

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL

**INVESTIGATION OF AKÇAT BASIN UNDER THE PRESSURE
OF POINT AND DIFFUSE SOURCE POLLUTION LOADS
USING THE SWAT MODEL**

ISMAIL KALAFAT

**A THESIS OF MASTER OF SCIENCE
DEPARTMENT OF EARTH AND MARINE SCIENCES**

ADVISOR: Assist. Prof. MELTEM ÇELEN

JULY 2024

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GEBZE TEKNİK ÜNİVERSİTESİ
LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

NOKTASAL VE YAYILI KİRLİLİK
YÜKLERİNİN ETKİSİNDE OLAN AKÇAT
HAVZASININ SWAT MODELİ İLE İNCELENMESİ

İSMAİL KALAFAT

YÜKSEK LİSANS TEZİ
YER VE DENİZ BİLİMLERİ ANABİLİM DALI

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*To my
Family*

ABSTRACT

Surface water nutrient concentrations are a major issue that have an impact on ecology and water quality. The impact of Akçat Stream's nitrogen and phosphorus load on water quality concentrations suggests that the basin has a pollution source that needs to be located and quantified. In this thesis study, the soil database (SSM), which was created with laboratory and field studies and revised according to the basin characteristics, as input for the Soil and Water Assessment Tool (SWAT) model, and the input parameters we classified as diffuse and point pollution load, were used to determine the nutrient pollution in the basin. Estimation and solution methods were evaluated throughout.

In this thesis study, to evaluate SWAT effectiveness in monthly simulations, the observed data set was used in the construction, calibration, and validation of the SWAT model. The model simulated the flow from 2000 to 2022 to simulate various water resource characteristics in the Akçat stream basin, with a focus on nitrogen and phosphorus as well as flow, and the model performance of TN, TP, and NO₃ parameters was evaluated based on the flow between July 2020 and March 2022. SUFI-2, an optimization procedure, was used in the study with SWAT-CUP software to improve model parameters and investigate model uncertainty. After calibration, the model from 2000 to 2016 and verified monthly from 2017 to March 2022. Observed minimum and maximum TN and TP loads have relatively low variability across the basin, while modeled TN and TP loads show relatively high variability. Modeled maximum loads for the two pollutants were observed in February, March, April and October. These months represent the months when organic and inorganic fertilizers are applied to agricultural and pasture areas.

As a result of this thesis study, it is aimed to evaluate the fate of the diffuse pollution load in the basins dominated by agricultural areas and to determine the extent to which pollution affects the hydrological cycle and water quality together with the agricultural activities that start in the soil, by obtaining the soil database through laboratory and field studies, although it requires high labor intensity during the calibration processes of the model. evaluated and aimed to make evaluations to reach the desired values of water quality with best management practice scenarios.

Keywords: SWAT, BMP, Water Quality Modeling

ÖZET

Yüzey suyundaki yüksek besin konsantrasyonları, su kalitesini ve ekolojiyi etkileyen ciddi bir sorundur. Akçat Deresi'ndeki azot ve fosfor yükünün su kalitesi konsantrasyonlarına etkisi, havzada tanımlanması ve ölçülmesi gereken bir kirlilik kaynağının varlığına işaret etmektedir. Bu tez çalışmasında, Toprak ve Su Değerlendirme Aracı (SWAT) modeli için girdi olarak laboratuvar ve arazi çalışmaları ile oluşturularak havza karakteristiğine göre revize edilmiş toprak veritabanı (SSM), yayılı ve noktasal kirlilik yükü olarak sınıflandırdığımız girdi parametreleri kullanılarak kurulan SWAT modeli ile nütrient kirliliğini havza genelinde tahminleme ve çözüm yöntemleri değerlendirilmiştir.

Bu çalışmada, aylık simülasyonlarda SWAT verimliliğini değerlendirmek için gözlemlenen veri seti kullanılarak SWAT modeli oluşturulmuş, kalibre edilmiş ve doğrulanmıştır. Akçat deresi havzasındaki farklı su kaynağı parametrelerini akış ile beraber azot ve fosfor odaklı simüle etmek amacıyla 2000-2022 yılları arasındaki akışı simüle edilmiş ve Temmuz 2020 ile Mart 2022 tarihleri arasında akışa bağlı olarak TN, TP ve NO₃ parametrelerinin model performansı değerlendirilmiştir. Model parametrelerini optimize etmek ve model belirsizliğini incelemek için bir optimizasyon algoritması olan SUFI-2 kullanılarak SWAT-CUP yazılımı çalışmaya dahil edilmiştir. Model 2000'den 2016'a kadar kalibre edilmiş ve 2017'den Mart ayının 2022 tarihine kadar aylık olarak doğrulanmıştır. Gözlemlenen minimum ve maksimum TN ve TP yükleri havza genelinde nispeten düşük değişkenliğe sahipken, modellenen TN ve TP yükleri nispeten yüksek değişkenlik göstermektedir. İki kirleticisi için modellenen maksimum yükler Şubat, Mart, Nisan ve Ekim aylarında gözlemlendi. Bu aylar tarım ve mera alanlarına organik ve inorganik gübrelerin uygulandığı ayları temsil etmektedir.

Bu tez çalışması sonucunda, tarımsal alanlar ile domine edilmiş havzalarda yayılı kirlilik yükünün akıbetini değerlendirmek ve modelin kalibrasyon işlemleri sırasında yüksek emek yoğunluğu gerektirmesine rağmen toprak veritabanının laboratuvar ve saha çalışmaları ile elde edilerek kirliliğin toprakta başlayan tarımsal aktiviteler ile beraber hidrolojik döngü ile su kalitesini ne ölçüde etkilediği değerlendirilmiş ve en iyi yönetim uygulamaları senaryoları ile su kalitesini istenilen değerlere ulaştırmaya yönelik değerlendirmeler yapılması hedeflenmiştir.

Anahtar Kelimeler: SWAT, En İyi Yönetim Uygulamaları, Su Kalitesi Modellemesi

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LIST OF SYMBOLS AND ABBREVIATIONS

SSM	: Specified Soil Map
FAO	: Food and Agricultural Organization
NSE	: Nash–Sutcliffe efficiency
UNEP	: United Nations Environment Program
TNSD	: Turkey Ministry of Agriculture and Forest
DEM	: Digital Elevation Model
GIS	: Geographical Information System
SWAT	: Soil and Water Assessment Tool
CORINE	: Coordination of Information on the Environment
SUFI-2	: Sequential Uncertainty Fitting
GUI	: Geographical User Information
HRU	: Hydrologic Response Unit
TMDL	: Total Maximum Daily Load
MGM	: Turkish General Directorate of Meteorology
BMP	: Best Management Practices

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1. INTRODUCTION

In this thesis, the hydrological cycle of the Kocaeli Akçat Stream Catchment is modeled using the Soil and Water Assessment Tool (SWAT) model. The soil database which is obtained from field and laboratory studies are used to compare the effect on hydrological processes. In this section, the theoretical background of the thesis study is presented. In this context, water resources over the World and Turkey in Agricultural Watershed, the hydrological modeling and the aim of the thesis were included in Section 1.1, in Section 1.2 and in Section 1.3 respectively.

1.1. Water Resources over the World and Turkey in Agricultural Watershed

Water is a critical natural resource that is essential for human life, economic development, and ecological sustainability. However, the increasing global population, rapid urbanization, and growing industrial and agricultural activities have put significant pressure on the world's limited water resources [1]. This situation has led to significant challenges in the management and conservation of water, particularly in agricultural watersheds, where water resources are heavily utilized. Agricultural watersheds play a crucial role in the overall management and sustainability of water resources. These watersheds encompass a complex system of surface water, groundwater, and atmospheric water interactions, which are critical for supporting agricultural production and maintaining ecosystem services [2]. Effective water management in agricultural watersheds is essential for ensuring the availability and quality of water resources, as well as addressing issues such as water scarcity, water pollution, and the impacts of climate change.

This thesis aims to provide a comprehensive analysis of the management of water resources in agricultural watersheds, with a particular focus on the status and challenges in both the global context and in Turkey. The study will examine the current water management practices, the impact of these practices on water quality and

the potential solutions and strategies for sustainable water resource management in agricultural watersheds.

Agricultural activities account for a significant portion of global water consumption, with estimates ranging from 60% to 90% of total water use [3]. This high water demand, coupled with the complex interactions within agricultural watersheds, underscores the critical importance of effective water resources management in these areas.

Proper management of water resources in agricultural watersheds is essential for ensuring the long-term sustainability of agricultural production, maintaining ecosystem services, and addressing issues such as water scarcity and water quality degradation. Effective water management strategies can help optimize water use, reduce water pollution, and enhance the resilience of agricultural systems to climate change and other environmental stressors [4].

Furthermore, the management of water resources in agricultural watersheds has far-reaching implications beyond the agricultural sector. Healthy, well-managed watersheds can contribute to the provision of clean drinking water, support biodiversity conservation, and help regulate flood and drought events, among other ecosystem services [5]. As such, the effective management of water resources in agricultural watersheds is a crucial component of integrated watershed management and sustainable development.

Water management practices in agricultural watersheds around the world vary significantly, reflecting the diversity of climatic, socio-economic, and political conditions across different regions. However, several common approaches and trends can be observed.

Many countries have adopted the principles of Integrated Water Resources Management (IWRM) in their agricultural watershed management strategies [6]. IWRM is concerned with the sustainable management of significant ecosystems while maximizing social and economic welfare through the coordinated use of land, water, and related resources. This method frequently entails putting laws and rules into place with the intention of lowering water pollution, increasing agricultural systems resilience, and optimizing water use. Using irrigation management techniques and water-saving technologies is another typical activity in agricultural watersheds. This

includes the adoption of efficient irrigation systems, the use of precision agriculture techniques, and the optimization of water application based on crop water requirements [7]. These practices can help reduce water consumption and improve water use efficiency in agricultural production.

In addition, many countries have implemented policies and programs to address water quality issues in agricultural watersheds. These efforts may include the regulation of agricultural practices, the implementation of best management practices, and the restoration of riparian areas and wetlands to mitigate the impacts of agricultural runoff and pollution [8].

Turkey, like many other countries, faces significant challenges in the management of water resources, particularly in its agricultural watersheds. The country's rapidly growing population, expanding agricultural and industrial activities, and the impacts of climate change have put significant pressure on its water resources.

Within the framework of the Water Basin Management Regulation, Turkey has been implementing integrated water resources management practices at the watershed scale [9]. These efforts aim to protect water resources, improve water quality, and enhance the sustainability of water use, including in agricultural watersheds.

One of the key water management strategies in Turkey's agricultural watersheds is the promotion of water-saving technologies and irrigation management techniques. This includes initiatives to modernize irrigation infrastructure, encourage the adoption of precision irrigation systems, and provide incentives for farmers to improve their water use efficiency [10].

Additionally, Turkey has undertaken measures to address water quality issues in agricultural watersheds. These efforts involve the regulation of agricultural practices, the implementation of best management practices to reduce agricultural runoff and pollution, and the restoration of riparian areas and wetlands to enhance water purification and habitat quality [11].

Turkey's management of water resources in its agricultural watersheds is nevertheless beset with serious difficulties in spite of these efforts. Constant concerns requiring creative and all-encompassing solutions include groundwater depletion, agricultural runoff contaminating water supplies, and the effects of climate change on water supply and quality.

Agricultural activities, such as the application of fertilizers and the management of livestock waste, can lead to the accumulation of nutrients, primarily nitrogen and phosphorus, in surface water and groundwater resources [12]. In addition to the direct impacts on water quality, nutrient pollution in agricultural watersheds can also have indirect effects on the surrounding environment. For example, the eutrophication of water bodies can lead to the loss of biodiversity, as sensitive aquatic species are replaced by more tolerant, opportunistic species [13].

Turkey receives an average of 643 millimeters of rainfall each year, equivalent to 501 km³ of water [14]. Approximately 274 km³ of this water evaporates into the atmosphere, 69 km³ of average rainfall feeds groundwater, and the remaining rainfall (158 km³) falls into seas and lakes in basins [15].

Turkey's overall water potential is 234 km³, which includes 41 km³ of water feeding aquifers and 7 km³ of water from transboundary streams. Only 44 km³ of the 112 km³ of yearly average groundwater potential can be utilized [15].

Turkey is not a rich country in terms of available water, it is one of the countries that may experience water shortages in the future. Amount of water available per capita in Turkey, which was over 3000 m³ about twenty years ago, has fallen to around 1400 m³ in recent years [16]. The General Directorate of State Hydraulic Works (DSİ) indicates that Turkey, whose population will reach 85 million by 2030, will become a water-deprived country with 1,100 m³ of usable water per capital [15].

1.2. Hydrological Modeling

Although it is simple to comprehend and evaluate the overall structure of the hydrological cycle, measuring and analyzing its individual components is more challenging. The way these processes react to changes in land use and cover, as well as the unique soil composition of the area, is crucial for the management of land and water resources. The primary elements influencing hydrological processes include topography, land use/cover, climate, and human activity. Modeling studies that consider these elements together can help us to better understand the temporal and spatial organization of hydrological processes.

Understanding the system's operation and the implications of its changes is the primary goal of watershed-based hydrological modeling.

The secondary goal was to generate a time series for forecasting and design purposes. Conversely, the goals of hydrological modeling can be clarified as follows in the research conclusions regarding water management [16].

- Predicting the data required for stream or dam development, operation, and planning to maximize the use of available water resources.
- Producing hydrological data in watersheds where there is a lack of measurement data.
- To demonstrate how the basin is being affected by changes in land use and climate.
- Estimating, administering, and calculating water budgets to guarantee sector-by-sector water distribution.
- Determining and estimating discharge to be utilized in mass balance studies to evaluate surface water quality.
- Studies on hydrological modeling have been conducted to estimate hydrological events, which are regarded as natural disasters, including droughts and floods.

The AGNPS or Agricultural NonPoint Source pollution model, is one of the most widely used agricultural models at the watershed scale. [17]. Annualized Agricultural NonPoint Source model or AnnAGNPS [18]. Hydrological Simulation Program-Fortran or HSPF [19]. the European Hydrological System model or MIKE SHE [20] and Soil and Water Assessment Tool or SWAT [21]. Each of these models was created with agricultural and hydrological uses in mind. Their main concerns are runoff, sediment, and nitrogen export; crop yield estimation is of minor importance.

The need for a specific watershed can be significantly affected using simulation models and various land-use data sources. The efficacy of these models must be understood by those aiming to enhance water quality, the following could be required to reduce the amount of pollutants in receiving waters. A simulation model for assessing the movement of sediment and nutrients from agricultural watersheds, the basis of the AGNPS Model is an individual storm event. Because it has equations that can simulate the phosphorus (P), chemical oxygen demand (COD), runoff, silt, and nitrogen (N) movement from discrete rainfall episodes, it is valuable. The AnnAGNAPS is an improved version of this model [18], for going on hydrology, soil erosion, and pesticide, fertilizer, and sediment transport simulations.

Its purpose is to assess how nonpoint-source contaminants from watersheds that are mostly used for agriculture affect the ecosystem. Its high computational demand stems from the fact that it has numerous parameters.

HSPF, the Hydrological Simulation Program – FORTRAN [23], is a model for continuously simulated watersheds that generates a time series of the amount and quality of water at every given place in the watershed. Various software tools created by the U.S. Geological Survey (USGS) are used by HSPF to provide interactive features for data storage, input-output analysis, model input, and calibration. It has been suggested that HSPF be used globally. Under a contract with the USEPA, Tetra Tech, Inc. [24] created the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), which includes HSPF as a nonpoint-source model (NPSM). Finding and creating Total Maximum Daily Load (TMDL) norms and guidelines is the primary goal of basins. One of the US government's Clean Water Act pollution control initiatives is TMDL [25].

MIKE SHE [20], based on SHE, the European Hydrological System [26], [27], simulates one-dimensional channels, two-dimensional overland grids, three-dimensional saturated flow layers, and one-dimensional unsaturated flow layers. It also includes sediment and water quality data. It is a distributed, all-inclusive model with a physical based model. It also offers the ability to simulate discrete events as well as continuous long-term processes.

Water resource managers can use SWAT to assist in anticipating and evaluating how land management selections will impact water, sediment, and agricultural nutrients in watersheds. Given that this original objective is widely accepted, SWAT has been used to understand runoff, nitrogen cycle, and agricultural management. The agricultural management options in the model are statically planned to represent the typical basin farm's management practices. An example of typical management behavior is the scheduling of regular tasks including as tillage, fertilizer operations, plant growing, pesticide applications and crop harvesting, each of those indicates significant barriers to the release of nutrients into stream networks within watersheds. The output of the SWAT model simulation is frequently used, however because the unprocessed data typically do not correspond with actual observations, it may be deceptive; instead, calibration and validation play a significant role in providing consistent output information [28], [29].

1.3. Aim of Thesis

Certain soil parameters, such as the quantity of soil layers, profile depths, organic matter content, hydraulic conductivity, and usable water holding capacity, were obtained from laboratory and field studies in accordance with the basin's characteristics and incorporated into the hydrological model. These parameters were typically used in the SWAT model by comparison with default values reported in the literature. This section summarizes state-of-the-art hydro-chemical models and their capacity to support optimal management practices, guide decision-making, and precisely measure the amount of TN, TP, NO₃-N exported from agricultural watersheds. The main model types are compared, and their applicability in watershed management is discussed. The SWAT model's relevance for this research is also justified.

Different surface runoff simulations in the same watershed are generally explained by reliability of climate and soil databases in hydrological models. In this context, the purpose of this study is; (i) Modeling of hydrological processes in Akçat Stream, located in the north-western part of Turkey and under agricultural pressure, (ii) to determine the characteristic features of the soil and water in the basin by laboratory and field studies, (iii) to evaluate the impact of the physical, chemical and biological database in soil and water obtained from this study on stream flow and Akçat basin by using SWAT., (iv) to examine the effect of point and diffuse pollution loads of the soil and water database on surface water quality using the SUFI-2 semi-automatic calibration technique. (v) to examine how the pollution load of the basin changes with scenarios by applying BMP.

This study is new in that it assesses how point and dispersed loads in agriculturally active basins affect the quality of water in a small-scale research basin in Turkey, and how optimum management methods improve the quality of the water. In this manner, recommendations for solutions to manage surface and groundwater quality in agricultural basins can be created.

2. LITERATURE REVIEW

2.1. Studies in Akçat Stream Watershed

The flow data of the General Directorate of Water Affairs (GDHV) of the DSI station located on the Avcıköy stream, which has the same characteristics as the Akçat Stream, has been integrated into the model as a result of the interpolation method, and soil samples were collected monthly between June 2020 and March 2022 in the region of 1 measurement station in the Akçat stream. stream and nutrients (TN, TP, NO₃-N) measurements were made.

It is crucial to thoroughly model and assess the pollution detection of the basin, as the water quality modeling of the Yalakdere Basin and Akçat Stream Basin is being researched for the first time. For this reason, there are no studies for analyzing and modeling parameters affecting hydrological processes of the stream.

2.2. Hydrological Modeling Studies Using SWAT

The SWAT model has been used in numerous studies to evaluate its performance in both large- and small-scale basins in Africa, America, Europe and the Far East. For instance, Rossi et al. [30], conducted a hydrological modeling study in the Lower Mekong River watershed, which has 630,000 km² area. The model was calibrated and validated for the years between 1985 and 1992, and between 1993 and 2000, respectively. Nash-Sutcliffe value calculated for predicted and observed surface runoff was found as 0.8 and 1. This study draws attention to the need for powerful computer hardware.

Duan et al. [31], An important river system in Western Asia that empties into the Persian Gulf is the Tigris-Euphrates River system. A hydrological modeling study was conducted to determine the best water management strategies in the Tigris Basin. The SWAT model was calibrated using data from 2012-2017 ($R^2 = 0.78$, $NSE = 0.75$) and validated for the period 2018-2022 ($R^2 = 0.82$, $NSE = 0.79$). The results revealed that the model could accurately predict the impacts of agricultural practices on water quality and soil erosion in the region.

Santhi et al. [32], The SWAT model has been extensively applied in the Mississippi River Basin to assess the impacts of land use changes, agricultural practices, and climate change on water quantity and quality. The model has been calibrated and validated using long-term monitoring data, with R^2 and NSE values typically ranging from 0.70 to 0.90.

Özcan et al. [33], Küçük Menderes River has a Mediterranean climate. This region experiences moderate, rainy winters and hot, dry summers. Most of the precipitation falls as rain. At heights of 900 meters and higher, snow typically falls. Annual rainfall is 600–700 mm. The SWAT model was calibrated using data from 2014-2019 ($R^2 = 0.83$, $NSE = 0.81$) and validated for the period 2020-2023 ($R^2 = 0.77$, $NSE = 0.74$). The results demonstrated that the model could reliably simulate the flow regime and nutrient loads in the basin.

Xu et al. [34], The SWAT model has been employed in the Yangtze River Basin to study the effects of urbanization, industrialization, and agricultural expansion on water resources. The model has been successfully calibrated ($R^2 = 0.82$, $NSE = 0.79$) and validated ($R^2 = 0.77$, $NSE = 0.74$), contributing to the development of sustainable water management strategies in the region.

Luo et al. [35], The impacts of industrialization, urbanization, and agricultural practices on the quantity and quality of water in the Haihe River Basin have been assessed using the SWAT model. The model performed well during calibration ($R^2 = 0.80$, $NSE = 0.77$) and validation ($R^2 = 0.75$, $NSE = 0.72$).

Lenhart et al. [36], To evaluate the effects of agricultural management and changes in land use on the amount and quality of water, the SWAT model has been used to the Wupper Basin. With good results, the model has been validated ($R^2 = 0.77$, $NSE = 0.74$) and calibrated ($R^2 = 0.82$, $NSE = 0.79$).

In a study conducted by Güzel [37], hydrological processes of Köyceğiz Dalyan Basin were examined using SWAT. The model was operated between 1976 and 2008, and monthly precipitation, runoff, subsurface flow, groundwater flow values were modelled. One of the most critical outputs in this study is that irrigation water used in agricultural activities feeds the groundwater flow.

Fohrer et al. [38], The Neckar River Basin's water quantity and quality have been evaluated using the SWAT model in relation to agricultural activities and changes in land use. The model has been calibrated ($R^2 = 0.82$, $NSE = 0.79$) and validated ($R^2 = 0.77$, $NSE = 0.74$) with good performance.

Göncü and Güngör [39], modeled the Porsuk Basin using SWAT. The model was operated between 1978 and 2004, calibrated between 1998 and 2004 and validated for all years. It was aimed to decide on the most appropriate water management strategy by applying different irrigation scenarios to the model.

Sajikumar et al. [40], studied the impact of land use change on runoff of two basins in Kerala India, using the SWAT model. The effect of land use on runoff has been clearly observed by changing the forest land suitable for agriculture. In this study, it was emphasized that storing rainfall for agriculture, and growing plants with high evaporation potential are important factors affecting runoff.

However, it was emphasized that more realistic results can be achieved by modifying the topographic and climate data in the long-term period. It is also stated that this situation can be solved by using the Green & Ampt method [41] and integrating hourly rainfall and flow data into the model.

3. MATERIAL AND METHOD

3.1. Study Area

The Akçat River System is in Turkey's northwest within the Yalakdere Watershed (**Figure 3.1**). The study area has been designated as the Akçat stream, which is situated in one of Turkey's most significant agricultural and industrial zones and flows along the Kocaeli-Yalova border. The stream is highly impacted by environmental factors. With a catchment area of about 15 km², the basin is categorized as small-scale. The stream network has been digitized using aerial photographs and complied to the GIS environment in this project.

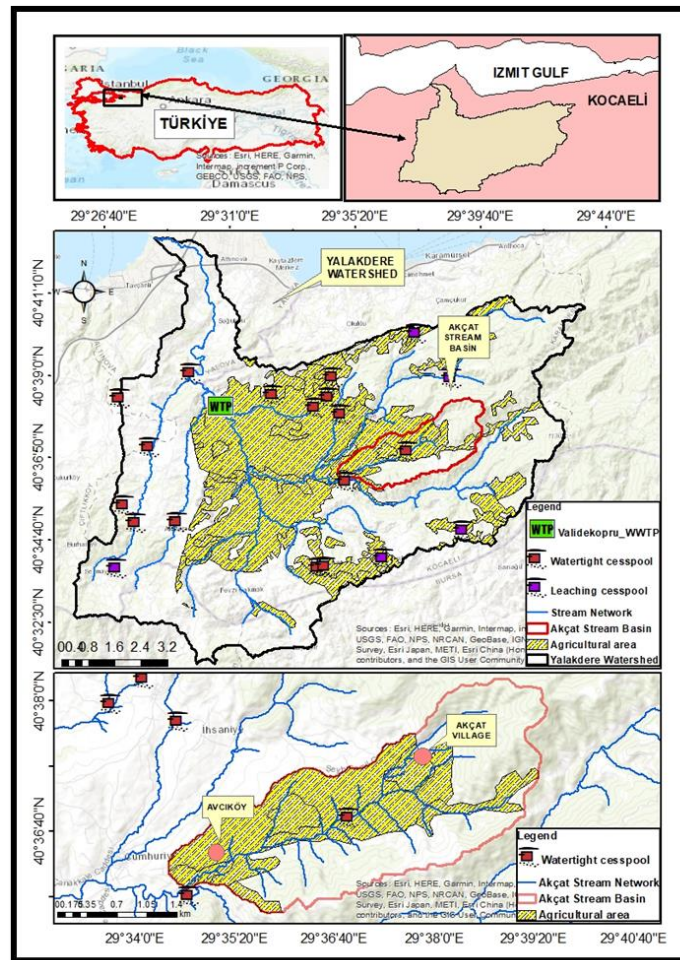


Figure 3.1: Location map of Yalakdere and Akçat stream basin system.

Since the Akçat Stream network is primarily found in forested and agricultural areas, it is becoming more challenging to identify these networks visually without the use of geographic analysis tools.

3.2. The SWAT Model

The SWAT (Soil and Water Assessment Tool) model is an efficient method of evaluating water sources and nonpoint source pollution with its many applications at different scales and environmental conditions [37], [42], [43]. SWAT is a modeling technique for hydrology and water quality that effectively shows how sources of pollution, sediment, and water affect watershed management. Geographic Information Systems (GIS) software is compatible with the sophisticated SWAT concept. The SWAT was developed by USDA (United States Department of Agriculture) and ARS (Agricultural Research Service) which are funded from EPA (Environmental Protection Agency) and incorporated into EPA BASINS 3.0 water quality modeling system (**Figure 3.2**). Several hydrologic components found in SWAT, such as surface runoff, ET, groundwater recharge, and stream flow, have been constructed and verified at lower scales in the models listed below: The Simulator for Water Resources in Rural Basins (SWRRB), Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS), Groundwater Loading Effects of Agricultural Management Systems (GLEAMS), Environmental Policy Integrated Model (EPIC), and Routing Output to Outlet model (ROTO) [44] - [46], has increased in size to encompass significant river basins. Surface-subsurface flow interactions in SWAT are based on ROTO, a connected surface-subsurface flow model created by [47]. Non-empirical recharge estimations, percolation accounting, and application to watershed-wide control evaluations using a multi-component watershed budget are aspects of the ROTO model. Utilizing sub-region data provided by the SWRRB model, the model for routing water and sediment continuously ROTO was created to calculate basin flow and sediment outputs [48]. The SWAT model can model hydrological processes such as surface runoff, infiltration, percolation, evapotranspiration, lake and reservoir storage, groundwater flow discharge, and plant nutrients and pesticide loads. Daily or long-term simulations can be made for the separate multiple sub-basins. The input data are meteorological, topographic, soil, vegetation, and land use data of the studied watershed. The modeled watershed is divided into customer hydrological components

and hydrological response units (HRUs), which differ according to drainage areas and input parameters. The process is conducted for each HRU [49].

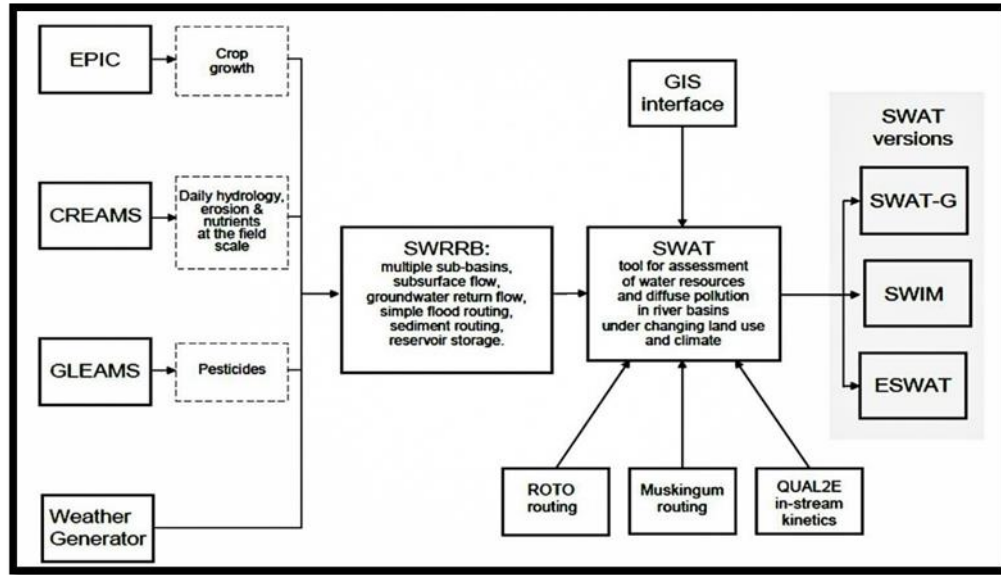


Figure 3.2: Historical development of SWAT.

The SWAT model's basis mostly relies on water balance. The intricate fusion and interplay of hydrological runoff, including precipitation, evapotranspiration, and surface and groundwater flow discharge, is known as water balance. The details of the SWAT model hydrological processes were given below (**Figure 3.3**). To create a location-specific model, the watershed is defined using a digital elevation model, and it is then further separated into subbasins that are categorized into Hydrologic Response Units (HRU) [50]. For every HRU, the following processes are simulated: evapotranspiration (ET), infiltration, surface runoff, subsurface flow, percolation, sediment erosion, crop growth, and N cycling. SWAT's hydrologic and nutrient transport strategy configuration depends on the method provided by [51]. Within the basin, water can be moved from one reach to another. By combining subwatersheds and hydrologic response units (HRUs), the model approximates a basin. The HRUs are the result of certain combinations of land use and soil [52]. The basins primary reach receives the resulting fluxes of nutrients and water from each HRU, which are gathered inside the associated subwatershed. By employing the variable storage routing approach, discharge and sediment fluxes move from one subbasin to the next

via the network of streams, finally ending at the outflow of the watershed [53]. or the Muskingum River routing method [54].

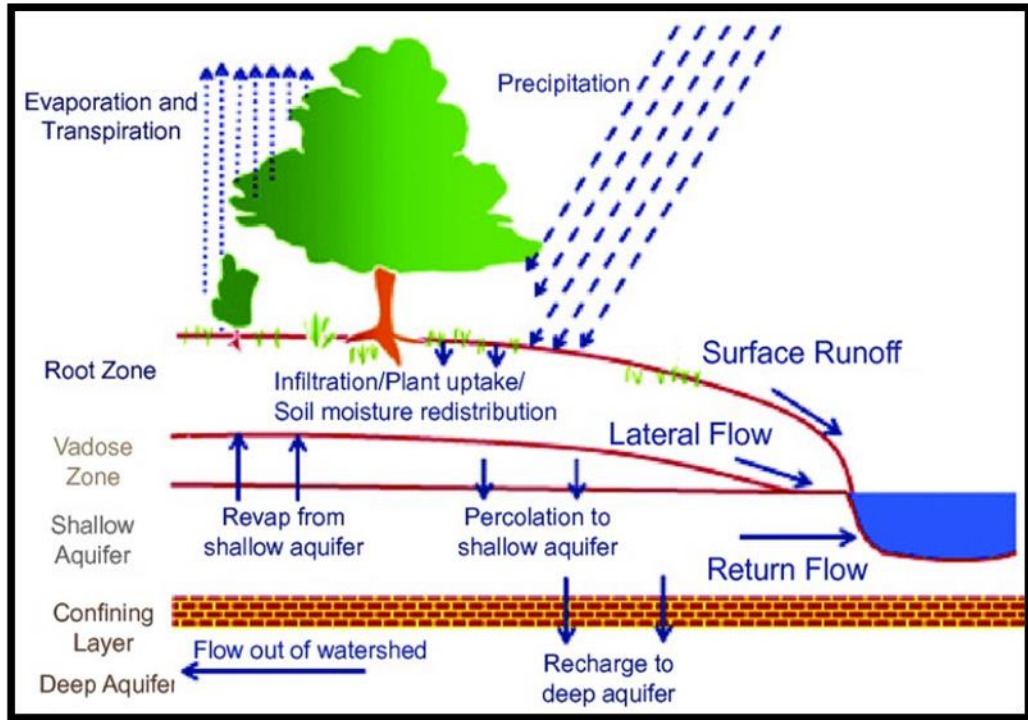


Figure 3.3: Diagram showing the hydrologic cycle.

In the SWAT model, calculations take place in two steps. The first step is the precipitation-flow distribution depending on the water mass balance for each sub-basin [10]. The second is the transportation section that connects all sub-basins to determine a positionally open outlet of watershed. The following water balance equation (Equation 3.1) is used in SWAT [6].

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (3.1)$$

Where SW_t is the final soil water content (mm H₂O), SW_0 is the initial soil water content on day i (mm H₂O), t is the time (day), R_{day} is the amount of precipitation on day i (mm H₂O), Q_{surf} is the amount of surface runoff on day i (mm H₂O), E_a is the amount of evapotranspiration on day i (mm H₂O), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H₂O), and Q_{gw} is the amount of return flow to the top layer, supposing a specific slope on day i (mm H₂O). Except for areas where irrigation is used, precipitation is the main way that water

enters the watershed system border of the SWAT model. The two options for precipitation inputs for hydrologic calculations are simulations using the weather generator in the SWAT model or measured precipitation data. For the parameter input database's missed days, these values must be interpolated. Based on the watershed's geomorphic features, land cover and soil, precipitation is divided into many water paths once it strikes the ground. Four storage volumes are present in the water balance of each HRU in the watershed: snow, the soil profile (0–2 m), the shallow aquifer (2–20 m), and the deep aquifer (>20 m). Multiple vertical strata may be present in the soil profile. Plant absorption, lateral flow, evaporation, percolation, and infiltration are among the soil-water processes. The U.S. Soil Conservation Society (SCS) curve number process (SCS, 1972) and the Green and Ampt infiltration method are the two methods used by SWAT to estimate surface runoff volume and infiltration. [41]. This study evaluated the runoff component of the Modified DRAINMOD [55], a runoff technique included into SWAT. The SCS curve number approach was chosen since it has been extensively tested and applied to several SWAT projects. In calculating the watershed time of concentration, the peak rate component considers both channel and overland flow, using Manning's formula. What happens in a watershed when there is a precipitation event is called the time of concentration. In a watershed, it is the amount of time it takes for water to go from its furthest point to its outlet [56]. The soil profile of the SWAT model allows for lateral subsurface flow, and groundwater flow simulates flow from the shallow aquifer to augment overall streamflow [57]. A recession constant obtained from daily stream flow recordings is used to lag the flow from the shallow aquifer to the stream [58]. In SWAT model, percolation is computed for every soil layer in the profile [41]. If the water content is more than the field capacity for that layer and the layer below is not saturated, water is permitted to percolate.

3.2.1. SWAT Model Nitrogen Assessment

This study examines the land phase's N cycle, which is based on the EPIC model, also known as the Erosion-Productivity Impact Calculator. One active and one passive organic N pool are distinguished by the SWAT conceptual approach. Gaseous N losses are not directly addressed in the SWAT model because nitrate (NO_3^-) and ammonium (NH_4^+), which can both be drained during the denitrification process, are the only forms of nitrogen that plants can absorb. However, organic nitrogen present in the active pool is directly used to generate nitrate. The process known as denitrification occurs when anaerobic soil conditions cause nitrate (NO_3^-) to be reduced to gaseous compounds such as N_2O , N_2 , and NO . The EPIC model serves as the foundation for denitrification in the original function used in the SWAT model [59]. The pace of denitrification is determined by the soil temperature and the consistent organic carbon content of the specific soil layer where denitrification takes place.

Denitrification is thought to occur when soil moisture exceeds 95% of its total moisture content at field capacity. When the threshold is crossed in relatively moist soil conditions, this can result in unreasonably high denitrification rates [60]. As a result, when the cascading (downward) percolation process exceeds the overlaying layer's field capacity, water only seeps into an unsaturated soil layer underneath. Consequently, before water begins to percolate, denitrification takes place at the highest layer, resulting in extremely large N losses and perhaps significant depletion of available N in the pools of each previous soil layer [60], **Figure 3.4** shows the elements of the standard nitrogen cycle, whereas **Figure 3.4** depicts the updated model of the N cycle. The fact that N emissions are specifically considered and a portion of the mineralized N is utilized for microbial development (immobilization) makes the model a gross-mineralization model. Ammonium is initially created (ammonification) in a step-by-step simulation of mineralization. Clay particles have some adsorbed ammonium on them, while the rest is either absorbed by plants or further mineralized [60]. The next step is nitrification, which involves the oxidation of nitrite (NO_2^-) to nitrate while specifically accounting for gaseous emissions of N_2O and N_2 .

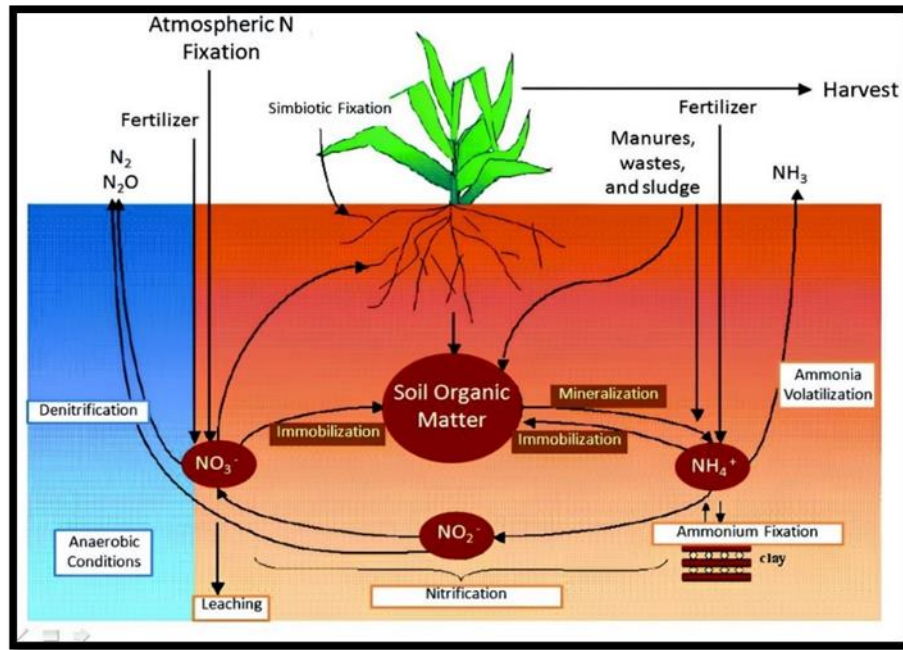


Figure 3.4: The nitrogen cycle's constituent parts as seen in the SWAT model.

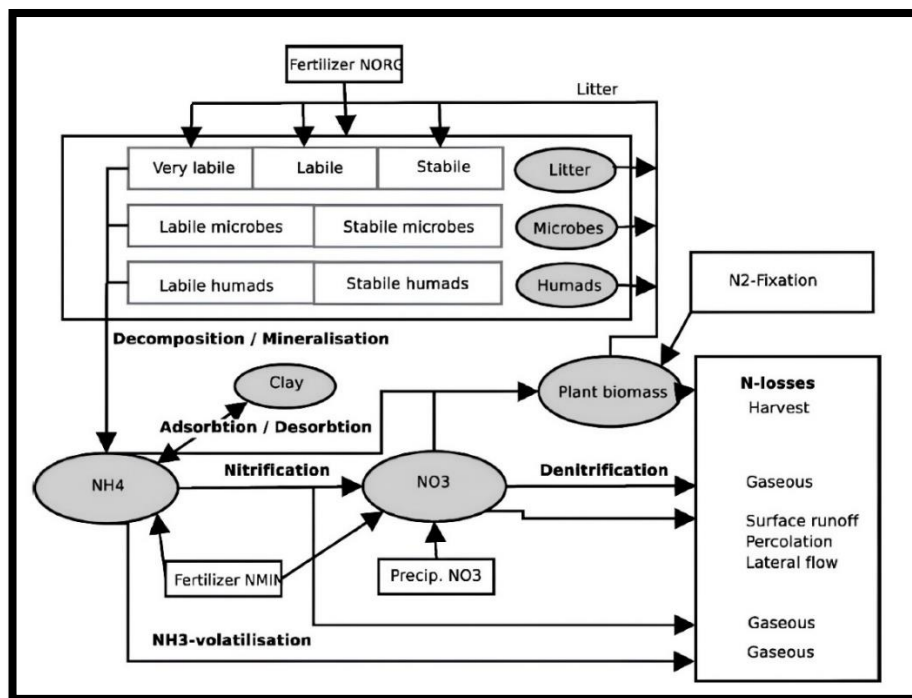


Figure 3.5: The SWAT model incorporates a new conception of the N cycle.

Given its mobility, nitrate can diffuse by subsurface flow, percolation to deeper soil profiles, or overland flow to the main channel. Five distinct nitrogen-rich soil pools are observed by SWAT. As seen in **Figure 3.6**, three of the nitrogen pools are organic, whereas the other two, NH_4^+ and NO_3^- , are inorganic. The humus fraction's stable and

active organic pools are open to nitrogen movement in this instance. Equation 3.2 below illustrates the calculation of the amount of nitrogen transported from one pool to the other.

$$Ntrns,ly = \beta trns * orgNact,ly * \left(\frac{1}{fractN} - 1 \right) - orgNsta,ly \quad (3.2)$$

The amount of nitrogen transferred between the active and stable organic pools is represented by $Ntrns,ly$ (kg N/ha), the rate of nitrogen transfer between the pools is represented by $\beta trns$ (1×10^{-5}), the amount of nitrogen in the active organic pool is represented by $orgNact,ly$ (kg N/ha), the fraction of humic nitrogen in the active pool is represented by $fractN$ (0.02), and the amount of nitrogen in the stable organic pool is represented by $orgNsta,ly$ (kg N/ha). Nitrogen gets moved from the active organic pool to the stable organic pool when $Ntrns,ly$ is positive. When $Ntrns,ly$ is negative in the SWAT model, The stable organic pool loses nitrogen as it moves to the active organic pool (**Figure 3.6**).

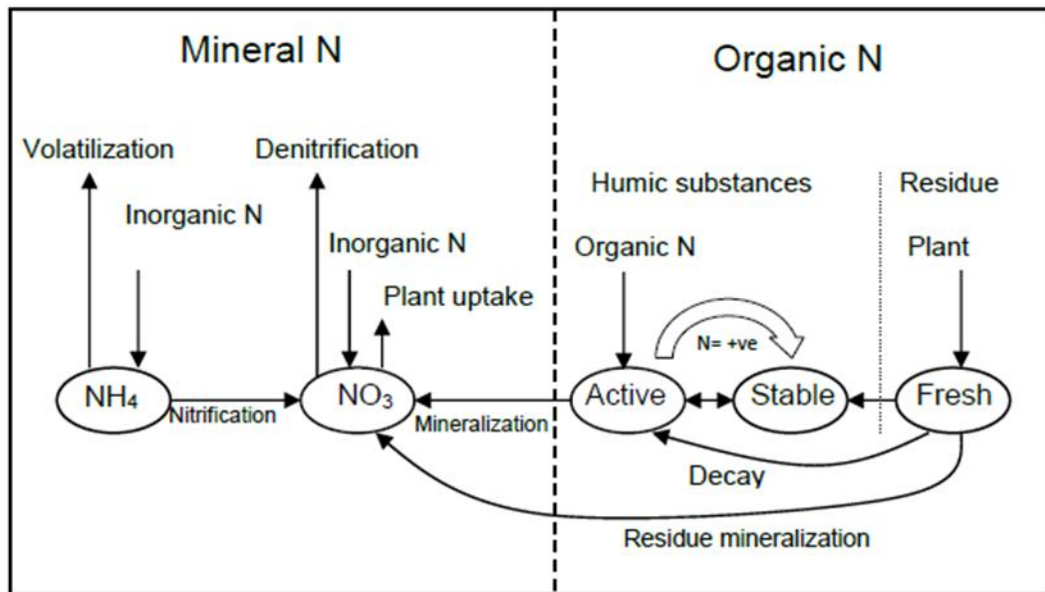


Figure 3.6: Diagram showing the soil N cycle as it is simulated in the SWAT model.

The organic and mineral pools interact with one another. Nitrogen moves from the active to the stable organic pool when $Ntrns,ly$ is positive ($N = +ve$). Microbial biomass and crop residues are linked to fresh organic nitrogen (N), whereas soil humus is linked to both active and stable biological N pools. To account for the variance in humic components availability to mineralization, the organic nitrogen linked with humus is

divided into two pools. If legumes are planted, SWAT incorporates nitrogen fixation by the legumes when the soil is not able to meet the plant's nitrogen requirement. In addition, it computes the amount of nitrate lost to denitrification and models nitrification and ammonia volatilization. The SWAT model simulates all soil N processes by utilizing the correlations outlined in the theoretical documentation of the model [61].

$$concNO3, mobile = NO3ly * \left(1 - \frac{\exp\left[\frac{-wmobile}{(1-\theta e) * SATly}\right]}{wmobile} \right) \quad (3.3)$$

The formula for calculating nitrate concentration in mobile water for a given layer is $concNO_3, mobile = kg \text{ N/mm H}_2O$; nitrate amount in layer = $NO_3ly = kg \text{ N/ha}$; $wmobile = mm$ of water in the layer; θe = soil moisture by volume; and $SATly =$ saturated water content of the soil layer = mmH_2O .

3.2.2. SWAT Model Phosphorous Assessment

To evaluate all phosphorus sections and assist in managing all phosphorus forms, identifying every cycle of phosphorus components and how SWAT replicates them from the land phase to the stream is essential. Although phosphorus can be found in soils and water in a variety of ways, the SWAT model calculates six different kinds of phosphorus in soil that can be classified as either organic or inorganic. For an uncontrolled area with natural vegetation, the condition at the beginning of soluble and organic P in the soil can only be determined with the SWAT default threshold of 5 mg P kg^{-1} and for cultivated areas, 25 mg P kg^{-1} [62].

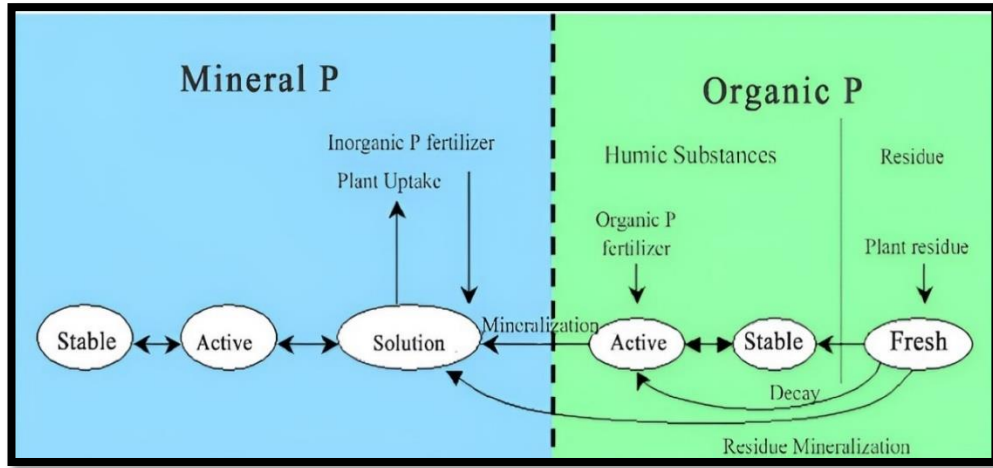


Figure 3.7: Phosphorus forms diagram.

The SWAT model uses the EPIC version to account for immobilization, breakdown, and mineralization. These forms are combined by the SWAT model to provide two primary output components: organic P (sediment P and organic P) and mineral P (tile and soluble P). TP is a measure of the P level in a stream that is calculated by adding the organic and mineral P. Using this equation, the phosphorus in the active mineral pool is defined:

$$\min P_{activ} = P_{solutionly} * \left(\frac{1-pai}{pai} \right) \quad (3.4)$$

$\min P_{activ}$ is the amount of active phosphorus in mineral pool (mg/kg).

$P_{solutionly}$ is the amount of phosphorus in solution (mg/kg).

pai is the phosphorus availability index

As opposed to this, the following formula is used to begin the stabilization of the mineral phosphorus process.

$$\min P_{stable} = 4 * \min P_{active} \quad (3.5)$$

The inputs for the model are Digital Elevation Model (DEM), Land Use/Land Cover, Soil Properties, Meteorological, Management Data.

3.2.3. Digital Elevation Model (DEM)

Determining the watershed requires a digital elevation model. DEM is also used to characterize the features of the stream network, such as the slope, length, and breadth of the channels, and to compute basin parameters like slope and slope length [11]. While the altitude unit is meters, centimeters, yards, feet, or inches, the grid resolution unit must be in meters, kilometers, feet, yards, miles, or decimal degrees.

3.2.4. Land Use and Land Cover

Among the most significant GIS data incorporated into the model are land use/cover data. Calculating various flows, nutrient loads, and erosion rates requires knowledge of land coverage [39]. Changes in land use and land cover have indirect impacts on global warming, climate change, biodiversity, and the economy and society.

Analysis of land use/cover changes in the past and present is often done using remote sensing and geographic information system (GIS) techniques [40]. Currently, the management of sophisticated GIS techniques, radar and aerial photos, high-resolution satellite images, and image processing techniques in an integrated structure yields more precise and detailed data in terms of the temporal and spatial dimensions. For the SWAT model, the land use / land cover map must be ESRI GRID, in shape file or in feature class formats.

The categories selected in the land use and land cover map should be reclassified into the SWAT database of land cover / plant species. The user has three options to reclassify the land use and cover categories:

- Creating land use / land cover lookup table in ArcSWAT interface (interface includes USGS LULC and NLCD 1992 lookup tables)
- Writing SWAT land use / land cover codes for each category
- Creating a user lookup table defining SWAT codes for different categories.

CORINE (Coordination of Information on the Environment) is the land use / land cover data determined by the European Environment Agency. This dataset was produced by computer-aided visual interpretation method on satellite images [12]. CORINE Project has been executed by 13 countries. The dataset reflecting 1990, 2000, 2006, 2012, 2018 years have been created for the European Union member countries

and Turkey [13], [14]. In Turkey, CORINE Project was started by Turkey Statistical Institute (TSI) in 2001. This project has been carried out by the Republic of Turkey Ministry of Agricultural and Forestry since 2005. In this study, the CORINE-2018 (Coordination of Information on the Environment) land use/land cover classification was used.

3.2.5. Soil Data

One of the most important input parameters for hydrological modelling is the digitized soil maps of the studied area. Soil maps that are produced because of soil etude and mapping studies and related reports presented constitute the soil database. The accuracy of the reports and detailed information provide acceptable results for future studies [15]. Digitized soil maps are important to reveal the unique hydrological characteristics of the studied catchment.

The terms Genetic or Taxonomic classification and Soil Taxonomy refers to the natural classification. These systems examine soils according to their natural properties and compare them with each other.

The systems reveal the relationships of the most important natural properties of soils without any practical and applied purpose. The main natural classification systems are generally Russia, Germany, France, Australia and the old American classification system.

In addition to these, The New American Soil Taxonomy and FAO/UNESCO soil classification system are used in scientific research all over the world.

In Turkey, soil maps have been categorized since 1958 using the Old American Soil Classification System. These digitally compatible, 1/25000 scale maps can be used with GIS software. A polygon characteristics table of soil mapping units is included in the digitalized soil maps. Data on the following topics is available to users:

Main soil groups (23 types); soil characteristics; other soil characteristics (salinity, alkalinity, stony, rocky, etc.); erosion level sensibility (1-non or very low, 2-medium, 3-high, 4-very high); area types (bare rocks, rubble areas, ricer flooded areas, sandy shores, reed bed on muddy areas, permanent snowed areas); groups of land capability classes (lands suitable or not suitable for plowing, lands not suitable for agriculture, etc.); and subgroups of land capability classes (non-capability due to slope, poor

drainage, flooding or wetness, climate restriction, etc.). In Turkey, soil maps have been categorized since 1958 using the Old American Soil Classification System. Detailed information on the integration of these soil data into the SWAT model is described in the Chapter 5.

One of the ESRI GRID, shapefile, or feature class formats must be used for the soil map. The simulated area should have at least 95% of the soil map covered. The SWAT soil database needed to be connected to the categories listed on the soil map. The SWAT soil database can have soil types and attributes added by users using the ArcSWAT editing database tool or by importing SWAT soil files (.sol). There are four ways that users can connect the soil map and soil database [6].

- Using the name option. Users of the model can input the name of the user-specified soil type as seen on the soil map. In this scenario, the user needs to write the soil data to the soil database or import the SWAT soil file (.sol).

3.2.6. Meteorological Data

For simulations, it is essential to obtain an appropriate meteorological dataset. The two primary meteorological parameters that drive the SWAT model are temperature and rainfall.

Furthermore, the model may generate parameters related to solar radiation, wind speed, and relative humidity by utilizing temperature and precipitation data or the user can input these values directly into the model. It is important to select gauge stations that accurately reflect the watershed under study. The model must be updated based on the latitude, longitude, and altitude of the stations. Furthermore, the SWAT model can interpolate missing data, which sets it apart from the other hydrological models.

For the daily resolution, the SWAT model requires six distinct meteorological datasets. Precipitation, wind speed, relative humidity, solar radiation, minimum and maximum temperatures, solar radiation. Users can introduce or obtain this data to the model by providing it daily, or they can also generate data with the help of the WGEN [16] model which is embedded in the SWAT using a few years of average monthly data.

3.2.7. Management Data

Watershed-based hydrological models are primarily used to track how human activity affects a system. Activities related to managing land and water are crucial for the foundation of this assessment. An HRU has an available SWAT management option. Researchers can obtain operational data on planting, harvesting, tillage, nutrient application, pesticide application, and irrigation.

The two sections of the management file were separated. First, a summary of the starting conditions or management techniques that remained constant throughout the simulation is provided. The second section includes a list of management procedures that occur at particular times.

General management variables, including initial conditions, are listed below:

- Initial plant growth parameters
- General management parameters
- Urban management parameters
- Irrigation management parameters
- Tile drain management parameters
- Management operations

Planting and the start of the growing season, irrigation, fertilizer application, pesticide application, harvest/kill, tillage, grazing, automatic irrigation and fertilizer initialization, street sweeping, release/impound, continuous fertilizer application, and end-of-year operations are the main scheduled management operations. The SWAT input / output file document has a detailed description of every management option mentioned above [6].

3.2.8. Hydrological Response Units (HRUs)

Given the hydrological response units, the water courses in the study basin were ascertained by simulating the SWAT model [38]. Hydrological Response Units (HRUs) were generated by overlay analysis in a GIS context, taking into account the topography, soil, and land use/cover of each sub-basin. The resulting HRUs represented units with comparable hydrological properties.

As the unit of modeling, HRUs streamline the modeling procedure and increase numerical effectiveness. The representation of HRUs produced for this study using SSM databases is detailed in Section 5.2.

3.2.9. The SWAT-CUP Calibration Technique

The sensitivity parameters are determined by modelers, and their ranges are modified systematically for model calibration using semi-automation. When running the model, the required outputs are found in the (TxtInOut) SWAT output file. Calibration, uncertainty, and sensitivity analyses of the SWAT model outputs can be readily carried out with the help of the SWAT_CUP interface. Connecting the inputs and outputs of the calibration program is the interface's main function. Particle Swarm Optimization (PSO), Sequential Uncertainty Fitting (SUFI-2), Markov Chain Monte Carlo (MCMC), Parameter Solution (PARASOL), and Generalized Likelihood Uncertainty Estimation (GLUE) are the five distinct optimization techniques SUFI_2 techniques that are specified for calibration and uncertainty analysis in SWAT-CUP are the most favored optimization techniques. It is clear that the sensitivity analysis between the simulation values and observations is the foundation of this approach. The most efficient parameters needed for the calibration and validation procedure are obtained by sensitivity analysis [17], [18]. In this study, the SUFI-2 optimization algorithm, it was selected for calibration since it can analyze the sensitivity of the parameters.

SUFI-2 can be used to estimate various runoff-related SWAT parameters. The discrepancy between the simulated and measured variables is the SUFI-2 defines by uncertainty. With the exception of outlier values, the measured data must be safeguarded to explain this ambiguity. To determine the uncertainty parameters, SUFI-2, and thus blend calibration with uncertainty analysis. In SUFI-2, the input value

uncertainty is expressed as a uniform distribution, and the model output uncertainty is defined as 95% estimation uncertainty (95PPU) [19].

To verify whether the simulation and observed values were consistent, model performance statistics were employed. Numerous statistical performance metrics, including p-factor, r-factor, R2, NSE, RMSE, SSQR, and PBIAS, were established to assess the hydrological model's performance. Without using any calibration approaches, the study used the determination coefficient (R2), percent bias (PBIAS), and Nash-Sutcliffe coefficient of efficiency (NSE) to assess the validity of the model outputs [20].

3.2.10. Summary of Data Acquisition

The summary of the input data is given on **Table 3.1**. The DEM with a resolution of 5 m was created by using aerial images obtained from the Turkish General Command of Mapping. Files containing contour data were blended using ArcGIS 10.5's mosaic function. The CORINE-2018 Project provides land use/coverage maps. Specified Soil Maps (SSM) generated through laboratory and field studies were used separately. Additionally, slope classes, stream network topologies, sub-basin boundaries, and basin boundary height bands were calculated using DEM.

Table 3.1: Summary of data collection methods.

Parameter	Summarized Obtained Method
Digital Elevation Model	Using aerial photographs which were taken from Turkish General Command of Mapping
Land use and Land Cover	Coordination of Information on The Environment (CORINE) - 2018
Soil Data	Specified with Laboratory and Field Studies Food and Agricultural Organization (FAO) Soil Map [21]
Meteorological Data	Turkish General Directorate of Meteorology (TMMS) & National Environmental Prediction Center (NCEP)

3.3. Data Preparation

3.3.1. Soil Data Preparation

Understanding processes like crop development, infiltration, surface runoff, and soil water is dependent on an understanding of soil structure. Gaining knowledge about the characteristics of soil helps one comprehend intricate watersheds. The Ministry of Agriculture and Forests in Turkey created a soil map (TNSD), Akçat stream basin includes 2 main soil groups: Sandy loam-limeness brown forest and silty loam-limeness brown forest. Studies in the field and in the laboratory were conducted to determine the required SWAT parameters. Since the basin is dominated by agricultural and residential areas, attention has been paid to take soil samples from points where the natural soil structure is not disturbed. Accordingly, 2 soil sampling points were chosen to represent the entire basin (**Figure 3.4**). To determine the locations of soil sampling points, main soil groups of the basin, slope / depth values obtained from the TNSD database and land use/cover status were considered. The degraded soil samples were taken approximately 1 kg from a depth of 15,30,100 cm.

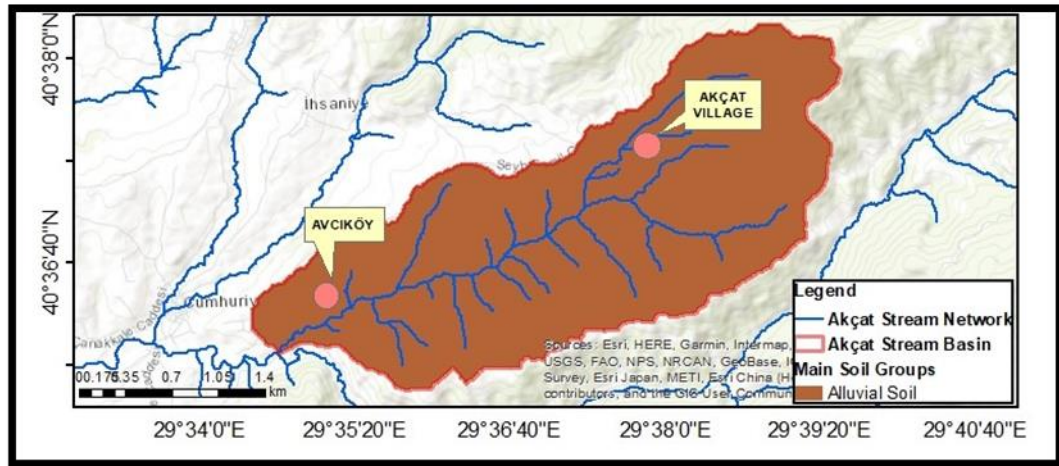


Figure 3.8: Soil sampling points and main soil groups provided by the Ministry of Agriculture and Forest.

The photos of soil sampling points are shown in **Figure 3.8**. Soil samples can be analyzed more homogeneously during and after field studies.



Figure 3.9: Selected soil sampling points.

Numerous physical and chemical soil parameters are used as input variables in SWAT. These parameters are hydrologic group, maximum rooting depth, maximum crack volume, texture of the specified soil, the soil erodibility factor, bulk density, organic carbon content, saturated hydrologic conductivity, available water content, clay, silt, sand, and rock/gravel content, and albedo. In this study, the data preparation procedure was derived from the SWAT Manual [10]. The description of these parameters and determination methods for this study are shown in **Table 3.2**. In contrast, bulk density, organic carbon content (%), maximum rooting depth, and depth from soil surface to layer bottom, clay - silt - sand - gravel content (%), USLE soil erodibility factor were analyzed and calculated by field and laboratory studies, the rest of these parameters are obtained from the literature studies, [10], [22], [23].

Table 3.2: SWAT-required soil parameters

Description	Determination Method
Hydrologic group	Turkey General Directorate of Rural Services (TNSD)
Depth from soil surface to bottom of layer (mm)	Field studies
Maximum rooting depth (mm)	Field studies
Fraction of porosity from which anions are excluded	Neitsch et al. [10]
Maximum crack volume (m^3/m^3)	Neitsch et al. [10]
Bulk density (g/cm^3)	Laboratory Analysis
Available water content (mm/mm)	Neitsch et al. [10]
Saturated hydraulic conductivity (mm/h)	Laboratory Analysis
Clay, silt, sand, rock/gravel content (%)	Laboratory Analysis
Albedo	Katharina [24]
USLE soil erodibility factor	Calculate according to Williams et al. [25]

Soil data preparation section is presented in detail in two subtitles named “soil input parameters obtained from the literature” and “soil input parameters measured/determined by field and laboratory studies”.

3.3.2. Soil Input Parameters Obtained from The Literature

SWAT uses many soil physico-chemical parameters as input variables that interact with one another either directly or indirectly. As an example, the erodibility factor of the examined region is a function of the rock content, sand, clay, and silt content of the soil [22]. The soil parameters gleaned from research in the literature are described in full below:

- According to the US Natural Resources Conservation Service (NRSC), one of the key soil factors is the soil hydrologic groups, which are established by taking the infiltration characteristics into account. Four main hydrological groups have been defined worldwide. These groups include high infiltration rate (A, about range between 7.5 - 10 mm h⁻¹), moderate infiltration rate (B, about range between 3 - 7.5 mm h⁻¹), slow infiltration rate (C, about range between 0.8 - 7.5 mm h⁻¹) and very slow infiltration rate (D, smaller than 0.8 mm h⁻¹). In this study, hydrological group values were determined using the TNSD database's primary soil classifications and soil characteristics combined [26]. The dominant hydrological group of the Akçat catchment is found as D.
- Normally, the pH of most soil minerals is negatively charged. As a result, these particle surfaces interact repulsively with anions like nitrate. This rejection is known as the proportion of porosity that excludes anions [27]. This study used the model's optional parameter, which has a value of 0.5. For maximum crack volume (m³ / m³) parameters, 0.5 was chosen for this study [6], [10].
- When soil samples are dried in an ash oven, the soil water content can range from zero to the saturation level of the soil (maximum-level). There are two intermediate steps of water transport between the plant and the soil that define this available water content. These are the permanent wilting point and field capacity, in that order. A well-moisturized soil's field capacity is the quantity of water left in it after two days or so of neglect. At what water content do plants start to wither. This is known as the permanent wilting point.

The metric for available water content is defined as the difference between the two amounts. Criteria for permanent wilting point and field capacity were provided in the SWAT papers [6].

- The percentage of solar radiation reflected by a surface soil body relative to the amount incident upon it is known as the "moist soil albedo". In this study, soil texture classes were taken into consideration while determining the albedo values. In addition, Fricke K's study was used to establish the albedo values of moist soil [24].

3.3.3. Field and Lab Studies Used to Measure and Compute Soil Input Parameters

To begin, soil texture was analyzed, which has a direct impact on other variables and is crucial for determining them. For example, soil albedo, accessible water content, and saturated hydraulic conductivity values were determined based on soil texture. In texture analysis, sieve analysis was used to evaluate the content of gravel/rock (particle diameter > 2mm) and sand (particle diameter varies between 2 and 0.5mm). Silt and clay content were determined using the Mastisizer-2000 Malvern equipment (Gebze Technical University Materials Science and Engineering Laboratory). Photographs showing the order of texture analysis are given in **Figure 3.6**.



Figure 3.10: Laboratory analysis steps for soil texture analysis.

Soil texture triangle system is generally preferred to distinguish between coarse and fine textured soil types. Using the soil texture triangle approach, the proportion contents of rock/gravel, sand, silt, and clay were considered (**Figure 3.10**). For the study area, soil groups were determined as sandy loam (51.6%), silt loam (48.4%), respectively. For the visualization of SSM, these soil textures and main soil groups were combined and soil sub-polygons of the catchment were created.

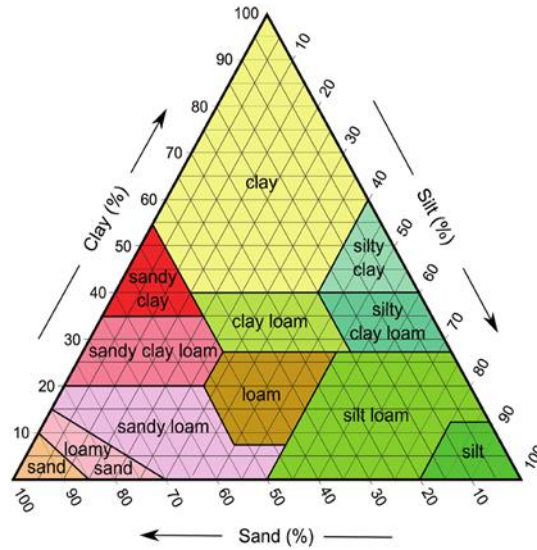


Figure 3.11: Examination of the soil texture analysis for the Akçat stream basin in the soil triangle system.

The loss-on-ignition method was used to determine the organic matter content of soil samples. A muffle furnace was used to burn 10 g of dried soil samples for four hours at 550 °C. Following a reweighing of the soil sample, the organic matter was determined by taking the difference.

The soil bulk density is defined as the mass of solid particles divided by the volume of the soil sample. In this investigation, bulk density was calculated as the ratio of soil sample volume to oven-dried soil sample volume.

Important physical characteristic that regulates soil permeability and, consequently, salt and agricultural chemical transfer and washing in the soils is saturated hydraulic conductivity. It is a crucial criterion for assessing drainage issues in basins [29].

In this study, A tin box with many holes in the bottom was used to hold samples of soil to determine the hydraulic conductivity while taking the soil's frequency in the field into consideration. Then, a container was gradually filled with water.

Through the sample and up to a specific level above the surface, water that enters the box through the perforations in the bottom passes through. After taking the box out of the water, a stopwatch was used to record how long the water remained on the soil. Hydraulic conductivity is finally computed using the following formula. (Equation 3.6).

$$K = \frac{L}{t} * \log_e \left(1 + \frac{h}{L} \right) \quad (3.6)$$

Whereby K is the saturated hydraulic conductivity (mm/h), L is the soil sample's thickness (mm), h is the water's height over the sample (cm), and t is the amount of time water has been removed from the sample's top surface (cm).

The Universal Soil Loss Equation (USLE) estimates long-term average annual erosion rate based on the field slope, soil type, precipitation pattern, topography of the field, crop activity and management practices. USLE Equation is given as follows:

$$A = R \times K_{USLE} \times LS \times C \times P \quad (3.7)$$

The possible average annual soil loss over a long period, expressed in tonnes per acre annually, is denoted by A. The geographical location-specific runoff and rainfall factors denoted by R. LS is the slope length-gradient factor. The length of the slope is 22.13 m (72.6 ft), with a "average" slope steepness of 9% in a field are represented by the LS factor, which indicates the rate of soil loss under specific conditions. The factor for crop/vegetation and management is C. The soil loss avoidance of crop management and soil management systems is compared using C. The quantity of soil lost from land managed with a certain crop and cropping pattern compared to the amount lost from tilled and continuously fallow ground is known as the C factor. P represents the provision of assistance. It illustrates how some applications can lessen the volume and speed of water flow, which in turn lessens erosion [24]. These factors are usually used in the calibration step in SWAT application.

The USLE soil erodibility factor quantifies how susceptible soil particles are to being separated and transported by precipitation and discharge. Along with soil structure, organic matter concentration, and permeability, soil texture is a significant factor

influencing this variable. (Equation 3.8- 3.12) were used in this study to calculate K_{USLE} which represent the soil erodibility factor.

$$K_{USLE} = f_{csand} \times f_{cl-si} \times f_{orgc} \times f_{hisand} \quad (3.8)$$

In the case of high-coarse sand soils, f_{csand} is a factor that yields low soil erodibility factors, whereas low-sand soils have high values. In soils with a high clay-silt rate, the low erodibility factor is denoted as $f_{(cl-si)}$. A component that reduces the erodibility of soil in high-organic carbon soil is f_{orgc} ; in soils with an extraordinarily high sand content, a factor that decreases soil erodibility is for sand.

$$f_{csand} = \left(0.2 + 0.3 \times \exp \left[-0.256 \times m_s \times \left(1 - \frac{m_{silt}}{100} \right) \right] \right) \quad (3.9)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}} \right)^{0.3} \quad (3.10)$$

$$f_{orgc} = \left(1 - \frac{0.25 \times orgC}{orgC + \exp[3.72 - 2.95 \times orgC]} \right) \quad (3.11)$$

$$f_{hisand} = \left[1 - \frac{0.7 \times \left(1 - \frac{m_s}{100} \right)}{\left(1 - \frac{m_s}{100} \right) + \exp[-5.51 + 22.9 \times \left(1 - \frac{m_s}{100} \right)]} \right] \quad (3.12)$$

In this case, m_s represents the percentage of sand (0.05–2.00 mm diameter), m_{silt} the percentage of silt (0.002-0.05 mm diameter), m_c the percentage of clay (< 0.002 mm diameter), and $org C$ the percentage of organic carbon in the layer. Depth from soil surface to bottom of layer refers to the layer that prevents the plant roots from developing downward. The top 150 cm of soil is where plants get their water and nutrients, and it has a big impact on how big a plant gets. The maximum rooting depth is taken to be the soil profile depth in this investigation. Field investigations are used to ascertain the soil profile's depth, which is then verified by comparison with the soil depths listed in the Turkish National Soil Database.

3.4. Flow Rate Monitoring

Flow rate is the most critical parameter for water yield and regime in watershed studies. Hence, in this study, locations of flow rate monitoring stations were determined to represent all river networks of the Akçat Stream (Figure 3.2). Flow rate values were determined by the multiplication of water velocity (m s^{-1}) and cross-sectional area (m^2). Water velocity was measured using the "Hydrometer 2 JDC" current meter. A reference depth point has been set. Considering this reference depth point, the cross-sectional area was calculated for each daily and monthly measurements (Equation 3.13).

$$Q = A \times V \quad (3.13)$$

Where Q is the flow rate ($\text{m}^3 \text{s}^{-1}$), A is the cross-sectional area (Calculated in R ver.4.0.3 Programming Language – m^2) and V is measured velocity (m.s^{-1}).

Each flow rate monitoring point was also defined as the outlet of basins designed in the SWAT, as present in Figure 4.1 in Chapter 4. At this station, flow rate was measured by Kocaeli Metropolitan Municipality Water and Sewerage Administration (ISU). Therefore, the flow rate values were obtained from ISU. These values were used to compare the observation and predicted runoff before and after calibration. Measurements were conducted at the other 1 flow monitoring stations, shown in **Figure 3.12**, in monthly periods within the scope of TUBITAK project (No: 121G066). These measurements were used to evaluate the typical characteristics of the basin, especially the flow rates from Akçat Stream.

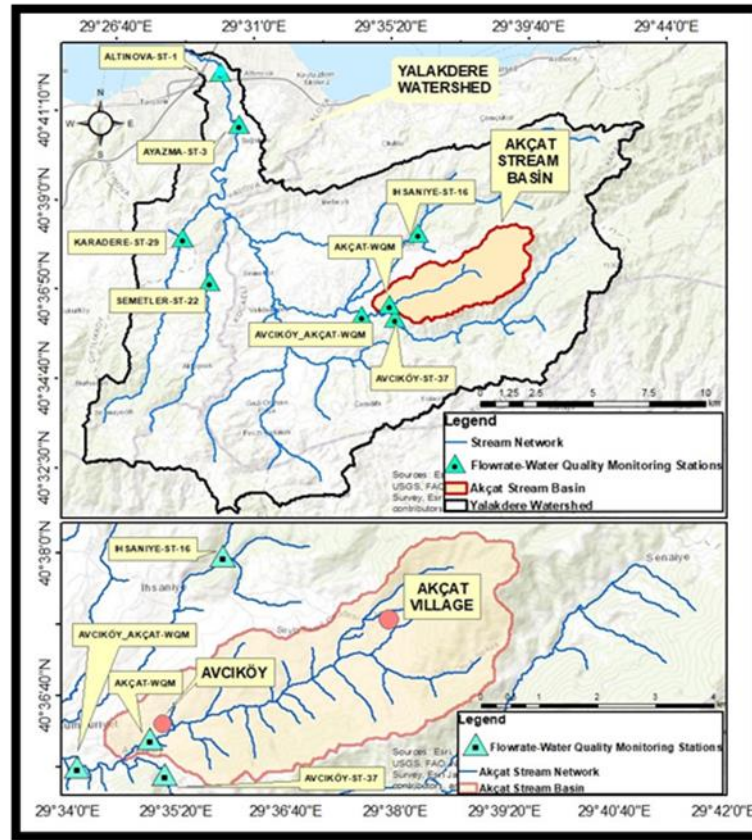


Figure 3.12: Examination of the flowrate and surface water quality monitoring the Yalakdere and Akçat stream basin.

Table 3.3: Location of surface water monitoring points and measurement periods and frequencies.

ID	Outlet Points	Latitude	Longitude	Measurement Period	Measurement Periodicity
1	Altınova-ST-1	40.70210	29.49760	July 1999 – March 2022	Monthly
2	Ayazma-ST-3	40.67760	29.50668	July 1999 – March 2022	Monthly
3	İhsaniye-ST-16	40.63148	29.59910	July 1999 – March 2022	Monthly
4	Semetler-ST-22	40.61443	29.48876	July 1999 – March 2022	Monthly
5	Karadere-ST-29	40.63248	29.47569	July 1999 – March 2022	Monthly
6	Avcıköy-ST-37	40.60137	29.57967	July 1999 – March 2022	Monthly

3.4.1. Surface Water Quality Data Monitoring

It illustrates parameters in NO₃-N, TN and TP concentrations at station Akçat-WQM. Situated on the same branch as Avcıköy-ST-37 station, Avcıköy-Akçat-WQM station marks the point following Avcıköy's septic tank discharge. However, Avcıköy-Akçat-WQM station's average NO₃-N readings are comparable to those of the Avcıköy-ST-37 station. However, the Avcıköy-Akçat-WQM station's TN values are marginally greater than those of the Avcıköy-ST-37 station. This can be explained by the fact that the Avcıköy-Akçat-WQM station is near the Avcıköy septic tank discharge, and extra nitrogen derivatives from the septic tank mix with the water. It is believed that the increased TP and TN values at this station compared to the Avcıköy-ST-37 site are caused by septic tank discharge.

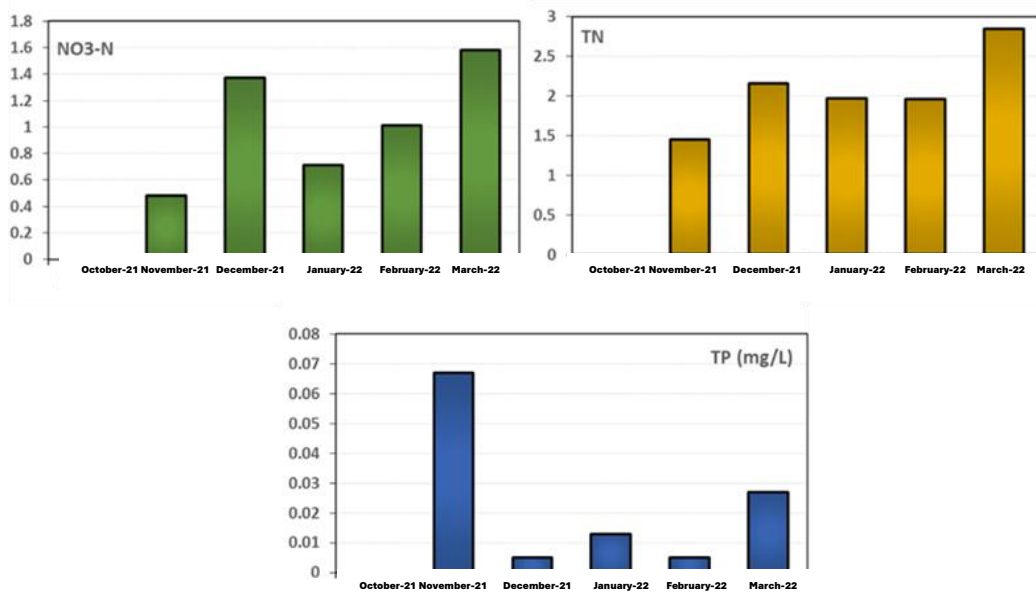


Figure 3.13: Monthly changes of Avcıköy-Akçat-WQM station NO₃-N, TN and TP concentrations.

Table 3.4: Location of surface water quality monitoring points and measurement periods and frequencies.

ID	Outlet Points	Latitude	Longitude	Measurement Period	Measurement Periodicity
1	Akçat-WQM	40.60199	29.57949	October 2021 – March 2022	Monthly
2	Avcıköy-Akçat-WQM	40.60067	29.57784	October 2021 – March 2022	Monthly

The parameters in NO₃-N, TN and TP concentrations at the Akçat-WQM station are provided. As previously stated, the location of this station represents diffuse sources. At this point, the highest values among all other stations were measured, with an average of 3.3 mg/L for NO₃-N. At this site, the highest TN values (average 4.35 mg/L) have been measured, which is comparable to the NO₃-N parameter. This station also had the highest value, with an average TP value of 0.15 mg/L at this time.

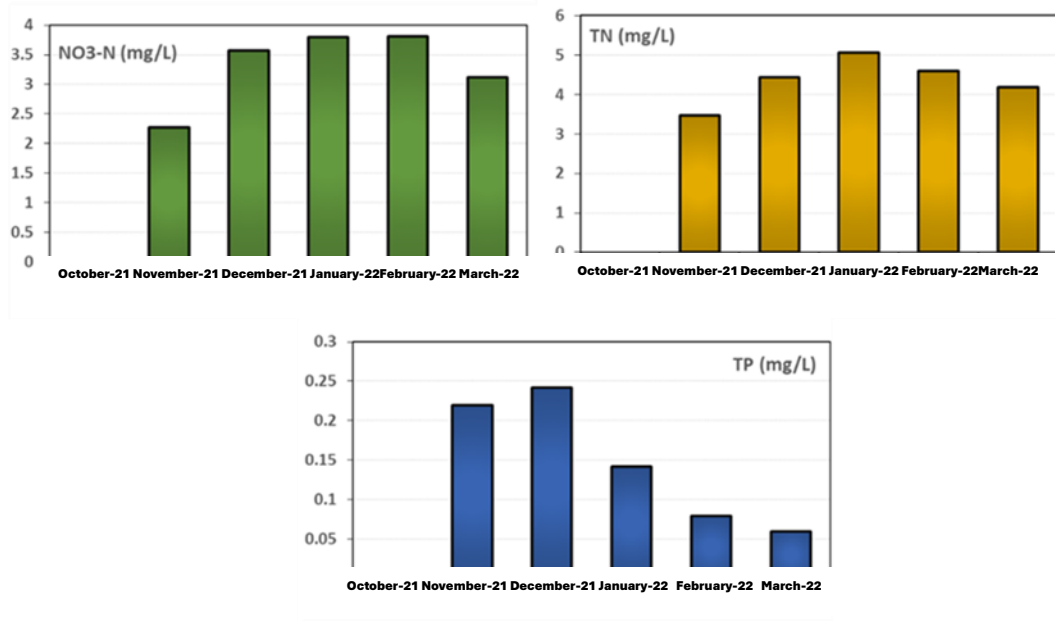


Figure 3.14: Monthly changes of Akçat-WQM station NO₃-N, TN and TP concentrations.

Two primary soil textures were identified because of the soil analysis: sandy-loam (52.6%) and silt-loam (47.4%). To run the SWAT model, every physicochemical property has been entered into the appropriate "soil look-up table" format after the primary soil groups and texture categorization have been combined. Within this soil database, the dominant soil type for half of the Akçat Basin, including the study area, is medium to fine textured (sandy loam) and for the other half it is medium to fine textured (sandy loam), with grain size intermediate between sand and clay, with water retention capacity due to its porous structure high (silty loam) soil structure is dominant.

4.2. Temporal and Spatial Variation of Flow Rate Measurements

Within the watershed delineator module of the SWAT model, a basin was created to make it easier to comprehend how the flow rate varied throughout the catchment. Every basin's outflow is intended to serve as the flow rate monitoring station. Surface-flow measurement points have been chosen to represent the entire Yalakdere Stream, within the scope of TÜBİTAK Project (No: 121G066). These measurement points were designed close to the intersection point with Avcıköy stream. The surface flow variability of Ayazma-ST-3 is shown in Figure 4.2 according to the evaluation date range of the model. The monthly measurement points (seen in **Table 3.3**) were used to assess the runoff condition of the catchment before model run.

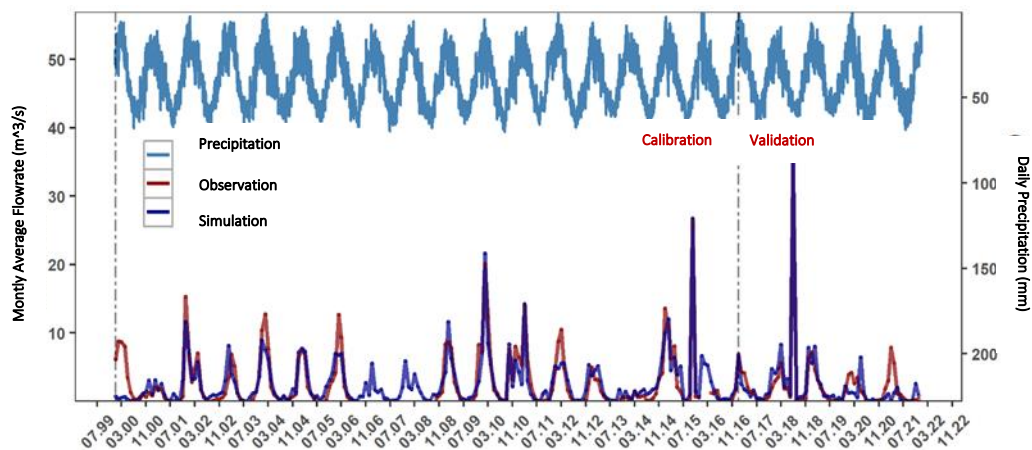


Figure 4.2: Comparison of monthly observation and prediction surface runoff in the basin outlet and their variation with daily average precipitation; Ayazma-ST-3.

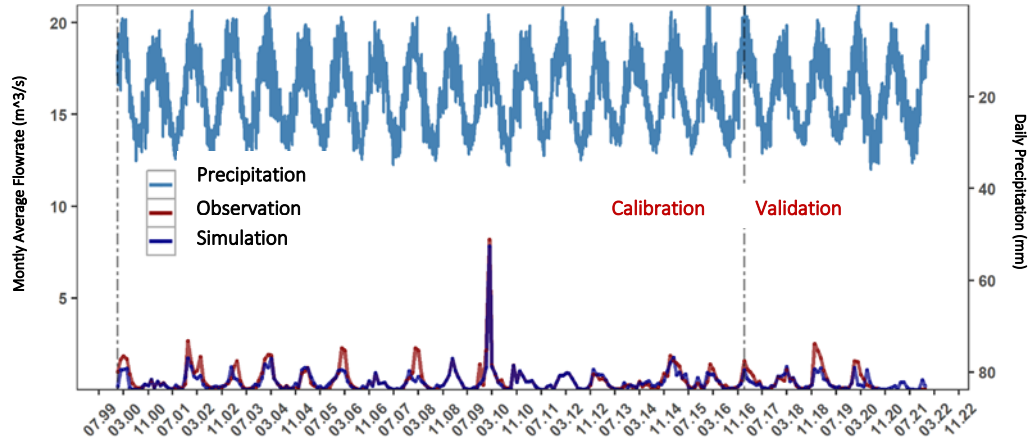


Figure 4.3: Comparison of monthly observation and prediction surface runoff in the basin outlet and their variation with daily average precipitation; Ihsaniye-ST-16.

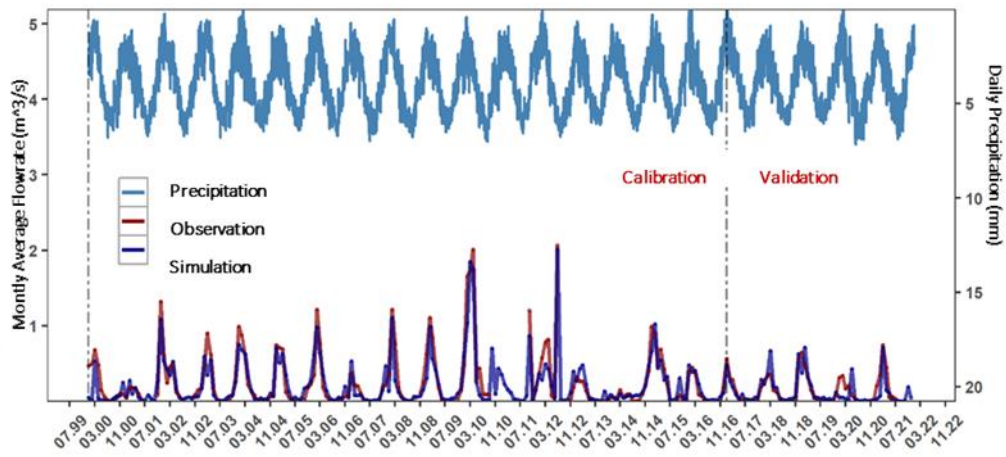


Figure 4.4: Comparison of monthly observation and prediction surface runoff in the basin outlet and their variation with daily average precipitation; Semetler-ST-22.

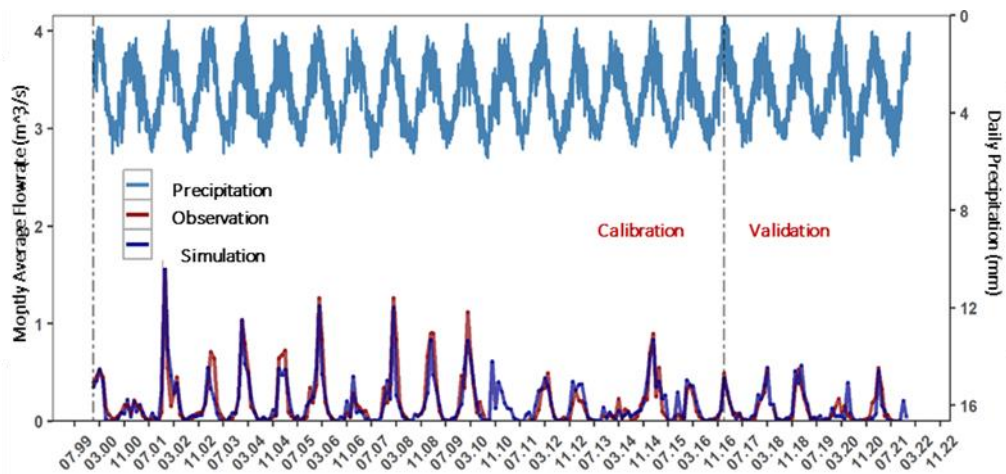


Figure 4.5: Comparison of monthly observation and prediction surface runoff in the basin outlet and their variation with daily average precipitation; Karadere-ST-29.

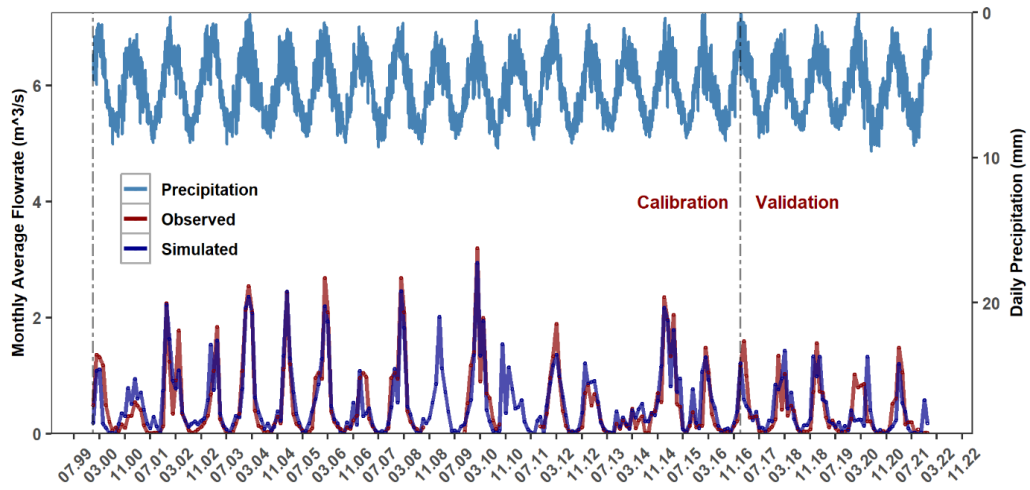


Figure 4.6: Comparison of monthly observation and prediction surface runoff in the basin outlet and their variation with daily average precipitation; Avcıköy-ST-37.

4.3. Surface Water Quality Monitoring Results

While the observed minimum and maximum total nitrogen and total phosphorus loads have relatively low variation across the basin, the modeled TN and TP loads show relatively high variation. Modeled maximum loads were observed for the two pollutants in February, March, April and October. These months represent the months when organic and inorganic fertilizers are applied to agricultural and pasture areas.

Relatively high TN and TP loads resulting from manure management practice explain the high variation in the dataset produced from the model. There is good agreement between the observed TN and TP loads in 2021 October – 2022 March. With NO₃-N loading, the results of the model and the observations are consistent. The other stations, Ihsaniye-ST-16, is overestimated by the model, although Ayazma-ST-3, Semetler-ST-22, Karadere-ST-29, Avcıköy-ST-37 are all expected to have low values. From this perspective, it is an obvious fact that these fertilizers, rich in organic nitrogen and phosphorus, reach the Akçat stream through surface and groundwater. In this context, considering the limitations of the SWAT model in modeling the nutrient loads reaching the basin outlet through groundwater, animal manures were integrated into the model by assuming that all these fertilizers were used in agriculture and pasture areas. In this respect, the high estimation made by the model in terms of phosphorus can be

considered as an expected situation. While the observed minimum and maximum total nitrogen and total phosphorus loads have low variation across the basin, the modeled TN and TP loads show high variation. These months represent the months when organic and inorganic fertilizers are applied to agricultural and pasture areas. The high TN and TP loads resulting from the fertilizer management practice explain the high variation of the data set produced from the model.

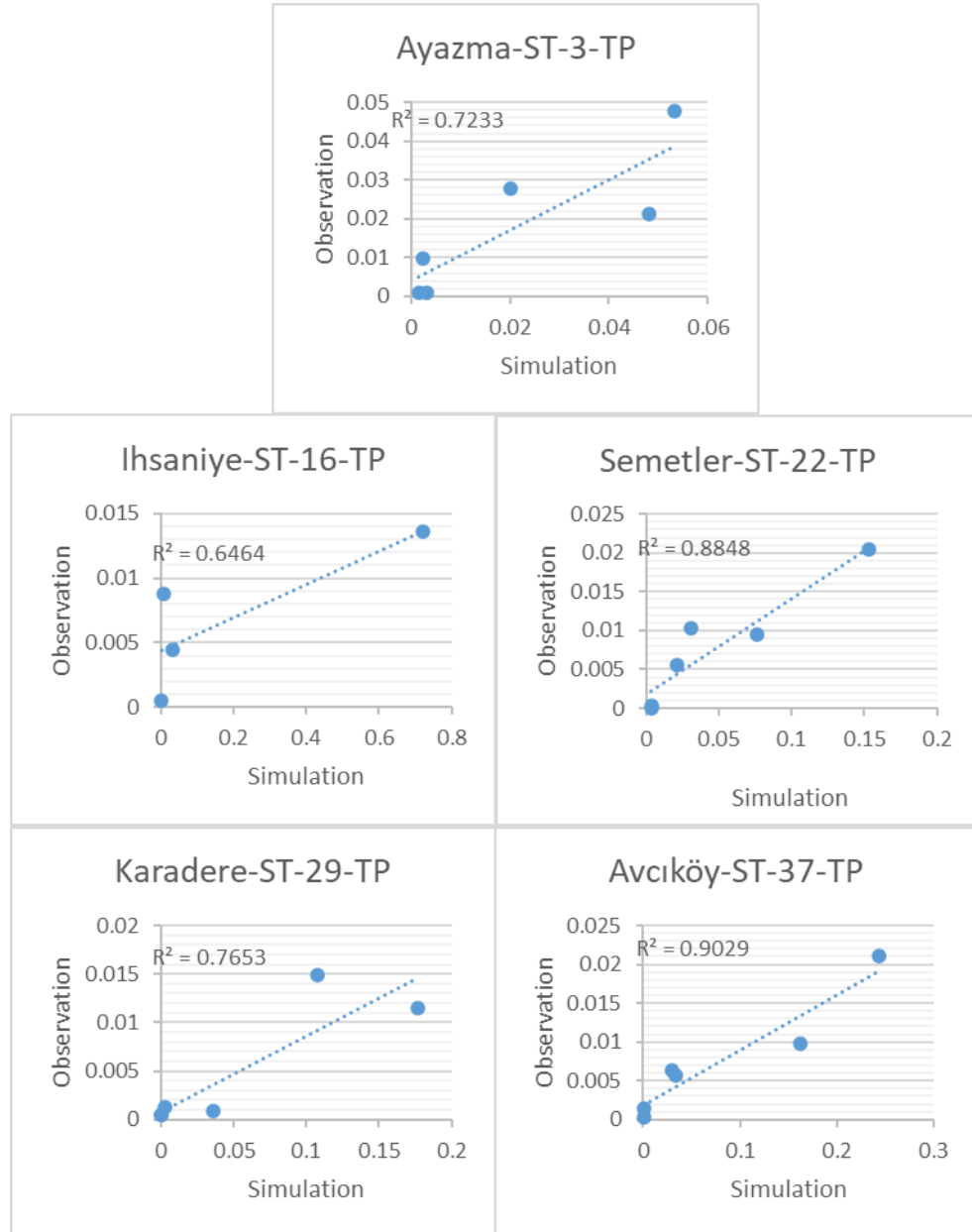


Figure 4.7: Graph of Observed and Simulated Water Quality TP loads from October 2021 to March 2022.

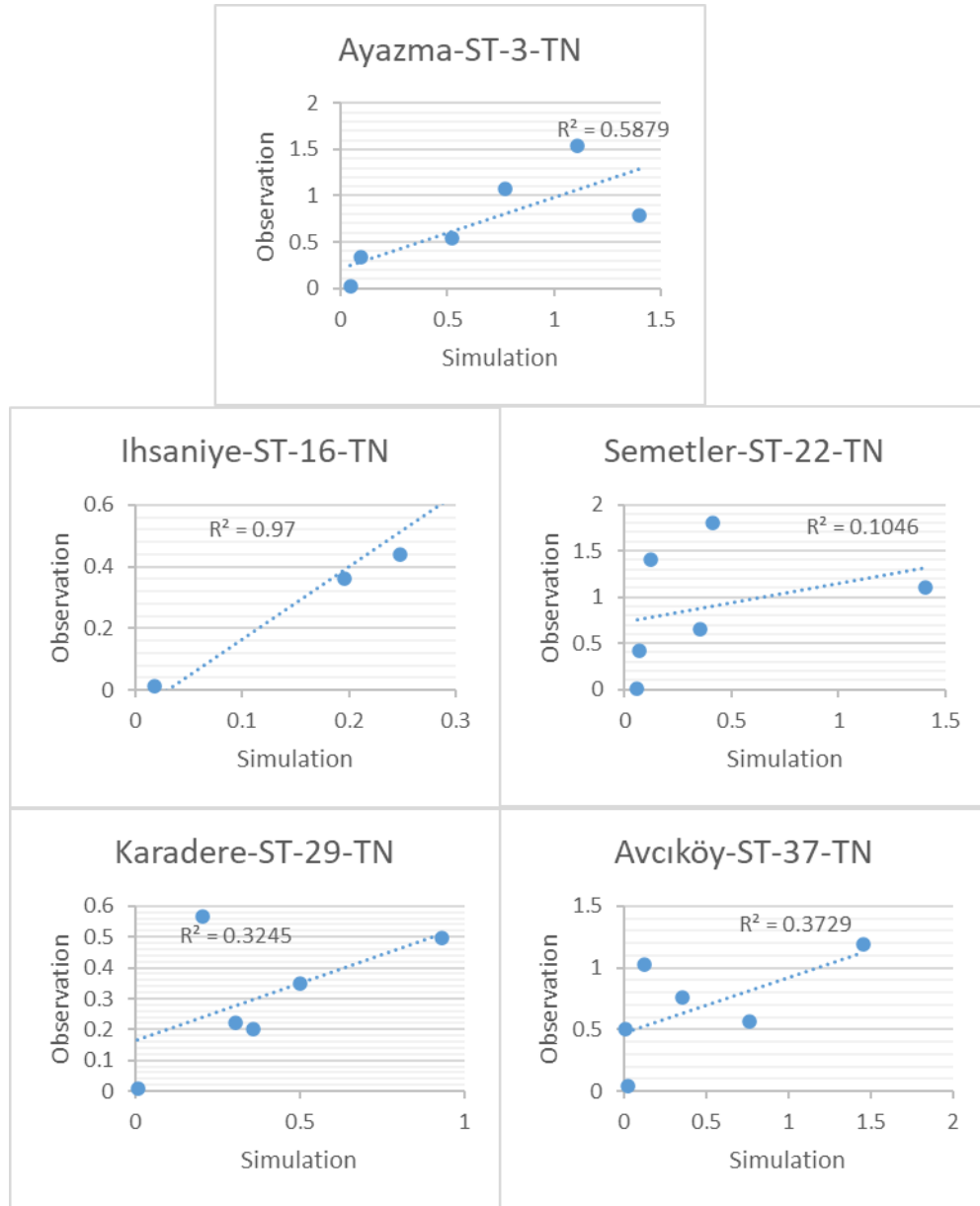


Figure 4.8: Graph of Observed and Simulated Water Quality TN loads from October 2021 to March 2022.

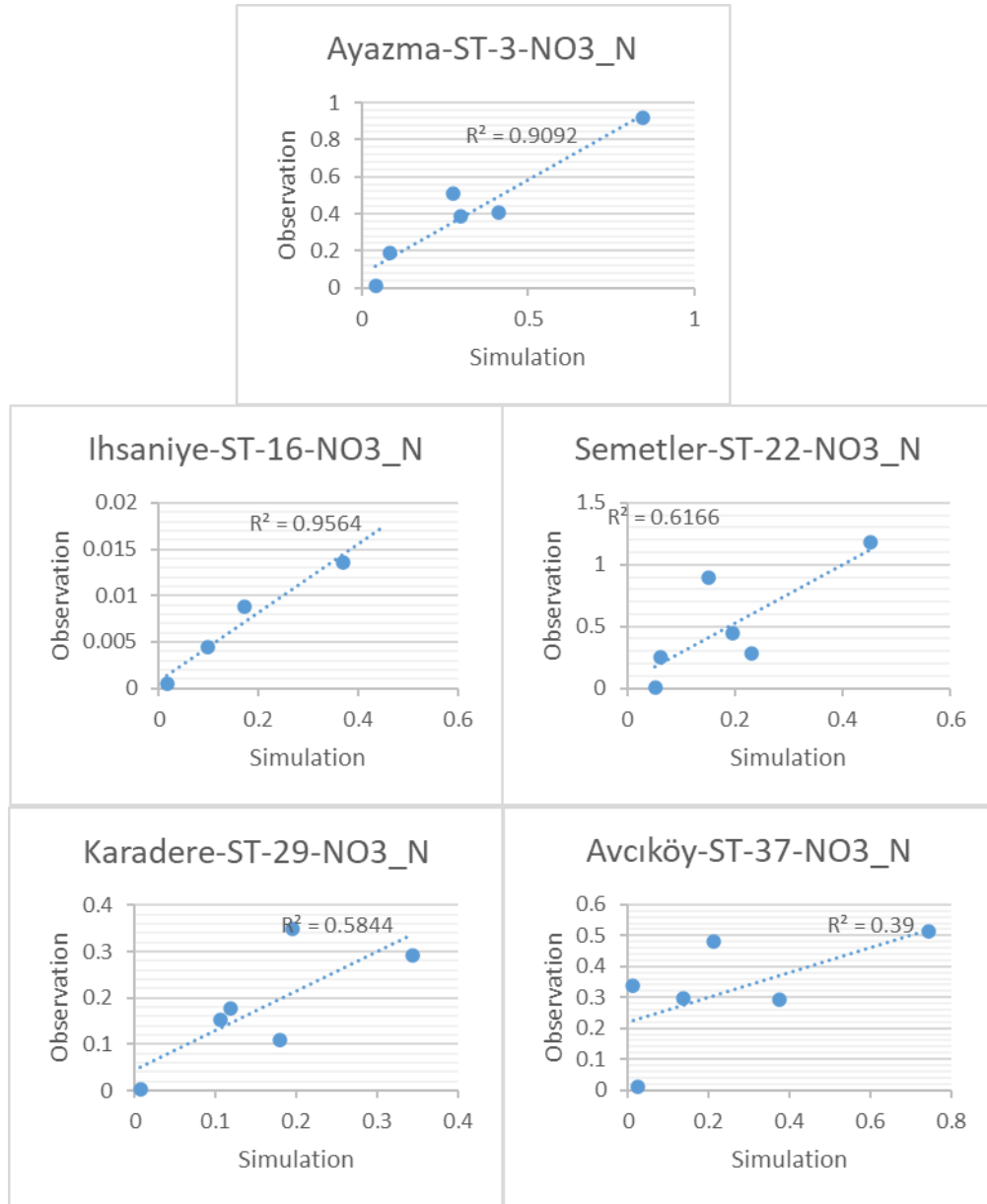


Figure 4.9: Graph of Observed and Simulated Water Quality NO₃_N loads from October 2021 to March 2022.

The observed NO₃_N values show good agreement at Ayazma-ST-3 and Ihsaniye-ST-16 stations between October 2021- March 2022. In the observed and modeled water quality graphs, a harmony that can be considered in the adequate class is observed for Semetler-ST-22 and Karadere-ST-37, while NO₃_N gives a low R² value for Avcıköy-ST-37.

5. APPLICATION OF SWAT MODEL

The ArcSWAT 2012 model interface was utilized. The required data was pre-processed to make it usable for the model. Figure 5.1 illustrates the input layers, calibration, and validation processes of the SWAT model to visualize the hydrological processes of the Akçat Stream. Initially, the model's input parameters such as DEM, land use/cover, soil database, slope definition, and meteorological parameters were carefully examined and adjusted to suit the input files of the SWAT model. In the second stage, no model calibration procedures were used; instead, the connection between the observed and expected runoff values generated from FAO and SSM soil databases was assessed. After employing a semi-automated calibration technique, the link between the predicted and observed runoff values was finally investigated.

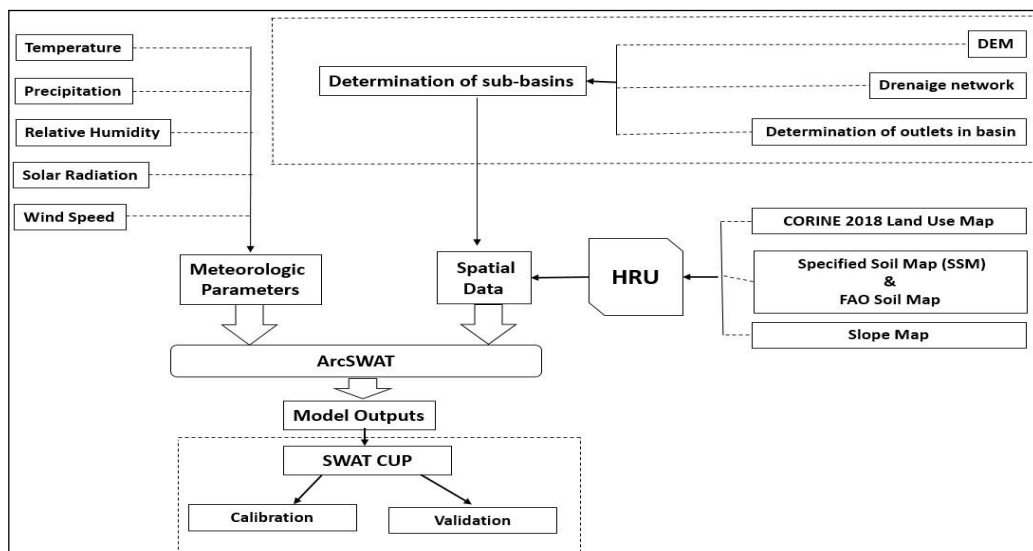


Figure 5.1: Flow chart of SWAT model.

5.1. Preparation of Model Input Layers for the SWAT Model

5.1.1. Watershed Delineator

During the initial setup phase of the model, the digital elevation model (DEM), which is the most basic base file on which many operations can be performed, was uploaded to the system (**Figure 5.2**). After this process is completed, the minimum, maximum and threshold values on the DEM for the sub-basins that can be created based on it are shown in the model.

The recommended threshold value was set manually as 10 ha and the drainage network was determined according to this value. This threshold value was seen as the value that gives the closest one to the current drainage network produced by using aerial photographs. The height of the basins was calculated maximum 855 m and average 133 m.

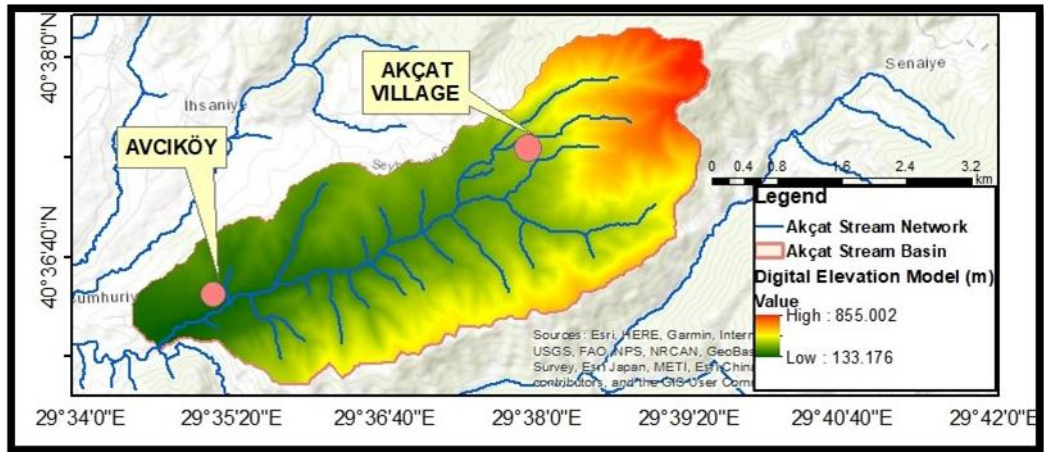


Figure 5.2: The Digital Elevation Model used in the watershed delineation steps of the SWAT.

The basin outlet points and the observation points were proposed by the system, after the drainage network was determined. Flow rate measurements were conducted on the Akçat stream networks within the scope of the TUBITAK (121G066) project.

5.1.2. Landuse and Land Cover Data

The land use code equivalent of the Coordination of Information on The Environment (CORINE-2018) data used in the model should be determined, assuming the CORINE land use data's attributes used to create hydrological units is inconsistent with the land use database of the model. Any standard method is not defined for the matching. In this study, the equivalent of the CORINE codes defined in the Akçat Stream was determined by considering the CORINE Level-1 (Anderson Classification) and Level-3 CORINE codes and their SWAT code equivalents are given in **Table 5.1**.

Table 5.1: Combining the SWAT and CORINE land use databases, as well as the percentage distribution for each class.

CLC Code	SWAT Code	Anderson Classes Level-1	Type	Percentage (%)
211	CRDY	Agricultural land	Nonirrigated arable land	28.67
242	AGRL		Complex cultivation patterns	7.55
243	CRGR		Mixed agriculture and natural vegetation	11.43
311	FRSD	Forest	Mixed forest	37.78
313	FRST		Broad-leaved forest (deciduous)	2.61
321	RNGE	Rangeland	Natural grasslands	2.72
324	SHRB		Transitional woodland-shrub	7.66

Remote sensing techniques provide the foundation of the CORINE method [12]. The CORINE Land Cover classification is based on three levels of hierarchy, each of which corresponds to a distinct scale. Level 3 data is mapped at a scale of 1/100,000 and is categorized into 44 groups. According to CORINE, when Level-1 is considered, 48 % of the basin consists of agricultural lands, 40 % forest, 2.7 % rangeland, 10.5 % rangeland. Figure 5.2 shows the 7-class land cover classification scheme that was used for the Level-3 classification over the study area.

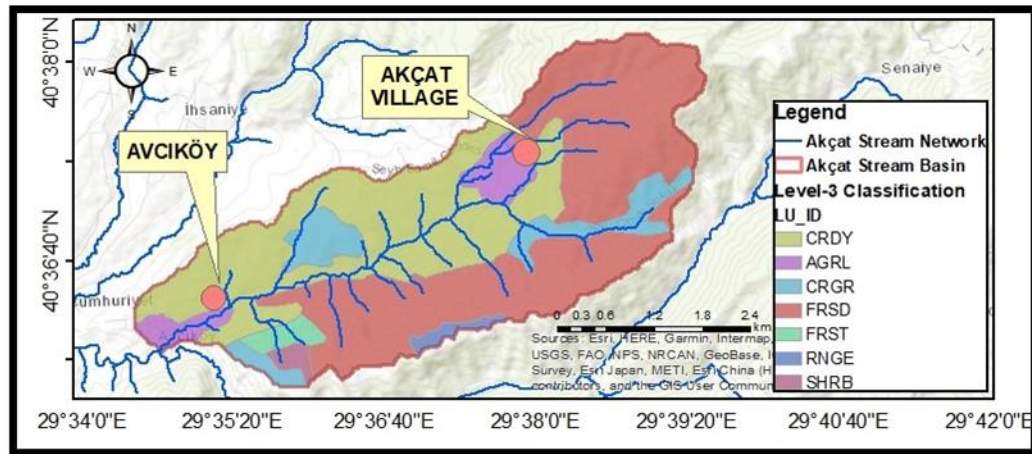


Figure 5.3: The spatial distribution of the land use classes of the region; CORINE Level-3 classification.

5.1.3. Soil Data

To evaluate the value of international soil databases in small-scale catchments, the Specified Soil Database (SSM), which generated laboratory and field studies, was directly integrated into the SWAT.

Raster format soil map consisting of polygons corresponding to each line in this file is needed, after the calculated values because of the analysis of the soil samples are transferred to the MS-Access file of the SWAT database.

5.1.4. Slope Definition

The definition of slope classes is one of the data that the model requires. DEM was the input parameter for this classification that was previously supplied in the watershed delineator step. The model allows for up to 4 slope classes. These classes have a great effect in HRU generation. For this study, the slope classes were separated 4 classes as <5%, 5-12% and 12-30%, >30% (**Figure 5.4**). These classes constitute 3.67%, 4.33%, 30.33% and 61.67% of the catchment, respectively.

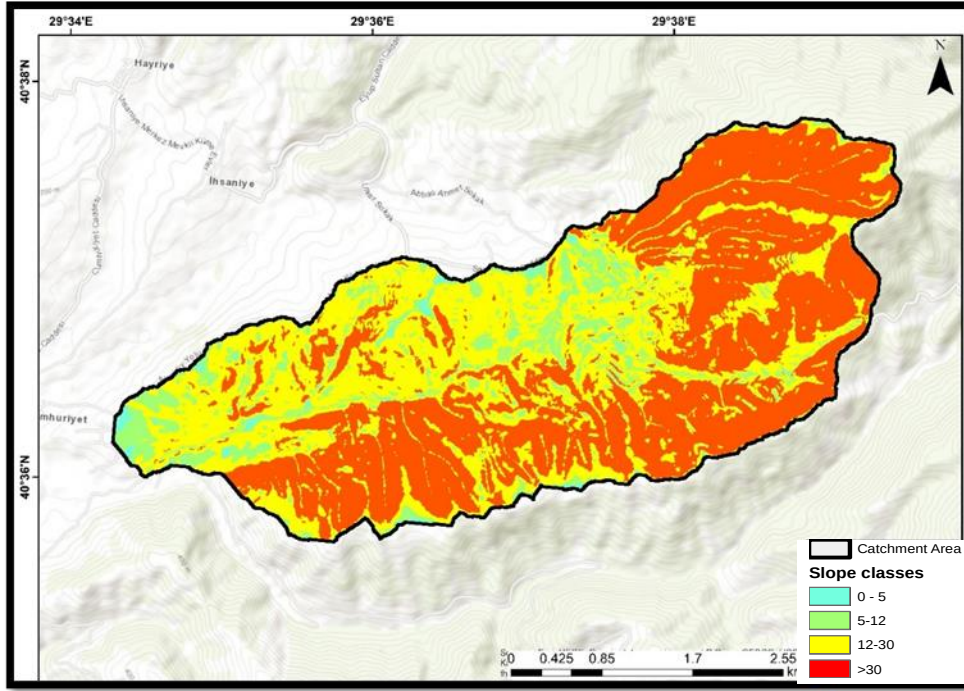


Figure 5.4: Slope map of the Akçat catchment.

5.1.5. Meteorological Data

The Meteorological data derived from the stations located at Karamürsel (40.649794°, 29.627054°), Ayvazpınar village (40.614079°, 29.681715°), Aktoprak village (40.577034°, 29.475782°), Altınova (40.714200°, 29.509200°) were used to represent the whole basin (**Figure 5.4**).

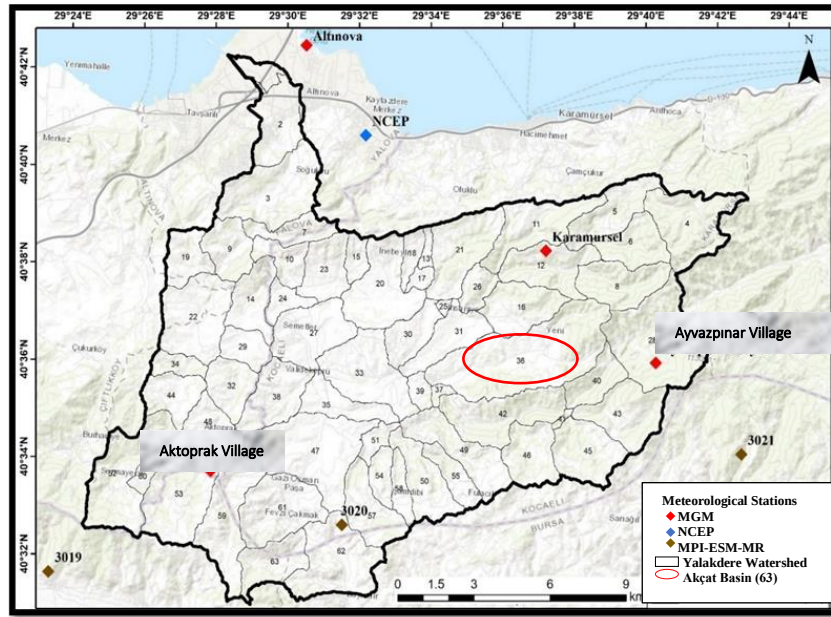


Figure 5.5: Location of meteorological stations in the Akçat sub-basin, which is the sub-basin of the Yalakdere basin.

Akçat Basin, which is the sub-basin of Yalakdere Basin, was described as Basin No.36 and the Thiessen Polygon method was utilized to analyze and interpret the fluctuations in both observed and projected flow and precipitation for the Akçat basin. As a result of this method, the meteorology station that best represents the basin outlet is Ayvazpınar Village station of the Turkish General Directorate of Meteorology (MGM). Wind speed and direction values of 4 meteorological stations representing all directions of the basin were taken into consideration.

Wind rose was comprised, with using R programming language, to determine the dominant wind direction of the Akçat catchment (**Figure 5.5**). Dominant wind direction of the watershed is northeastern (about 58%).

Besides, southern (13%) and south-eastern (17%) wind direction was introduced. The wind speed affecting the basin is relatively low. Considering the dominant wind direction, it is seen that the wind speed of 3-6 m/s is dominant over the catchment.

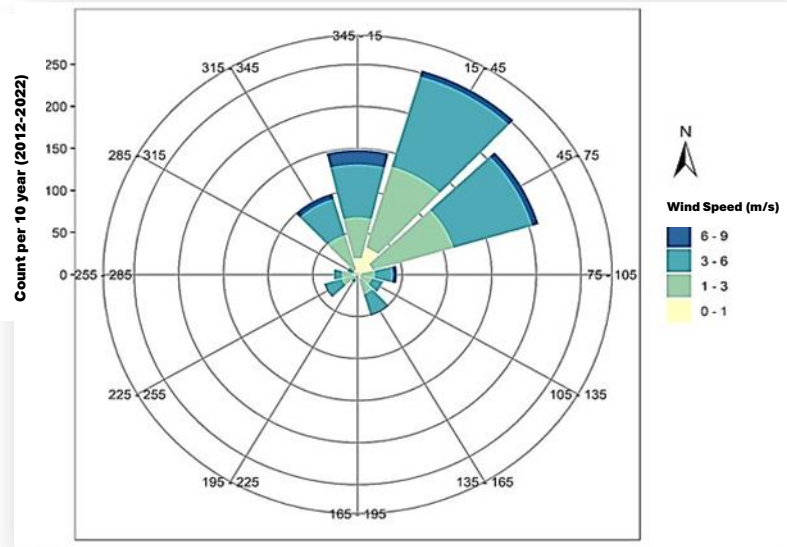


Figure 5.6: Wind speed (m/s) and direction (°) for Akçat stream basin.

Meteorological stations of the Turkish General Directorate of Meteorology (MGM), situated in the watershed area, provided meteorological data that are crucial for hydrological processes. Furthermore, the National Oceanic and Atmospheric Office (NOAA), which was founded to study global weather patterns and marine occurrences, collaborates with the National Environmental Prediction Center (NCEP) to create meteorological data.

Every hour, the weather parameters were acquired from MGM. The R programming language was used to convert the data to daily resolution, which was then incorporated into the SWAT. The daily parameters that are provided are relative humidity, wind speed, solar radiation, precipitation, and maximum and lowest temperatures. The temperature at which the dew point occurs, the quantity of dry days, and the likelihood of wet days needed for the SWAT were computed using the information mentioned above. Additionally, days for which there are no readings for MGM stations were substituted using NCEP re-projection data.

Precipitation and temperature are the two key variables that best capture the dynamics of each region's climate. As a result, monthly periods were used to analyze the temporal change of the temperature, dew point temperature, and precipitation data recorded during the working time in the 4 MGM stations (**Figure 5.6**).

Variation of temperature and dew-point temperature have similar seasonal trend for 4 stations. While small differences were observed between the two meteorological parameters during the winter season, high differences were observed in the summer season.

For instance, while the average temperature value of 4 stations was 5 °C in winter season, the average dew point temperature value was recorded 4 °C. In summer, the average temperature value was recorded 25 °C, while the average dew point temperature value was 17 °C. In this context, the lower difference between the two parameters in winter is related to the amount of moisture in the atmosphere. In terms of monthly average precipitation, the variation of values at the 4 stations has a similar trend, as seen in temperature values. For example, similar peaks occurred at 4 MGM stations for episodes seen on November 1998 and on April 2022.

The obtained meteorological data consists of a 24-year data set covering the years 1998-2022. The values of each parameter were prepared as a .txt file in a single column in the month and year order. Afterwards, the statistical values of the meteorological data were calculated and integrated into the "WGEN file". Calibration and validation processes must be determined for simulation of the model, after all data of the SWAT model has been successfully inserted. The time interval of meteorological input data determines the modeling period. For this reason, the model running period was carried out between January 1st 1999 and December 31st 2021.

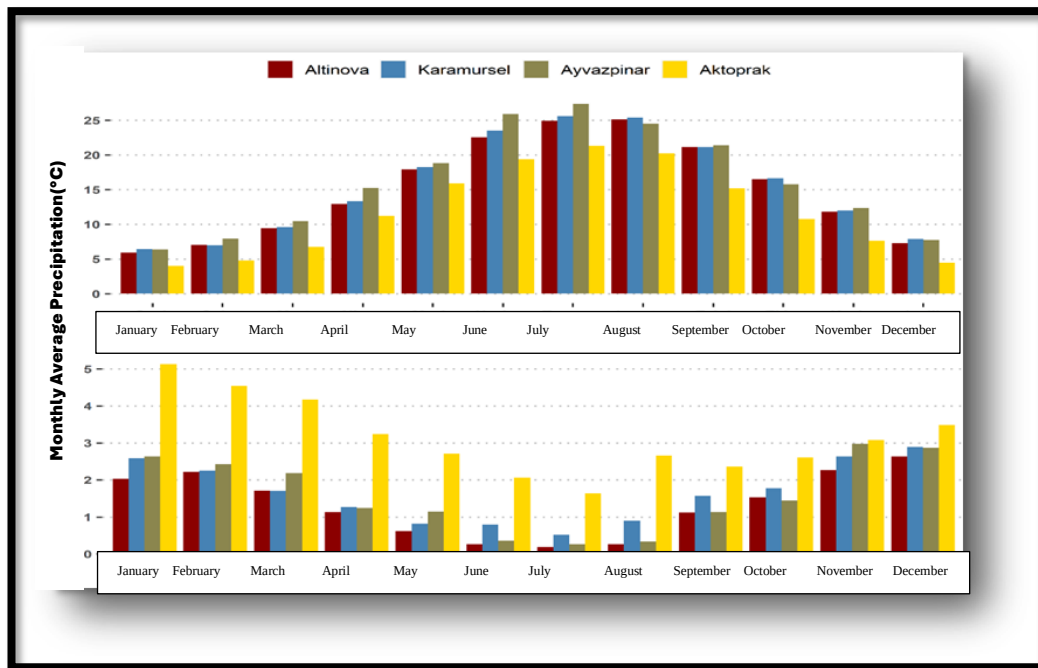


Figure 5.7: Variation of precipitation, temperature measured at the four meteorological stations.

5.1.6. Hydrological Response Units (HRUs) Definition

Hydrological response units (HRUs) are the smallest area in a homogeneous structure created on the base of land use, slope and elevation properties in catchment (**Figure 5.7**). Thus, HRUs definition is critical to examine the unique characteristics of the watershed.

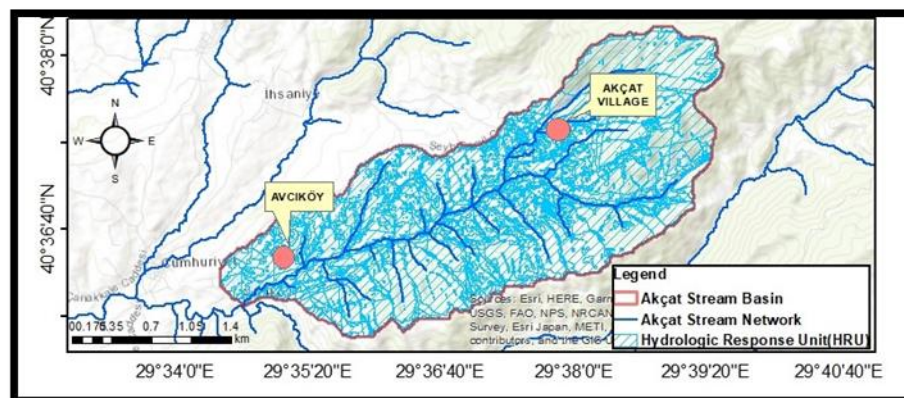


Figure 5.8: Hydrological response units (HRUs) definition for Akçat catchment.

In this study, the default threshold value of 10 ha. was given in the watershed delineation section of the model and 513 HRUs were defined for SSM soil databases, respectively. This model provides the opportunity to define threshold percentages for land use, soil and slope that can be included in the model in the definition of HRU.

5.1.7. Agricultural Land Operations

To analyze the consequences on surface water, the SWAT model needs comprehensive information about agricultural practices carried out in the watershed. Every action needs to be planned for that day with specific information, such as the proportion of water bodies that will be impacted. Limited information about land operations in the Akçat stream basin may be found in land operation data that was collected from TNSD; Therefore, considering the agricultural land operations of that region, the main land operations included in the Akçat Basin Model are as follows:

- Planting
- Crop Rotation
- Harvest
- Grazing
- Cover crop
- Tillage
- Fertilizer Application

Tillage practices remove land cover and enable erosion by wind and runoff, they have a significant effect on the watershed's yearly sediments. According to TNSD, the tillage system in the Akçat Stream basin is mostly traditional, and conservative type production has been carried out in recent years. In the Akçat stream basin, conventional tillage is still widely used; nevertheless, conservation tillage greatly enhances water quality by lowering stream TN, TP, and sediment load. Specific information about each tillage system is required by SWAT, such as the tillage ID, the day and month of operation, and the CNOP (SCS runoff curve number for moisture condition II).

Table 5.2: The typical Tillage system in Akçat stream basin

Tillage type	Time
Conventional Tillage	January&September
Conservative Tillage	January&September
Reduce Tillage	January&September

Tillage operation is a fundamental agricultural practice that involves the mechanical manipulation of soil to create favorable conditions for crop growth and development. Tillage's main goals are to prepare the seedbed, eliminate weeds, and incorporate organic materials and soil structure improvement. There are various tillage systems that differ in terms of the intensity and frequency of soil disturbance. Conventional tillage, which involves extensive plowing and disking, has been a widely adopted approach, but it can lead to soil degradation, erosion, and loss of organic matter over time. In response to these concerns, conservation tillage systems, such as no-till and reduced-till, have gained popularity in recent decades. These systems aim to minimize soil disturbance, agricultural leftovers should be left on the surface to prevent soil erosion and preserve soil organic matter. No-till farming has been recognized for its benefits in enhancing soil health, improving water infiltration, and reducing greenhouse gas emissions. By eliminating the need for plowing, no-till systems can also save time, labor, and fuel, making them more cost-effective for farmers.

Reduced-till, on the other hand, involves limited soil disturbance, often using specialized equipment like strip-till or vertical-till implements. This approach aims to balance the benefits of conservation tillage with the management requirements of specific crops and soil conditions. Choosing the right cropping system depends on a variety of factors, including crop type, soil conditions, climate and the farmer's management goals. It is important to carefully consider these factors to successfully implement a sustainable agricultural strategy. Fertilizer application rates are considered the primary source of nutrients for surface water and are therefore a key input to water management systems. Numerous fertilizer parameters, such as date and other elements, are necessary for the SWAT model and are shown in **Table 5.3**.

Table 5.3: Fertilizer parameters in SWAT input

Variable	Definition
FRT_KG	Amount of N and P applied to HRU (kg/ha)
FRT_SURFACE	Fraction of fertilizer applied to top 10mm of soil
FERT_ID	Fertilizer identification number from fertilizer database
Day	Day of operation
Month	Month of operation

The "FRT_SURFACE" variable denotes the fraction of the applied fertilizer that is deposited on the top 10 millimeters of the soil surface. This factor is relevant for modeling the distribution and fate of nutrients, as surface-applied fertilizers are more susceptible to processes such as runoff, volatilization, and potential transport to nearby water bodies.

The "FERT_ID" variable serves as an identification number that links the applied fertilizer to a corresponding entry in a fertilizer database. This database typically contains detailed information about the chemical composition, formulation, and other relevant properties of the fertilizer products, which can be used to further characterize the nutrient inputs and their potential impacts. The "Day" and "Month" variables provide temporal information about the fertilizer application, specifying the day and month when the operation took place. Knowing the timing of fertilizer applications is crucial for understanding the synchronization between nutrient supply and crop demand, as well as the potential for environmental losses during different climatic conditions or growth stages. Following the integration of all land management practices utilized in the Akçat stream basin, These operations will be specified by SWAT at the HRU level and stored in the database's "mgt2" table.

Table 5.4: Fertilizer operations in Akçat stream basin

Fertilizer Types	Contents		Agricultural Activity Types	
	Azote (N%)	Phosphorus (P%)	Arable land(kg/ha.)	Fruit and Vegetable Cultivation (Including Greenhouse) (kg/ha.)
Compound Fertilizer (20.20.0)	20	9	250	5
Calcium Ammonium Nitrate (26% N)	26	0	200	-
Urea	46	0	150	150
Ammonium Sulfate (21% N)	21	0	-	500
Potassium Sulfate	0	0	-	250
Phosphorus Fertilizer	0	26	-	150
Compound Fertilizer (15.15.15)	15	7	-	500
Compound Liquid Fertilizer	15	7	-	400

Compound fertilizers (20-20-0, 15-15-15) contain both nitrogen (N) and phosphorus (P), and are widely used in both arable land and fruit/vegetable cultivation (including greenhouses).

Nitrogen-based fertilizers (Calcium Ammonium Nitrate, Urea, Ammonium Sulfate) have higher nitrogen (N) content and are particularly used in larger quantities on arable lands. Phosphorus fertilizers (Phosphorus Fertilizer) have high phosphorus (P) content and are more preferred for fruit and vegetable cultivation. Potassium Sulfate is a fertilizer that solely contains potassium (K) and is used in fruit and vegetable cultivation. Liquid compound fertilizers act faster compared to solid compound fertilizers, and are therefore recommended for fruit and vegetable cultivation. The fertilizer content and application rates vary depending on the agricultural activity. Proper fertilizer selection and dosage are crucial to improve crop yield and quality.

Overall, the table provides a comprehensive overview of different fertilizer types, their nutrient compositions, and the recommended application rates for arable land versus fruit and vegetable cultivation. Understanding these fertilizer characteristics is key for optimizing agricultural practices and enhancing productivity.

Table 5.5: SWAT model agricultural land operations in Akçat stream basin.

Current agricultural operations	Month	Operation No.
Fruit and Vegetable Cultivation		
Fertilizer operation (Sheep Manure)	February	1
Tillage Operation and crop cultivation	February	2
Fertilizer application (Potassium Sulphate-Urea- Ammonium Sulphate- 20.20.0)	March	3
Fertilizer application (CAN)	April	4
Fertilizer application (Phosphorus)	May	5
Fertilizer application (Compound Liquid Fertilizer)	July	6
Harvest	July	7
Arable agricultural lands		
Fertilizer operation (Dairy Manure)	September	1
Tillage Operation and crop cultivation	September	2
Fertilizer application (20.20.0)	November	3
Fertilizer application (Urea)	January	4
Fertilizer application (CAN)	March	5
Harvest	July	6

Fruit and Vegetable Cultivation: In February, the first operation is the application of dairy manure as a fertilizer. Also in February, tillage operation and crop cultivation take place. In March, a combination of fertilizers is applied, including Potassium Sulfate, Urea, Ammonium Sulfate, and 20-20-0 compound fertilizer.

In April, Calcium Ammonium Nitrate (CAN) fertilizer is applied. In May, a phosphorus-based fertilizer is applied. In July, a compound liquid fertilizer is applied. The harvest also takes place in July.

Arable Agricultural Lands: In September, dairy manure is applied as a fertilizer. Also in September, tillage operation and crop cultivation are performed. In November, a 20-20-0 compound fertilizer is applied. In January, Urea fertilizer is applied. In March, Calcium Ammonium Nitrate (CAN) fertilizer is applied. The harvest takes place in July.

The schedule shows a well-planned sequence of fertilizer applications and other agricultural activities throughout the year for both fruit and vegetable cultivation and arable land management. The timing and selection of fertilizers align with the nutrient requirements of the crops at different growth stages, which is crucial for optimizing yield and quality.

In the SWAT model, agricultural land operations are defined using a set of parameters that specify the timing, intensity, and management strategies associated with these activities [64]. The accurate representation of these operations is essential for capturing the temporal dynamics of nutrient cycling, soil erosion, and crop growth within the simulated watershed [65].

The SWAT model allows users to input detailed information about agricultural land operations, including the specific dates, types of equipment used, and application rates of inputs such as fertilizers and pesticides [66]. This level of detail enables the model to account for the spatial and temporal variability of agricultural practices, which can have significant implications for water quality and quantity [64]. As the request of sustainable agricultural practices continues to grow, the accurate representation of agricultural land operations in hydrological models like SWAT becomes increasingly important for informing decision-making and supporting the development of effective conservation strategies [64].

5.1.8. Animal Manure Production and Nutrient Content in Land Application

For every 1,000 pounds of average daily live weight, dairy animals produce around 1.61 feet (32.0 gallons) of fresh manure (feces and urine) per day. 14.4 pounds of total solids per AU per day are present in the manure. Among them are nitrogen (N), potassium (K), phosphorous (P), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), copper (Cu), zinc (Zn), chlorine (Cl), boron (B), iron (Fe), sulfur (S), and molybdenum (Mo). Phytonutrients come from the foods, supplements, medicines and water that animals consume. Dairy manure can be used as a fertilizer for crops and trees to meet some or all of the plant's needs.

Table 5.6: Nutrient content comparison between semi-solid and solid dairy manure.

Nutrient data compiled from Barker (1990) and data compiled from South Carolina farms.				
Manure Type	Fresh Manure	Scraped Paved Outside Lot	Solids From Settling Basin	Solids From a Stationary Screen
Moisture	86%	67%	89%	80%
Total Solids	14%	33%	11%	20%
	----- lb / ton-----			
NH ₄ -N	1.7	2.0	0.4	0.2
NO ₃ -N	0.02	0.10	---	---
Organic - N	8.28	13.0	5.8	4.7
Total - N ¹	10.0	15.1	6.2	4.9
P ₂ O ₅ ²	5.0	7.9	4.0	3.1
K ₂ O ³	8.1	14.1	1.0	1.9
Ca	3.7	24.6	5.5	5.0
Mg	1.7	3.0	0.7	1.2
Zn	0.043	0.10	0.19	0.06
Cu	0.010	0.03	0.14	0.10
Mn	0.044	0.08	0.07	0.04
S	1.2	2.0	1.1	0.8
Na	1.2	1.5	0.2	0.5

¹ Total-N = (Organic-N + NH₄-N + NO₃-N)
² Total phosphorus expressed as P₂O₅. To get elemental P multiply by 0.44.
³ Total potassium expressed as K₂O. To get elemental K multiply by 0.83.

The total nitrogen content is calculated as the sum of Organic-N, NH₄-N, and NO₃-N. Similarly, total phosphorus is expressed as P₂O₅, and total potassium is expressed as K₂O, with conversion factors provided for elemental calculations. The nutrient composition of dairy manure plays a crucial role in soil fertility and crop nutrition. Exposing animal manure to sunlight in open fields or specially designed manure beds is effective for breaking down the organic matter in it and reducing pathogenic microorganisms [67].

Table 5.7: Akçat Basin animal manure data calculation.

Village Name	Quantity of Animal		Quantity of Animal Manure (kg/year)					
			Pasture areas		Fruits, Vegetables and Arable Lands			
	Dairy	Sheep	Dairy	Sheep	Dairy	Sheep	Dairy	Sheep
AKÇAT	338	89	380	37	3809	55	15584	1991
AVCIKÖY	272	649	306	273	3065	403	11232	6280

Table 5.8: Amounts of animal manure on a yearly basis.

Sheep	Quantity	kg/day	Length of Stay	Net Value	9 month	3 month	kg/year
Pasture	1	2.5	5/8 day	1.5625	421.875	0	421.875
Barn		3.5	3/8 day	1.295	349.65	271.463	621.113
Dairy	Quantity	kg/day	Length of Stay	Net Value	9 month	3 month	kg/year
Pasture	1	10	5/12 day	4.17	1125	0	1125
Barn		41	7/12 day	23.78	6420.6	4845	11265.6

The annual fertilizer production potential of cattle and sheep in the livestock system reflecting the characteristics of the basin is given in Table 5.8, as a result of the information received from the local people engaged in agriculture and animal husbandry in the basin and the data obtained from the Yalova Provincial Directorate of Agriculture, in which 10 tons of animal manure will be applied to 1 hectare of land.

Based on this situation, the values calculated on an annual basis for dairy and sheep according to the livestock system within the borders of Turkey and regionally changing livestock practices are shown in **Table 5.9**. The length of time that animals spend in pastures, barns, and pens is permitted based on the features of the agricultural and livestock systems in the Akçat basin, according to livestock activities.

5.1.9. Examination of Point Sources

Agricultural activities are a significant contributor to water pollution, with point sources being a major concern in many watersheds. Point sources, such as livestock facilities, manure storage, and processing plants, can have a substantial effect on the water quality of nearby surface water bodies [68]. These concentrated sources of nutrients, pathogens, and other contaminants can lead to eutrophication, algal blooms, and the degradation of aquatic ecosystems [69]. In watersheds dominated by agricultural land use, point sources can be a significant driver of water quality impairment. Runoff and leaching from concentrated animal feeding operations (CAFOs) can contribute high levels of nitrogen, phosphorus, and microbial contaminants to rivers, lakes, and groundwater [70]. Similarly, improper storage and application of manure from livestock operations can result in the introduction of these pollutants into nearby water resources [71]. The effect of point sources on surface water quality can be exacerbated by the presence of other non-point sources, such as diffuse agricultural runoff and atmospheric deposition [72]. The combined effects of these pollution sources can lead to complex water quality issues, requiring comprehensive management strategies to mitigate their impacts [73]. Addressing the water quality challenges posed by point sources in agricultural watersheds requires a multifaceted approach, including improved manure management practices, strengthened regulations, and the implementation of best management practices (BMPs) at the farm level [74]. By targeting point sources and integrating them into a broader watershed-scale approach, water quality improvements can be achieved, benefiting both the environment and the local community [75]. The table presents key data on two point sources, Akçat and Avcıköy, in the agricultural watershed. These point sources, likely representing municipal or industrial wastewater discharges, can have a significant impact on the water quality of the surrounding surface waters. The Akçat village point source has an average population of 408 people and a discharge rate of 78.7 m³/day. This discharge contains 0.08 kg/day of total phosphorus (TP), 0.12 kg/day of nitrate azote (NO₃-N), 1.9 kg/day of total Kjeldahl nitrogen (TKN), and 2.04 kg/day of total nitrogen (TN). In comparison, the Avcıköy village point source has a smaller average population of 244 people and a lower discharge rate of 47.1 m³/day.

However, the pollutant concentrations in this discharge are higher, with 0.19 kg/day of TP, 0.36 kg/day of NO₃-N, 1.27 kg/day of TKN, and 1.45 kg/day of TN.

Table 5.9: Values of point sources within the Akçat stream basin.

Point Sources	Average Population	Discharge (m ³ /day)	TP (kg/day)	NO ₃ (kg/day)	TKN (kg/day)	TN (kg/day)
Akçat	408	78.7	0.08	0.12	1.9	2.04
Avcıköy	244	47.1	0.19	0.36	1.27	1.45

5.2. Examination of Model Outputs

5.2.1. Evaluation of the Model Results with Calibration and Validation

The model for the watershed under investigation was calibrated using the SWAT-CUP (SWAT Calibration and Uncertainty Procedures) tool. The most widely used program for automatically calibrating SWAT model outputs is called SWAT-CUP. Results from the SWAT model can be easily calibrated and their sensitivity and uncertainty examined with the help of the SWAT-CUP tool. One of five possible optimization techniques, the SUFI-2 (Sequential Uncertainty Fitting) method was employed by the program for the calibration stages [18].

In SWAT-CUP, average surface runoff data on a daily, monthly, and annual basis can be used for calibration procedures. In this work, the daily average surface flow values were used for the calibration and validation procedures.

In the calibration process, the most critical variable is known to be runoff before modeling of hydrological processes, sediment transport or water quality of the studied basin. The calibration process of the surface flow was applied according to the downstream points of the basin and the measurement values at these points were used.

Measurement periods are between October 2021 and March 2022. The SWAT-CUP program was run once for the basin and a total of 500 simulations were performed. Given the short period, only calibration operations were performed at these locations. After calibration, the model's output was validated. In literature studies, it was advised that the calibration and validation processes be separated by 70% and 30% of the analyzed period in the dataset, respectively.

Validation and calibration processes are performed at the same measurement point [6]. Also, validation is generally preferred apart from the period of the calibration. Detailed explanation of all sources of uncertainty, observation data error, structure of the model, setup procedures in SUFI-2 algorithm has been detailed by [17]. In the calibration processes, the ranges of the selected parameters, their final values, and 15 flow parameters were optimized to obtain the best fitted between the simulated and daily runoff (**Table 5.11**).

Table 5.10: A list of the optimal parameter settings for the database, together with explanations, calibration ranges, and SWAT-CUP sensitivity parameters.

Streamflow Parameters	Definition	Calibration Range		Best fitted values
		Min	Max	SSM
r__CN2.mgt	SCS curve number for moisture condition II	-0.2	0.2	-0.15
r__ALPHA_BF.gw	Base flow alpha factor (days)	0	1	0.01
r__GW_DELAY.gw	Ground water delay (days)	30	450	98
r__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	-0.2	0.2	0.15
r__SOL_K().sol	Soil saturated hydraulic conductivity (mm h^{-1})	-0.2	0.2	-0.15
r__USLE_K().sol	Soil erodability factor in USLE	-0.2	0.2	-0.15
r__SOL_AWC().sol	Available water capacity of the soil layer (mm mm^{-1})	-0.5	0.5	0.35
r__GW_REVAP.gw	Groundwater "revap" coefficient	-0.5	0.5	0.2
r__SNOCVMX.bsn	Minimum snow water content that corresponds to 100% snow cover, SNO100, (mm H ₂ O).	-0.2	0.2	0.12
a__ESCO.hru	Soil evaporation compensation factor	-0.2	0.2	0.15
r__SURLAG.bsn	Surface runoff lag coefficient	-0.5	0.5	0.35
r__SOL_BD().sol	Soil bulk density (g/cm^3)	-0.5	0.5	-0.15
r__RCHRG_DP.gw	Deep aquifer percolation fraction	-0.5	0.5	0.25
a__CH_K2.rte	Effective channel hydraulic conductivity (mm h^{-1})	-0.5	0.5	0.1985
a__CH_N2.rte	Manning coefficient for main channel	-0.5	0.5	0.1648
¹ Type of change: r_ = relative change, a_ =absolute change				

Both soil databases were modified while selecting calibration parameters so that the relative error was less than 5%. The default water balance parameters used to calibrate surface flow are the (CN2), (SOL-AWC) and (ESCO), as recommended in the SWAT manual. The SOL-AWC was examined with 50% variations to get the best-suited value. These methods were used to calibrate additional parameters.

The calibration period of measurement station is between January 1st 2000 and December 31st 2016 and validation period was between January 1st 2017 and March 31rd 2022. Figure 5.10 shows the month-to-month temporal variation of validated and

calibrated runoff values generated from SSM databases containing observation data. However, peak runoff values that appeared after precipitation agreed with model predictions, contingent upon the growing volume of precipitation. Moreover, the decrease in the actual runoff is consistent with the projected baseflow that developed following the rainfall. Relative deviation was seen when the flow decreased. This is primarily explained by the fact that the surface runoff lag coefficient, or SURLAG parameter, cannot be altered based on the sub-basin and that the model incorporates a single parameter value for the basin under study [18].

In the high flow conditions recorded in February 2010, the actual and modeled flow rates were in good agreement. The estimated flow rate values for high flow situations between October 2015 and September 2018 align well with observed data. Using the percentage change ($r_{\%}$) procedure of a previously calculated value for the investigated calibration parameters across Turkey, the best suitable values for flow rate calibration were selected. The parameters' minimum and maximum values were computed as $\pm 20\%$ or $\pm 50\%$ change percentages during the eye's lifetime. According to the input values, it is demonstrated that the ideal values of many storages in the soil (.sol), basin (.bsn), and breeding water (.gw) sections grow. The soil, land use, and hydrological conditions in the Akçat stream basin all influence the CN_2 value, which is contingent upon circumstances that are anticipated to be lower than the input values.

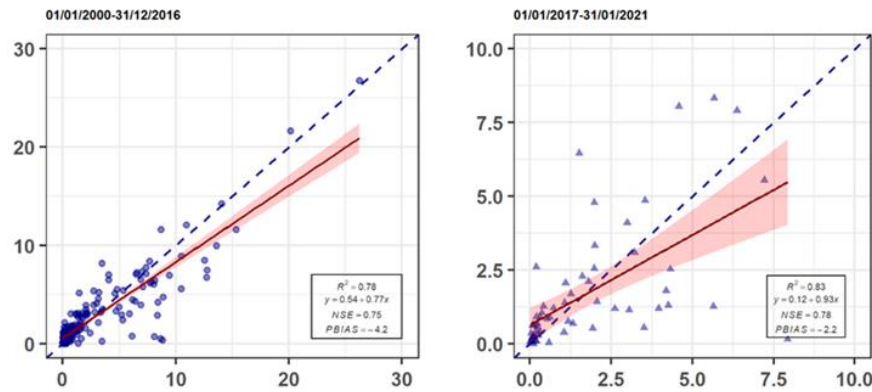


Figure 5.9: Temporal variation of precipitation and daily flow rates at the station Ayazma-ST-3.

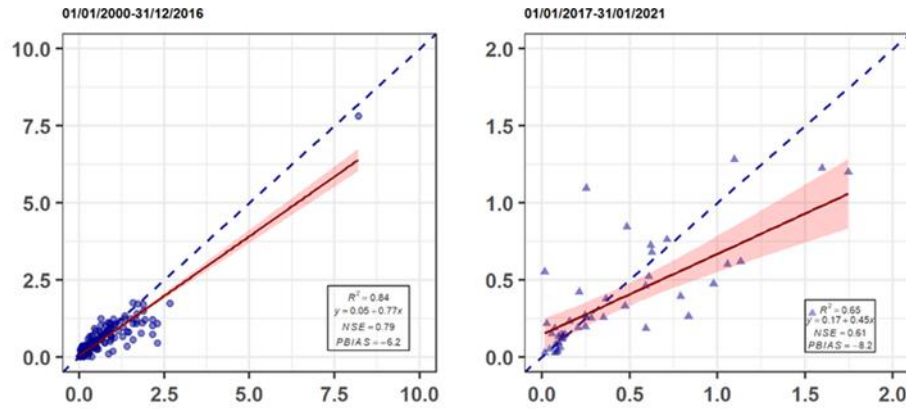


Figure 5.10: Temporal variation of precipitation and daily flow rates at the station Ihsaniye-ST-16.

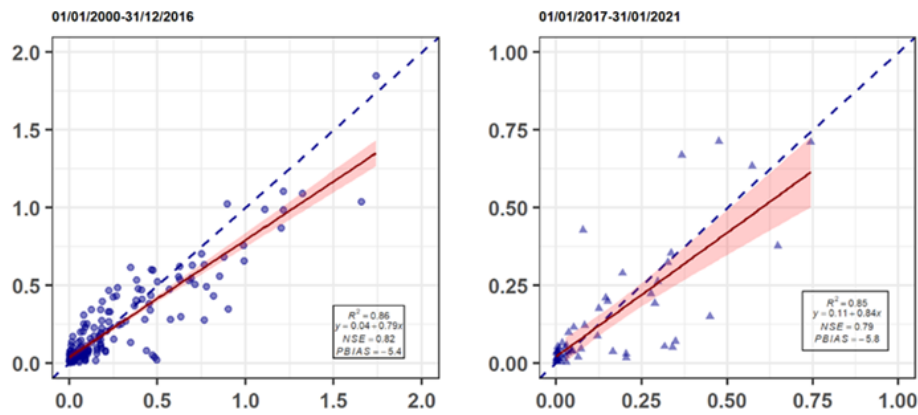


Figure 5.11: Temporal variation of precipitation and daily flow rates at the station Semetler-ST-22.

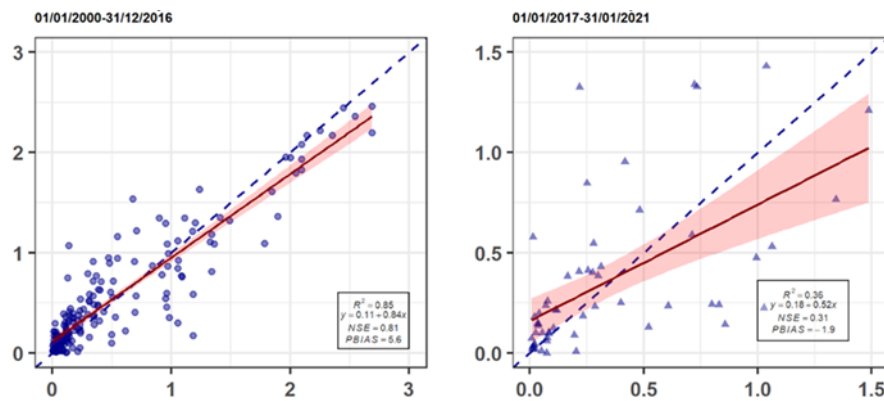


Figure 5.12: Temporal variation of precipitation and daily flow rates at the station Karadere-ST-29.

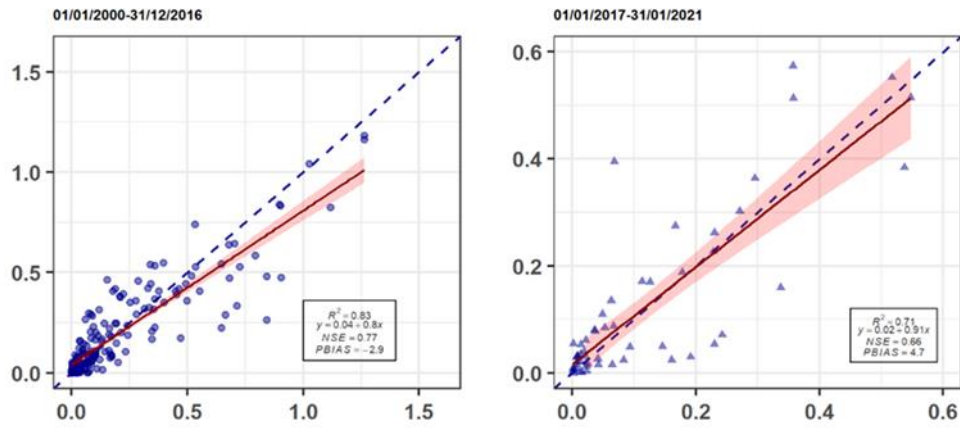


Figure 5.13: Temporal variation of precipitation and daily flow rates at the station Avcıköy-ST-37.

Figure 5.9 – Figure 5.13 shows scatter plots that show the calibration and validation procedures for the flow rate values predicted by observation to evaluate the performance of the model. The model performed better in the calibration process (2000–2016) than during the validation process (2017–2022) for every subbasin that was looked at. There are two reasons for this situation: First, statistical assumptions like heterogeneity and linearity in the data sets are easier to achieve because the calibration procedure is lengthier. Second, the statistical values were more impacted by tiny changes since the flow rate values on the validation dates had change scales that were around three times less than those in the calibration.

The model's performance was assessed using the ranges of the statistical markers R2, NSE, and PBIAS provided in Figure 4.2 - Figure 4.6.

- The R2 values between Ayazma-ST-3 and Avcıköy-ST-37 were computed as follows: 0.78, 0.84, 0.86, 0.85, and 0.83 for calibration. The NSE values between Ayazma-ST-3 and Avcıköy-ST-37 were found to be 0.76, 0.79, 0.82, 0.81, and 0.77, but the PBIAS values were found to be -2.9, -4.2, -6.2, -5.4, and -5.6.
- The R2 values between Ayazma-ST-3 and Avcıköy-ST-37 that were computed for validation were 0.83, 0.65, 0.85, 0.36, and 0.71, respectively. PBIAS values were ascertained to be -2.2, -8.2, -5.8, -1.9, and -4.7, whilst NSE values were ascertained to be 0.78, 0.61, 0.79, 0.31, and 0.66 between Ayazma-ST-3 and Avcıköy-ST-37.

The calibration process exhibits "very good" model performance. Ayazma-ST-3 and Karadere-ST-29 were classified in the "very good" class for the validation process, while Ihsaniye-ST-16 and Semetler-ST-22 were classified in the "good" class and

Avcıköy-ST-37 in the "adequate" class. The missing around six months of flow measurements throughout the five-year validation period can be used to explain the sufficient model performance shown at the Avcıköy-ST-37 outlet for the validation process. In contrast, negative PBIAS values show that the model underpredicts during the validation and calibration stages. The fact that the points representing the flow rate values in the scatter plots are close to the reference line indicates that the model performance is particularly good. Accordingly, the calibration results showed that the model performed better in high flow conditions than in low flow conditions.

5.2.2. Best Management Practices Application

Within the scope of the thesis, these management practices are taken into consideration. Moreover, during the study period, field studies determined that there were serious point source pollution pressures throughout the general region, and the reduction of these losses and the change in nutrient loads were analyzed within the scope of scenarios.

The most efficient, technically achievable, and financially viable strategy to decrease or lower the pollutant load produced by NPS to a rate that satisfies water quality objectives involves the use of a best management practice (BMP), which can be an action or a combination of actions. The United States government adopted BMPs in the 1980's through a variety of incentive schemes that motivated agricultural producers to prevent runoff and erosion. BMP effects on watershed quality were examined and recorded using site-specific information received from grant reporting and monitoring, which frequently overlooked the long-term impact of applying such measures at the watershed scale. When establishing BMPs, it is vital to select, target, and implement the most appropriate BMP or suite of BMPs in a watershed within the budget constraints. Furthermore, because many BMPs include expenses and management changes that will almost certainly harm landowners as well, BMP adoption will rise with fair and equitable financial support and technical help provided by cost-share initiatives. Additionally, identifying and differentiating the effects of BMPs from other landscape components presents a substantial challenge for watershed managers. Watershed managers can overcome this challenge by utilizing technologies that help them decide which kind and quantity of BMPs to apply in relation to the key areas that have been identified as having a substantial impact on the pollution levels in

receiving water. It takes time and effort to examine non-point source (NPS) areas, sediments, and nutrient loads, followed by the implementation of appropriate BMPs, to find a suite of conservation projects that can defend watershed quality, remain within budget, and have a markedly positive impact at the watershed scale.

Table 5.11: BMP Scenarios.

Scenarios code	Scenarios	Explanation
A-S0	Control Scenario	The A-S0 scenario represents the baseline scenario that reflects current terms and practices in the agricultural watershed.
A-S1	Reduced Tillage (Fertilization Practices)	Reduced tillage practices are implemented compared to the control scenario. The CNOP value is set to 0.1 to represent reduced soil disturbance and tillage intensity.
A-S2	Fall and Spring Operations	The soil undergoes tillage operations with a CNOP value of 0.4 during the fall season. The soil is tilled with a CNOP value of 0.3 during the spring season.
A-S3	Fertilization Practices	Involves reducing the application of organic and inorganic fertilizers by 10-20-30% sequentially.
A-S4	Point Sources	Point sources of pollution are reduced by 20-35-60-80% to mitigate nutrient inputs from concentrated sources.
A-S5	Afforestation	Areas with slopes greater than 12 ^o are designated as deciduous forests to prevent soil erosion and nutrient runoff.
A-S6	Buffer Strip Establishment (10m)	Buffer strips with a width of 10 meters are established in arable lands with slopes ranging from 2-12 ^o to reduce sediment and nutrient runoff.
A-S7	Terracing	Involves implementing terracing methods in arable lands with slopes ranging from 5-20 ^o to reduce soil erosion and improve water retention.
A-S8	Unified Scenarios	Combinations of A-S1 to A-S3, A-S3 to A-S4, A-S4 to A-S5

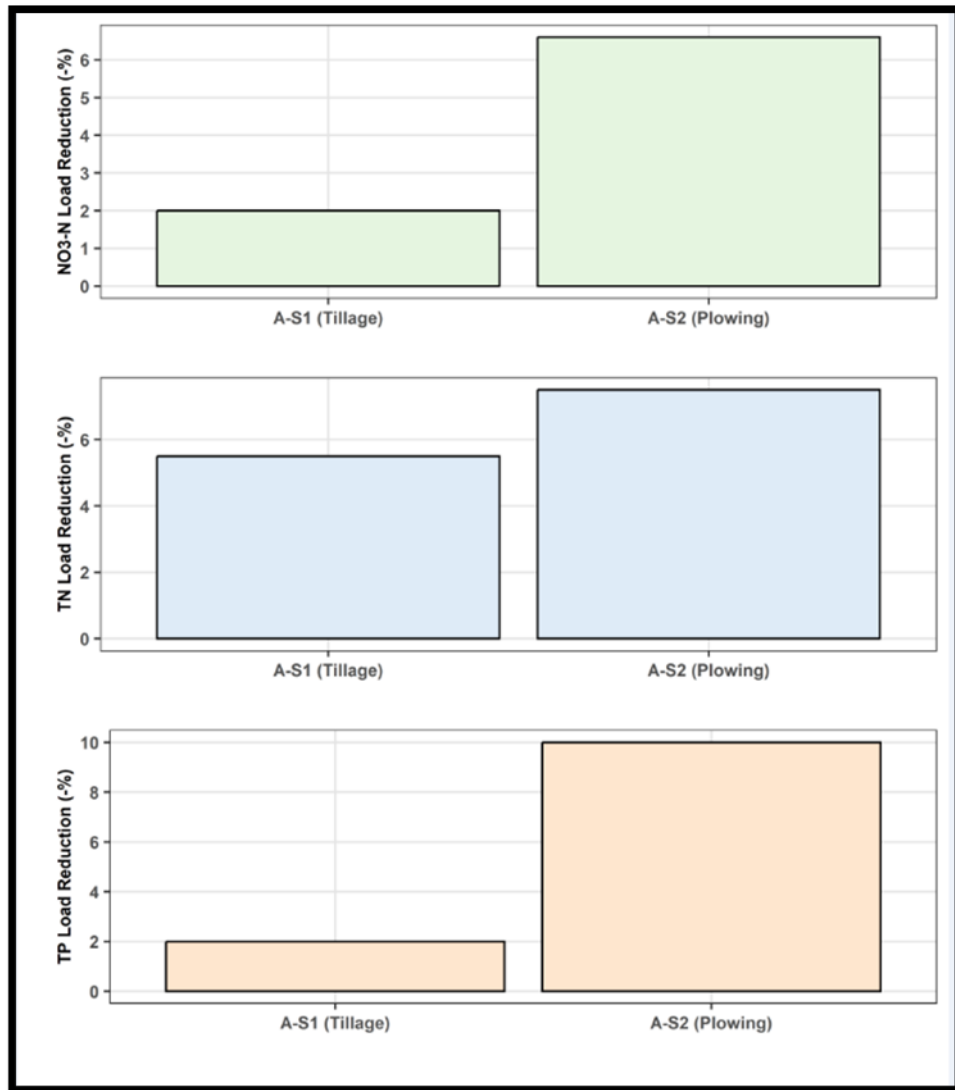


Figure 5.14: AS-1 and AS-2 soil tillage of BMP operations.

The provided bar graphs illustrate the percentage reduction of NO₃-N, TN, and TP load in an agricultural context under two scenarios: Tillage (A-S1) and Plowing (A-S2). The graphs show that Plowing (A-S2) generally leads to a greater reduction in nutrient loads compared to Tillage (A-S1).

In the first graph, representing NO₃-N load reduction, Plowing (A-S2) demonstrates a higher percentage reduction than Tillage (A-S1), as indicated by the taller light green bar for A-S2.

The second graph, showing TN load reduction, also highlights a more significant reduction in TN under the Plowing scenario (A-S2) with a taller blue bar compared to Tillage (A-S1).

Lastly, the third graph displays TP load reduction, with Plowing (A-S2) resulting in a larger reduction percentage than Tillage (A-S1), as depicted by the taller orange bar for A-S2. These findings suggest that implementing Plowing practices in agricultural activities may lead to more effective reductions in nitrogen, phosphorus, and other nutrient loads, contributing to improved water quality and environmental sustainability in the watershed.

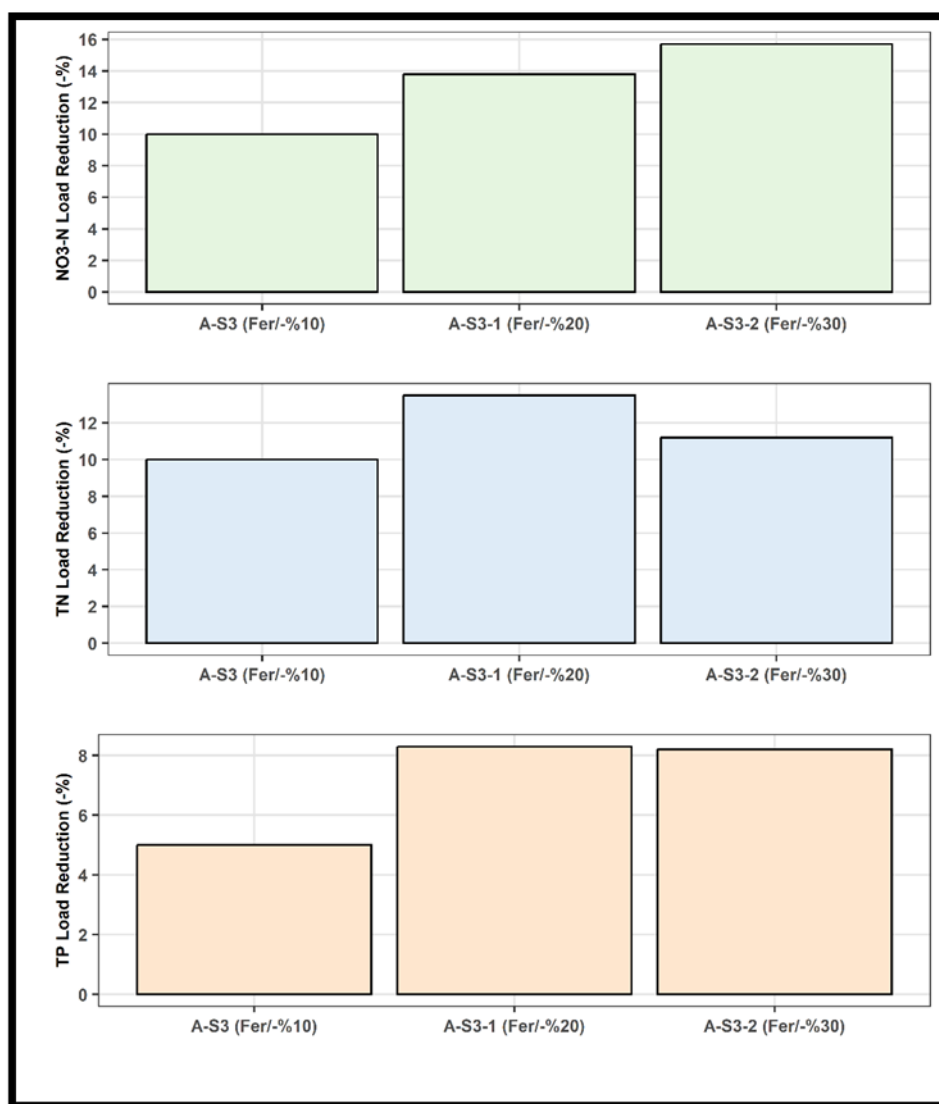


Figure 5.15: A-S3, A-S3-1 and A-S3-2 fertilizer application of BMP operations.

The image displays bar graphs representing the reduction percentages of TN, TP, and NO₃-N values in an agricultural watershed under different management scenarios. Each scenario is labeled with variations in the reduction percentage of fertilizer application (Fertilizer-%).

A-S3-1 (Fertilizer-%10): Scenario A-S3 with a 10% decrease in fertilizer application.

A-S3-2 (Fertilizer-%20): Scenario A-S3 with a 20% decrease in fertilizer application.

A-S3-3 (Fertilizer-%30): Scenario A-S3 with a 30% decrease in fertilizer application.

The graphs indicate the effect of reducing fertilizer application on the reduction of TN, TP, and NO₃-N values in the watershed. As the percentage of fertilizer application decreases, there is a corresponding decrease in the nutrient values, suggesting that implementing lower fertilizer application rates can lead to improved water quality by reducing nutrient inputs.

These findings highlight the importance of optimizing fertilizer management practices in agricultural activities to minimize nutrient pollution and enhance environmental sustainability in the watershed. By implementing best management practices that promote efficient nutrient use and reduce excess fertilizer application, it is possible to mitigate nutrient runoff and improve water quality in agricultural areas.

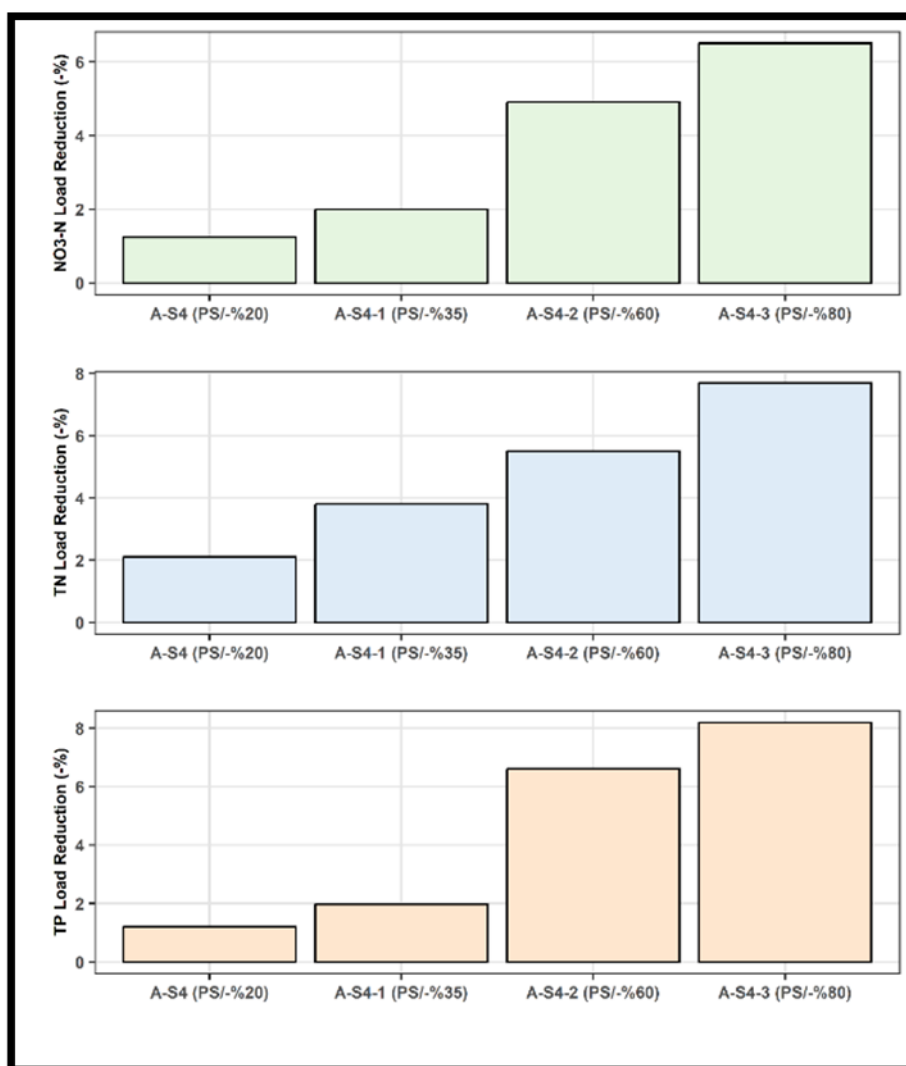


Figure 5.16: A-S4, A-S4-1, A-S4-2 and A-S4-3 point sources of BMP operations.

The image displays bar graphs representing the reduction of TN, TP, and NO3-N values in an agricultural watershed under different management scenarios based on scientific outputs. Each scenario is labeled with variations in the reduction percentage of point sources (PSI/PS/).

A-S4 (PSI-%20): Scenario A-S4 with a 20% reduction in point sources.

A-S4-1 (PSI-%35): Scenario A-S4-1 with a 35% reduction in point sources.

A-S4-2 (PSI-%60): Scenario A-S4-2 with a 60% reduction in point sources.

A-S4-3 (PSI-%80): Scenario A-S4-3 with an 80% reduction in point sources.

The graphs illustrate the impact of reducing point sources on the reduction of TN, TP, and NO3-N values in the watershed. Decreasing the input of pollutants from point

sources can significantly contribute to improving water quality and reducing nutrient pollution in agricultural areas. Analyzing these graphs provides valuable insights into the efficacy of different management practices in decreasing nutrient levels in the watershed. Implementing strategies to reduce point source pollution, such as improved waste management practices, treatment technologies, and regulatory measures, can lead to a substantial decrease in TN, TP, and NO₃-N values, thus promoting a healthier and more sustainable agricultural ecosystem in the watershed. According to Figure 5.16, the scenario coded A-S4-3 gives the best reduction in TN, TP and NO₃-N load. The highest reduction in pollution loads occurs because of the scenario in which we reduce the point source by 80%.

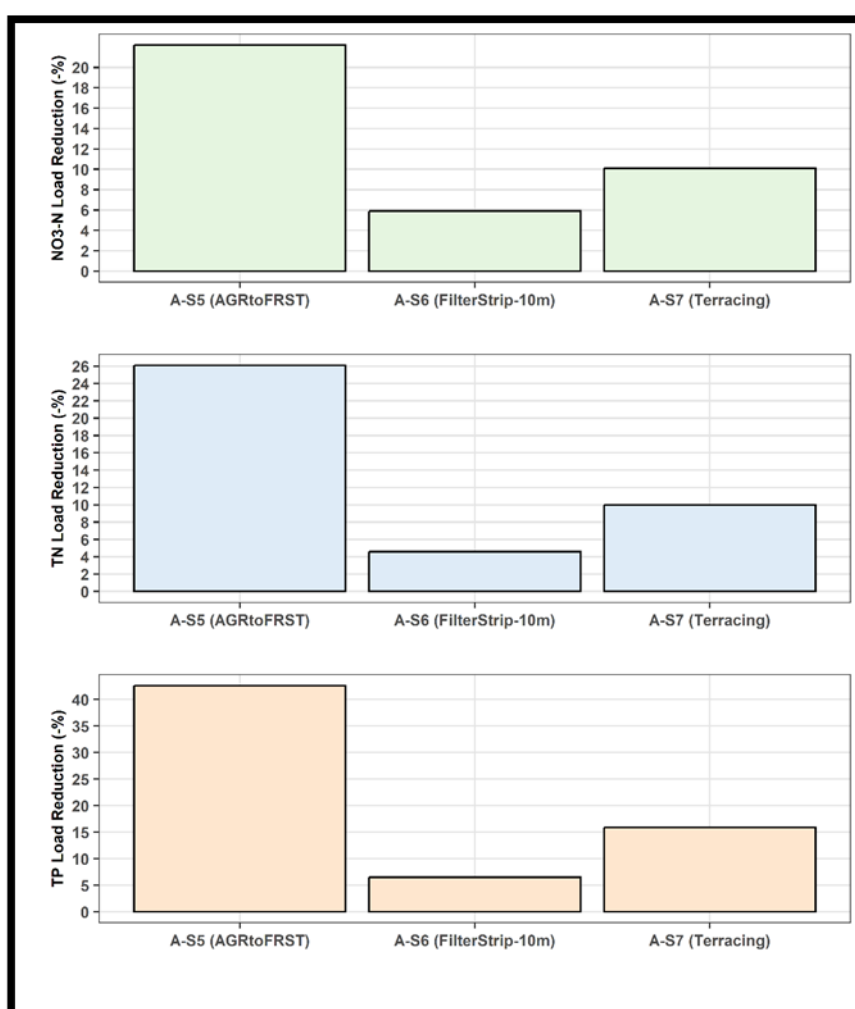


Figure 5.17: A-S5, A-S6, A-S7 BMP operations.

The image presents bar graphs illustrating the reduction of TN, TP, and NO₃ values in an agricultural watershed based on scientific outputs and different management scenarios. Each scenario is labeled with specific management practices aimed at reducing nutrient levels in the watershed.

A-S5 (AGRL to FRST): Scenario A-S5 with Agricultural to Forestation practice.

A-S6 (Filter Strip-10m): Scenario A-S6 involving the establishment of a 10-meter Filter Strip.

A-S7 (Terracing): Scenario A-S7 implementing terracing methods in the agricultural area.

The bar chart shows the impact of these management practices on reducing TN, TP, and NO₃-N values in the watershed. Agricultural to Forestation practices, Filter Strips, and Terracing are effective strategies for mitigating nutrient runoff, soil erosion, and improving water quality in agricultural areas. By converting agricultural land to forested areas, establishing filter strips to reduce sediment and nutrient runoff, and implementing terracing techniques to prevent soil erosion, these management practices can contribute to the overall reduction of TN, TP, and NO₃ values in the watershed. According to **Figure 5.17**, it is the scenario coded A-S5 that gives a decrease in TN, TP and NO₃-N load. The highest reduction in pollution loads occurs because of afforestation of agricultural areas.

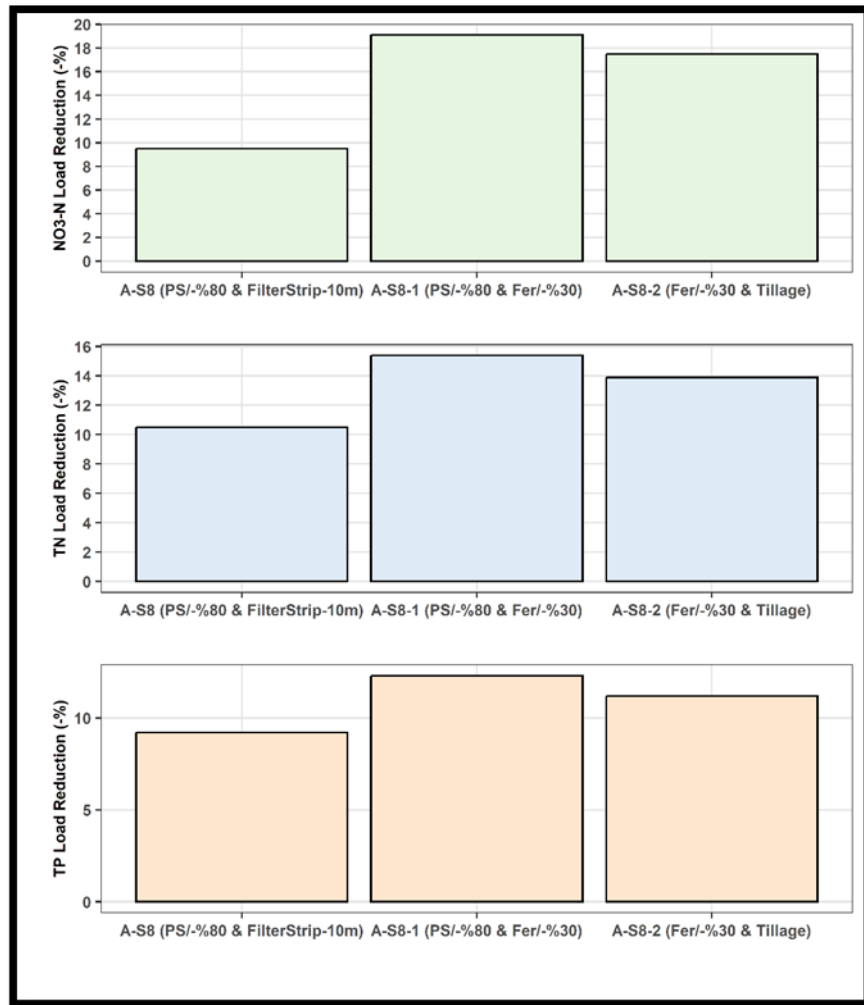


Figure 5.18: A-S8, A-S8-1, A-S8-2 Unified scenarios BMP operations.

The image illustrates the effect of various agricultural management practices on reducing TN, TP, and NO3-N values in a watershed based on scientific outputs. The bar charts represent the percentage reduction in nutrient loads for each practice:

A-S8 (PSI-%80 & FilterStrip-10m): This scenario involves an 80% decrease in point sources combined with the establishment of a 10-meter Filter Strip.

A-S8-1 (PSI-%80 & Fer/-%30): In this scenario, there is an 80% decrease in point sources along with a 30% reduction in fertilizer application.

A-S8-2 (Fer/-%30 & Tillage): This scenario includes a 30% decrease in fertilizer application combined with specific tillage practices.

The bars in each chart represent the percentage reduction in TN, TP, and NO₃ values achieved by implementing the respective management practices. By analyzing the bars, we can infer the success of each strategy in reducing nutrient levels in the watershed. The visual comparison provided by the bar charts allows for a clear understanding of which management practices result in the most significant reduction in TN, TP, and NO₃-N values. This information is crucial for determining the best management practices to optimize water quality and sustainability in agricultural areas within the watershed.

Among the combined scenarios, the scenario coded A-S8-1 gives the best decrease in TN, TP and NO₃-N load. The highest reduction in pollution loads occurs because of reducing 80%- point source and 30% fertilizer.

6. DISCUSSION

Application of the Soil and Water Assessment Tool (SWAT) model to agricultural watersheds provides a potent framework for understanding and analyzing nutrient pollution processes. The ability of the SWAT model to simulate the movement and fate of critical nutrients such as nitrogen and phosphorus, is particularly relevant in addressing water quality concerns in these environmentally sensitive areas. First and foremost, the accurate representation of the watershed's physical characteristics, such as topography, soil properties, land use, and meteorological data, is crucial for the SWAT model's performance. The fine-textured nature of silty loam soils with high silt content provides a large surface area for the adsorption of cationic nutrients such as ammonium, calcium, and magnesium, which is an important consideration in the model's representation of nutrient transport. In this study, SWAT was created because of laboratory and field studies to estimate the diffuse pollution loads and point pollution loads resulting from agricultural activities and evaluate its performance in Akçat stream, For the SSM, two soil samples representing the entire catchment were collected. Seven parameters were measured by field and laboratory studies. The main differences in the database are soil texture and farming pressure. Sand and silt content is dominant in the soil texture of the catchment. While a silty loam soil structure is seen in the region where agricultural operations are carried out, a sandy loam soil structure is seen in the region where forest zones expand, and this situation is seen to be suitable for agriculture due to the onset of silty growth due to widespread precipitation loads and in cases of excessive fertilizer use, models of improvement in nutrients appear to emerge.

Another probable reason for this situation is that the SWAT model was run for catchments dominated by agricultural areas in the mentioned studies, contrary to our study. Besides, both studies stated that elaborating soil databases better reflects the infiltration potential in the specific regions in the catchments. The study region was defined as small-scale (15 km²), with agricultural and forest basins. The fine texture and high silt content of silty loam soils play a significant role in affecting the infiltration capacity of these soils. The abundance of silt particles in the soil matrix facilitates the effective movement of water into the soil profile, providing a large surface area for water to infiltrate.

This feature promotes the effective use of applied water and nutrients as they can easily infiltrate into the root zone accessible to plants. The moderate to high infiltration capacity of silty loam soils makes them well-suited for agricultural applications where maintaining adequate soil moisture and nutrient availability is crucial to maintaining crop productivity. When the effect of meteorological processes combines with the effect of agricultural operations, it contributes significantly to the production of diffuse pollution burdens in the hydrological cycle. Turkey currently lacks comprehensive soil databases with the soil physical and chemical properties required for hydrological models and as consequence, basin nutrient modeling studies are insufficient. Since the available soil databases are prepared according to main soil groups, these databases reduce the reliability of hydrological model outputs.

Decision-makers can utilize the model results as a valuable tool to identify strategies for increasing the watercourse's nutrient yield and to concentrate on the crucial subcomponents that deliver most of their nitrogen and phosphorus loads to the Akçat stream. The model also pinpointed regions with high sediment and nutrient richness where BMPs are required to successfully lower nutrient loads and enhance the Akçat stream's health.

7. CONCLUSION AND RECOMMENDATIONS

As a result of field studies, two point discharge sources have been identified along the Akçat catchment. Accordingly, 6-month measurement data of discharge point sources are of critical importance in terms of revealing more clearly the physical and chemical processes in the examined basin. Regulating and monitoring point sources is more feasible than non-point sources. Given all of these considerations, it is clear that the SWAT model's performance is acceptable for the Akçat stream basin, where agricultural regions dominate in terms of nutrient pollution. A hydrological nitrogen and phosphorus cycle model for the Akçat stream basin in the Yalakdere basin has been produced using SWAT and SWAT-CUP. SWAT investigated the present concerns about elevated nutrient levels in the Akçat stream basin by modeling nutrient flux at the basin scale and predicting NO₃-N, TP, and TN yields. The model evaluation revealed that the findings for the TN and TP parameters were satisfactory. The calibration process of the surface flow was applied according to the downstream points of the basin and the measurement values at these points were used. Measurement periods are between October 2021 and March 2022. The calibration processes increased SWAT efficiency by over 80% of the observed data. SWAT-CUP was run over 500 times to investigate model uncertainty and provide the best results. A significant portion of the daily observed data were captured by the calibrated SWAT model and the average annual nutrient production was estimated at the watershed outflow. Every year, significant amounts of nutrients are exported to the Akçat stream, with SWAT estimating 0,85 kg/ha of TP and 6,43 kg/ha of TN.

In this thesis study the model's nutrient load prediction performance was tested for two different soil groups, as well as the influence of agricultural and forest lands. The origination of national soil database inventory and determining the soil physico-chemical properties throughout Turkey is critical because of the unique characteristics of the basins in Turkey. Subsequently, Sub-dynamics of the model were then built, allowing for simulation and prediction. These sub-dynamics are essential in terms of showing the possible consequences of human-induced activities such as the change in the number of animals in the basin, the management of fertilizer use, and land use change on water quality change.

1. Continuously monitor nutrient concentrations along the Akçat stream basin to detect increases in nutrient levels in the stream and adjust land management accordingly.
2. To accurately estimate the total N and P applied to the soil, all farms are surveyed to determine the rate at which manure or fertilizer is applied.
3. Take soil samples regularly to assess nitrogen and phosphorus loss due to runoff.
4. To accurately calculate the basin's water resource components, factors such as precipitation, solar radiation, wind speed, evaporation, and transpiration are considered. Observe climate conditions and trends in the basin, especially.
5. The Akçat stream basin is a large agricultural basin that contributes to surface water pollution as it has runoff and point sources. Consequently, measures are needed to reduce the impact of these types of water sources on water quality.
6. Implementation of in-field erosion control structures in the basin, especially to reduce the traditional tillage system and switch to a protective tillage system, thus minimizing the nutrient and sediment loads that occur during hydrological conditions.
7. To ensure public participation in the monitoring program system, document all management procedures used at the facility and increase awareness of the results of these activities.

In the future studies, It was concluded that in future studies, by determining the irrigation capacity according to crop types for each parcel with a longer-term flow data set and integrating it into the model with the groundwater data set, both surface and groundwater nutrient loads can be controlled throughout the basin and better results can be obtained.

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PUBLICATIONS AND PRESENTATIONS FROM THE THESIS

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