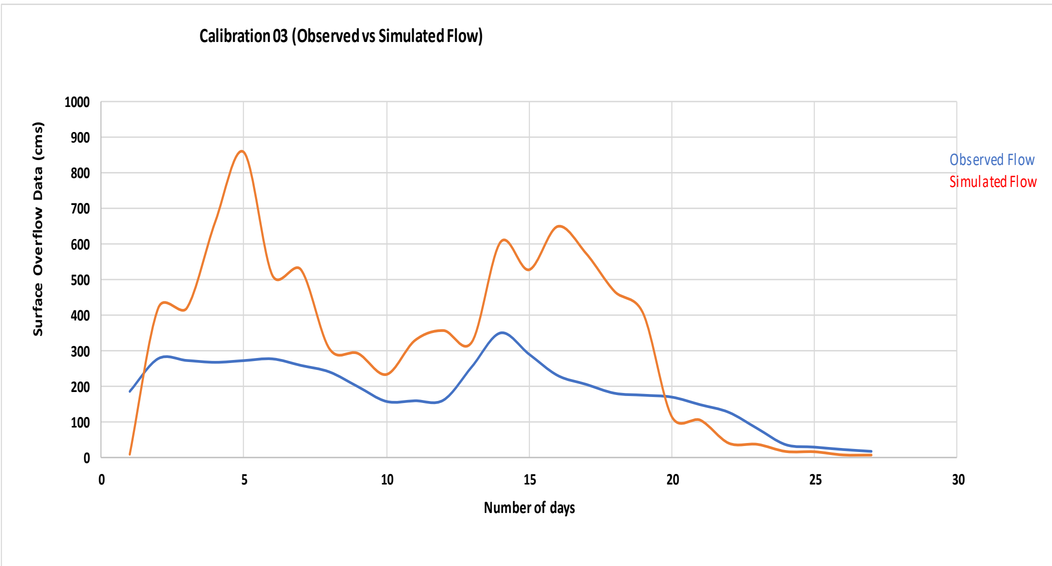

Fig. 2.12 Calibration 03 (Observed vs Simulated Flow)

Since the value of R^2 was greater than the satisfactory criteria, the third calibration (slpX0.9 & cn2X1.1) was fixed for the next validation.

Chapter 3 Finalization of Design and Model Implementation

After the calibration to complete the design, we have the input data for the SWAT model's validation, and following this, future values can be monitored. In this chapter, the implemented solution is demonstrated and the finalization of the design is shown as well.

3.1 Development of the prototype

A simple, workable simulation, model, or representation of the real data is referred to as a prototype, and it forms the basis for all other forms. The primary goal of prototyping is to confirm the dataset's design. A prototype is built, tested, and modified as necessary to build a working prototype (Validation) from which the whole system can be produced. The process in question is the prototyping model. The figures, images, and diagrams from the model calibration section 2.2.1 of the previous chapter are used to construct the prototype of the solution.

3.2 Performance evaluation of implemented solution against design requirements (Validation of Model)

Examining the model's performance and accuracy in respect to historical data for which we already have actuals is the aim of model validation. After the model is built, it needs to be validated. We have determined whether or not the model will be useful for simulating future dates.

Therefore, we contrasted the real and simulated data for the years 2021 and 2022 for validation purposes.

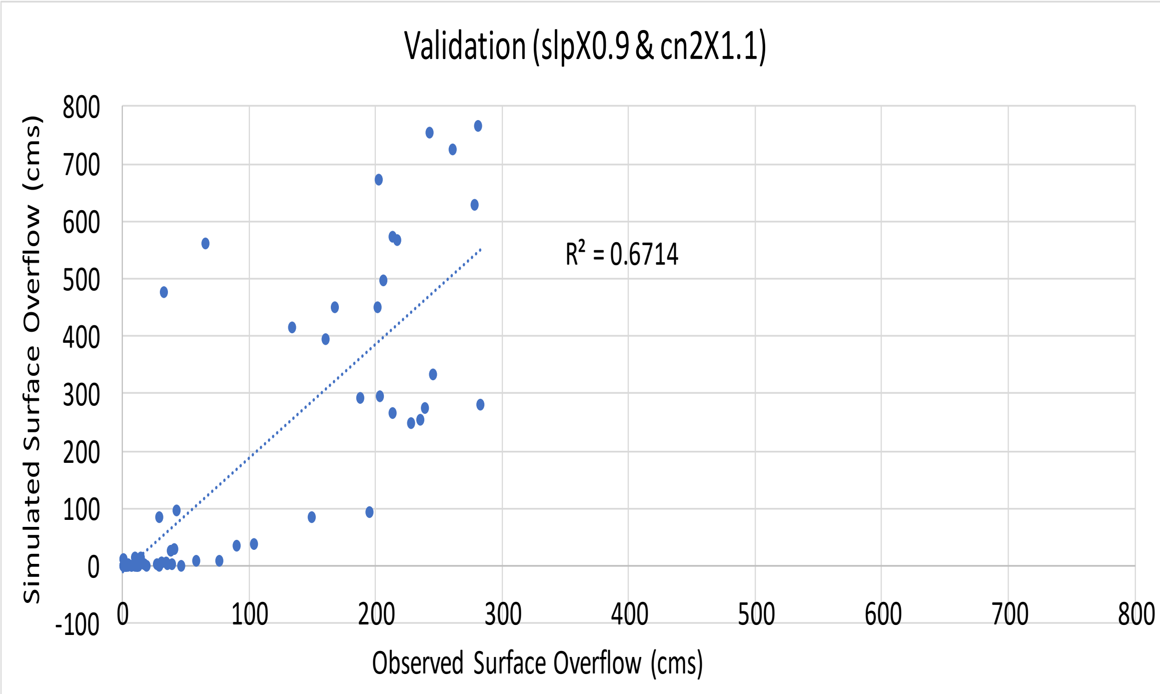

Fig. 3.1 Surface overflow data comparison of 2021 and 2022

The surface overflow comparison graph for the years 2021 and 2022 is shown in Fig. 3.1 as well. There are numerous techniques to verify a model. R squared value is one of the ways. When attempting to validate a model, if the R square value rises above 0.5, we may declare that the model has been successful. Our R square value is greater than 0.5, as we discovered after charting the data. So, we can now say that our model has been validated.

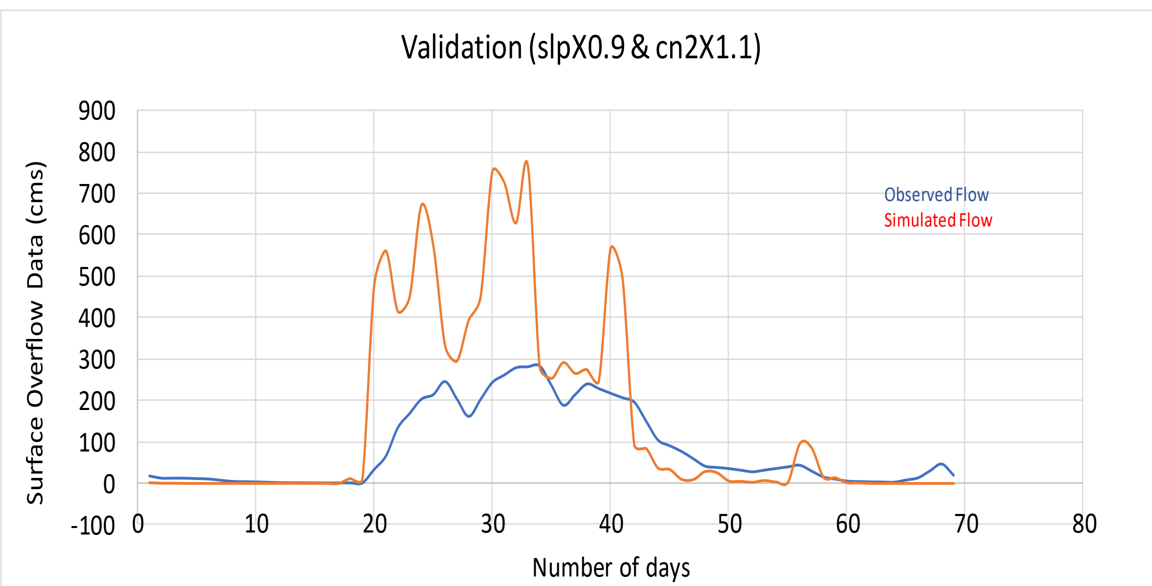

Fig. 3.2 Validation (Observed vs Simulated Flow)

As we can see from Fig. 3.2 that, the maximum time in the validation there was an over-prediction in the simulated data. It may be because the observed data was not measured properly.

3.3 Finalization of design

Calibration Analysis was done for the finalization of this design. The calibration was done with the data from the year 2020 (2020 observed vs. 2020 simulated). We have done a total of four calibrations for our analysis. By doing this analysis we got 2 values one was from the third calibration and another was from the fourth calibration which was upper than 0.65 as per the requirement but we had to take just one value as a best to finalize the design. So, by comparing the third and fourth calibrations the best value we had taken was 0.654 from the third calibration. The curve number was increased by 10% in the third calibration and the R^2 value we got was 0.654 which is larger than other calibrations. Since the value of R^2 was greater than the satisfactory criteria, the third calibration (slpX0.9 & cn2X1.1) was finalized for this design, and based on this the validation was conducted.

3.4 Use of modern engineering tools

To assess the consequences of land management practices in large, complex watersheds, the Soil & Water Assessment Tool (SWAT), a model built at the scale of a river basin, was developed. The design, modeling, simulation, and performance assessment of the chosen solution were carried out using the Arc SWAT software tools, which are state-of-the-art engineering tools. Arc SWAT is an add-on for ArcGIS and ArcView that integrates SWAT. The geographical representation of HRUs in the SWAT mode does not account for pollutant channeling within a sub-watershed, which is one of its key drawbacks. Formulas for a model are empirical. Not appropriate for hydraulic 2D or 3D applications.

3.5 Future Flow Outcome Prediction (2021 vs 2052)

From Fig. 3.3 we can see that, the Observed avg. Surface overflow in 2021 for different months. The flow decreased in November and December, also we can observe that there is very low flow from January to April. It is because from November to April there was a winter or dry season.

After that, in the summer season from June, the irrigation is increased as the flow is increased. In the rainy season from August to September the surface overflow is high.

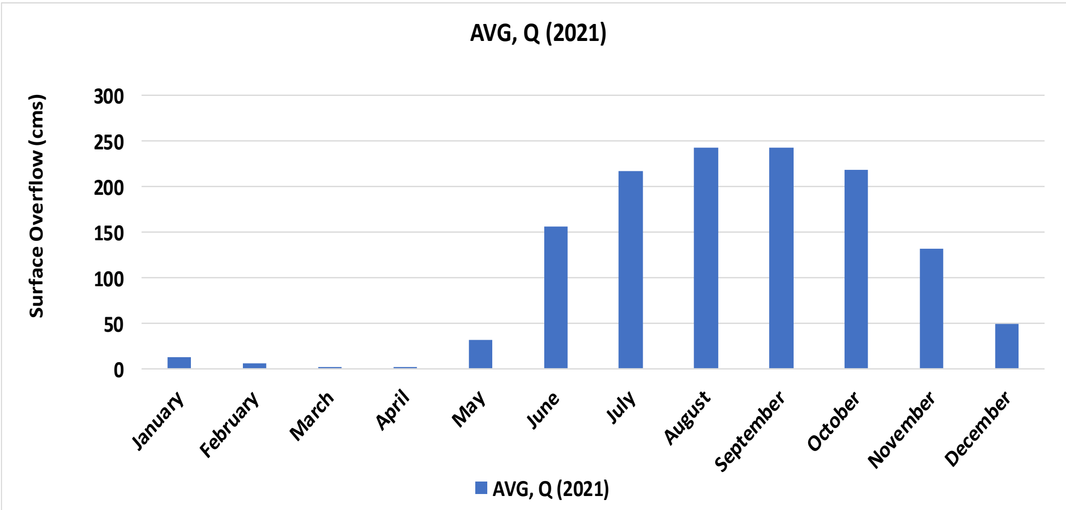

Fig. 3.3 Observed avg. Surface overflow (2021)

If we compare fig. 3.3 and fig 3.4 we can see that where there is more surface overflow, there is more Nitrogen load in the river. We also can notice that in June the irrigation is started, for this reason by irrigating the croplands all the nitrogen washed up and flow down to the river that's why in June there is the highest nitrogen load. After that, when the rainy season comes, because of the massive precipitation all the nitrogens are washed up from the cropland and fall into the river for this reason we also can see the more nitrogen load value in August and September in the graph (fig. 3.4).

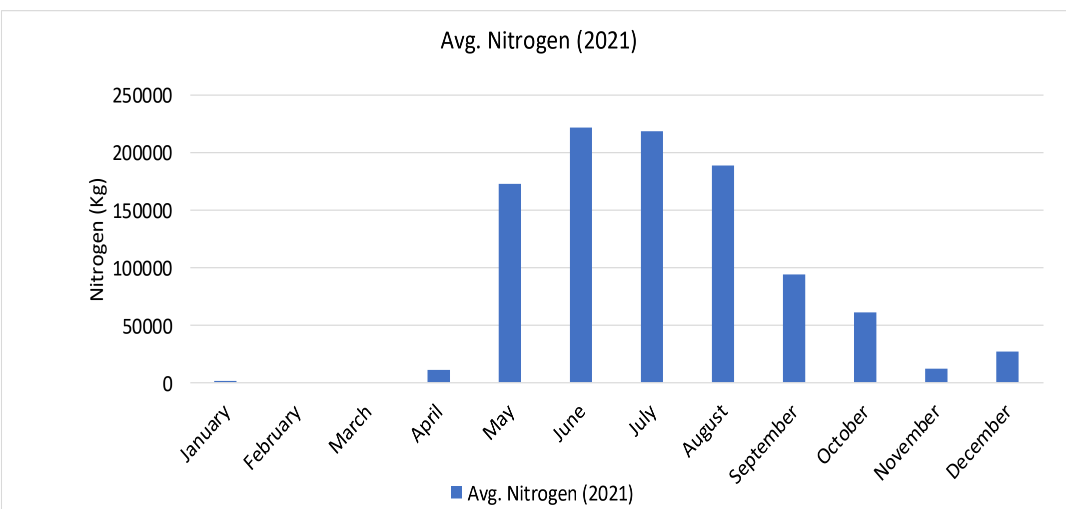

Fig. 3.4 Observed avg. Nitrogen load (2021)

Based on our model, we tried to simulate the surface overflow data for the year 2052. Then we compared it to the observed data for 2021. By comparing both data we get an overall overview of the changes in flow in various months. It gives us a clear picture of how the future flow outcome will change from the present scenario. From Fig. 3.5 we can say that after 30 years the surface overflow will be decreased.

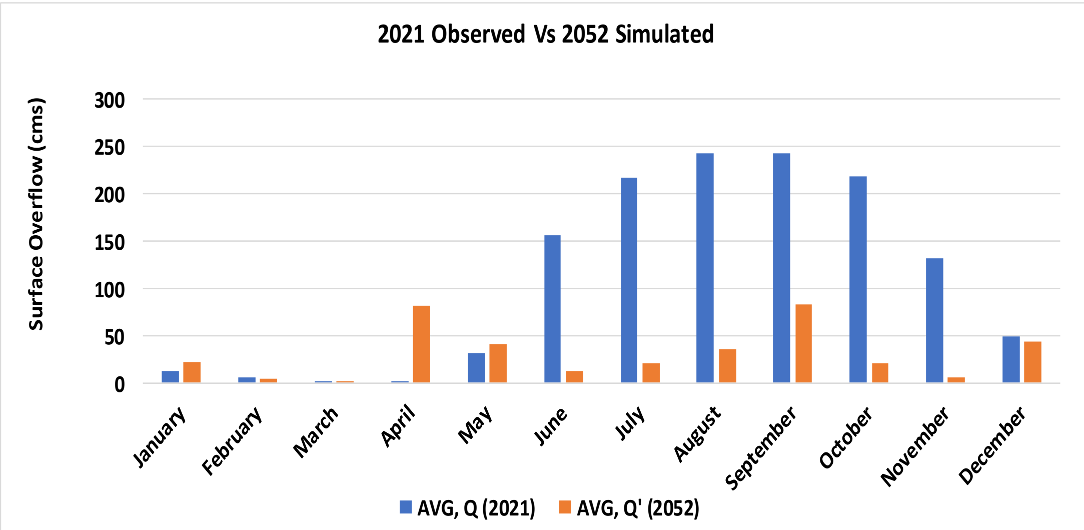

Fig. 3.5 Surface Overflow Data Comparison of 2021 and 2052

Here is the comparison data chart of 2021 observed data against 2052 simulated data. This is a graphical representation.

3.6 Nature-Based Solution

"Activities to protect, sustainably manage, and restore natural or modified ecosystems that solve societal challenges effectively and adaptively, bringing advantages to human well-being and biodiversity at the same time" is how nature-based solutions (NBS) are characterized (IUCN, International Union for Conservation of Nature, 2016). With this strategy, we want to reduce the nutritional burden by 25%. We want to build the vegetative filter strip as a natural solution to reduce the nutrient load by 25%.

3.6.1 Effect of Vegetative Filter Strips (VFS) for Surface Overflow

Vegetated regions that delay surface runoff are known as vegetative filter strips. As it moves more slowly, some of the water may sink into the ground below, screening out additional contaminants. In order to lessen the number of pollutants that are lost from agricultural areas to receiving water bodies, vegetative filter strips (VFS) are frequently installed along the boundaries of agricultural fields. Additionally, VFS decreases soil erosion on agricultural lands and safeguards water bodies. Vegetative filter strips create a region where pollutants can be decreased by reducing the energy needed to convey the sediment. Pollutant reduction in the buffer is additionally aided by infiltration, adsorption, and plant nutrient uptake. Significant variance in the VFS's capacity to filter silt and nutrients was discovered in this investigation.

3.6.2 Solution for Nitrogen Overflow

In aquatic ecosystems, nitrogen is a nutrient that naturally exists. The element that is most prevalent in the air we breathe is nitrogen. The nitrogen and phosphorus-maintained aquatic plants known as algae serve as a food source and habitat for fish, shellfish, and other aquatic life.

However, the air and water can become contaminated when considerable amounts of nitrogen and phosphorus enter the environment—typically as a result of a variety of human activities. Over the past few decades, nutrient pollution has adversely affected numerous streams, rivers, lakes, bays, and coastal waters, posing major risks to both human and environmental health.

Algae grow more quickly than ecosystems can cope with when there is an excess of nitrogen and phosphorus in the water. Significant increases in algae degrade water quality, habitats, and food supplies while reducing the oxygen required for fish and other aquatic species to thrive. Algal blooms are huge growths of algae that can drastically reduce or completely remove oxygen in the water, causing fish diseases and mass fish mortality. Some algal blooms are dangerous to humans because they produce heightened toxins and bacterial growth that can make people sick if they come into touch with polluted water, consume tainted fish or shellfish, or drink contaminated water.

Even at modest levels, nutrient contamination in groundwater, the source of drinking water for millions of Americans, can be dangerous. Nitrates, a nitrogen-based substance found in drinking water, are dangerous to infants. An excess of nitrogen in the atmosphere can result in the production of pollutants like ammonia and ozone, which can be harmful to plant growth, visibility, and human ability to breathe. Forests, soils, and streams may suffer if an excessive amount of nitrogen from the atmosphere seeps back into the ground. As you can see, conservationists are very concerned about nitrogen overuse.

Fig. 3.6 Vegetative Filter Strips (VFS)

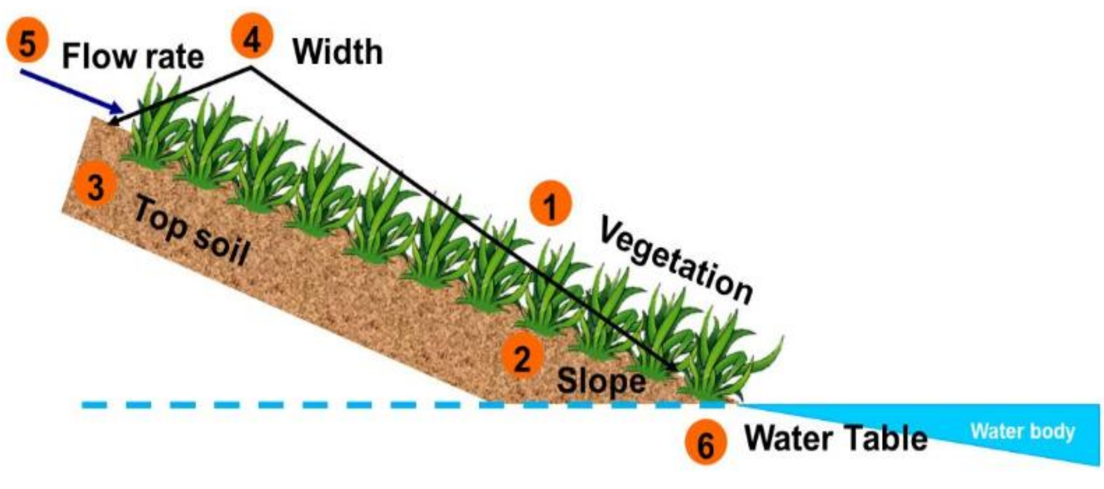

Fig. 3.7 Vegetative Filter Strips (VFS)

Why Vegetative Strip is Being Used:

A vegetative strip is the most natural and free-of-cost solution for controlling this type of nutrient pollution. Because:

- Full nature-based solution.
- Preserves biodiversity.
- Reduces erosion, Controls sedimentation.
- High Rate of pollutant filtration.
- Improves the chemical status of the field.
- Prevents Surface water deterioration.
- Protects the ecosystem.

Vegetative fields are designed in such a way that they can work as a barrier for the sub-basin to reduce its pollution.

3.6.3 Graphical Representation

June is the month when the farmers cultivate their land mostly and also start the irrigation in this season. Because of this cultivation farmers usually use different kinds of pesticides insecticides and other chemical fertilizers for the maximum growth of their crops. But doing so increases the amount of nitrogen overflow on land and the surrounding water body.

Through our simulation and analysis, we have found that using vegetative stripes can reduce the overflow of nitrogen by almost 25%. Here the fig. 3.8 is the comparison data chart of 2021 simulated nitrogen load data before applying the vegetative filter strip against 2021 simulated nitrogen load data after applying the vegetative filter strip.

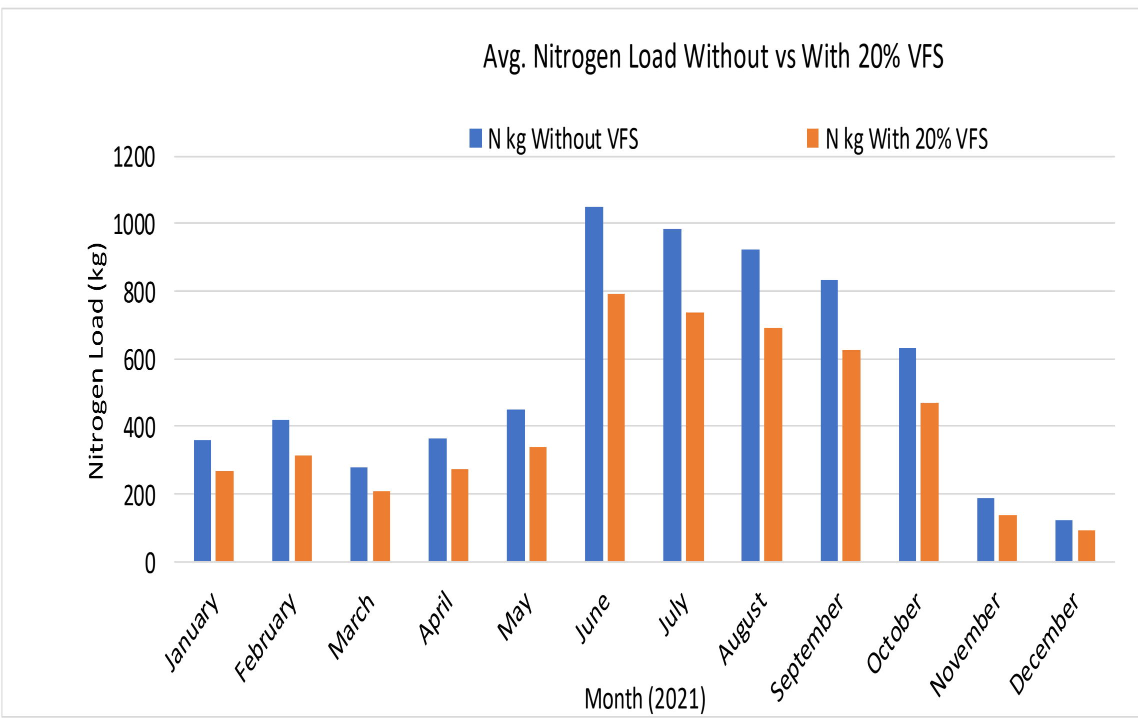

Fig. 3.8 Avg. Nitrogen Load Without vs With 20% VFS (2021)

We can see from fig. 3.8 that the highest Nitrogen load is in June. Based on the highest Nitrogen load in June, the Nitrogen load for each day is shown in fig. 3.9 for June.

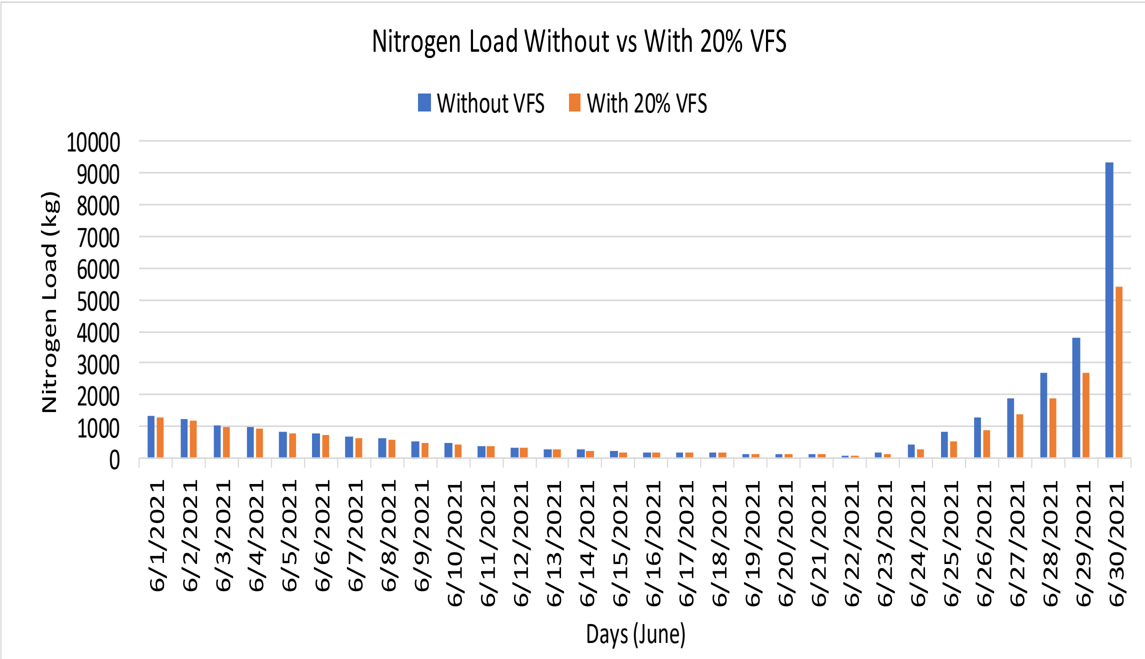

Fig. 3.9 Nitrogen Load Without vs With 20% VFS (June)

Here the fig. 3.10 is the comparison data chart of June 2021 simulated nitrogen load data before applying the vegetative filter strip against June 2021 simulated nitrogen load data after applying the vegetative filter strip. It shows that through our simulation and analysis, we have found that using vegetative stripes can reduce the overflow of nitrogen by almost 25%.

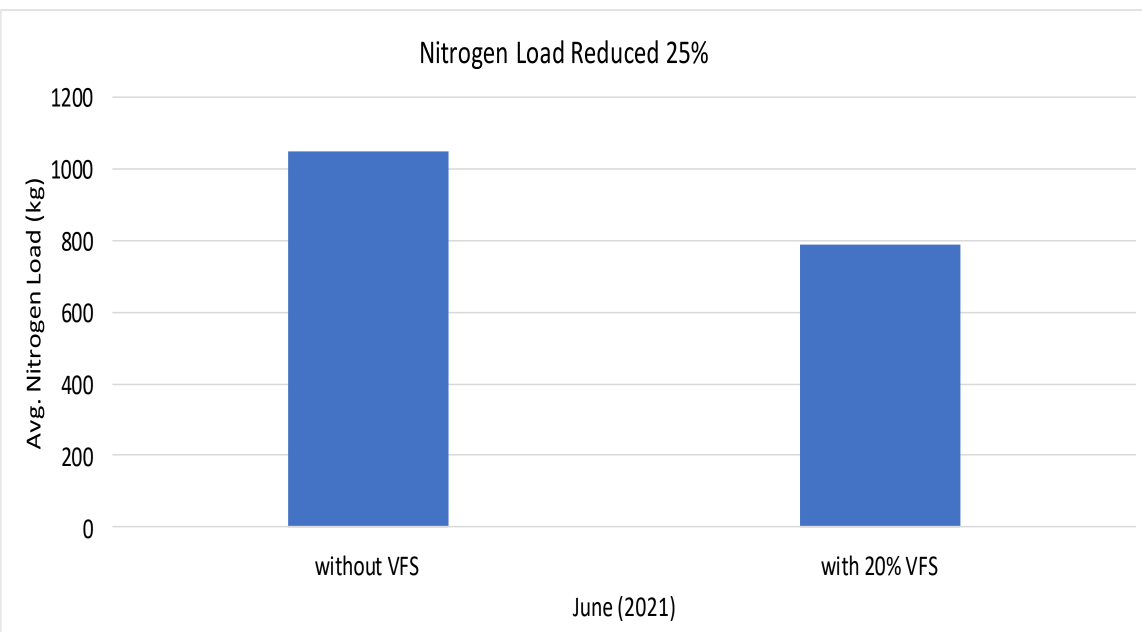

Fig. 3.10 Nitrogen Load Reduction 25%

Chapter 4 Review of Milestone Achievements

The review of milestone achievements of this project is given below., which met the following requirements of model development and design:

(1) In this project, the minimum Nash-Sutcliffe Efficiency (NSE) values for the model calibration and validation were 0.65 and 0.55, respectively.

(2) Important weather information like rainfall (mm), maximum and minimum temperatures (° c temperature), wind speed (km/hr), relative humidity (%), and solar radiation (cal/cm2) were added to this model.

(3) This model incorporates the effects of numerous land uses, including urban, agricultural, water, forest, and pasture.

(4) The soil classes, land cover types, and slope classes were integrated into the hydrologic response unit (HRU) in this model.

(5) The quantity and quality of water are projected over the next 30 years in this project.

(6) During the busiest farming month in this project, the vegetative filter strip was able to lower nitrogen load by 25%.

Chapter 5 Cost of Solution and Economic Analysis

5.1 Bill of materials cost of the solution

One of the most affordable methods for managing stormwater runoff is the use of filter strips. Superoxide dismutase (SOD) can cost $125 per 1,000 square feet, depending on the site circumstances ($0.40 to $6.25 per linear foot for a 20 to 50-foot-wide strip), whereas planting expenditures could be between $20 and $100 per 1,000 square feet. The vegetative filter strip has labor costs ranging from $2 to $8 (on average $4) per square foot. The average annual cost of upkeep is $0.009 per square foot or $350 per acre.

We have applied the VFS at the sub-basin where the outlet is situated. Thus, our watershed area is 938212330 ft^2 and we have taken the VFSRATIO (Ratio of field area to filter strip area) is 20 which means the vegetated filter strip area we have taken is,

938212330/20 = 46910616.5 ft^2

So, the estimated area to provide the vegetative filter strip = 46910616.5 ft^2

Cost per unit area = $125 per 1000 square feet = $0.125 per square feet

Cost of labor = $4 per square feet

Total cost per square feet = ($0.125 + $4) = $4.125

Total cost of the vegetative filter strip construction = (46910616.5 × $4.125) = $193506293

Maintenance costs = $0.009 per square feet per year

Maintenance cost per year = (46910616.5 × $0.009) = $422196

5.2 Economic analysis

VFSRATIO	Estimated Area for VFS	Construction Cost of VFS ($)	Reduction of Nitrogen Load (%)
10	93821233 ft^2	$387012586	48%
20	46910616.5 ft^2	$193506293	25 %
30	31273744.33 ft^2	$129004195	17%

We have done three analyses. We can see from this table if we use VFSRATIO 10, the estimated area of VFS will be 93821233 ft^2 and the construction cost will be $387012586. For this, we can reduce the nitrogen load by 48%. If we use VFSRATIO 20, the estimated area of VFS will be 46910616.5 ft^2 and the construction cost will be $193506293. For this, we can reduce the nitrogen load by 25%. If we use VFSRATIO 30, the estimated area of VFS will be 31273744.33 ft^2 and the construction cost will be $129004195. For this, we can reduce the nitrogen load by 17%.

By doing this analysis we can say that, if we take VFSRATIO 10, the cost will be increased, though the reduction of nitrogen load will be 48%. On the other hand, If we take VFSRATIO 30, the cost will be decreased and the reduction of nitrogen load will be 17%. But In our project, we need to reduce the nutrient load by 25%. By taking VFSRATIO 20 we can meet the required value of the reduction of nitrogen load. So, we finalize the VFSRATIO 20 to do an optimum design for the vegetative filter strip.

Chapter 6 Conclusion

In order to mitigate the consequences of nutrient, surface, and climate change, the model is used to generate the right measures and put them into practice. Predictions are important in this. Our model predicts nutrient and surface overflow in the future using a number of data simulations. By doing this, we can accurately determine how the flow result has changed over time. It can also alert us to any potential future flooding or droughts. In this way, we can meet the objectives of this project.

ACTIVITY CHART

Timeline of Project Activity

Task Name	Start Date (MM-DD-YYYY)	End Date (MM-DD-YYYY)	Duration (Days)
Introduction	02/12/2022	02/21/2022	7
Guidelines on software	02/22/2022	04/20/2022	57
Ob. Data Collection	04/21/2022	05/23/2022	32
Necessary SWAT Input File Collection	05/24/2022	06/01/2022	7
Building swat model	06/02/2022	06/08/2022	7
Running the model	06/09/2022	06/16/2022	7
Calibration	06/17/2022	07/01/2022	14
Validation	07/02/2022	07/09/2022	7
comparing ob. vs sim. future flow data	07/10/2022	07/24/2022	14
Applying VFS in Model	07/25/2022	08/08/2022	14
Comparing Nitrogen load Before and After	08/09/2022	08/16/2022	7
Guidelines on Report	08/17/2022	08/24/2022	7
Completing First Draft of Project Report	08/25/2022	09/01/2022	7
Checking and Revising Project Report	09/02/2022	09/04/2022	2
Completing First Draft of Project Presentation	09/05/2022	09/06/2022	1
Checking and Revising Project Presentation	09/07/2022	09/07/2022	1

JUSTIFICATION OF COMPLEX ENGINEERING PROBLEM

Attribute	P1 and some or all of P2 to P7 are characteristics of complex engineering problems.	Covered in the project? (Y/N)	Explain/justify
Depth of knowledge required	P1: Cannot be resolved without thorough engineering expertise at the level of one or more of K3, K4, K5, K6, or K8, which enables a first-principles, fundamentals-based approach. the use of analysis	Y	This project is an analysis-based project.
Range of conflicting requirements	P2: Contains complex or opposing technological, engineering, and other topics.	Y	This project involves several incompatible technological, engineering, and other difficulties.
Depth of analysis required	P3: There isn't a clear answer, thus developing appropriate models requires creative analysis and abstract thought.	Y	There is no obvious solution about decreasing the future surface overflow.
Familiarity of issues	P4: Involves difficulties that are infrequently faced.	Y	Rarely occurring problems are involved in this project.
The extent of applicable codes	P5: Do standards and rules of practice for professional engineering apply to issues outside its purview	Y	In this project there used of different codes and standards.
The extent of stakeholder involvement and conflicting requirements	P6: Includes numerous groups of stakeholders with a wide range of needs.	Y	Different Stakeholders are taken into account.
Interdependence	P7: Major issues with numerous auxiliary issues or minor issues	Y	Future surface overflows decrease the problem along with the nitrogen load problem.

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