EVALUATION OF THE ALTERNATIVES TO IMPROVE WATER QUALITY IN GÜRDÜK WATERSHED USING SWAT MODEL

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ABSTRACT

EVALUATION OF THE ALTERNATIVES TO IMPROVE WATER QUALITY IN GÜRDÜK WATERSHED USING SWAT MODEL

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Gürdük Watershed is a part of Gediz Watershed and it is located is in Aegean Region. The Watershed covers an area of approximately 3,200 km^2. Within the boundaries of Gürdük Watershed, there are 10 districts of Manisa. Since Gürdük Watershed has fertile soil and a suitable climate for agriculture, the region is at the forefront of agricultural production in Turkey. More than 50 % of the watershed consists of areas with agricultural lands. Within of the scope of this thesis, the current pollution status of the Gürdük Watershed due to point and diffused sources was examined via considering Surface Water Quality Regulation and three different Water Quality Indices (WQIs) and evaluation of the alternatives to improve water quality in terms of Sediment, and Nitrate was conducted by using Soil and Water Assessment Tool (SWAT). Meteorological data of the watershed, digital elevation model (DEM), land use/land cover (LULC) map, soil texture properties and point discharges from both municipal and industrial waste water treatment plants and the information on agricultural management are needed to set-up SWAT model. The calibration of the Model was done via SWAT-CUP for stream flow, sediment, and nitrate by using monthly data from DSİ Monitoring Station. Different management alternatives were identified to improve water quality of Gürdük Watershed considering the point and diffused sources, namely decreasing the amount of fertilizer usage, increasing the WWTP efficiencies and applying conservation tillage. Goal of this study was to evaluate the water quality in Gürdük Watershed and develop management strategies to improve the water quality. Results of this study have shown that, decreasing the fertilizer usage and improving the waste water treatment efficiency can significantly increase the water quality of the watershed.

Keywords: Integrated Watershed Management, Watershed Modelling, Surface Water Quality, Water Quality Indices, Point and diffused Pollution

ÖZ

SWAT MODELİ KULLANILARAK GÜRDÜK HAVZASI SU KALİTESİNİ GELİŞTİRME ALTERNATİFLERİNİN DEĞERLENDİRİLMESİ

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Gürdük Havzası Ege Bölgesinde yer almakta olup, Gediz Havzasının bir parçasıdır. Havza yaklaşık 3,200 km^2'lik bir alanı kapsamaktadır. Gürdük Havzası sınırları içerisinde Manisa'nın 10 ilçesi bulunmaktadır. Gürdük Havzası verimli topraklara ve tarıma elverişli bir iklime sahip olduğundan bölge, Türkiye'de tarımsal üretimin ön saflarında yer almaktadır. Havzanın % 50'den fazlası tarımsal arazi sınıfına sahip alanlardan oluşmaktadır. Bu tez kapsamında, Gürdük Havzası'nın noktasal ve yayılı kaynaklarından kaynaklanan mevcut kirlilik durumu, Yüzeysel Su Kalitesi Yönetmeliği ve üç farklı Su Kalitesi Endeksi (WQI) dikkate alınarak incelenmiş ve su kalitesini iyileştirme alternatiflerinin değerlendirilmesi çalışması, sediman, nitrat yönünden, Soil & Water Assesment Tool (SWAT) kullanılarak yapılmıştır. SWAT Modelinin kurulumu için, su havzasının meteorolojik verileri, dijital yükseklik modeli (DEM), arazi kullanım / arazi örtüsü (LULC) haritası, toprak özellikleri ve hem evsel hem de endüstriyel atık su arıtma tesislerinden kaynaklanan noktasal deşarjlar ve tarımsal yönetim verileri gerekmektedir. SWAT modelinin kalibrasyonu, DSİ İzleme İstasyonu'ndan sağlanan aylık veriler kullanılarak akım, sediman, BOİ, azot ve fosfor için SWAT-CUP üzerinden yapılmıştır. Gürdük havzasının su kalitesini geliştirmek için, noktasal ve yayılı kirlilikler göz önünde bulundurularak, farklı alternatifler belirlenmiştir. Bu alternatifler temel olarak, kullanılan gübre miktarının azaltılması, AAT'lerin veriminin arttırılması ve koruyucu toprak işleme aktiviteleridir. Bu çalışmanın amacı, Türkiye'deki diğer havzalarla birlikte Gürdük Havzası'nda su kalitesinin iyileştirilmesi konusunda karar vermelerinde karar vericilere yardımcı olmaktır. Bu çalışmanın sonuçları, gübre kullanımının azaltılmasının ve atık su arıtma verimliliğinin artırılmasının havzanın su kalitesini önemli ölçüde artırabileceğini göstermiştir.

Anahtar Kelimeler: Entegre Havza Yönetimi, Havza Modellemesi, Yerüstü Su Kalitesi, Su Kalitesi Endeksleri, Noktasal ve Yayılı Kirlilik

To my family

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LIST OF ABBREVIATIONS

ABBREVIATIONS

°C	Degrees Celsius
95PPU	95% prediction uncertainty
ARS	Agricultural Research Service
BOD	Biochemical Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CORINE	Copernicus Land Monitoring Service
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Management Systems
da	Decares
DEM	Digital Elevation Model
DSİ	State Hydraulic Works
EC	European Commission
EPA	Environmental Protection Agency
EPIC	Environmental Impact Policy Climate
ESRI	Environmental Systems Research Institute
GDWM	General Directorate of Water Management
GIS	Geographic Information System

GLEAMS	Groundwater Loading Effects on Agricultural Management Systems
GLUE	Generalized Likelihood Uncertainty Estimation
ha	Hectares
HRU	Hydrological Response Unit
İZSU	Izmir Water and Sewerage Administration
LULC	Land Use & Land Cover
MAP	Monoammonium phosphate
Max	Maximum
MCMC	Markov chain monte carlo
MBAS	Methylene Blue Active Anionic Substances
Min	Minimum
mm	Millimeters
MoFWA	(Abolished) Ministry of Forestry and Water Affairs
Mon. Pt.	Monitoring Point
NO_3-N	Nitrate Nitrogen
P_i	Relative Weights
nm	Nanometer
NSE	Nash-Sutcliffe Efficiency
OIZ	Organized Industrial District
P_2O_5	Phosphorus pentoxide

PBIAS	Percent Bias
R^2	Coefficient of Determination
ROTO	Routing Outputs to Outlet
SO_4	Sulphate
SUFI-2	Sequential Uncertainty Fitting ver.2
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration & Uncertainty Program
SWRRB	Simulator for Water Resources in Rural Basins
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TSP	Triple Super Phosphate
TUBITAK	The Scientific and Technological Research Council of Turkey
US	United States
USDA	United States Department of Agriculture
WFD	Water Framework Directive
WPCR	Water Pollution Control Regulation
WQI	Water Quality Indices
WWTP	Waste Water Treatment Plant

CHAPTER 1

INTRODUCTION

Water can be considered amongst the most important natural resources on earth and having a sustainable management on water sources possesses a great importance in Turkey as in the whole world. The immense population rise that Turkey has witnessed have resulted in doubling of the water demand during last five decades and the total water demand in Turkey is expected to increase higher and higher each day (Bayram, 2014). This fact composes a challenge to have a sustainable water management, and make it necessary to understand the elements threating the water sources and determining the means to protect and improve the water quality.

The fact that improving water quality has become such a critical issue has led the concept of “integrated watershed management” be more brought into consideration in Turkey. Integrated watershed management can easily be defined as an understanding the essential characteristics of a watershed to have a sustainable management on its resources and sustain and enhance watershed function for all the living creatures living in (Guangyu Wang, 2016). Thus; assessing the pollution sources of a watershed adequately and classifying them is one of the top priorities of an integrated watershed management. Environmental pollutants affecting a watershed can be classified within two categories; point and diffused sources.

The European Union has issued several directives since its establishment in order to protect water resources and prevent water pollution. The Water Framework Directive (WFD) (2000/60/EC) was formed in order to gather the obligations of various directives regarding water management under a single umbrella. The process of establishing the WFD was completed between 1995 and 2000 and the Directive came into force in 2000 (Voulvoulis, 2016).

The main purpose of the Water Framework Directive (WFD) is to provide a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater via constructing an integrated watershed management system.

There are some basic steps to be taken in order to construct a proper integrated watershed management system. First of all, a comprehensive water quality evaluation study must be realized in order to understand current pollution status and possible environmental stressors of the watershed (van Puijenbroek, 2015). Secondly, a watershed model needs to be constructed to determine management strategies for the watershed.

The purpose of this study is to evaluate the water quality in Gürdük Watershed and develop management strategies to improve the water quality. A study including useful methodology for calculating for pollution load calculations, developing scenarios for land management practices formulating a benchmark will be constructed.

Gürdük Watershed was examined in the context of integrated watershed management within the scope of this thesis. Gürdük Watershed is located within the boundaries of Gediz Watershed which is located on the Aegean coast of Turkey. The watershed is located between the 38°40′ N and 39°13′ N and the 27°31′ E and 28°3′ E. It is surrounded with high mountains on the east and west and has an outlet reaching to Gediz River. The maximum elevation inside the basin is about 1,380 meters. The watershed is currently known to be affected from both point diffused pollution sources (Harmancioglu, 2008).

The current water quality status of the watershed was evaluated according to Surface Water Quality Management Regulation and three different Water Quality Indices to understand the level of the water pollution in the watershed. The purpose of the Surface Water Quality Management Regulation is to determine and classify the biological, chemical, physico-chemical and hydro-morphological qualities of surface waters, to monitor the quality and quantity of the surface waters. Within the scope of this regulation, water quality evaluation is done by considering a set of parameters and classifying them according to limit values of four different water quality classes; high quality, less contaminated, contaminated highly contaminated water.

The use of water quality indices (WQI) is a simple practice that allows the public and decision makers to receive unified water quality information. WQI also lets us to assess changes in the water quality and to identify temporal trends. WQI is a unitless number that describes a quality value to an aggregate set of measured parameters. Water quality indices generally consist of sub-index scores assigned to each parameter by comparing its measurement with a parameter-specific rating curve, optionally weighted, and combined into the final index.

As described above, understanding the both point and diffused sources pollution of a watershed has become a difficult subject while constructing the integrated watershed management plans. This difficulty has brought about a drastic increase in the use of basin scale models in Turkey (Özcan, 2016). SWAT models was used to analyse the point and diffused sources of pollution

Basin scale models are being used as a tool to evaluate water pollution status occurring from both point and diffused sources and to monitor and predict the potential status of water sources under various scenario conditions. In addition, basin scale models are widely used around the world to analyse the correlation between land management practices and activities affecting the water quality in a watershed. Moreover, these models are often applied by decision makers for evaluating water pollution status and evaluating the alternatives to improve the water quality. For this purposes, various models with different scales can be used.

Soil and Water Assessment Tool (SWAT) is a basin scale water quality model extensively used around the world. Considering that Gürdük Basin is one of the most important agricultural production area, SWAT is a suitable selection for water quality modelling as it has a competence to analyse agricultural practices, and eliminate some uncertainties. In conclusion within the scope of this thesis, SWAT model was applied in Gürdük Watershed.

Within the context of this study; watershed models are explained briefly and SWAT model is introduced in detail with its modelling approach, inputs, and outputs. SWAT Model is constructed, calibrated and validated for this study. In addition, three different alternatives were evaluated to improve the water quality of the Gürdük Watershed.

Within the context of this thesis; the literature review about water quality evaluation techniques, a brief description of the watershed models and a detailed introduction of SWAT model with its modelling approach, inputs, and outputs are explained in the Second Chapter.

In the third chapter, the general information (e.g., climate, land use, soil structure, agricultural activities, and etc.) about Gürdük Watershed is given and water quality assessment is presented based on Surface Water Quality Management Regulation and three different Water Quality Indices.

In the fourth chapter of the thesis, application of SWAT model in the case study area is explained. The water quality calibration, verification and the explanations of the simulations are presented in this chapter.

In the fifth chapter, results of the simulations were discussed and, in the last section conclusion and recommendations are provided.

CHAPTER 2

LITERATURE REVIEW AND THEORETICAL BACKGROUND: SOURCES OF POLLUTION, WATER QUALITY INDICES AND SWAT MODEL

2.1. Sources of Water Pollution

Definition of water pollution was made as anthropogenic or natural caused, direct or indirect introduction of substances, energy, organisms or genetic material that has a probability to cause adverse effects to human health, or harm to living resources or to the environment (ERA, 2019). On the other hand, Turkish Water Pollution Control Regulation identifies water pollution as discharge of material or energy wastes which may cause negative deterioration in biological resources, human health, fishing, water quality and other uses of water directly or indirectly observed as a negative change in the chemical, physical, bacteriological, radioactive and ecological characteristics of the water resource.

Water pollution affecting a watershed can be classified within two categories; i) point and ii) diffused sources. Due to population rise in the basin and the fact that different industries are located within the basin; various sources of pollution can be determined. Yet some specific stressors are more important than others are.

Sources of the pollution in a watershed are summarised in figure below:

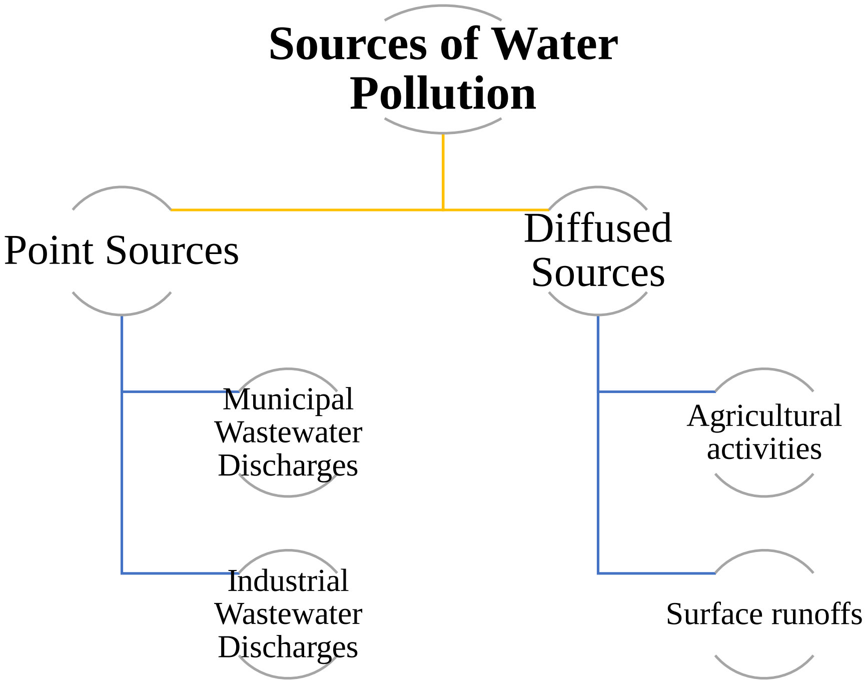

Figure 2.1. Sources of Pollution

Point sources of pollution can be described as a type of pollutant which enter a water body from and from easily identified and confined point (EPA, 2019). Discharges from a pipe, ditch, ship or industrial facility etc. can be given examples of point sources of water pollution. (WED, 2013).

Diffused pollution often occurs due to runoff, precipitation, atmospheric deposition, drainage. Diffused pollution is hard to track as it does not arise from a single source (EPA, 2019).

Diffused pollution can include:

- Fertilizer, herbicide and insecticide used at agricultural and urban areas
- Oil, grease and toxic chemicals reaching to a water body due to urban runoff
- Sediment erosion coming from poorly managed agricultural lands, and eroding stream banks
- Bacteria and nutrients formed at livestock, sewerages and faulty septic systems (EPA, 2019)

2.2. Surface Water Quality Management Regulation

The legislation on the protection and management of water resources in the European Union, which was founded in 1951 with the European Coal and Steel Community and established with the Maastricht Treaty of 1991, has an important place in EU legislation and there are more than twenty directives in this field. The most important of these directives is the Water Framework Directive 2000/60 / EC of 23 October 2000 (Akkaya, 2006).

The main purpose of the Water Framework Directive (WFD) is to provide a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater via constructing an integrated watershed management system.

After the harmonization process with the European Union legislation has kicked off, some important developments have occurred regarding water pollution control. As an EU candidate country, Turkey has already initiated the harmonization process and important steps have been taken especially for the prevention of water pollution. Adaptation of the legal framework was one of the first steps of this harmonization and new legislation was introduced within the context of water pollution control and integrated watershed management. Surface Water Quality Management Regulation is one of the regulation which was developed and revised according to harmonization with Water Framework Directive (Bilen, 2008).

The purpose of the Surface Water Quality Management Regulation is to determine and classify the biological, chemical, physico-chemical and hydro-morphological qualities of surface waters, to monitor the quality and quantity of the surface waters.

The biological, microbiological, hydrological, physicochemical and chemical parameters identified in the Appendix-5 of the Surface Water Quality Management Regulation was taken into consideration.

According to Surface Water Quality Management Regulation, surface water quality can be evaluated in four classes:

Class I - High Quality Water

1) Surface waters with high potential for drinking water,

2) Water that can be used for recreational purposes, including body-contacting requirements such as swimming,

3) Water, which can be used for trout production,

4) The quality of water which can be used for animal production and farm needs,

Class II - Less Contaminated Water

1) Surface waters with potential for drinking water,

2) Water, which can be used for recreational purposes,

3) Water which can be used for fish production outside of trout,

4) Providing irrigation water quality criteria determined by the legislation, irrigation water, and husbandry

Class III - Contaminated Water

Water and industrial water, which can be used for aquaculture production after a proper treatment, except facilities that require qualified water, such as food, textile,

Class IV - Highly Contaminated Water

Surface waters that are of lower quality than the quality parameters given for Class III and that can only be achieved by upgrading to a higher quality class.

Analysis results for the sampling point has been assessed. According to the calculation, surface water quality is determined for each parameter type. Water Quality Threshold Limits are given in Table 2-1;

Table 2-1. Water Quality Threshold Limits according to Surface Water Quality Management Regulation

Water Quality Parameters	**Water Quality Classes**			
	I (Very Good)	**II (Good)**	**III (Moderate)**	**IV (Poor)**
pH	6-9	6-9	6-9	6-9
Conductivity (µS / cm)	< 400	1000	3000	> 3000
Dissolved oxygen (mg / L)	> 8	6	3	< 3
Color - RES 436 (m^{-1}) (nm)	≤ 1,5	3	4,3	> 4.3
Color - RES 525(m^{-1})	≤ 1,2	2,4	3,7	> 3,7
Color - RES 620 (m^{-1})	≤ 0,8	1,7	2,5	> 2,5
Oil and Grease (mg / L)	< 0,2	0.3	0.5	> 0,5
Chemical oxygen demand (COD) (mg / L)	< 25	50	70	> 70
Biochemical oxygen demand (BOD_5) (mg / L)	< 4	8	20	> 20
Sulphur (µg / L)	≤ 2	5	10	> 10
Nitrate nitrogen (mg NO_3 ~ -N / L)	< 3	10	20	> 20
Ortho phosphate phosphorus (mg o-PO_4-P / L)	< 0,05	0.16	0.65	> 0.65
Fluoride (µg / L)	≤ 1000	1500	2000	> 2000
Manganese (µg / L)	≤ 100	500	3000	> 3000
Total phosphorus (mg P / L)	< 0,08	0.2	0.8	> 0.8
Selenium (µg / L)	≤ 10	15	20	> 20
Total nitrogen (mg N / L)	< 3,5	11.5	25	> 25
Total kjeldahl-nitrogen (mg N / L)	< 0,5	1.5	5	> 5
Ammonium nitrogen (mg NH_4 + -N / L)	< 0,2	1	2	> 2

Article 13 of the Surface Water Quality Regulation was also considered during evaluating the water quality status. This article states that, in the evaluation of the water quality monitoring results for the parameters in Annex-5 Table 2 , the data which is below 5% probability of not to be exceeded and above 95% of probability of not to be exceeded is excluded from the data set. The arithmetic mean of the remaining data is the basis for the classification. When the number of data is less than 10, the percentage value is not calculated, the arithmetic mean of the data is evaluated.

2.3. Water Quality Indices

Water quality can be described as a concept where physical, chemical and biological parameters are evaluated. When the values of these parameters are above the specified limits, they become harmful to human health. Therefore, water quality index, which is the most effective way to determine water quality, is used to determine the suitability of water resources for human consumption. The water quality index uses water quality data and aids in the modification of policies formulated by various environmental monitoring organizations (Tyagi, 2013)

The first primitive form of the water quality index was introduced more than 150 years ago in Germany by identifying the presence or absence of certain organisms in water as an indication of the suitability of a water source. However, the actual forms of the indices were not used until the end of the 1960s. Water quality indexes were then used by board of directors or research institutes in various countries, particularly in the United States and Canada (Taner, 2007).

The use of water quality indices (WQI) is a simple practice that allows the public and decision makers to receive unified water quality information. WQI also lets us to assess changes in the water quality and to identify temporal trends. WQI is a unitless number that describes a quality value to an aggregate set of measured parameters. Water quality indices generally consist of sub-index scores assigned to each parameter by comparing its measurement with a parameter-specific rating curve, optionally weighted, and combined into the final index.

The construction of WQI requires first a normalization step, where each parameter is transformed into a specific scale by determining the highest quality. The next step is to apply weighting factors that reflect the importance of each parameter as an indicator of the water quality. This constructed WQI gives a number that can be associated with a quality percentage, easy to understand for everyone, and based on scientific criteria for water quality (Pesce, 2002).

The most widely used and best known water quality index is the National Sanitation Foundation Water Quality Index (NSFWQI). This index was developed by examining more than one hundred and forty water quality experts with approximately thirty-five quality tests. Following the National Sanitation Foundation Water Quality Index, the index of the Oregon Environmental Quality Department, where they developed their own indices for the evaluation of surface waters used for recreational purposes, including swimming and fishing, was used until 1983 and was later upgraded to a more developed form. In addition to the United States, another important index British Columbia was developed and called "BC-WQI". Then the Canadian Council of Ministers changed and implemented the "BC-WQI" method (Taner, 2007).

In this thesis, on the other hand, three different WQIs which are applied less around the world was used this thesis to see outcomes of different approaches on water quality evaluation. WQIs having different normalization techniques and different weights for each parameter have been used to analyse the water quality in Gürdük Basin.

First of them is the water quality index which was used during water quality evaluation of Suquia River of Cordoba City, Argentina (Pesce, 2002). This index will be referred as Suquia WQI throughout this thesis. This WQI is selected as it shows the ability of a point for aquatic life preservation (Pesce, 2002).

Second of them is the water quality indices which was used during water quality evaluation of Aksu River of Kahramanmaraş, Turkey (Şener, 2017). This index will be referred as Aksu WQI throughout the document. This WQI is selected to show the status of a point in terms of drinking water quality (Şener, 2017).

Third and last of them is the Smith's Water Quality Index which determined in 1990 (Abbasi, 2002). This index will be referred as Smith's Index throughout the document. This WQI is selected since it represents a general approach for the status of the surface water in terms of potable water usage (Abbasi, 2002).

2.3.1. Suquia WQI

Suquia WQI is calculated by considering the parameters that are listed below:

- Temperature
- Conductivity
- Dissolved Oxygen
- pH
- Turbidity
- Suspended Solids
- Total Coliform
- Total Phosphorus (TP)
- BOD
- COD
- Oil & Grease
- Active Chlorine (Cl^-)
- Sulphate
- Nitrate Nitrogen (NO_3-N)
- Nitrite Nitrogen (NO_2-N)
- Ammonium Nitrogen (NH_4-N)
- Magnesium (Mg)
- Calcium (Ca)
- MBAS

Normalization is done by having a score for each parameter from "0" to "100", "0" is least desired value whereas "100" is the most desired one. Scoring of each parameter is done according to Table 2:2.

Table 2-2: Normalization Factor and Relative Weight for Each Parameter

Parameter	P_i	Normalization factor (C_i)										
		100	**90**	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**	**0**
NH_4-N	3	<0.01	<0.05	<0.10	<0.20	<0.30	<0.40	<0.50	<0.75	<1.00	<1.25	>1.25
BOD_5	3	<0.5	<2	<3	<4	<5	<6	<8	<10	<12	<15	>15
Calcium	1	<10	<50	<100	<150	<200	<300	<400	<500	<600	<1000	>1000
Chloride	1	<25	<50	<100	<150	<200	<300	<500	<700	<1000	<1500	>1500
Conductivity	1	<750	<1000	<1250	<1500	<2000	<2500	<3000	<5000	<8000	>12,000	>12,0
COD	3	<5	<10	<20	<30	<40	<50	<60	<80	<100	<150	>150
DO	4	>7.5	>7.0	>6.5	>6.0	>5.0	>4.0	>3.5	>3.0	>2.0	>1.0	<1.0
Hardness	1	<25	<100	<200	<300	<400	<500	<600	<800	<1000	<1500	>1500
Mg	1	<10	<25	<50	<75	<100	<150	<200	<250	<300	<500	<500
Nitrates	2	<0.5	<2.0	<4.0	<6.0	<8.0	<10.0	<15.0	<20.0	<50.0	<100.0	>100.
Nitrites	2	<0.005	<0.01	<0.03	<0.05	<0.10	<0.15	<0.20	<0.25	<0.50	<1.00	>1.00
Oil and	2	<0.005	<0.02	<0.04	<0.08	<0.15	<0.30	<0.60	<1.00	<2.00	<3.00	>3.00
pH	1	7	7/8	7/8.5	7/9	6.5/7	6/9.5	5/10	4/11	3/12	2/13	1/14
Total	1	<0.16	<1.60	<3.20	<6.40	<9.60	<16.0	<32.0	<64.0	<96.0	<160.0	>160.
Total Solids	4	<250	<750	<1000	<1500	<2000	<3000	<5000	<8000	<12,000	<20,000	>20,0
Sulphates	2	<25	<50	<75	<100	<150	<250	<400	<600	<1000	>1500	>1500
MBAS	4	<0.005	<0.06	<0.10	<0.25	<0.50	<0.75	<1.00	<1.50	<2.00	<3.00	>3.00
Temp.	1	21/16	22/15	24/14	26/12	28/10	30/5	32/0	36/-2	40/-4	45/-6	>45/<
Total	3	<50	<500	<1000	<2000	<3000	<4000	<5000	<7000	<10,000	<14,000	>14,0
Turbidity	2	<5	<10	<15	<20	<25	<30	<40	<60	<80	<100	>100

In Table 2-2, relative weights (P_i) for each parameters are also identified. Highest value means the most important and lowest value means the least important parameter. As it can be seen from the table above, Dissolved Oxygen, Total Solids, and Surfactants as MBAS are the most important quality parameters when considering the Suquia Water Quality Index.

After determining the normalized values for each sampling and relative weight for each parameter is done, WQI is calculated by the formula below:

$$WQI_{Suquia} = \frac{\sum_i C_i \times P_i}{\sum_i P_i} \quad \text{Equation 1}$$

Where

C_i is normalized value of the i^{th} parameter and,

P_i is relative weight for the i^{th} parameter (unitless)

Quality of Water is assessed according to the final score of WQI;

> 90: Excellent Quality

70 – 90: Good Quality

50 – 70: Medium Quality

25 – 50: Poor Quality

0 – 25: Very Poor Quality

2.3.2. Aksu WQI

Aksu WQI is calculated by considering the parameters that are listed below:

- pH
- COD
- Active Chlorine (Cl^-)
- Sulphate
- Nitrate Nitrogen (NO_3-N)
- Nitrite Nitrogen (NO_2-N)
- Sodium (Na)
- Magnesium (Mg)
- Calcium (Ca)
- Total chromium (T. Cr)
- Manganese (Mn)

Normalization is done by dividing the concentration of each value by the World Health Organization (WHO) Limit Value by the formula below:

$$C_i = \frac{S_i}{S_{WHO}}$$ Equation 2

Where

C_i is normalized value of the i^{th} parameter,

S_i is the value of the i^{th} parameter and,

S_{WHO} is the WHO limit value for the parameter

WHO Limit values for each parameter is given in Table 2-3:

Table 2-3: WHO Limit Values (WHO, 2017)

Parameter	Limit	Unit
pH	6.5 - 8.5	-
COD	10	mg/L
Active Chlorine (Cl^-)	250	mg/L
Sulphate	250	mg/L
Nitrate Nitrogen (NO_3-N)	50	mg/L
Nitrite Nitrogen (NO_2-N)	3	mg/L
Sodium (Na)	200	mg/L
Magnesium (Mg)	30	mg/L
Calcium (Ca)	300	mg/L
Total chromium (T. Cr)	50	µg/L
Manganese (Mn)	50	µg/L

Relative weight for each parameter is determined as depicted in Table 2-4.

Table 2-4: Relative Weights of Each Parameter According to Aksu WQI

Parameter	Relative Weight
pH	4
COD	4
Active Chlorine (Cl-)	3
Sulphate	4
Nitrate Nitrogen (NO_3-N)	5
Nitrite Nitrogen (NO_2-N)	5
Sodium (Na)	2
Magnesium (Mg)	2
Calcium (Ca)	2
Total chromium (T. Cr)	5
Manganese (Mn)	5

Highest value means the most important and lowest value means the least important parameter. As it can be seen from Table 2-4, Total Chromium and Manganese (Mn) are the most important parameters when considering the Aksu Water Quality Index.

After determining the normalized values for each sampling and relative weight for each parameter is done, WQI is calculated by the formula below:

$$WQI_{Aksu} = \frac{\sum_i C_i \times P_i}{\sum_i P_i} \qquad \text{Equation 3}$$

Where;

C_i is normalized value of the i^{th} parameter and,

P_i is relative weight for the i^{th} parameter

Quality of Water is assessed according to the final score of WQI;

0 – 0.5: Excellent Quality

0.5 – 1: Good Quality

1 – 2: Medium Quality

2 – 3: Poor Quality

> 3: Very Poor Quality

2.3.3. Smith's Index

Smith's Index is calculated by considering the parameters that are listed below:

- DO Saturation
- BOD
- pH
- Faecal Coliforms

Normalization is done according to different formulas for each parameter and for different concentration ranges. Normalization according to Smith's Index is explained in detail in Table 2-5.

Table 2-5: Normalization Equations for Smith's Index

Parameter	Range	Equation	Explanation
DO Saturation (%)	0 – 40 % 40 – 100 % 100 – 140 %	$C_{DO} = 0.18 + 0.66 \times S_{DO}$ $C_{DO} = -13.5 + 1.17 \times S_{DO}$ $C_{DO} = 263.34 - 0.62 \times S_{DO}$	C_{DO}: Normalized Value of Dissolved Oxygen Saturation S_{DO}: Actual Value of Dissolved Oxygen Saturation
BOD (mg/L)	0 – 10 10 – 30 > 30	$C_{BOD} = 96.67 - 7 \times S_{BOD}$ $C_{BOD} = 38.9 - S_{BOD}$ $C_{BOD} = 2$	C_{BOD}: Normalized BOD Value S_{BOD}: Actual BOD Value
pH	2 – 5 5 – 7.3 7.3 – 10 10 – 12 < 2, > 12	$C_{pH} = 16.1 + 7.35 \times S_{pH}$ $C_{pH} = -142.67 + 33.5 \times S_{pH}$ $C_{pH} = 316.96 - 29.85 \times S_{pH}$ $C_{pH} = 96.17 - 8.0 \times S_{pH}$ $C_{pH} = 0$	C_{pH}: Normalized pH Value S_{pH}: Actual pH Value
Faecal Coliforms (counts/100 mL)	1 – 10^3 10^3 – 10^5 > 10^5	$C_{Coli} = 97.2 + 26.60 \times Log(S_{Coli})$ $C_{Coli} = 42.33 - 7.75 \times Log(S_{Coli})$ $C_{Coli} = 2$	C_{Coli}: Normalized Faecal Coliforms Value S_{Coli}: Actual Faecal Coliforms Value

Relative weight for each parameter is determined as depicted in Table 2-6.

Table 2-6: Relative Weights of Each Parameter According to Smith's Index

Parameter	Relative Weight
DO Saturation	31
BOD	19
pH	22
Faecal Coliforms	28

Highest value means the most important and lowest value means the least important parameter. As it can be seen from Table 2-6, Dissolved Oxygen Saturation is the most important parameter when considering the Smith's Index.

After determining the normalized values for each sampling and relative weight for each parameter is done, WQI is calculated by the formula below:

$$WQI_{Smith's\ Index} = \frac{\sum_i C_i \times P_i}{\sum_i P_i} \qquad \text{Equation 4}$$

Where;

C_i is normalized value of the i^{th} parameter and,

P_i is relative weight for the i^{th} parameter

Quality of Water is assessed according to the final score of WQI;

> 80: Excellent Quality

60 – 80: Good Quality

40 – 60: Medium Quality

20 – 40: Poor Quality

0 – 20: Very Poor Quality

2.4. Watershed Modelling

The "watershed modelling" can be described as a type of model which is constructed for simulation of the water movement and its processes that may affect its quantity and quality (Band, 1991). Computerized watershed models are being used since 60s for simulation of the hydrological events, sediment erosions at a watershed, and point and diffused pollution in a watershed (Novotny, 2008).

The first model constructing for simulation of the complete hydrological cycle in a watershed was Stanford Watershed Model – SWM which was developed in 1966 by Crawford and Linsley (Crawford, 1966). And more and more mathematical computerized models kept being developed since then (Singh, 2002).

Soil and Water Assessment Tool (SWAT) is one of the most used watershed models which can simulate all major components (hydrology, sediment, and chemical) and able to assess long-term impacts of hydrological modifications and watershed management practices (Borah, 2003). Therefore, SWAT model is selected as the watershed model for this study.

2.5. SWAT Model

SWAT stands for Soil and Water Assessment Tool, which is established as a watershed model. USDA Agricultural Research Service (ARS) and Texas A&M University have developed the model. SWAT Modelling Program is often used for many locations around the world for both water budget calculations and water pollution evaluation (Wendy Francesconi, 2016).

SWAT firstly divides watershed area into smaller sub-watersheds that has homogenous hydrological features. The total basin behaviour is a clear result of the sum of the small sub-basins. The land use land cover (LULC) map and soil texture map within watershed boundaries are used to generate unique combinations that is called Hydrological Response Unit (HRU). Each HRU combination has homogeneous physical properties in terms of land use, soil texture and slope.

SWAT schedules irrigation either automatically or manually considering the criteria. Moreover, after time schedule of irrigation and fertilizer usage are identified source of irrigation has to be determined in terms of canal water, reservoir, shallow aquifer, deep aquifer, or a source outside the watershed (Wendy Francesconi, 2016).

2.5.1. Historical Development

SWAT Model program has been used for more than 30 years by various federal agencies including but not limited to the US Environmental Protection Agency (EPA), Natural Sources Conservation Service, National Oceanic and Atmospheric Administration and Bureau of Indian Affairs to model point and diffused sources of pollution. SWAT has started to be developed during 90s by United States Department of Agriculture (USDA), Agricultural Research Service (ARS). Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980), the Groundwater Loading Effects on Agricultural Management Systems (GLEAMS)

(Leonard, 1987), and the Environmental Impact Policy Climate (EPIC) models (R. César Izaurralde, 2017) can be considered as the main foundations of the SWAT model (Gassman, 2007).

Simulator for Water Resources in Rural Basins (SWRRB) model was founded in order to simulate water and sediment movement and to evaluate the effects of management practices, which are conducted at rural areas after having daily rainfall hydrology component of CREAMS, pesticide fate component of GLEAMS, and crop growth component of EPIC as input (Gassman, 2007).

Historical development of SWAT's, with selected SWAT adaptations is given in Figure 2.2.

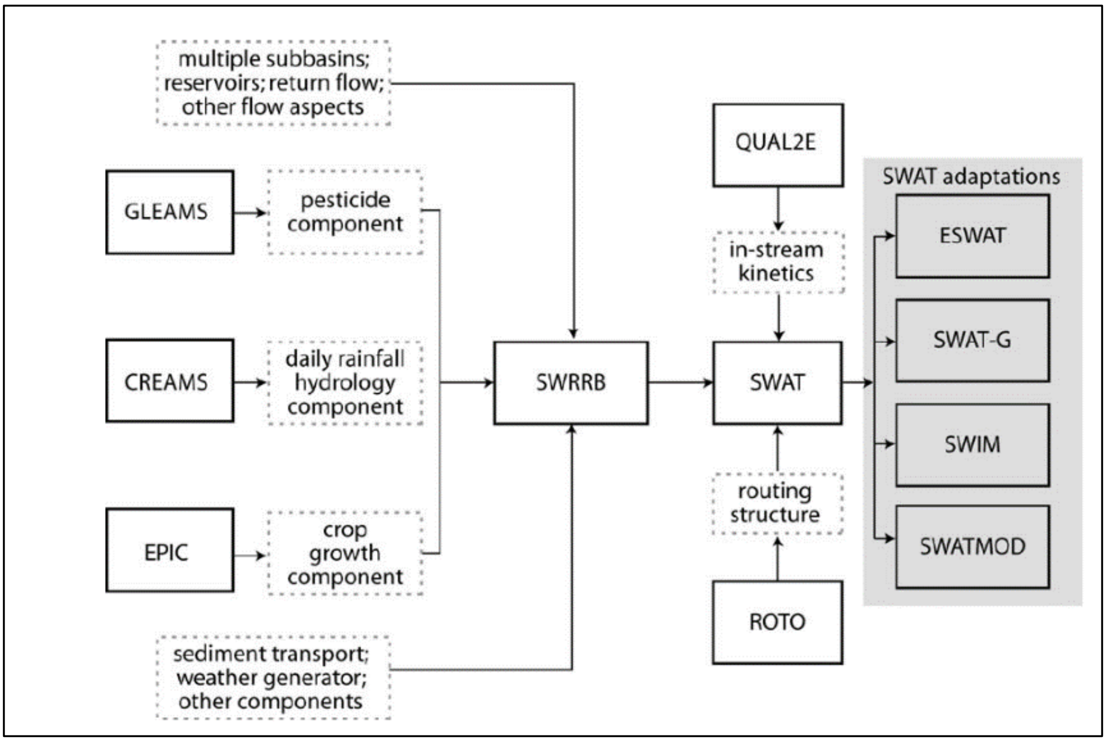

Figure 2.2. SWAT development history including selected SWAT adaptations (Gassman, 2007)

Furthermore, SWAT has gained the ability to simulate various number of watershed water quality management evaluations after obtaining the USDA-SCS technology for calculating peak runoff rates, and sediment yield equations modifications (Gassman, 2007).

QUAL2E which is a modification of SWRRB model was able to simulate in-stream kinetic, Routing Outputs to Outlet (ROTO) which is another modification of SWRRB model was able to simulate routing structure of the watershed. (Arnold J. G., 1995). SWAT model was generated. SWAT model was developed to simulate the impact of land management activities on water sediment, and agricultural chemical yields in the watersheds which have varying soils and land use conditions (Neitsch S. L., 2002). The SWAT model cannot only simulate small basins, but large and complex basins as well. SWAT is capable of having of continuous simulations (Gassman, 2007).

2.5.2. Model Requirements

SWAT is a basin scale model developed to analyse the possible effects of land management practices on surface water quality, sediment status considering soil characteristics, land use data, meteorological and topographic conditions and management over long period of time (Neitsch S. L., 2002).

Therefore; soil texture characteristics, land use information, meteorological and topographic data and long period of time management is needed as model inputs.

Weather, soil texture, topographical information, vegetation, and land use practices are some of the specific information needed by SWAT model (Figure 2.3). Since SWAT is known to be simulating large basins without time and money consumption, it is considered as a computationally efficient model. Up-to 100 years of simulation can be conducted by SWAT on daily basis to evaluate discharge, sediment, nutrient, and pesticide yields from agricultural watersheds (Neitsch S. L., 2002).

SWAT MODEL INPUT

- Digital Elevation Model (DEM)
- Hydrological information
- Meteorological data
- Land use & land cover (LULC)
- Soil texture
- Agricultural management data
- Point source information

SWAT MODEL OUTPUT

- Flowrate
- Pollution concentrations

Figure 2.3. SWAT Model Inputs and Outputs (Sunggu Heo, 2012)

For SWAT to run successfully, input data quality (especially GIS data) possess great significance. Therefore, spatial resolution of the input data to be used has great importance, since; it can affect output’s uncertainty (Cotter, 2003).

Model outputs are directly affected by the DEM resolution to be used as input. Minimum and optimum resolution for DEM data, land use and soil to have for flowrate, sediment movement NO3-N, and TP calculations are given in Table 2-7 and Table 2-8.

Table 2-7. Minimum GIS input data resolutions to attain less than 10 percent error in model predictions (Cotter, 2003)

Output	**Minimum Input Data Resolution (m)**		
	DEM	**Land Use**	**Soil**
Flow	300	1000	1000
Sediment	30	30	500
NO_3-N	200	500	500
TP	30	300	500

Table 2-8. Optimum DEM Resolutions (Zhang, 2014)

Output	DEM Resolution (m)
Flow	30 – 200
Sediment and TP	30 – 100
DO and NO_3-N	30 – 300
NH_4-N	30 – 70
TN	30 – 150

Basic components of the SWAT model can be briefly listed as data on weather, hydrology, soil texture, cultivation pattern, nutrient loads, pesticide usage, pathogen status and land use. Main working principle of the SWAT model is simulating the watershed and river. SWAT firstly, divides whole watershed into sub-basins and later into the smallest unit of the SWAT namely hydrologic response units (HRUs). HRUs are the units with same land use, management, and soil features. SWAT has been altered, reviewed and gained new capabilities since its creation during the beginning of the 90s (Gassman, 2007).

Operation of the SWAT model is conducted on daily, monthly or yearly basis. SWAT generates various output files for the whole watershed, sub-basins, HRUs and main reach. Output data of SWAT model can be obtained as in daily, monthly and yearly time scales (Arnold J. G., 2012).

Three different modules are used for SWAT model construction. SWAT Watershed Delineator Module is the first module which is used for the division of the studied watershed, into sub-basins. Topographical information obtained from the Digital Elevation Model (DEM) data is needed for Watershed Delineator Module. This process automatically occurs after the DEM data is loaded. Users can determine the limits parameters to identify the size and number of sub-basins to be created. Moreover, pre-defined watershed and stream network can be defined during the construction of the model (K. R. Douglas-Mankin, 2010).

During the watershed delineation process, studied watershed is firstly divided into sub basins after a threshold area for the minimum drainage area to identify the beginning of the stream is specified in hectares. After this process, sub-basins are divided into in Hydrologic Response Units (HRUs) which can be stated as the smallest and reference hydrological unit of the model. HRUs are the areas that have unique land cover, soil and slope (Neitsch S. L., 2009).

ArcGIS and Spatial Analyst extension functions are used as the means of The Watershed Delineation module during the delineation of the watershed. A Digital Elevation Model (DEM) in ESRI grid format is needed for the Watershed Delineation module. Pre-defined digital steams can be loaded to the model in ArcView shapefile or geodatabase feature class (PolyLine) format (Arnold J. G., 2012).

After the watershed delineation, Topographic Report having the details on the elevation distribution within the watershed and each sub basin is obtained in the studied watershed.

Watershed delineation process is briefly described below;

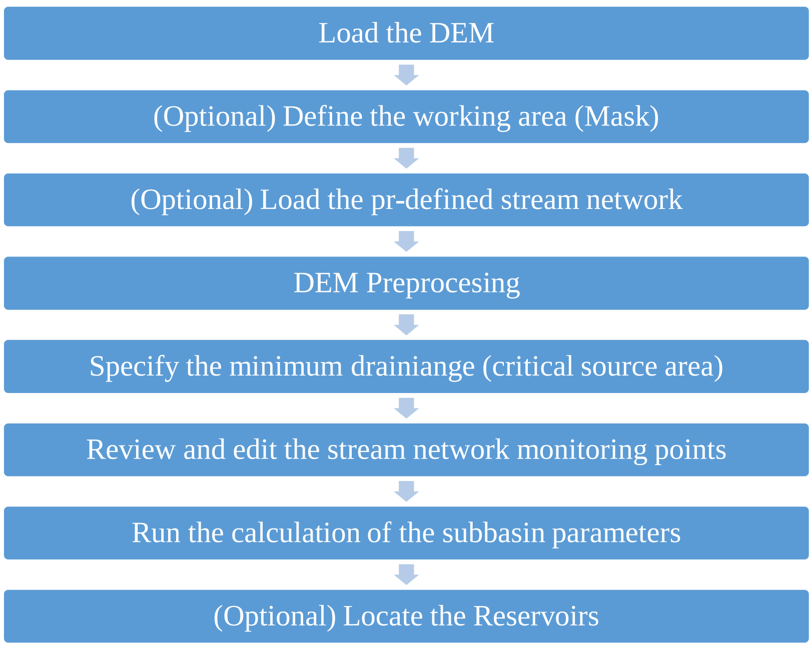

Figure 2.4. Watershed delineation process

The second module is the SWAT Hydraulic Response Unit (HRU) Analysis Tool, that constitutes the information obtained from land use data, soil characteristics and slope maps in order to determine the HRUs.

With HRU module, characterization of land use, soil texture and slope of the basin can be conducted. Land use and land class map, soil texture map and slope class can be loaded to the SWAT model to identify the LULC/Soil texture/Slope combinations and distributions for each sub-basin. Format of the data to be loaded to the SWAT should be in ESRI grid, shapefile, or geodatabase feature class formats (Betrie, 2013).

After loading the land use / land class and soil texture maps and number of slope class of the studied are identified, HRU distribution can be determined by user. For each delineated sub-basin, one or more combinations of land use, soil and slope (hydrologic response units or HRUs) can be identified.

SWAT Input Editor is the third module that enables users to identify specific input databases to be loaded and modifying them.

Meteorological data to be loaded to the SWAT model in order to conduct the simulation after the HRU distribution is identified. This data is imported to the model via SWAT toolbar. This toolbar enables users to import weather station and meteorological data. For each meteorological data to be imported, each weather station is assigned for a sub-basin.

Necessary watershed input values should be determined before running SWAT model. Input values are identified automatically based on the watershed delineation and land use\soil\slope characterization or from as default.

Figure 2.5 constitutes a schematic depiction of the hydrological cycle SWAT simulates. precipitation, evapotranspiration, infiltration, surface runoff, subsurface flow, base flow, soil moisture redistribution and percolation to deep aquifer are the main processes SWAT uses during hydrological simulation (Tuppad, 2010).

Land phase and channel/floodplain phase are the two main hydrological processes when considering hydrological cycle SWAT simulates. Sediment, nutrient and pesticide loads which are the subject of surface run-off transportation are calculated for each HRU within the land phase.

In channel/floodplain phase, SWAT simulates the transportation of each load from every sub-basin via channel/stream network (Tuppad, 2010).

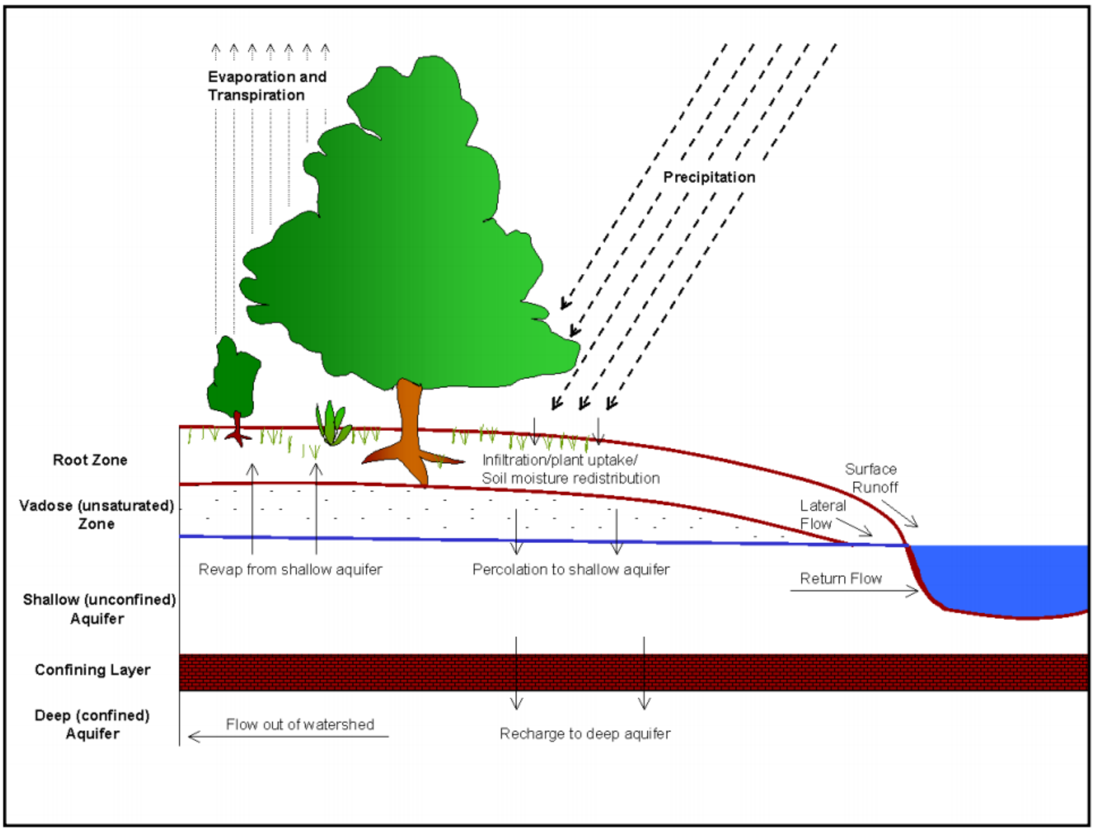

Figure 2.5. Schematic depiction of the hydrologic cycle that SWAT simulates (Neitsch S. L., 2009)

Water balance equation which is given below is considered by SWAT while simulating the hydrological cycle:

$$SW_t = SW_0 + \Sigma(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \qquad \text{Equation 5}$$

Where;

SW_t = the final soil water content (mm H_2O),

SW_0 = initial soil water content on day i (mm H_2O),

t = time (days),

R_{day} = amount of precipitation on day i (mm H_2O),

Q_{surf} = amount of surface runoff on day i (mm H_2O),

E_a = amount of evapotranspiration on day i (mm H_2O),

W_{seep} = amount of water entering from the soil profile on day i (mm H_2O),

Q_{gw} = amount of return flow on day i (mm H_2O) (Neitsch S. L., 2009).

Precipitation, maximum and minimum air temperature, solar radiation, wind speed and relative humidity are needed for SWAT for hydrological simulation (Tuppad, 2010). Calculation of un-off is done for every sub-basin separately via considering differences in evapotranspiration for different crops, soils etc. Afterwards, calculation of total run-off for whole watershed is done by routing each run-off from the sub-basins (Arnold J. G., 1999).

Evapotranspiration is a process that includes all kinds of processes that liquid or solid phase water transforms to atmospheric water vapour. On the other hand, potential evapotranspiration means "*the rate at which evapotranspiration would occur from a large area completely and uniformly covered with growing vegetation which has access to an unlimited supply of soil water*" (Neitsch S. L., 2009).

SWAT can simulate evapotranspiration via three different alternatives; i) Hargreaves (Society & Agricultural, 1985), ii) Priestley-Taylor (Priestley and Taylor, 1972), iii) Penman-Monteith (Monteith and Moss, 1977).

Penman-Monteith method needs more data than other two methods. solar radiation, air temperature, wind speed and relative humidity are needed when using the the Penman-Monteith method. Hargreaves or Priestley-Taylor method can also be used during the lack of relative humidity, wind speed, and solar radiation data (Arnold J. G., 1999)

Sediment yield simulation via Modified Universal Soil Loss Equation (MUSLE) (Neitsch S. L., 2009). Two basic processes have an influence on sediment yield, i) sediment deposition, ii) degradation. Moreover, sediment loads from the areas with higher slopes and transport capacity of the reach systems determine which process will occur (Arabi, 2006). Bagnold's sediment transport equation is considered when simulating the channel sediment routing (Santhi, 2001)

The nitrogen (N) and phosphorus (P) yield is simulated via SWAT via modelling the interactions of nitrogen and phosphorus between organic and inorganic pools in the nutrient cycle (Tuppad, 2010)

Schematic depiction of nitrogen transformations which SWAT simulates is given in Figure 2.6. Fertilizer application, manure or residue application, bacteriological fixation, and rain are the main sources of nitrogen. Plant uptake, soil erosion, leaching, volatilization, and denitrification, on the other hand, are the removal processes (Zhai, 2014). A supply and demand approach is depicted when calculating the nitrogen consumption of plants. Plant biomass is the main parameter that affects nitrogen requirement of a plant. Available nitrogen content supplies the nitrogen needs of the plants. Nutrient stress appears when nitrogen needed by the plant is less than available nitrogen in the soil (Santhi, 2001).

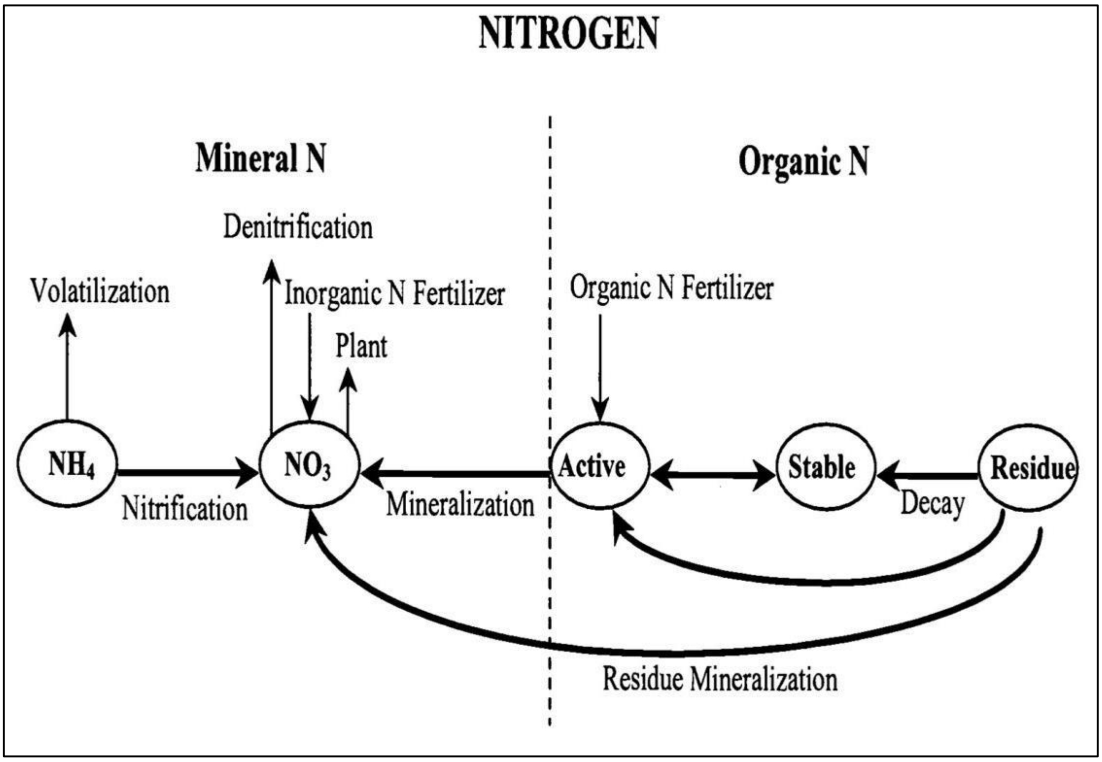

Figure 2.6. Nitrogen forms and transformations simulated by SWAT (Santhi, 2001)

SWAT can simulate transport and transformation of different forms of phosphorus. A schematic depiction on forms and transformations of phosphorus is shown in Figure 2.7. Similar to the nitrogen calculations, phosphorus utilization of plants via constructing a supply and demand approach. Soluble P removal via surface runoff is simulated via the concept of partitioning pesticides into the solution and sediment forms (Santhi, 2001).

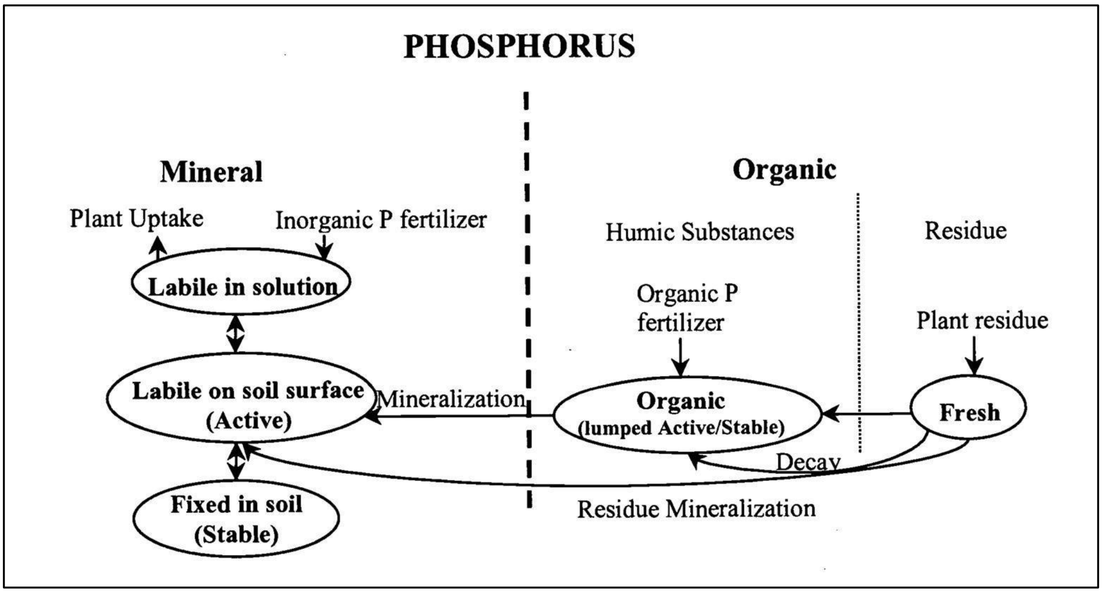

Figure 2.7. Phosporus forms and transformations simulated by SWAT (Santhi, 2001)

2.5.3. Advantages of the SWAT Model

SWAT is used all over the world and has advantages on hydrological basis, nutrient load calculations, data requirements etc. To compare other worldwide used basin scale simulation models, SWAT's advantages can be described as (Betrie, 2013)

- SWAT simulation is based on elevation or meteorological effects such as precipitation and temperature.

- SWAT has been successful for simulating basins in arid regions

- SWAT successfully links the relations between cultivation pattern, schedule and irrigation practices.

- SWAT can use either observed or statistically generated weather data for long-term simulations

Since SWAT model is a physically based model and used all over the world, and requires generally easy-to-find data, it can be stated as beneficial for the basins having no monitoring data to be evaluated and generate improvement recommendations (Busteed, 2009).

2.6. SWAT-CUP Interface

The uncertain model parameters are changed systematically required by automated model calibration, the model is run and the necessary outputs are taken from the model output files. The main function of the interface is to provide a connection between the model and the inputs and outputs of the calibration program. Using the SWAT-CUP interface, the calibration, uncertainty or sensitivity analysis of SWAT model outputs can be easily performed.

SWAT-CUP has 5 different optimization methods for calibration and uncertainty analysis. These; Particle Swarm Optimization (PSO), Sequential Uncertainty Fitting ver.2 (SUFI-2), Markov chain monte carlo (MCMC), parameter solution (Parasol) and Generalized Likelihood Uncertainty Estimation (GLUE) methods (Abbaspour K. C., 2015).

The SUFI_2 algorithm is the most remarkable optimization method. This method is based on sensitivity analysis that determines which parameter has the greatest effect of a change from observation values on the simulation values (Abbaspour K. C., 2007). Sensitivity analysis provides the most effective parameters required in the calibration and verification process (Jajarmizadeh, 2012). . In the calibration stage of Gürdük Basin simulation, SUFI-2 optimization algorithm with sensitivity analysis of parameters was preferred. Connection diagram between SWAT model and parameter optimization methods according to SUFI-2 Algorithm was given in Figure 2.8.

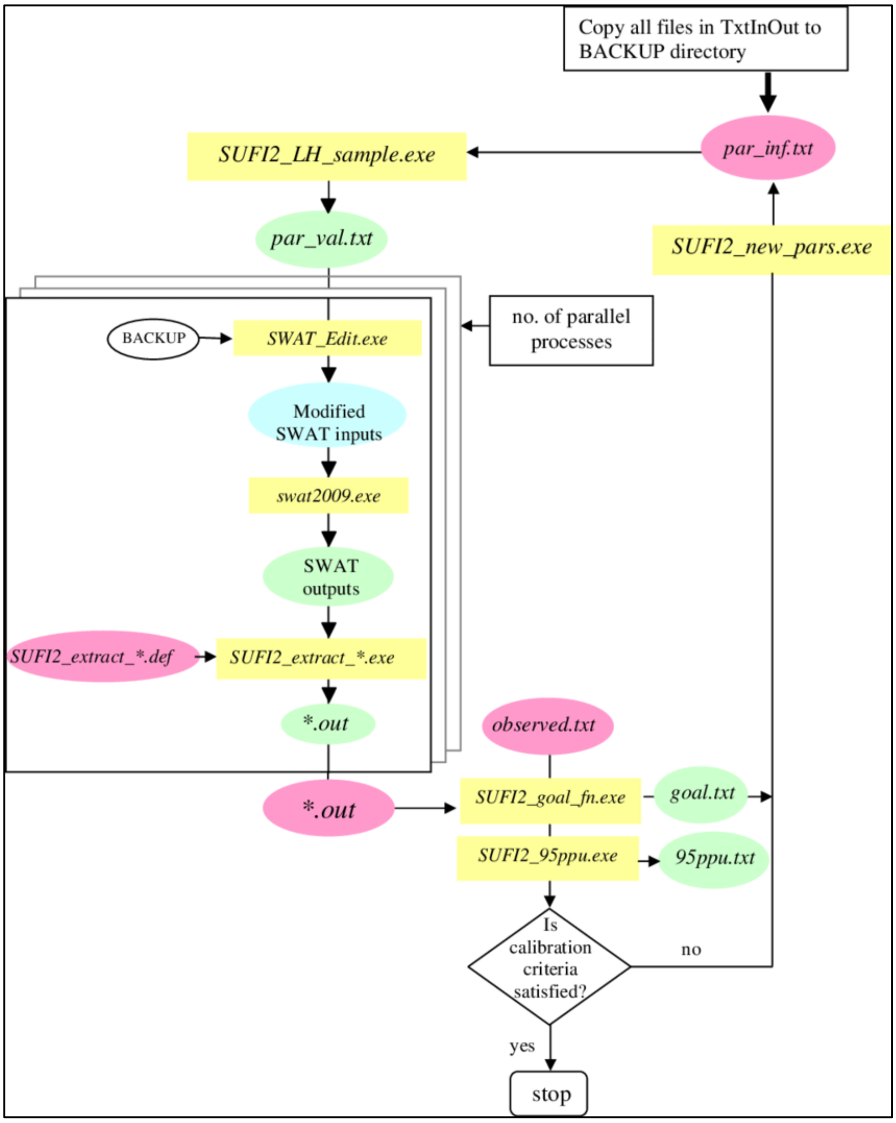

Figure 2.8. Connection diagram between SWAT model and parameter optimization methods (Freund R., 2012)

Various SWAT parameters related to the flow can be estimated using the SUFI-2 algorithm. Uncertainty in SUFI-2; it is defined as a mismatch between measured variables and simulation variables. To explain this uncertainty, it is necessary to maintain the measured data, except deviating values. Thus, SUFI-2 combines calibration and uncertainty analysis to find uncertainty parameters. These uncertainty parameters; shows all sources of conceptual model, uncertainties, strengthened inputs and parameters. In SUFI-2, model output uncertainty is measured at 95% prediction uncertainty (95PPU), while input parameter uncertainty is expressed as a uniform distribution (Rostamian, 2010).

2.7. Performance Requirements for Model Calibration

Model performance statistics are used to test how the simulation values correspond to the observed values. Many performance statistics are used to test the performance of the hydrological model. These are p-factor, r-factor, R2, NSE, bR2, MSE, SSQR, PBIAS, mean of simulation and standard error of simulations. In this study, the coefficient of clarity R^2, Nash-Sutcliffe efficiency coefficient (NSE) and percentage error statistics (PBIAS) were used to test the performance of the model. In addition, the overall performance evaluation chart of model statistics was prepared by using a study by (Moriasi, 2015) and presented in Table 2-9.

Table 2-9. Performance Evaluation Chart for Calibration (Moriasi, 2015)

Parameter	**Streamflow**			
	Very Good	**Good**	**Satisfactory**	**Not Satisfactory**
R^2	$R^2 > 0.85$	$0.75 < R^2 \leq 0.85$	$0.60 < R^2 \leq 0.75$	$R^2 \leq 0.60$
NSE	NSE > 0.80	0.70 < NSE ≤ 0.80	0.50 < NSE ≤ 0.70	NSE ≤ 0.50
PBIAS	PBIAS < ± 5	± 5 < PBIAS ≤ ± 10	± 10 < PBIAS ≤ ± 15	PBIAS ≥ ± 15
	Sediment			
R^2	$R^2 > 0.80$	$0.70 < R^2 \leq 0.80$	$0.50 < R^2 \leq 0.70$	$R^2 \leq 0.50$
NSE	NSE > 0.80	0.70 < NSE ≤ 0.80	0.45 < NSE ≤ 0.70	NSE ≤ 0.45
PBIAS	PBIAS < ± 10	± 10 < PBIAS ≤ ± 15	± 15 < PBIAS ≤ ± 20	PBIAS ≥ ± 20
	Nutrient (N, P)			
R^2	$R^2 > 0.70$	$0.60 < R^2 \leq 0.70$	$0.30 < R^2 \leq 0.60$	$R^2 \leq 0.30$
NSE	NSE > 0.65	0.50 < NSE ≤ 0.65	0.35 < NSE ≤ 0.50	NSE ≤ 0.35
PBIAS	PBIAS < ± 15	± 15 < PBIAS ≤ ± 20	± 20 < PBIAS ≤ ± 30	PBIAS ≥ ±30

2.7.1. Coefficient of Determination (R^2)

R^2, specifies the size of the total change in measured data that can be explained by the model. The value range is 0-1. Higher values indicate better fit (Jain, 2010).

$$R^2 = \left[\frac{\sum_i^N [Qi - Qavg][Si - Savg]}{\sqrt{\sum_i^N [Qi - Qavg]^2 \times \sum_i^N [[Si - Savg]}} \right]^2 \qquad \text{Equation 6}$$

Here;

Q_i: Observed i^{th} value,

Q_{avg}: Average of observation parameters,

S_i: i^{th} simulation parameter,

S_{avg}: Mean of model simulation parameters,

N: Total number of samples

2.7.2. Nash Sutcliffe Efficiency Coefficient (NSE)

NSE shows the estimated capacity of the model. The value of the statistic takes values from negative infinity to 1. NSE is considered the most appropriate proportional error or the most useful performance statistic due to its simple physical interpretation (Legates, 1999).

$$NSE = 1 - \frac{\sum_1^N [(Qi - Si)^2]}{\sum_1^N [(Qi - \bar{Q}\,)^2]} \qquad \text{Equation 7}$$

Here;

Q_i: Observed i^{th} value,

S_i: Simulation flow rate,

$\bar{Q}$: Average of observation parameters,

N: Total number of samples.

2.7.3. Percent Bias (PBIAS)

Whether the simulation data is larger or smaller than the observed data can be determined using the percentage error statistics. It gets the best value at ‘0’ point. The positive PBIAS value indicates that the measured values are greater than the simulation values, whereas the negative PBIAS value indicates the opposite. The PBIAS statistic is calculated as follows (Abbaspour K. C., 2015):

$$PBIAS = 100 \times \frac{\sum_i^N (Qm - Qs)i}{\sum_i^N Qmj} \qquad \text{Equation 8}$$

Here;

Q_m : i^{th} observed flowrate,

Qs : i^{th} simulated flowrate,

N: Total number of samples.

CHAPTER 3

WATER QUALITY EVALUATION OF GÜRDÜK BASIN

3.1. General Information

Gürdük Basin is at the northern part of the Gediz Basin, which is located in the Aegean Region at the western side of Turkey (see Figure 3.1)

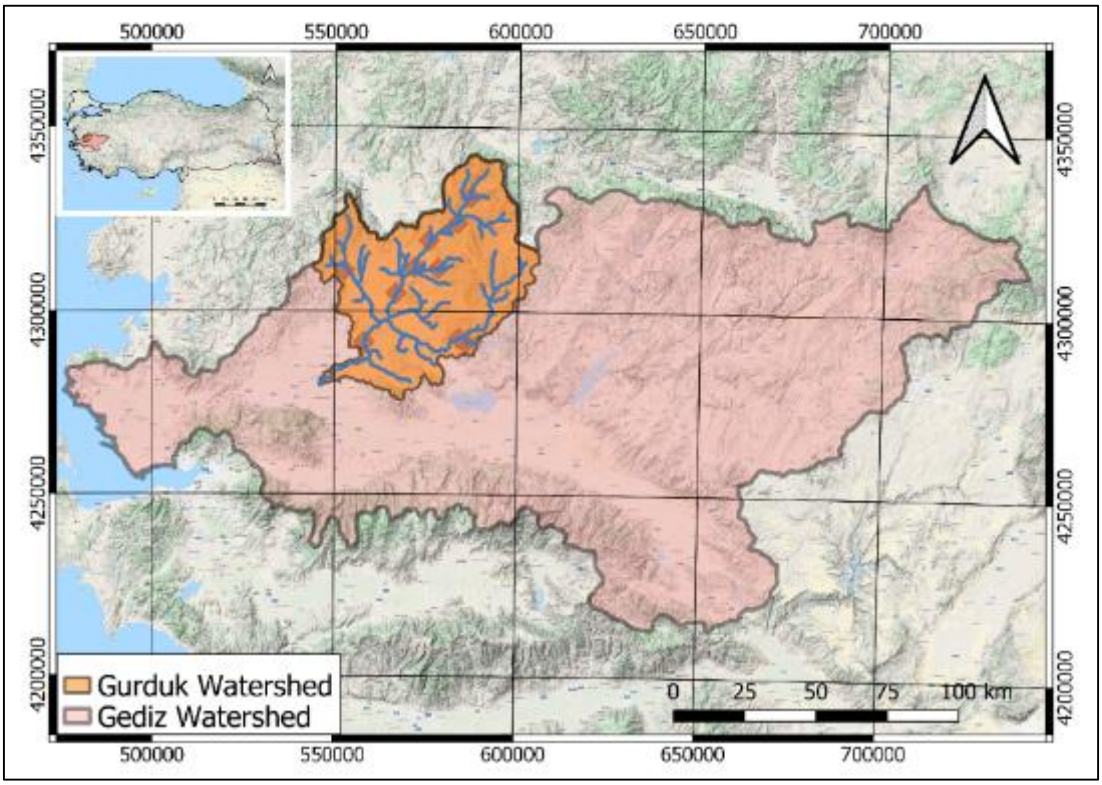

Figure 3.1. Gürdük Watershed within Gediz Watershed

The Gürdük River, which gives the name to the basin, is the largest water source of the basin with a length of 75 km. The total area occupied by the basin is calculated as 3,200 km^2 (MoFWA, 2013).

Gürdük Basin includes the district of Sındırgı of Balıkesir Provinces, Turgutlu, Saruhanlı, Gördes, Ahmetli, Kırkağaç, Gölmarmara, Akhisar, Soma and Centre districts of Manisa Province but the majority of the basin is situated within Akhisar District boundaries (Figure 3.2).

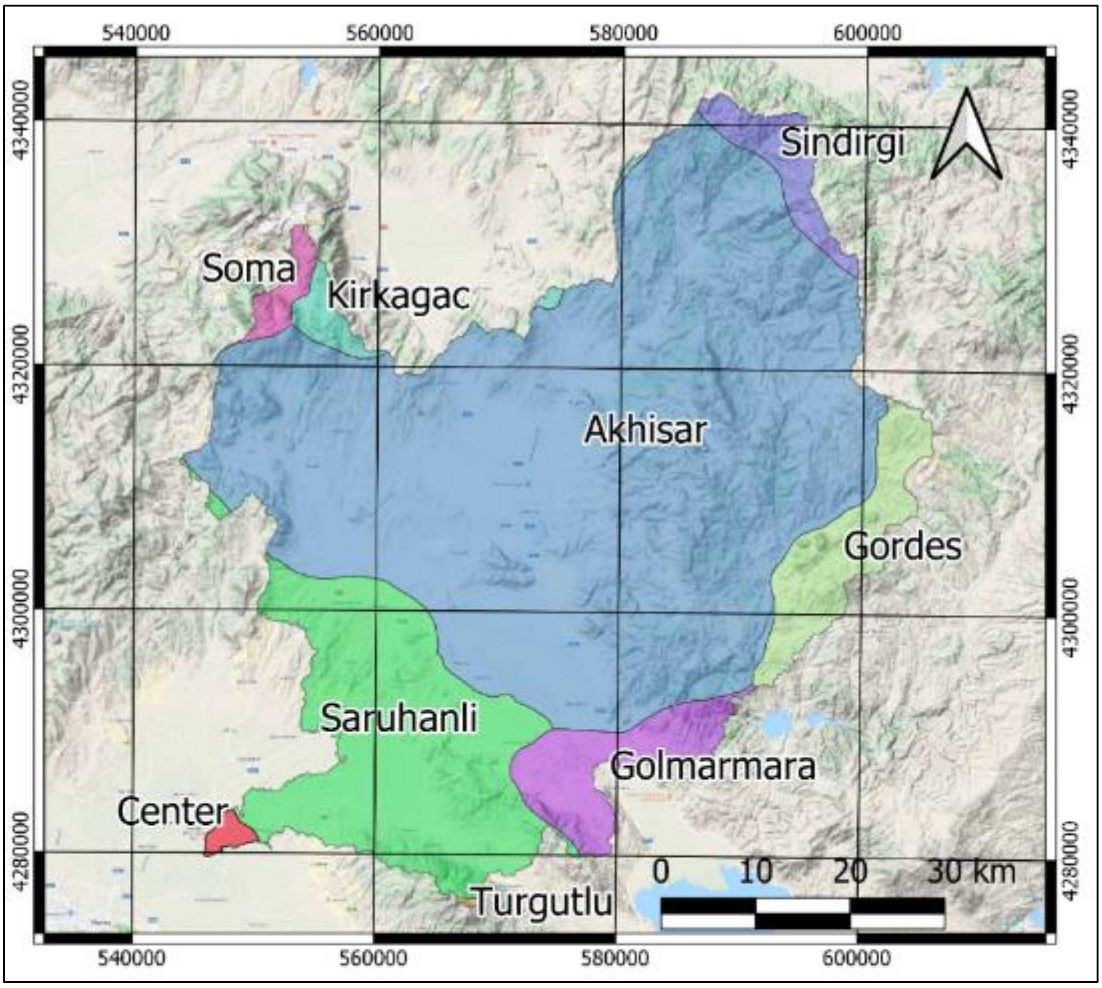

Figure 3.2. Districts of the Gürdük Watershed

3.2. Land Use

In general, two thirds of the basin are in natural state or can be specified as unused areas. There are mountainous areas at the northern and north-eastern parts of the basin. This mountainous geography causes limited transportation and lack of accessibility to the infrastructure services. This factor, along with the lack of suitable agricultural areas, prevents development at the mountainous areas. Consequently, it can be said that only one third of the basin has a convenience for settlement and anthropogenic activities, mainly along the central valley (Kıymaz, 2006)

Gürdük sub-basin is located in northern part of the Gediz Basin. This sub-basin constitutes the part of the basin from the downstream of Gördes Dam to the Manisa Central District (MoFWA, 2013). According to Corine Land Cover 2012 data, over 60 % of the basin is composed of coniferous forest, olive groves, complex cultivation patterns and transitional woodland-shrubs. Figure 3.3 shows the distribution of land use practises within the boundaries of the basin and Table 3-1 shows the magnitude of the land use types within the basin.

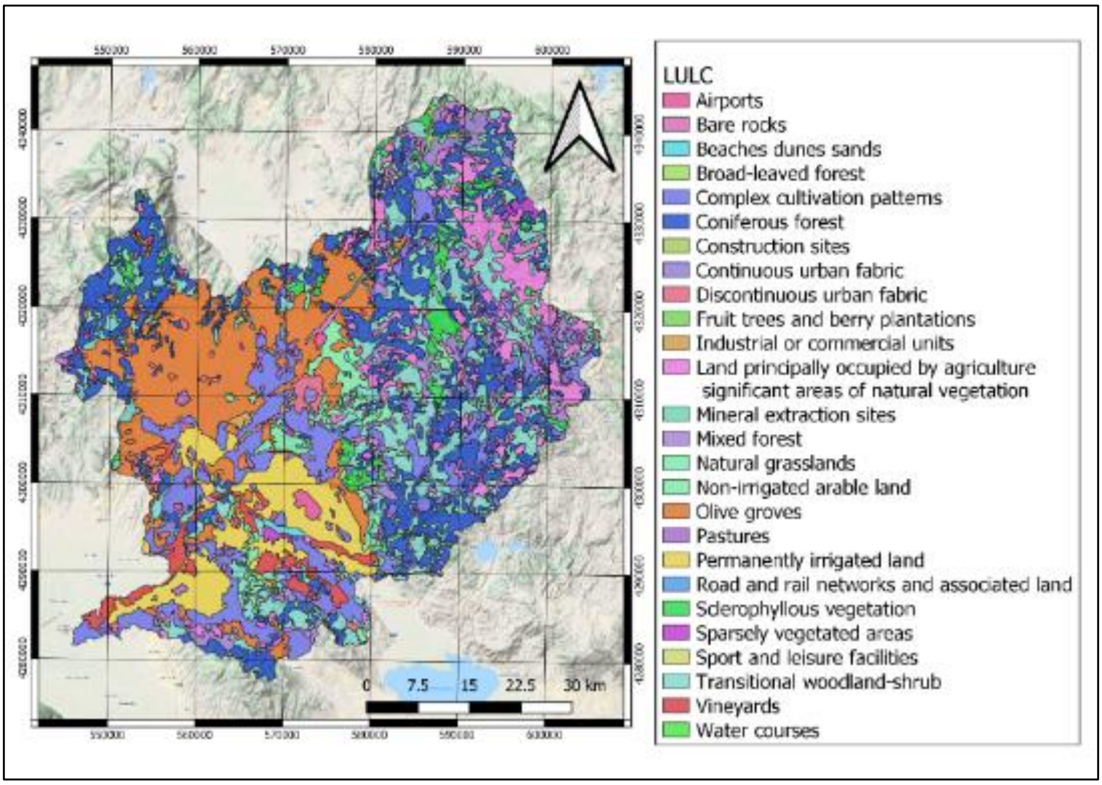

Figure 3.3. Corine 2018 Land Use / Land Cover Map of Gürdük Basin

Table 3-1. Corine Land Use / Land Cover Distribution of Gürdük Watershed

Land Use	**Percentage**
Coniferous forest	18.82%
Olive groves	16.37%
Complex cultivation patterns	15.32%
Transitional woodland-shrub	14.29%
Land principally occupied by agriculture, with significant areas of natural vegetation	9.56%
Permanently irrigated land	8.17%
Mixed forest	3.57%
Vineyards	3.14%
Natural grasslands	2.70%
Sclerophyllous vegetation	2.45%
Discontinuous urban fabric	1.64%
Non-irrigated arable land	1.18%
Pastures	0.66%
Sparsely vegetated areas	0.39%
Industrial or commercial units	0.36%
Airports	0.35%
Broad-leaved forest	0.32%
Beaches, dunes, sands	0.27%
Mineral extraction sites	0.17%
Construction sites	0.13%
Continuous urban fabric	0.09%
Fruit trees and berry plantations	0.04%
Sport and leisure facilities	0.02%

There are two municipal wastewater treatment plants located in the watershed namely Akhisar WWTP and Saruhanlı WWTP.

Solid wastes collected in lower basin are stored irregularly. In the sub-basin, agricultural activities are considered to be the main pressure sources. Last but not the least, olive oil production is intensely concentrated in the watershed (MoFWA, 2013).

3.3. Point Sources

3.3.1. Industrial Wastewater Discharges

15% of Turkey's industrial production is executed within the Aegean Region. A wide range of manufacturing activities covering almost every kind of industry is being carried out in the region. Region's raw material resources, qualified work force, transportation facilities, proximity to the inner and outer markets has become the driving force for industrial development. It is observed that the sectors are developing especially in fields such as various food-based industries, weaving, and leather production (MoFWA, 2013).

Eighteen industrial facilities have been considered within the scope of this study. As it can be seen from the Figure 3.4, industrial activities are mostly concentrated along the central part of the Gürdük Basin and (MoFWA, 2013). It can be said that, food processing, (particularly olive processing), is the main industrial activity in the region. More detailed information is given in the Figure 3.4.

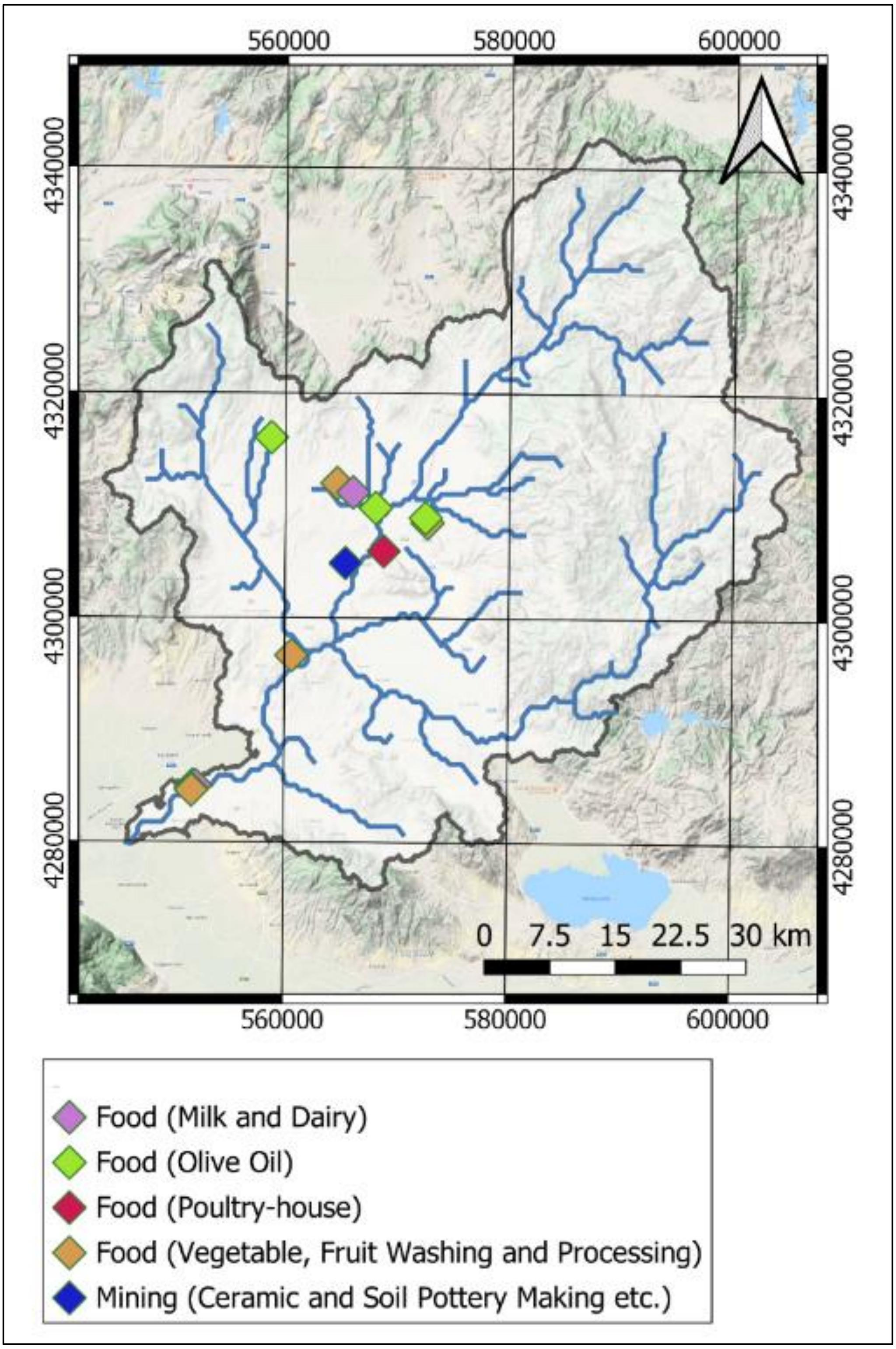

Figure 3.4. Industrial Wastewater Discharges' Locations (MoFWA, 2013)

Table 3-2. Information on Industrial Wastewater Discharges (MoFWA, 2013)

District	**Facility**	**Flow rate (m^3/day)**	**WPCR Table**	**Sector**
Akhisar	Durullar (Serali) Food Inc.	30	Table 5.9	Food (Vegetable, Fruit Washing and Processing)
Akhisar	Graniser Granit Ceramics Inc.	800	Table 7.4	Mining Industry (Ceramic and Soil Pottery.)
Akhisar	İdeal Agricultural Products Inc.	40	Table 5.9	Food (Vegetable, Fruit Washing and Processing)
Akhisar	Keskinoğlu Poultry and Breeding Enterprises Inc.	3,800	Table 5.15	Food Industry (Poultry-house)
Akhisar	Kurtuluş Oil Agricultural Products Inc.	50	Table 5.4	Food Industry (Olive Oil)
Akhisar	Uretici Food Agriculture Animal and Dairy Products Ltd.	10	Table 5.3	Food Industry (Milk and Dairy Products)
Akhisar	Yeniçağ Food Trade Inc.	30	Table 5.5	Food Industry (Olive Oil)
Akhisar	Kybele Special Food Trade Inc.	50	Table 5.9	Food (Vegetable, Fruit Washing and Processing)
Akhisar	Osman Akça Agricultural Products Inc.	1,000	Table 5.9	Food (Vegetable, Fruit Washing and Processing)
Akhisar	Yonca Food Industry Management Inc.	2,000	Table 5.9	Food (Vegetable, Fruit Washing and Processing)
Salihli	Macolive Agricultural Products Inc.	160	Table 5.9	Food (Vegetable, Fruit Washing and Processing)
Saruhanlı	Has Süt Dairy Milk Products Manufacturing	60	Table 5.3	Food Industry (Milk and Dairy)
Saruhanlı	Hasgönül Agricultural Products Inc.	150	Table 5.9	Food (Vegetable, Fruit Washing and Processing)
Saruhanlı	Özgür Agricultural Products Inc.	500	Table 5.9	Food (Vegetable, Fruit Washing and Processing)
Saruhanlı	Pagmat Food Inc.	500	Table 5.9	Food (Vegetable, Fruit Washing and Processing)
Saruhanlı	Yonca Food Canned Foods	100	Table 5.9	Food (Vegetable, Fruit Washing and Processing)
Saruhanlı	Ertürk Grape Processing Enterprises	300	Table 5.9	Food (Vegetable, Fruit Washing and Processing)
Saruhanlı	Baktat Food Inc.	150	Table 5.9	Food Industry (Olive Oil)

3.3.2. Municipal Wastewater Discharges

There are two municipal wastewater treatment plants located in the region namely Akhisar WWTP and Saruhanlı WWTP. Locations of the municipal wastewater discharge points are given in the Figure 3.5 and more detailed information on municipal wastewater treatment plants in the basin is given in Table 3.2 (MoFWA, 2013).

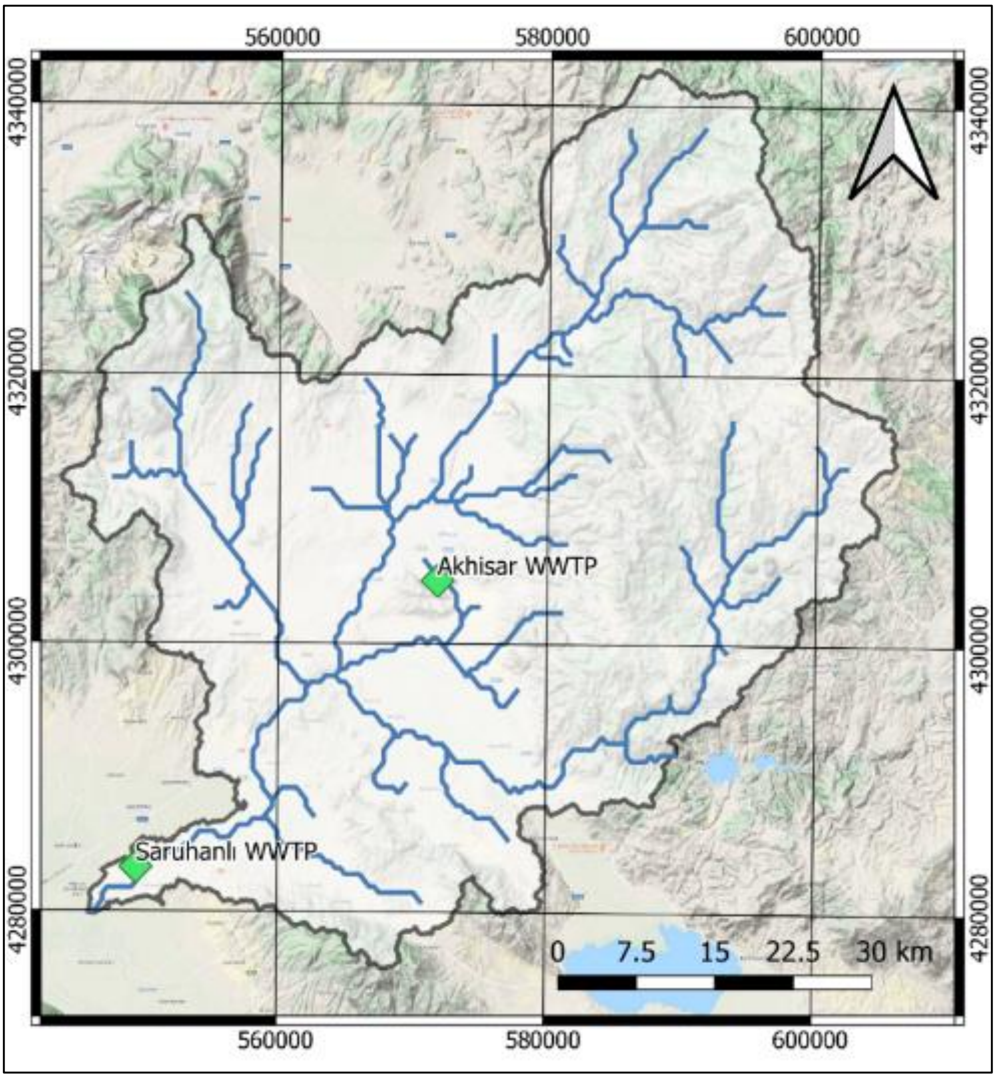

Figure 3.5. Municipal Wastewater Discharges' Locations

Table 3-3. Municipal Wastewater Discharges (MoFWA, 2013)

WWTP	Flowrate (m3/g)	Equivalent Population
Akhisar WWTP	26,000	> 100,000
Saruhanlı WWTP	5,040	10,000-100,000

As the quality of the discharged treated wastewater was unknown for all of the point sources, it was assumed that, each treatment plant is discharging the treated wastewater according to the related discharge limits for each sector specified in Water Pollution Control Regulation and Urban Wastewater Treatment Regulation. Thus discharge quality of each point source and annual pollutant load in terms of tons is given in Table 3-4.

Table 3-4. Assumed Discharge Qualities and Annual Loads of Each Point Source

Source	Flowrate (m^3/d)	COD (mg/L)	COD (tons/ year)	TSS (mg/L)	TSS (tons/ year)	TN (mg/L)	TN (tons/ year)	TP (mg/L)	TP (tons/ year)
Akhisar WWTP	26,000	120	1,139	45	427	10	94.90	2	18.98
Saruhanlı WWTP	5,040	140	258	45	83	10	18.40	2	3.68
Keskinoğlu Poultry	3,800	500	694	200	277	20	27.74	3	4.16
Yonca Canned Food	2,000	150	110	200	146	10	7.30	2	1.46
Graniser Granit Ceramics	800	80	23	100	29	10	2.92	2	0.58
Özgür Agr.	500	150	27	200	37	10	1.83	2	0.37
Pagmat Food Inc.	500	150	27	200	37	10	1.83	2	0.37
Macolive Agr.	160	150	9	200	12	10	0.58	2	0.12
Baktat Food Inc.	150	150	8	200	11	10	0.55	2	0.11
Has Gönül Agr.	150	150	8	200	11	10	0.55	2	0.11
Yonca Food	100	150	5	200	7	10	0.37	2	0.07
Has Milk	60	170	4	70	2	10	0.22	2	0.04
Kurtuluş Agr.	50	200	4	70	1	10	0.18	2	0.04
İdeal Agr.	40	150	2	200	3	10	0.15	2	0.03
Durullar Food	30	150	2	200	2	10	0.11	2	0.02
Yeniçağ Food	30	250	3	200	2	10	0.11	2	0.02
Üretici Food	10	170	1	70	0	10	0.04	2	0.01
TOTAL	**39,420**		**2,323**		**1,087**		**158**		**30**

As it can be seen from Table 3-4 Akhisar WWTP and Saruhanlı WWTP discharges the highest amounts of the wastewaters, on the other hand, Keskinoglu Poultry discharges significantly high amount of pollutant loads. More than 2000 tonnes of COD, more than 1000 tonnes of TSS, more than 100 tonnes of TN and more than 30 tonnes of TP is annually discharged directly to the watershed Figure 3.6 shows Observed Streamflow values of the discharge point of outlet (E05A018 and Total WWTP Discharge Flowrates. It can be seen that observed flow in the river can reach significantly high amounts and contribution of the WWTP discharges is fairly low.

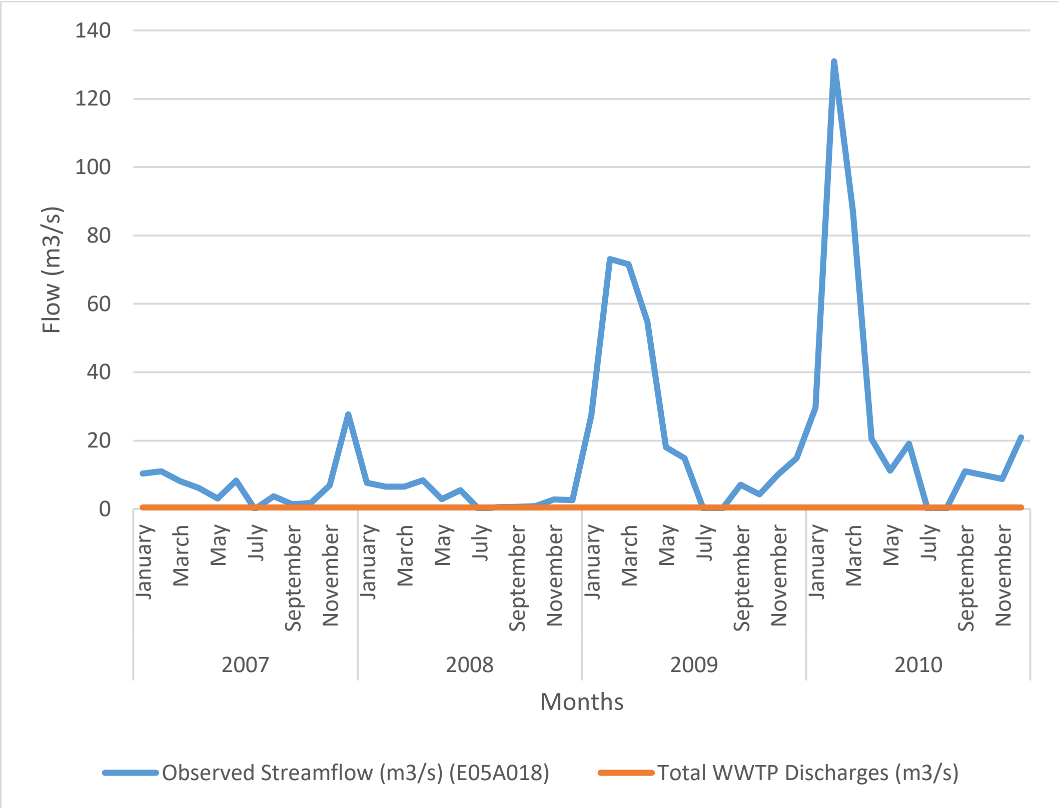

Figure 3.6. Observed Streamflow values vs Total WWTP Discharge Flowrate

3.4. Diffused Sources

The basin has an important place in the overall agriculture of the Aegean region since it has a very fertile plains formed by the Gürdük River and has a suitable climate for agriculture (MoFWA, 2013).

The average annual rainfall in the basin is around 450-800 mm, and average plant development cycle lasts as long as 176-184 days, enabling almost all types of cultivated plants to grow. Main products are olive, wheat, barley, rye, maize, oat, rice, broom, chickpea\ bean, cowpea, tobacco, cotton, sesame and potato. In addition, numerous types of vegetables such as tomatoes, fresh beans, spinach, aubergines, peppers, fresh beans, cabbages and fruit varieties such as grapes, pears, olives, apples, quince, plums, cherries, peaches, almonds, apricots and figs are also produced (MoFWA, 2013). Most of the agricultural production within the basin is being conducted at the great plain which was identified by Ministry of Agriculture and Forestry as the areas with high agricultural potential (Figure 3.7).

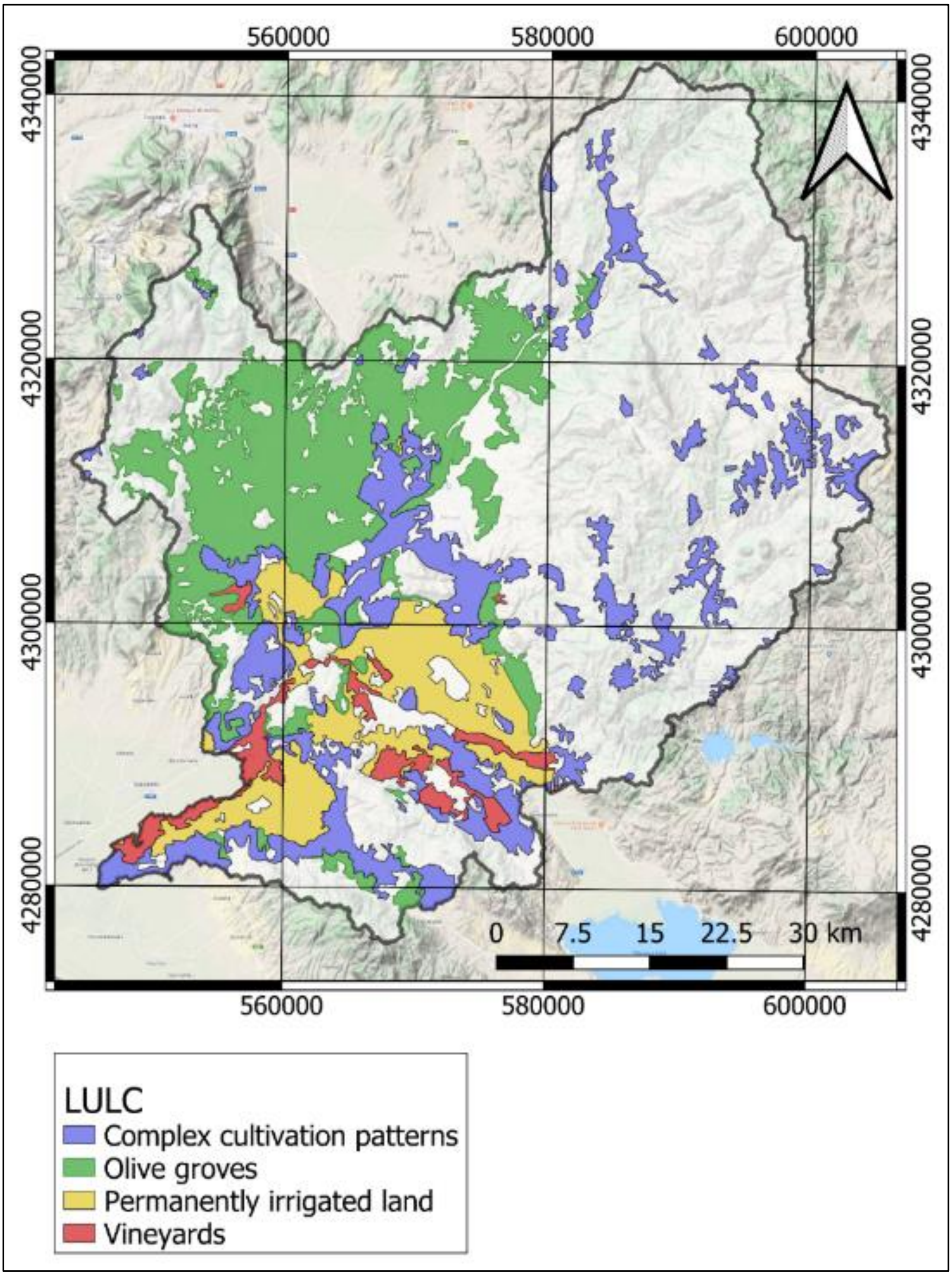

Figure 3.7. Agricultural Practices Conducted Within the Watershed

Agricultural activities are very important to consider within the scope of this study, as it is important source of diffused pollution in terms of phosphor and nitrogen. Therefore, amount of agricultural areas needs to be assessed for calculating the amount of water needed the production and the amount and type of the fertilizer utilized.

Information on the agricultural production within the year 2016 is provided from (Abolished) Ministry of Food, Agriculture and Livestock and a brief summary is provided below;

Table 3-5. Agricultural Information for Gürdük Watershed

District	**Harvested Area (da)**
Ahmetli	27,823
Akhisar	278,049
Gölmarmara	39,517
Gördes	203,980
Kırkağaç	67,466
Centre	-
Saruhanlı	147,047
Soma	120,882
Turgutlu	79,840

Since fertilizer usage is the main source of nutrient pollution, information of quantity and type of the fertilizer that is being used within the basin very important. According to the information obtained from Gediz Basin - Basin Management Plan (TUBITAK, 2018), the following types of fertilizers are being used in each district located in the watershed in a year:

- $(NH_4)_2SO_4$ 21%
- NH_4NO_3 26%
- NH_4NO_3 33%
- Urea 46%
- TSP (42-44% P_2O_5)
- DAP 18.0.46
- Composite 20.20.0

- Composite 15.15.15
- MAP 11.52
- KNO_3 13.0.46
- KSO_4 50%
- $CaNO_3$ 15.5 + 26.5
- 18.24.12
- 13.24.12 Composite
- 25.10.20+20 (SO_3)
- 12.10.25.20+ (SO_3) + MA
- 15.15.15 + ME

As stated in Chapter 3.2, the majority of the basin is situated within Akhisar District of Manisa Province boundaries, on the other hand, only small parts Ahmetli, Kırkağaç, Soma and Turgutlu Districts are located within the Watershed Boundaries. Therefore, it would be wrong to assume that, all the fertilizer known to be used within a district is also being used within the watershed boundaries. Thus, it was assumed that there is a correlation between the percentage of a district's area located in the watershed and the amount of fertilizer usage of the district within the watershed boundaries.

Table 3-6, shows the total area of each district and the amount of the district within the watershed. As it can be seen below, 91.90 % of Akhisar District is located within the Gürdük Wateshed, which means 91.90 % fertilizer known to be used in Akhisar District is used within the watershed.

Table 3-6. Percentages of Each District within the Basin

District	Area in watershed (km^2)	Total Area of District (km^2)	% of District
Akhisar	1511.69	1645	91.90%
Saruhanlı	418.52	771	54.28%
Gölmarmara	104.5	310	33.71%
Gördes	108.35	902	12.01%
Kırkağaç	14.74	541	2.72%
Sındırgı	35.99	1395	2.58%
Soma	7.82	820	0.95%
Turgutlu	2.9	549	0.53%
Ahmetli	1.17	227	0.51%

The fertilizer usage information in Gürdük Basin is given in Table 3-7 according to the districts' percentages.

Table 3-7. Fertlizer Usage Information of the Gürdük Basin (tons / year) (TUBITAK, 2018)

District	Ahmetli	Akhisar	Gölmarmara	Gördes	Kırkağaç	Köprübaşı	Saruhanlı	Soma	Turgutlu
$(NH_4)_2SO_4$ 21%	252	4,196	509	337	92	48	2,279	14	1,520
NH_4NO_3 26%	121	818	137	714	3	91	324	6	1,103
NH_4NO_3 33%	429	3,603	796	527	43	174	1,638	13	1,445
Urea 46%	100	2,677	318	691	127	111	3,158	23	3,614
TSP (42-44% $P2O_5$)	12	95	7	0	5	0	204	2	149
DAP 18.0.46	97	2,391	257	263	39	94	919	10	1,029
Composite 20.20.0	23	1,318	211	1,767	30	115	880	13	689
Composite 15.15.15	107	2,507	494	215	35	15	1,802	17	1,264
MAP 11.52	8	114	36	15	1	0	790	0	41
KNO_3 13.0.46	7	154	77	5	1	16	441	0	55
$CaNO_3$ 15.5 + 26.5	2	39	39	0	2	0	21	0	24
18.24.12	3	0	0	0	0	0	0	0	0
13.24.12 Composite	58	1,340	157	302	48	70	542	4	37
25.10.20+20 (SO_3)	0	104	30	48	3	0	0	1	133

Table 3 -7 (cont'd). Fertlizer Usage Information of the Gürdük Basin (tons / year) (TUBITAK, 2018)

District	**Ahmetli**	**Akhisar**	**Gölmarmara**	**Gördes**	**Kırkağaç**	**Köprübaşı**	**Saruhanlı**	**Soma**	**Turgutlu**
12.10.25.20+ (SO_3) + MA	0	15	0	9	3	0	0	0	5
15.15.15 + ME	163	1,844	337	224	56	49	1,094	5	1,285
TOTAL	1,430	21,357	3,486	5,131	492	798	14,436	108	12,639

Fertilizer type possesses a great importance since the it affects the amount of nutrient load to be introduced to soil. Total load of nutrient which are being introduced to soil via fertilizer usage was calculated as percentage nutrients in each fertilizer is known (Table 3-8).

Table 3-8. Nutrient Ratios of Each Fertilizer

Parameter	**NH_3-N**	**Org-N**	**NO_3-N**	**P_2O_5-P**
Ammonium Sulphate 21%	21%	0%	0%	0%
Ammonium Nitrate 26%	13%	0%	13%	0%
Ammonium Nitrate 33%	17%	0%	17%	0%
Urea 46%	0%	46%	0%	0%
TSP (42-44% P_2O_5)	0%	0%	0%	44%
DAP 18.0.46	13%	0%	0%	16%
Composite 20.20.0	20%	0%	0%	20%
Composite 15.15.15	15%	0%	0%	15%
MAP 11.52	11%	0%	0%	52%
Potassium Nitrate 13.0.46	0%	0%	13%	0%
$Ca(NO_3)_2$ 15.5 + 26.5	1%	0%	14%	0%
18.24.12	9%	9%	0%	24%
13.24.12 Composite	8%	5%	0%	24%
25.10.20 + 20 (SO_3)	8%	2%	0%	25%
12.10.25.20+ (SO_3) + MA	8%	4%	0%	10%

Table 3-8 (Cont'd). Nutrient Ratios of Each Fertilizer

Parameter	**NH_3-N**	**Org-N**	**NO_3-N**	**P_2O_5-P**
15:15:15 + ME	6%	9%	0%	15%
12.30.12	9%	3%	0%	30%
Crop 13.25.5	10%	3%	0%	25%

Thus, nutrient load of each district was identified (Table 3-9). As it can be seen from table below, more than 7000 tons of total nitrogen and 3500 tons of total phosphorus is introduced to soil every year in Gürdük Watershed.

Table 3-9. Nutrient loads of the districts located in Gürdük Watershed (tons/year)

District	**NH_3-N**	**Org-N**	**NO_3-N**	**TN**	**P_2O_5-P**	**In-P**	**TP**
Akhisar	2632.73	1393.02	689.78	4715.53	1660.61	730.67	2391.28
Saruhanlı	849.45	863.16	203.84	1916.45	759.3	334.09	1093.39
Gölmarmara	150.12	62.38	55.55	268.05	92.69	40.78	133.47
Gördes	92.87	46.09	23.44	162.4	72.11	31.73	103.84
Kırkağaç	23.56	30.41	3.63	57.6	19.09	8.4	27.49
Turgutlu	7.01	9.94	2.19	19.14	4.54	2	6.54
Soma	3.76	3.33	0.85	7.94	2.73	1.2	3.93
Ahmetli	0.96	0.33	0.45	1.73	0.43	0.19	0.62
TOTAL	**3760.46**	**2408.66**	**979.73**	**7148.84**	**2611.5**	**1149.06**	**3760.56**

3.5. Water Quality Evaluation

In order to analyse water quality status of Gürdük River Basin, data of the DSİ Quality Monitoring Station numbered 05-02-00-061 (2008-2018) as upstream data and DSİ Quality Monitoring Station numbered 05-02-00-003 (2016 (2 data), 2018 (12 data)) was used (Figure 3.8). Furthermore, four additional water quality from 2013 obtained from *Final Report of Monitoring and Reference Points Determination for Gediz River Basin*" prepared for (Abolished) Ministry of Forestry and Water Affairs was used as one of the monitoring points was located next to the 05-02-00-003.

Water quality evaluation of the basin was done according to Surface Water Quality Management Regulation and Water Quality Indices of Suquia, Aksu and Smith's Index respectively.

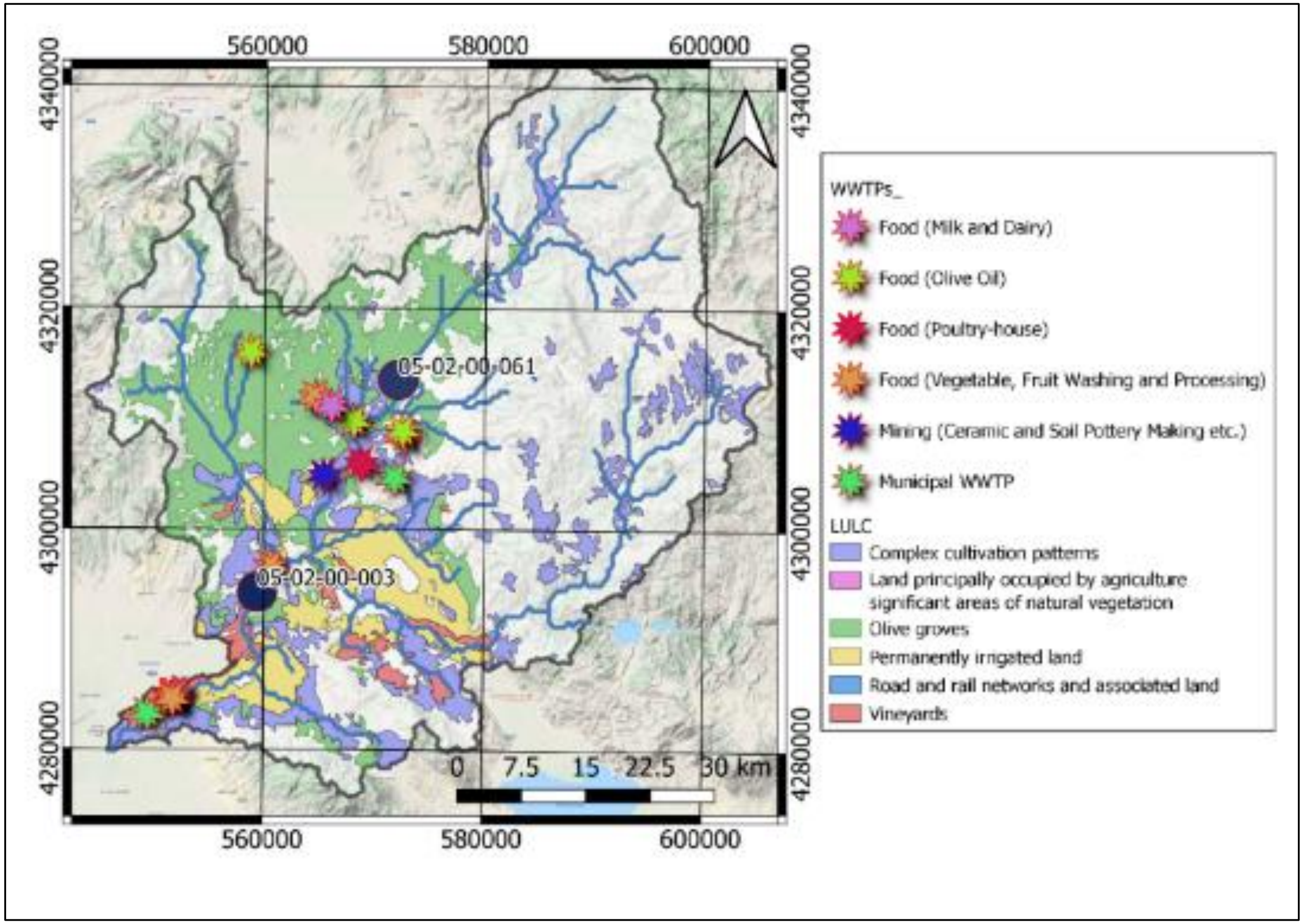

Figure 3.8. Location of DSİ Quality Monitoring Stations numbered 05-02-00-061 and 05-02-00-003

Table 3-10. Surface Water Quality of Gürdük Basin according to SWQR

Parameter	Unit	05-02-00-061 (Upstream)		05-02-00-003 (Downstream)	
		Analysis Result	SWQR Status	Analysis Result	SWQR Status
pH	-	8.08	Class I	7.81	Class I
Conductivity	µS/cm	280	Class I	290	Class I
DO	mg/L	8.27	Class I	**3.8**	**Class III**
Color (RES 620 nm)	m^-1	<0,1	Class I	<0,1	Class I
Color (RES 525 nm)	m^-1	<0,1	Class I	<0,1	Class I
Color (RES 436 nm)	m^-1	<0,1	Class I	<0,1	Class I
COD	mg/L	8.2	Class I	**64.42**	**Class III**
BOD	mg/L	4.25	Class I	**26.49**	**Class IV**
S^{-2}	mg/L	<0,1	Class I	<0,1	Class I
NO_3-N	mg/L	2.18	Class I	1.9	Class I
O-PO_3	mg/L	0.18	Class I	**3.49**	**Class IV**
Fluoride	mg/L	0.1	Class I	0.16	Class I
Manganese	mg/L	0.03	Class I	0.015	Class I
Total Phosphorus	mg/L	0.1	Class I	**4.30**	**Class IV**
Selenium	mg/L	0.5	Class I	0.5	Class I
Oil and grease	mg/L	<10	Class I	<10	Class I
Total Nitrogen	mg/L	2.2	Class I	**15.3**	**Class III**
TKN	mg/L	0.6	Class I	**18.1**	**Class IV**
Ammonium Nitrogen	mg/L	0.06	Class I	**8.3**	**Class IV**

As it can be seen from the Table 3-6, water quality of the watershed in the upstream of the watershed is in good state as all the parameters are in **Class-I** status. On the other hand, the water quality at the downstream of the Gürdük Basin is **Class-I** in terms of pH, Conductivity, Color, S^{-2}, NO_3-N, Fluoride, Manganese, Selenium and Oil and grease, **Class III** in terms of COD, Total Nitrogen and **Class IV** in terms of BOD, Total Phosphorus, TKN and Ammonium Nitrogen. Overall, Gürdük River water is considered to be a **Class IV** type water and therefore, it is safe to say that, Gürdük Basin is under organic and nutrient contamination threat.

3.6. Water Quality Indices

Water quality status of the watershed was evaluated for the upstream and downstream of the watershed with three different water quality indices. Results have shown that the basin is considered to be in good status in the upstream and in bad status in the upstream;

- Suquia WQI is calculated for the upstream as 80.95 (Good) and for the downstream as 66 (Medium)
- Aksu WQI is calculated for the upstream as 0.86 (Good) and for the downstream as 2 (Poor)
- Smith's Index is calculated for the upstream as 68.8 (Good) and for the downstream as 46 (Medium)

3.7. Evaluation of Results

Water Quality of the Gürdük Basin was evaluated within the scope of Surface Water Quality Management Regulation and three different WQIs. Each WQI has different concern as different parameters with different relative weights are considered.

A summary of the evaluation is given in Table 3-11.

Table 3-11: Water Quality Summary Matrix

	05-02-00-061 (Upstream)		05-02-00-003 (Downstream)		
Parameter	**Result**	**Class**	**Result**	**Class**	**Limit**
SWQR	**-**	**Class I**	BOD=26.49 mg/L O-PO_3=3.49 mg/L TP=9 mg/L TKN=12 mg/L NH_4-N=12 mg/L	**Class IV**	BOD>20 mg/L O-PO > 0.65 TP>0.8 mg/L TKN>5 mg/L NH_4-N>2 mg/L
Suquia WQI	80.95	**Good (convenient for aquatic life)**	70	**Medium (needs further treatment)**	> 90: Excellent 70 – 90: Good 50 – 70: Medium 25 – 50: Poor 0 – 25: Very Poor
Aksu WQI	0.86	**Good (convenient for potable uses)**	0.5	**Good (convenient for potable uses)**	0 – 0.5: Excellent 0.5 – 1: Good 1 – 2: Medium 2 – 3: Poor > 3: Very Poor
Smiths Index	68.8	**Good (good general quality)**	58.9	**Medium (needs further treatment)**	> 80: Excellent 60 – 80: Good 40 – 60: Medium 20 – 40: Poor 0 – 20: Very Poor

As it can be seen from Table 3-11, downstream water quality can be evaluated as medium quality water for aquatic, potable and general usage whereas upstream water quality is in good status.

Due to the fact that Aksu Index considers Guidelines for drinking-water quality of WHO, an internationally recognised organisation it can be considered as a more reliable source of assessment. Moreover, since it uses a set of water quality limits, it would be more appropriate to use this WQI or any of its modification for water quality evaluation for future studies.

Many types of agricultural activities are being performed in the watershed and cattle, sheep and poultry farming activities are heavily conducted within the area. This fact constitutes an important environmental pressure on the watershed.

Seventeen of the eighteen industrial wastewater discharge points belonged to food industry and many of them were related to olive processing industries. Considering that, nutrient parameters was higher and exceeding the limits of Surface Water Quality Management Regulation, agricultural activities and olive processing industry is considered to be the main reason behind the poor water quality status of the Gürdük Watershed.

The fact that upstream of the water quality is in very good status, however; water quality has worsened in the downstream shows the activities conducted within the basin have significantly adverse effects on the watershed. COD, TN and TP values are shown in Figure 3.9 and Figure 3.10 to have a better understanding on the water quality of the watershed outlet (05-02-00-003). As shown in the figures, water quality values tend to show high values to have a better watershed management.

As it can be seen from the figures, pollution status can reach significantly high values, especially in dry seasons (June – October). General trend of the pollution in the watershed shows that water quality status can vary due to time which means it is highly dependant on the activities conducted within the basin.

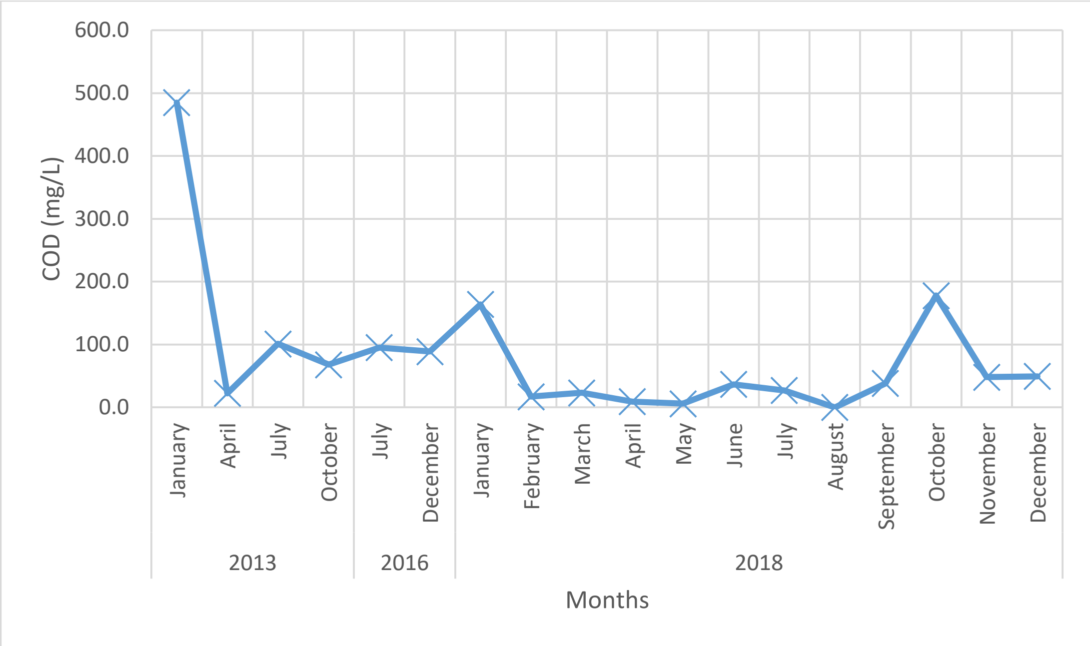

Figure 3.9. COD Analysis Results of 05-02-00-003

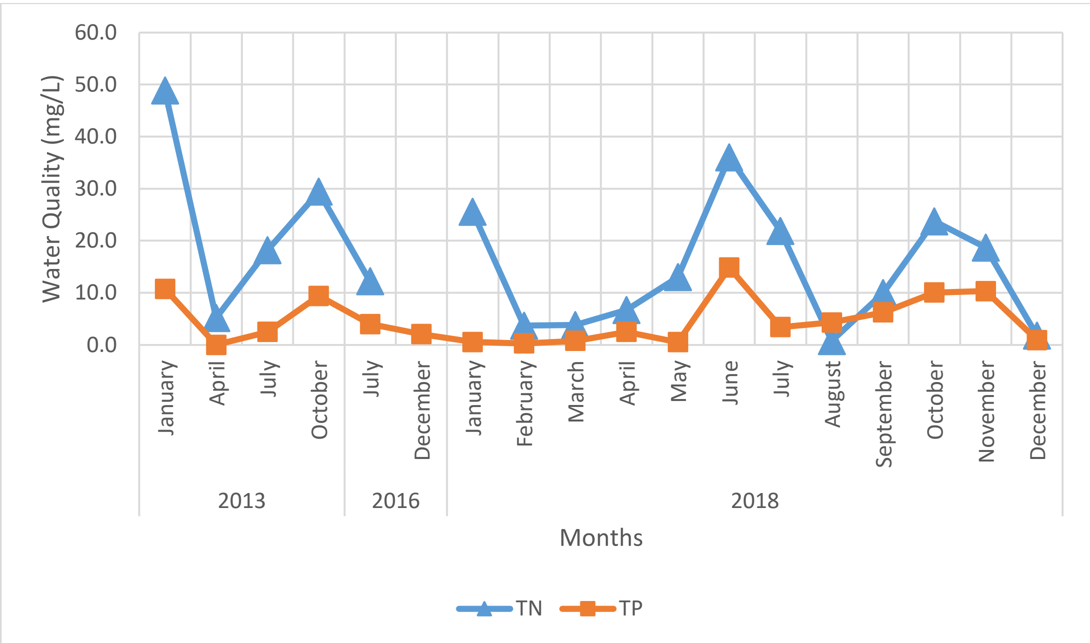

Figure 3.10. TN & TP Analysis Results of 05-02-00-003

CHAPTER 4

SWAT MODEL APPLICATION

The goal of this study was to evaluate the water quality in Gürdük Watershed and develop management strategies to improve the water quality via analysing the point and diffused sources of pollution. SWAT model was selected for this study since it is a proper mean for water quality modelling as it has a competence to analyse both point sources and agricultural practices, and eliminate some uncertainties. Digital Elevation Model (DEM), soil texture map, land use/land cover (LULC) map, meteorological data and information on point sources agricultural management information are required to build the model. The sources and definitions of data used for Gürdük watershed are summarized in Table 4-1.

Table 4-1. Model Input Data Information for Gürdük Watershed (Sources and Descriptions)

Data Type	Source	Data Description/Properties
Topography	Geodatabase of Final Report of Monitoring and Reference Points Determination for Gediz River Basin	SWAT uses DEM to create sub-basins and classify slope. 10 m x 10 m resolution was used.
LULC	CORINE Land Cover (CLC) inventory – Corine 2018 Land Cover Map	For land use and use classification (agricultural land, pasture, forest etc.).
Soil	FAO - The Digital Soil Map of the World Version 3.6	Properties such as soil hydrologic group, maximum rooting depth, fraction of porosity that affects water routing was obtained.
Meteorology	General Directorate of Meteorology (Akhisar 17184)	Daily precipitation, temperature, relative humidity, wind speed and solar radiation information was used for water budget calculations (01/01/2005 – 30/12/2018).

Table 4-1 (Cont'd). Model Input Data Information for Gürdük Watershed (Sources and Descriptions)

Data Type	Source	Data Description/Properties
Point Sources	Final Report of Monitoring and Reference Points Determination for Gediz River Basin	Information on location of the WWTPs and daily flow rates were obtained
Agricultural Management Information	Final Report of Monitoring and Reference Points Determination for Gediz River Basin Face to face interviews with Provincial Directorate of Agriculture and Forestry Gediz Basin - Basin Management Plan. Kocaeli: Ministry of Agriculture and Forestry.	Information on main cultivated products, agricultural management schedule and fertilizer usage information was obtained.

4.1. Model Set-up

4.1.1. Digital Elevation Model (DEM)

A DEM file in the format of ESRI GRID is needed for delineation of watershed. DEM file of the Gürdük Basin was obtained from the geodatabase of *Final Report of Monitoring and Reference Points Determination for Gediz River Basin*" prepared for (Abolished) Ministry of Forestry And Water Affairs and it is given in Figure 4.1. DEM is also required to evaluate sub-basin parameters, like slope, length of slope and to establish stream network characterization (Busteed, 2009).

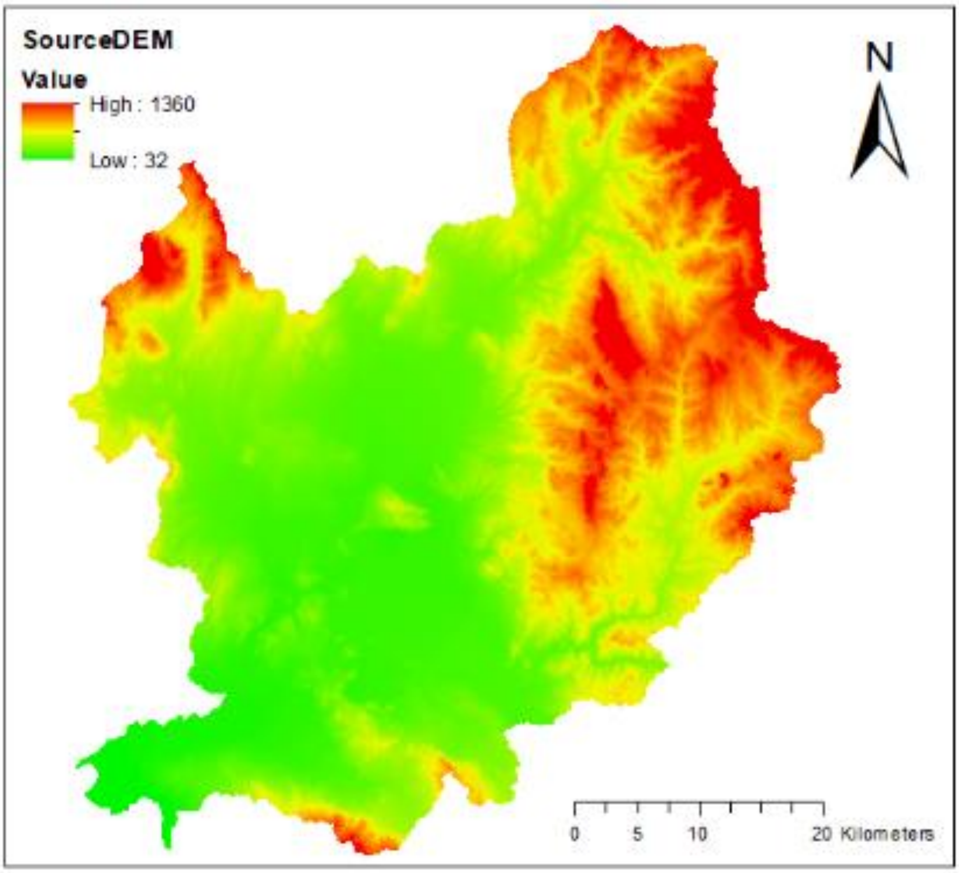

Figure 4.1. DEM of Gürdük Basin (MoFWA, 2013)

4.1.2. Watershed Delineation

Watershed delineation must be conducted so as to complete land and routing phases such as hydrology, transport of nutrients and pesticides. Sub-watersheds need to be created by DEM after an automatic procedure. ArcGIS and Spatial Analyst extension functions are needed to conduct watershed delineation. Furthermore, number of sub-watersheds can be specified by the user (Güzel, 2010). In this study, outlet points were identified automatically by SWAT. After watershed delineation step of Gürdük Basin, total number of 39 outlets and 39 sub-watersheds were created (Figure 4.2).

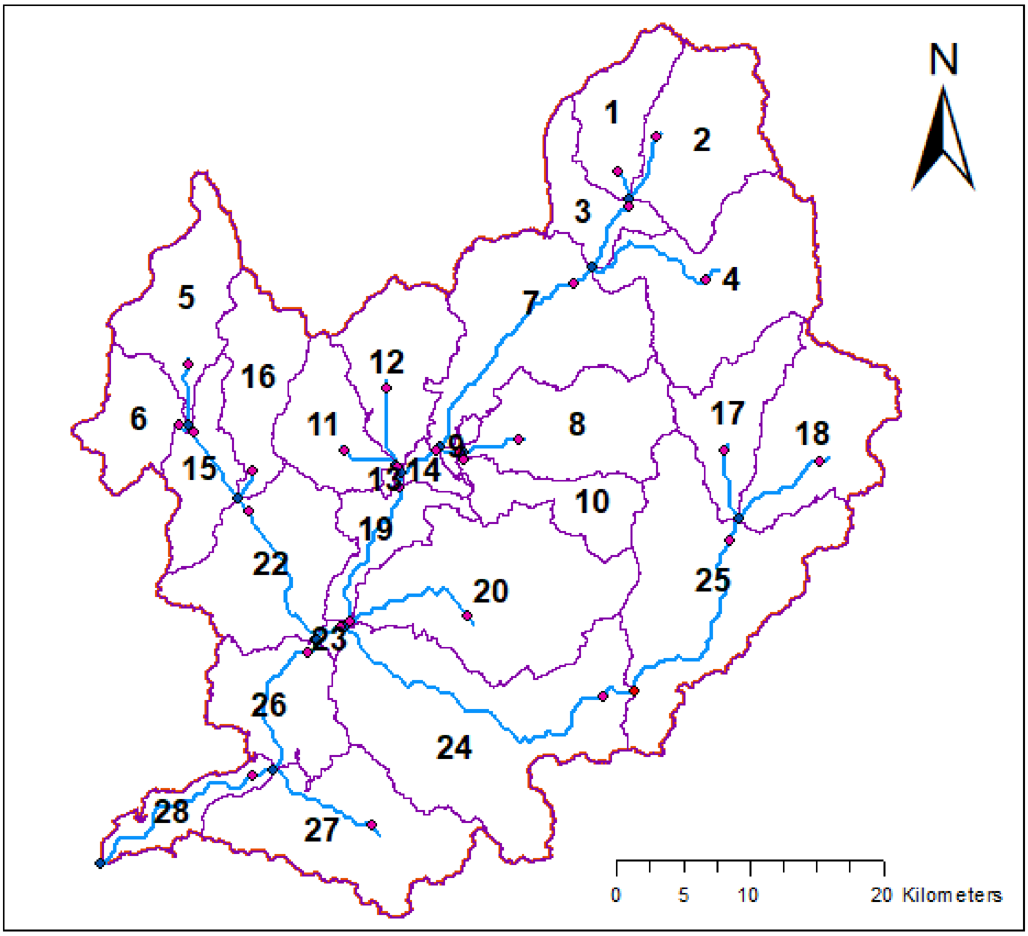

Figure 4.2. Result of Watershed delineation

4.1.3. Land use and land cover

SWAT requires Land Use / Land Cover (LULC) data in ESRI GRID shape file or feature class formats. The LULC Map to be used in SWAT must over at least 95 % of the study area to be simulated (Güzel, 2010). In this study, LULC Map obtained from The CORINE Land Cover (CLC) inventory – Corine 2018 Land Cover Map – was used after establishing a land use/land cover look up table for the SWAT, determining accurate SWAT land use/land cover codes for each category and identifying a user look up table that includes SWAT codes for each type of LULC. The resulting LULC map is given in Figure 4.3.

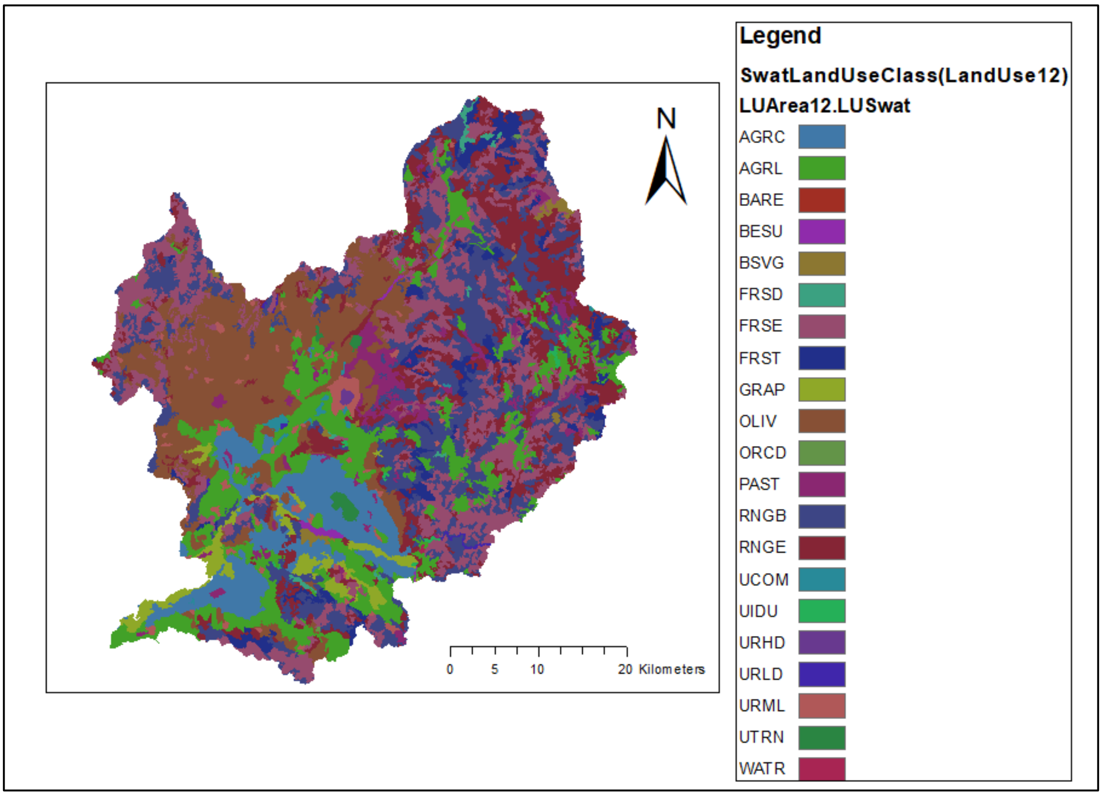

Figure 4.3. Land use/Land cover map of the Gürdük Watershed

Land cover data is one of the most significant GIS layers required for the model. Land cover simply determines runoff, nutrient loads and erosion rates (Busteed, 2009).

According to the created LULC map, agricultural land-generic, forest-evergreen, range-brush, olives, range-grasses, mixed forest, vineyard, residential-med/low density, pasture, forest-deciduous, transportation, commercial, industrial, water, arid range, residential-high density and orchards are present in the basin (Table 4-2).

Table 4-2. LULC Information of the Gürdük Basin

Land Use Class	LULC Code	Area (ha)	Percentage (%)
Range-Brush	RNGB	41536.72	18.15
Forest-Evergreen	FRSE	41332.11	18.06
Olives	OLIV	37593.52	16.43
Agricultural Land-Generic	AGRL	31250.34	13.65
Range-Grasses	RNGE	29964.25	13.09
Agricultural Land-Close-grown	AGRC	17134.22	7.49
Forest-Mixed	FRST	8348.253	3.65
Pasture	PAST	7329.627	3.2
Vineyard	GRAP	5543.493	2.42
Residential-Med/Low Density	URML	3473.789	1.52
Transportation	UTRN	862.4743	0.38
Forest-Deciduous	FRSD	848.9433	0.37
Commercial	UCOM	782.6584	0.34
Industrial	UIDU	458.9542	0.2
Residential-Low Density	URLD	345.7058	0.15
Residential-High Density -->	URHD	205.8254	0.09
Orchard	ORCD	85.8864	0.04

4.1.4. Soil properties

For this study, The Digital Soil Map of the World Version 3.6, (FAO, 2003) was used. Soil texture parameters for the watershed is given Table 4-3.

Table 4-3. Soil database parameters of SWAT model (Arnold J. G., 2012)

Parameter	Definition
SNAM	Soil name to be seen in HRU summary tables (optional).
NLAYERS	Number of layers (max 10, and max depth of each layer is 2,5 m)
HYDGRP	Soil hydrologic group (A, B, C,D)
SOL_ZMX	Maximum rooting depth of soil profile (mm). If no depth is specified, the model assumes the roots can develop throughout the entire depth of soil profile (required)
ANION_EXCL	Fraction of porosity (void space) from which anions are excluded (optional).
SOL_CRK	Potential or maximum crack volume of soil profile expressed as a fraction of the total soil volume (optional).
TEXTURE	This data is not processed by the model (optional).
SOL_Z1	Depth from soil surface to bottom of the layer (mm) (required).
SOL_BD1	Soil bulk density (1,1-1,9 μ/m^3, g/cm^3) (required).
SOL_AWC1	Available water capacity of soil layer (mmH_2O/mm soil) (required).
SOL_K1	Saturated hydraulic conductivity (mm/hr) (required).
SOL_CBN1	Organic carbon content (% soil weight) (required).
CLAY1	Clay content, percentage of soil particles which are < 0.002 mm in equivalent diameter (% soil weight) (required).
SILT1	Silt content, percentage of soil particles which have an equivalent diameter between 0.05 and 0.002 (% soil weight) (required).
SAND1	Sand content percentage of soil particles which have an equivalent diameter between 2 and 0.05 (% soil weight) (required).
ROCK1	Rock fragment content, the percent of sample which has a particle size diameter >2 mm (% total weight) (required).
SOL_ALB1	Moist soil albedo. The ratio of the amount of solar radiation reflected by body to the amount incident upon it. (fraction) (required).
USLE_K1	USLE equation soil erodibility factor (metric ton m^2 hr/ m^3 metric ton cm) (If the sand and clay content of soil is high, less erodible) (required).
SOL_EC1	Electrical conductivity (dS/m)

The created Soil Map of the Gürdük Basin is presented in Figure 4.4 and Soil texture parameters of the Gürdük Basin is given in Table 4-4.

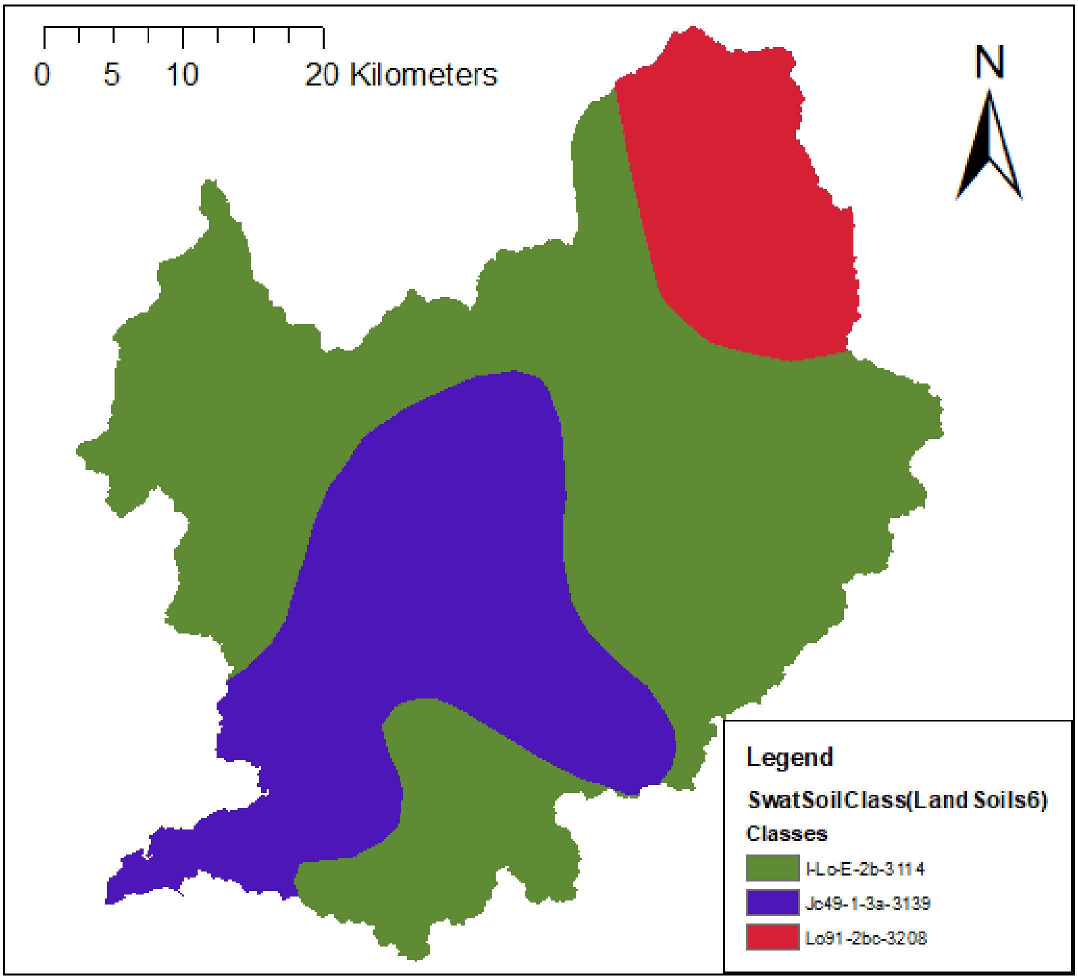

Figure 4.4. Soil Map of the Gürdük Watershed

Table 4-4. Soil texture parameters of the Gürdük Basin

SNAM	I-Lc-E-2b-3114	Jc49-1-3a-3139	Lo91-2bc-3208
NLAYERS	2	2	2
HYDGRP	D	C	D
SOL_ZMX	460	1000	800
ANION_EXCL	0.5	0.5	0.5
SOL_CRK	0.5	0.5	0.5
TEXTURE	LOAM	LOAM	LOAM
SOL_Z1	300	300	300
SOL_BD1	1.3	1.2	1.4
SOL_AWC1	0.078	0.175	0.106
SOL_K1	8.21	13.39	5.95
SOL_CBN1	1.2	1.1	1
CLAY1	23	23	22
SILT1	35	33	34
SAND1	42	43	44
ROCK1	0	0	0
SOL_ALB1	0.0484	0.0587	0.0712
USLE_K1	0.2449	0.3148	0.287
SOL_EC1	0	0	0

4.1.5. Slope Characteristics

Slope features of the watershed must be identified for using SWAT as it has great importance on water, sediment and nutrient transport. SWAT can either be used with multiple number of slopes or with single slopes (Güzel, 2010). For this study, multiple slopes were used by specifying the upper limits of the slopes, as single slope option tends to simulate whole watershed with the mean slope value. Within this study, study area was classified in to three slope classes, 0-10 %, 10-25 %, and 25-9999 %. Results of the slope characterization is given in Table 4-5 and Figure 4.5.

Table 4-5. Gürdük Basin slope characteristics

Slope (%)	Area (ha)	Percentage (%)
0-10	98149.3602	42.88
10-25	60464.1595	26.42
25-9999	70262.4103	30.70

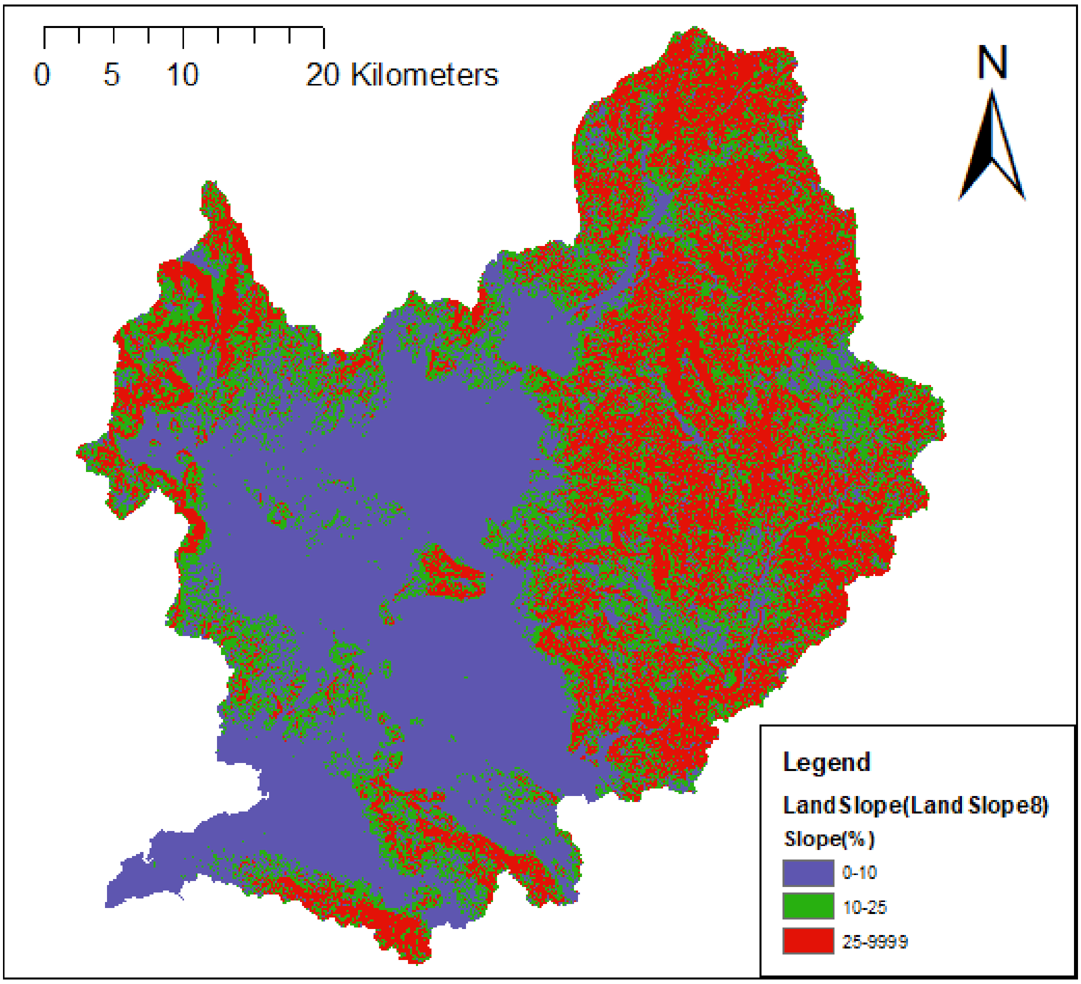

Figure 4.5. Gürdük Basin Slope Characterization Result

4.1.6. Hydrological Response Unit (HRU) analysis

The smallest unit of SWAT is a Hydrological response unit (HRU). A HRU means a section of the sub-watershed with a unique land use, soil texture and slope combination. After conducting the watershed delineation step, HRUs were created considering specified ratios of land use, soil texture and slopes between 0% and 100%.

HRUs are important as each one consists of different land management practices such as fertilizer usage, irrigation schedule, crop growth etc. having sub-basins with a dominant type of land use, soil type, and land management practices so as to have sub-basins as HRU as well (Gassman, 2007).

The hydrologic balance was calculated for a HRU, by simulating canopy interception of precipitation, partitioning of precipitation, snowmelt water, and irrigation water between surface runoff and infiltration, redistribution of water within the soil profile, evapotranspiration, lateral subsurface flow from the soil profile, and return flow from shallow aquifers (Gassman, 2007). The map showing the created HRUs is given in Figure 4.6.

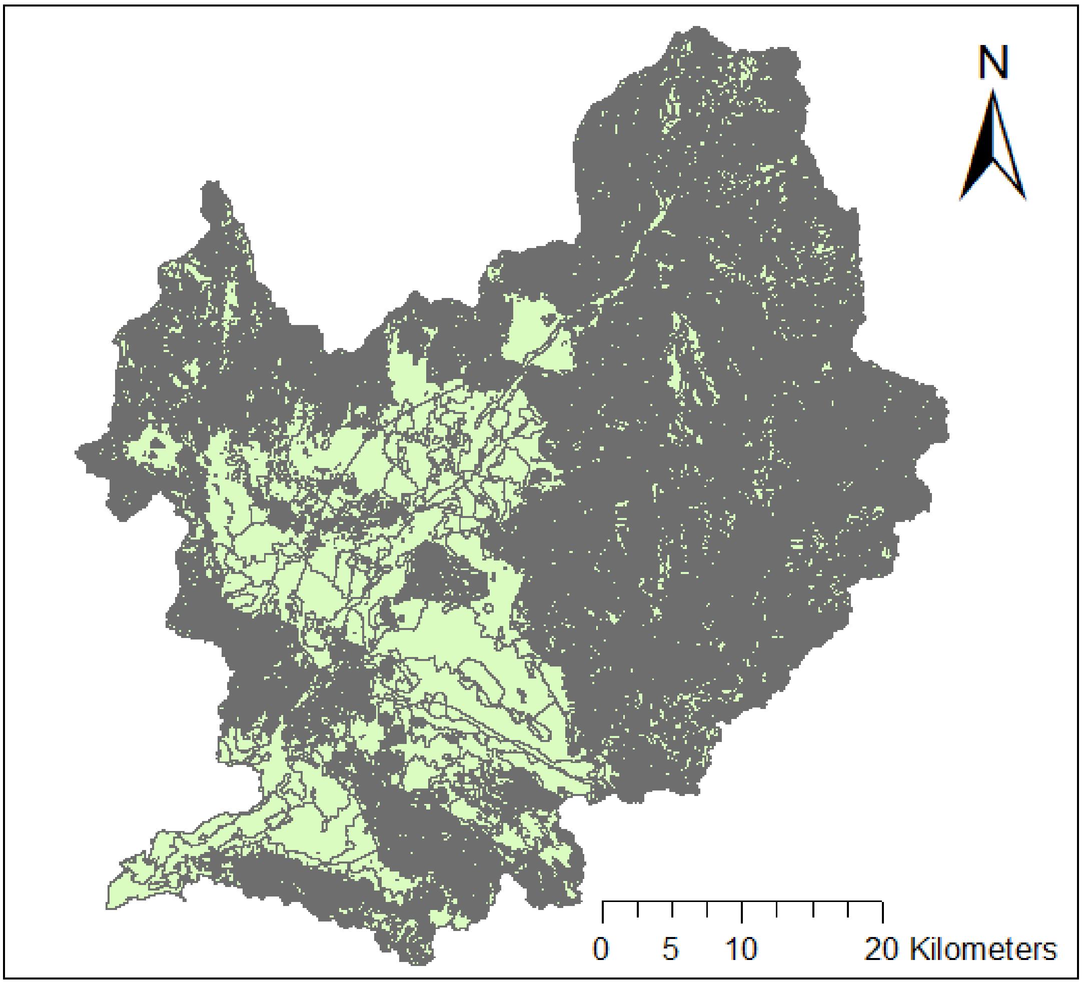

Figure 4.6. Created HRU Map

4.1.7. Meteorological data

Meteorological data is one of the most critical input data for SWAT. Adequacy of the meteorological dataset is therefore key to have a representative simulation. The main required meteorological parameters for SWAT are precipitation and temperature as well as solar radiation, wind velocity, relative humidity. Weather gage location that includes latitude, longitude and elevation are also needed. SWAT needs daily or sub-daily precipitation data. Unlimited number of precipitation gages in a simulation can be used for the study as long as they are located in the study area (Güzel, 2010).

For this study daily data obtained meteorological stations of Ministry of Agriculture and Forestry, General Directorate of Meteorology, namely; Akhisar 17184, (01/01/2005 – 30/12/2018) was used. Location of the meteorological station is presented in Figure 4.7. Moreover; measured precipitation, temperature, wind velocity, relative humidity values are given in Figure 4.8 to Figure 4.12.

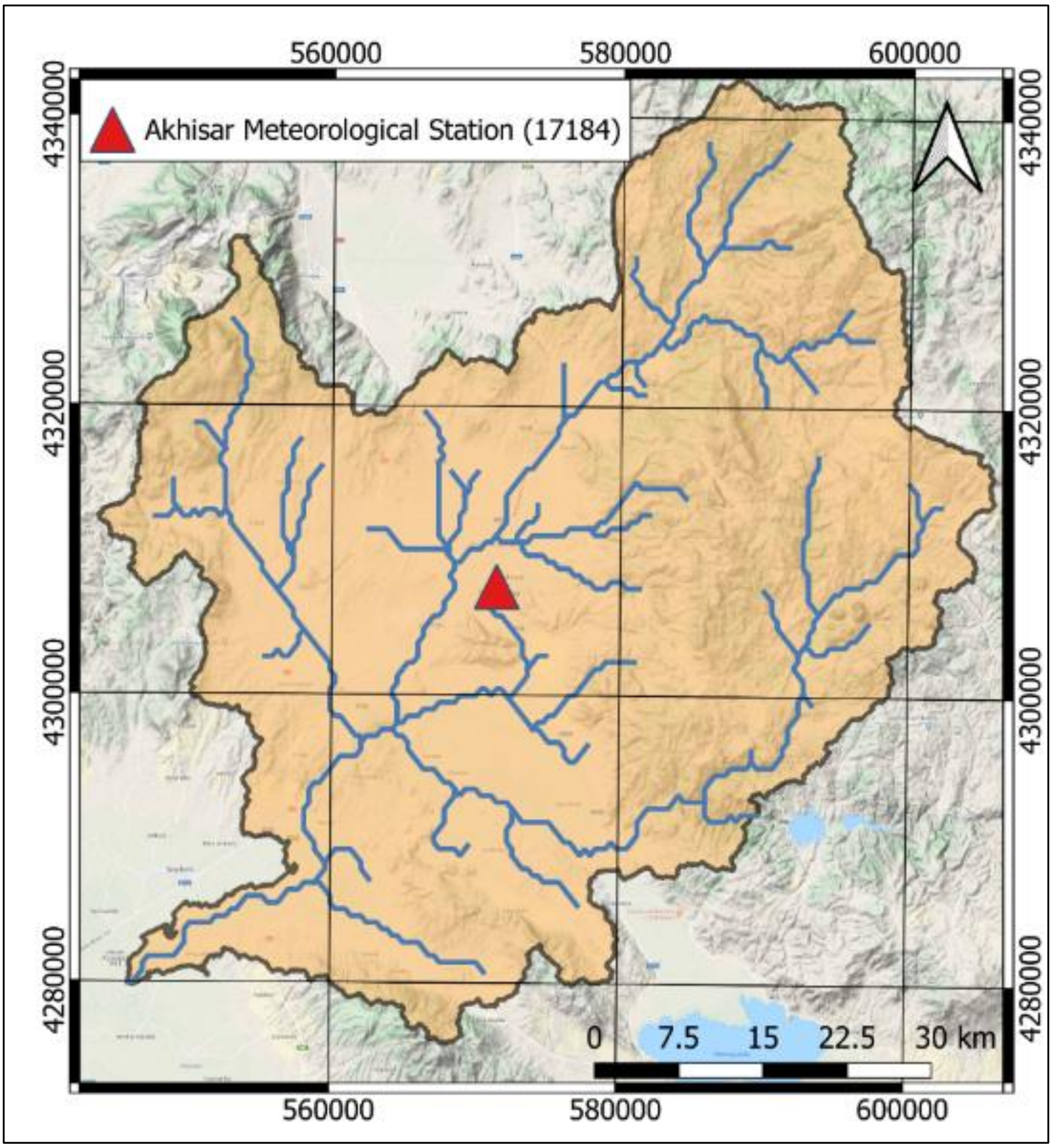

Figure 4.7. Location of Akhisar 17184 Meteorological Station

When the average maximum temperature values measured at the Akhisar Station are evaluated, it is seen that maximum temperature is observed during August as 35.74 °C (Figure 4.8).

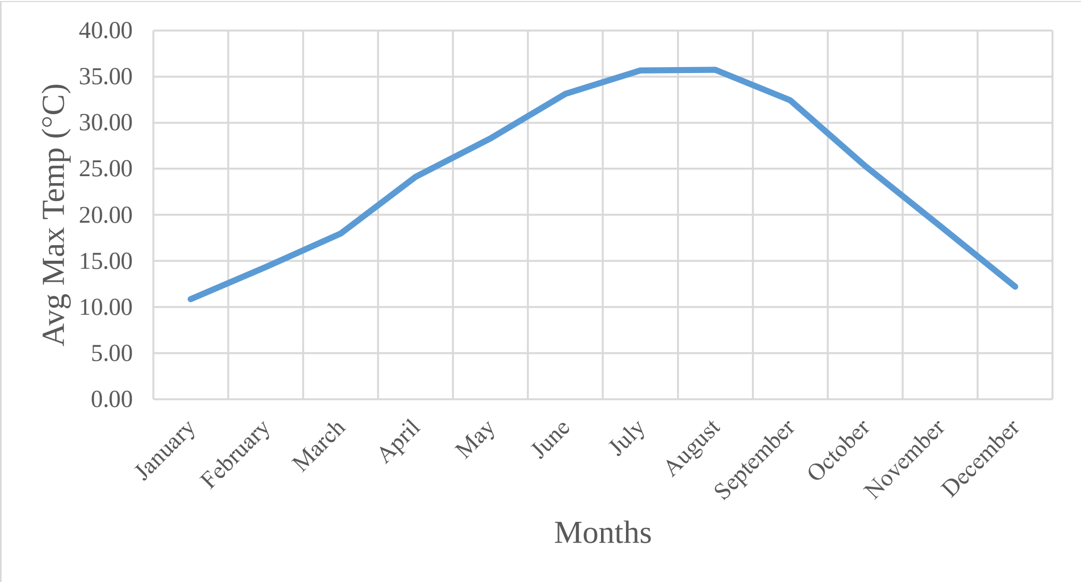

Figure 4.8. Average Maximum Temperature Values Measured at the Akhisar Station

When the average minimum temperature values measured at the Akhisar Station are evaluated, it is seen that minimum temperature is observed during January as 2.01 °°C (Figure 4.9).

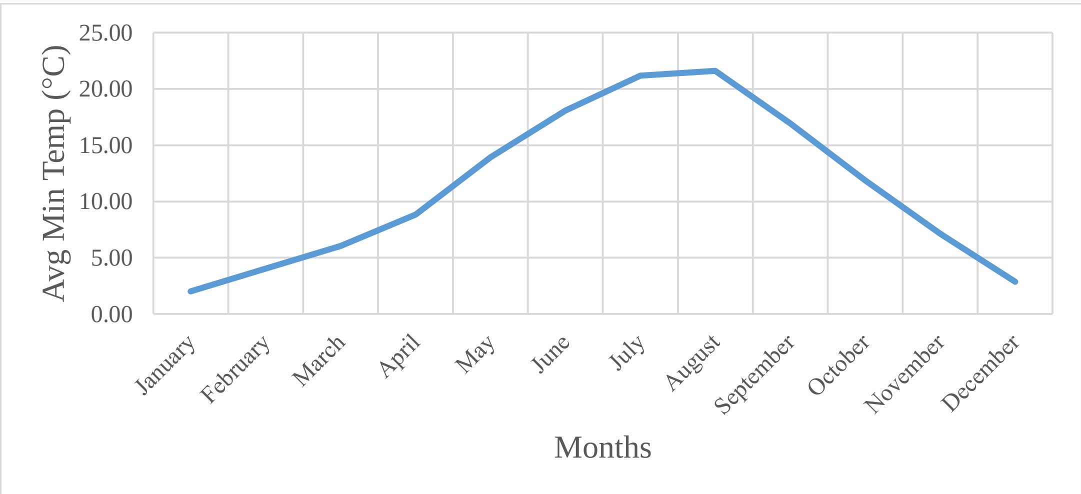

Figure 4.9. Average Minimum Temperature Values Measured at the Akhisar Station

When the average daily precipitation values measured at the Akhisar Station are evaluated, it is seen that maximum rainfall is observed during January as 4.19 mm and minimum rainfall is observed during July as 0.02 mm (Figure 4.10).

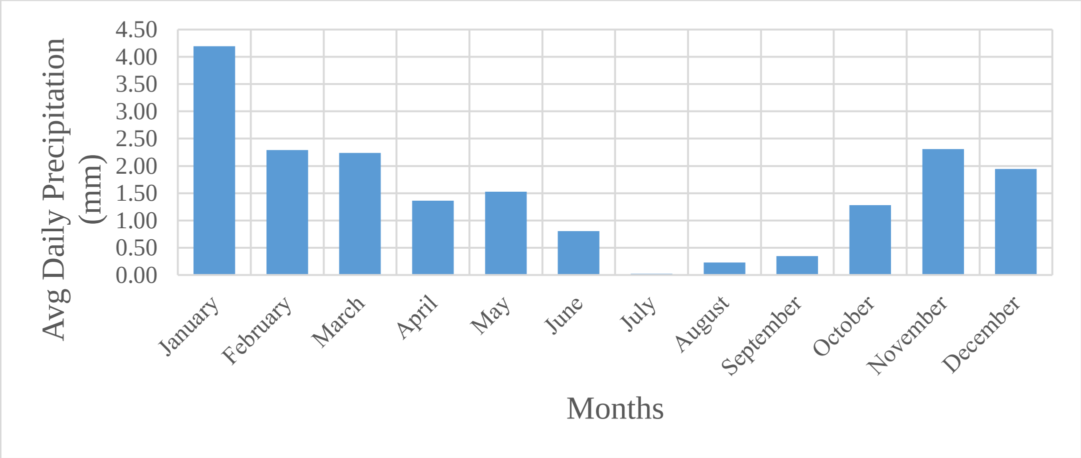

Figure 4.10. Average Daily Precipitation Values Measured at the Akhisar Station

When the average daily wind speed values measured at the Akhisar Station are evaluated, it is seen that maximum wind speed is observed during July as 2.87 m/s and minimum wind speed is observed during December as 1.38 m/s (Figure 4.11).

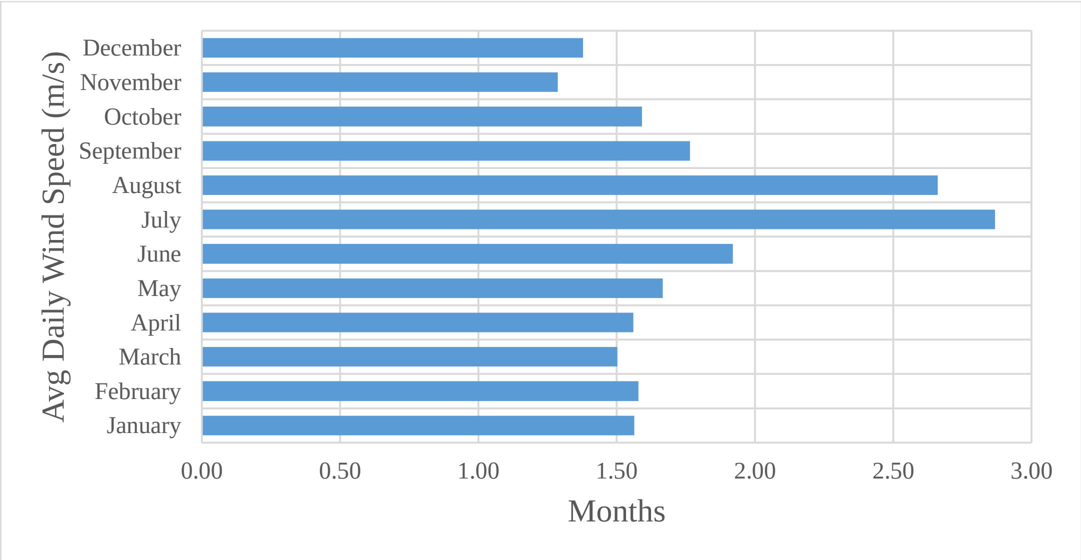

Figure 4.11. Average Daily Wind Speed Values Measured at the Akhisar Station

When the average daily relative humidity values measured at the Akhisar Station are evaluated, it is seen that maximum humidity is observed during January as 80.63 % and minimum humidity is observed during December as 45.57 % (Figure 4.12).

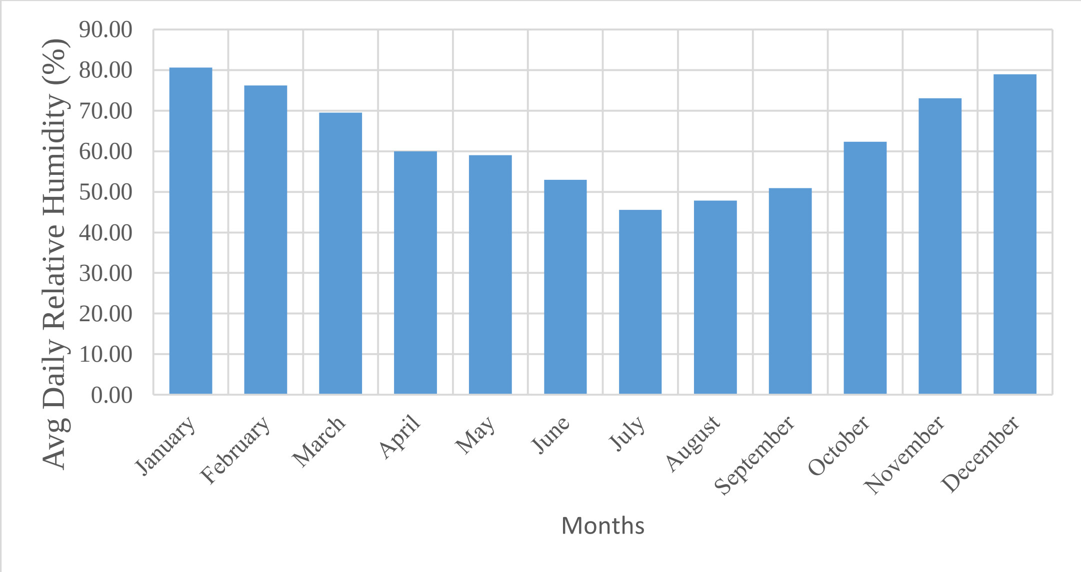

Figure 4.12. Average Daily Relative Humidity Values Measured at the Akhisar Station

4.1.8. Point Sources

As discussed in Chapter 3.3, it was assumed that, each treatment plant is discharging the treated wastewater according to the related discharge limits for each sector specified in WPCR and UWTR.

WPCR and UWTR set discharge limits mainly in terms of COD, BOD, Total Nitrogen and Total Phosphorus. On the other hand; SWAT requires discharged waste water quality in terms of Flow (m^3/d), CBOD (kg/d), Organic N (kg/d), Nitrate – N (kg/d), NH_3 – N (kg/d), Nitrite – N, Organic – P (kg/d) and Mineral – P (kg/d). Therefore, typical ratio of CBOD in COD, typical ratios of Organic N (kg/d), Nitrate – N (kg/d), NH_3 – N (kg/d), Nitrite – N in Total Nitrogen (Table 4-6) and typical ratios of Organic – P and Mineral – P in Total Phosphorus were evaluated (Table 4-7);

$$\frac{BOD}{COD} = 0,6$$ (Metcalf & Eddy, 2002) Equation 9

$$\frac{BOD}{CBOD} = 1,1$$ (Woodie Mark Muirhead, 2006) Equation 10

$$\frac{COD}{CBOD} = \frac{\frac{BOD}{CBOD}}{\frac{BOD}{COD}} = \frac{1,1}{0,6} = 1,84$$ Equation 11

Table 4-6. Typical Ratios of Organic N (Kg/D), Nitrate – N (Kg/D), NH3 – N (Kg/D), Nitrite – N in Total Nitrogen (WDNR, 2004)

Parameter	**Average Effluent Concentration (%)**
Ammonia nitrogen	38%
Nitrate + Nitrite	5%
Organic Nitrogen	57%
Total Nitrogen	100%

Table 4-7. Typical Ratios of Organic – P and Mineral – P in Total Phosphorus (Rybicki, 1997)

Parameter	**Average Effluent Concentration (%)**
Organic Phosphorus	10%
Mineral Phosphorus	90%

Typical ratio values given in the tables above represents typical domestic wastewater (Metcalf & Eddy, 2002), (Rybicki, 1997). Nevertheless, since the majority of the point sources includes the Municipal WWTPs and Food Industry WWTPs, and the typical wastewater of food industries show similar characterization to municipal wastewater (Falletti, 2014). Thus, these ratios are considered to be applicable for all the wastewater discharged to the watershed.

Table 4-8. Daily Pollutant Load for Each WWTP

Source	Subbasin	Flowrate (m3/d)	COD (mg/L)	CBOD (mg/L)	CBOD (kg/d)	TN (mg/L)	OrgN (kg/d)	NO_3 (kg/d)	NH3 (kg/d)	TP (mg/L)	OrgP (kg/d)	MinP (kg/d)
Kurtuluş Agr.	9	50	200	109.09	5	10	0.19	0.29	0.03	2	0.01	0.09
İdeal Agr.	11	40	150	81.82	3	10	0.15	0.23	0.02	2	0.01	0.07
Üretici Food	11	10	170	92.73	1	10	0.04	0.06	0.01	2	0	0.02
Baktat Food Inc.	12	150	150	81.82	12	10	0.57	0.86	0.08	2	0.03	0.27
Durullar Food	14	30	150	81.82	2	10	0.11	0.17	0.02	2	0.01	0.05
Yeniçağ Food	16	30	250	136.36	4	10	0.11	0.17	0.02	2	0.01	0.05
Graniser Granit	19	800	80	43.64	35	10	3.03	4.56	0.41	2	0.16	1.44
Keskinoğlu	19	3,800	500	272.73	1,036	20	28.81	43.33	3.86	3	1.14	10.26
Akhisar WWTP	20	26,000	120	65.45	1,702	10	98.57	148.24	13.19	2	5.2	46.8
Macolive	26	160	150	81.82	13	10	0.61	0.91	0.08	2	0.03	0.29
Has Gönül Agr.	28	150	150	81.82	12	10	0.57	0.86	0.08	2	0.03	0.27
Has Milk	28	60	170	92.73	6	10	0.23	0.34	0.03	2	0.01	0.11
Özgür Agr.	28	500	150	81.82	41	10	1.9	2.85	0.25	2	0.1	0.9
Pagmat Food Inc.	28	500	150	81.82	41	10	1.9	2.85	0.25	2	0.1	0.9
Saruhanlı WWTP	28	5,040	140	76.36	385	10	19.11	28.74	2.56	2	1.01	9.07
Yonca Canned	28	2,000	150	81.82	164	10	7.58	11.4	1.01	2	0.4	3.6
Yonca Food	28	100	150	81.82	8	10	0.38	0.57	0.05	2	0.02	0.18

SWAT allows to have only one point source for one sub-basin. Therefore, it was assumed that simple mixing occurs for each point source located in one sub-basin. Thus, point source loads for each sub basin are calculated and given in Table 4-9.

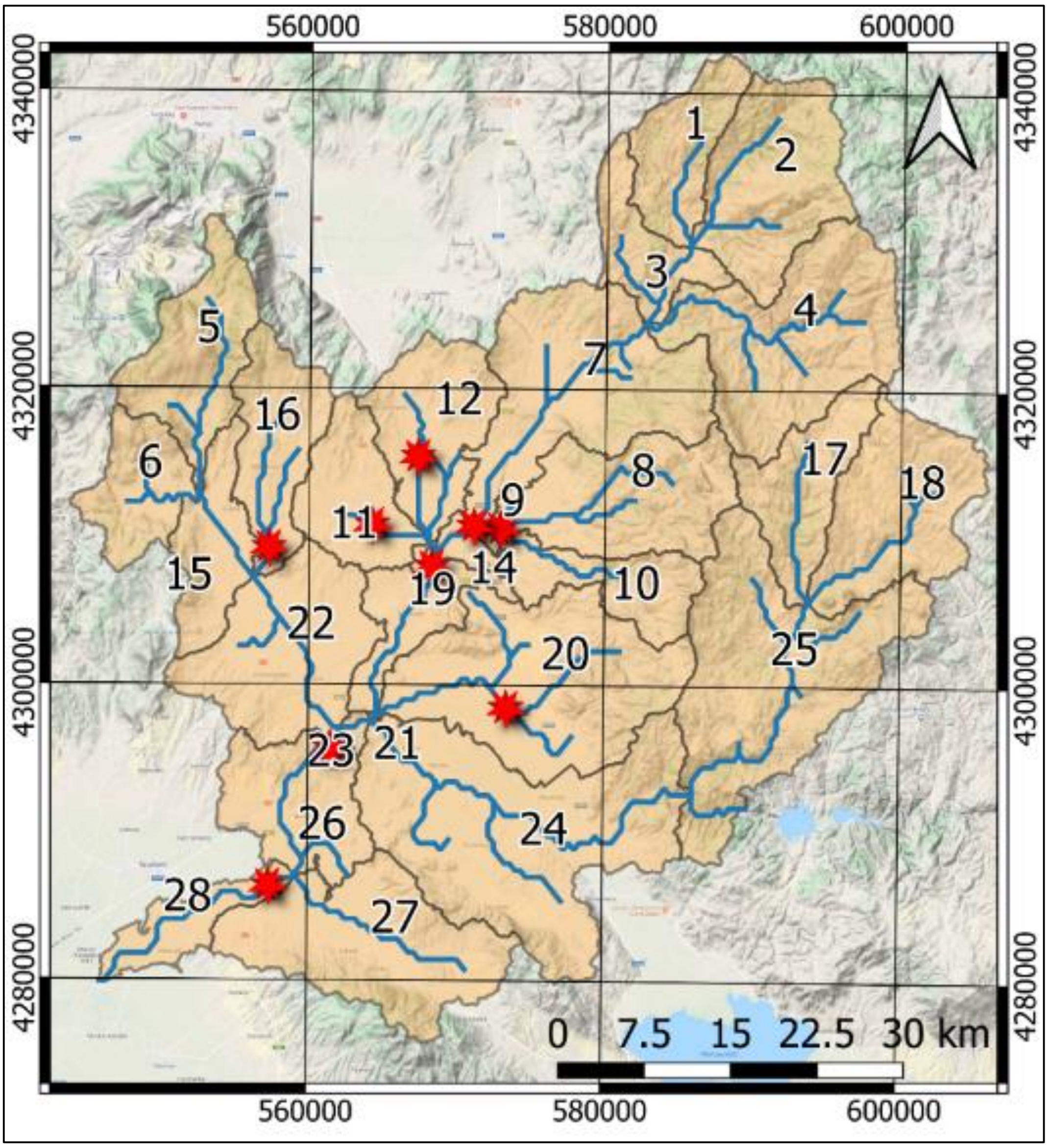

Figure 4.13. Locations of the Point Sources

Table 4-9. Daily Pollution Load for Each Sub-basin

Subbasin	Flowrate (m^3/d)	CBOD (kg/d)	OrgN (kg/d)	NH_3 (kg/d)	NO_3 (kg/d)	OrgP (kg/d)	MinP (kg/d)
9	50	5	0.19	0.03	0.29	0.01	0.09
11	50	4	0.19	0.03	0.29	0.01	0.09
12	150	12	0.57	0.08	0.86	0.03	0.27
14	30	2	0.11	0.02	0.17	0.01	0.05
16	30	4	0.11	0.02	0.17	0.01	0.05
19	4,600	1,071	31.84	4.26	47.89	1.30	11.70
20	26,000	1,702	98.57	13.19	148.24	5.20	46.80
26	160	13	0.61	0.08	0.91	0.03	0.29
28	8,350	656	31.66	4.24	47.61	1.67	15.03

4.1.9. Management Practices

The goal of SWAT, as discussed before, is to simulate effects of human practices. Therefore, land and water management activities has a great importance and can be considered as main considerations of this study. SWAT management option is operable for a HRU unit. Management file (.mgt) requires input information for harvesting, irrigation application, nutrient applications, pesticide applications, and tillage operations (Özcan, 2016).

Management file can be classified into two groups. Firstly, initial conditions or management practices that stays unchanged during simulation are realized. Second group is the management operations occurring on a specific time schedule.

Main unchanged management parameters are: initial plant growth, general management, urban management, irrigation management, tile drain management and management operations. Management operations occurring on a specific time schedule includes; planting/beginning of growing season, irrigation operation, fertilizer application, pesticide application, harvest and kill operation, tillage operation, harvest operation, kill operation, grazing operation, auto irrigation and fertilizer initialization, street sweeping operation, release/impound operation, continuous fertilizer operation, end of year operation (Neitsch S. A., 2005).

During this study, agricultural applications were examined for the whole watershed. As discussed before, An HRU is the smallest unit of SWAT. Areas with AGRL, AGRC, OLIV and GRAP LULC code are the ones that considered to have agricultural management practices. OLIV code stands for olive gardens and GRAP code stands for vineyard. Therefore, product pattern for these areas are olives and grapes respectfully. On the other hand, specifying the product pattern for AGRL AGRC coded areas is a challenge as there is a vast amount of agricultural area located in the watershed and there is a variety of the products cultivated.

As discussed in Chapter 3.2.1, each district has a dominant type of cultivated product. So it was assumed that product pattern of each HRU is the dominant product of the district which occupies the largest area within that HRU. Wheat, cotton, olive, tomatoes and grapes are the main products cultivated in the Gürdük Watershed (Figure 4.18).

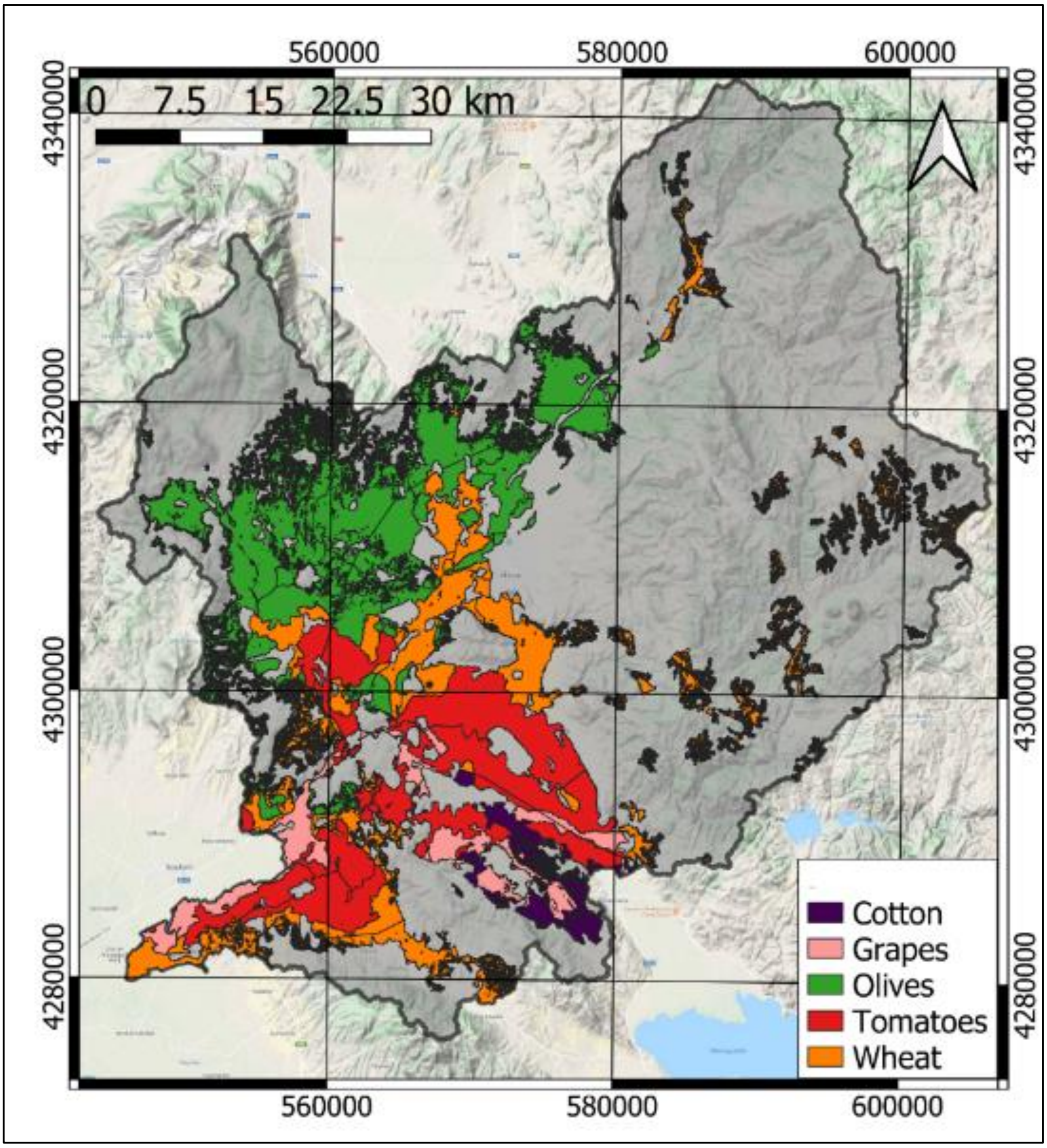

Figure 4.14. Products Cultivated in Gurduk Basin

As discussed before time schedule for agricultural practices is key for having an accurate simulation for the watershed. Time schedules for each product is learnt from the interviews conducted with the experts from the Provincial Directorate of Agriculture and Forestry. Time schedule for each cultivated pattern is presented in Table 4-10;

Table 4-10. Agricultural Management Practice Schedule for Gürdük Basin

Product	**Schedule**
Wheat	November 15th Begin cultivation Tillage (Duckfoot) November 15th Fertilizing (half of the nitrogenous and all of the phosphorus fertilizer) March 30th Bolting (half of the nitrogenous fertilizer) June 1st Harvesting
Grapes	February 1st Begin cultivation Tillage (Duckfoot) February 1st Fertilizing (half of the nitrogenous and all of the phosphorus fertilizer) July 1st – September 1st Irrigation September 1st Harvesting October 1st Fertilizing (half of the nitrogenous fertilizer)
Olives	January 1st Begin cultivation January 1st Fertilizing (all of the nitrogenous fertilizer) March 1st – May 1st Irrigation October 1st Harvesting November 1st Fertilizing (all of the phosphorus fertilizer)
Cotton	March 15th Begin cultivation January 1st Fertilizing (all of the nitrogenous and phosphorus fertilizer) July 1st – August 1st Irrigation October 1st Harvesting
Tomatoes	March 1st Fertilizing (half of the nitrogenous and all of the phosphorus fertilizer) March 15th Begin cultivation Tillage (Duckfoot) March 15th – April 15th Irrigation March 30th Fertilizing (half of the nitrogenous fertilizer) May 15th Harvesting

Afterwards, amount of annual nitrogen and phosphorus intake amounts in terms of from fertilizers were calculated for each HRU considering the amount of fertilizer usage amounts given in Chapter 3.4.

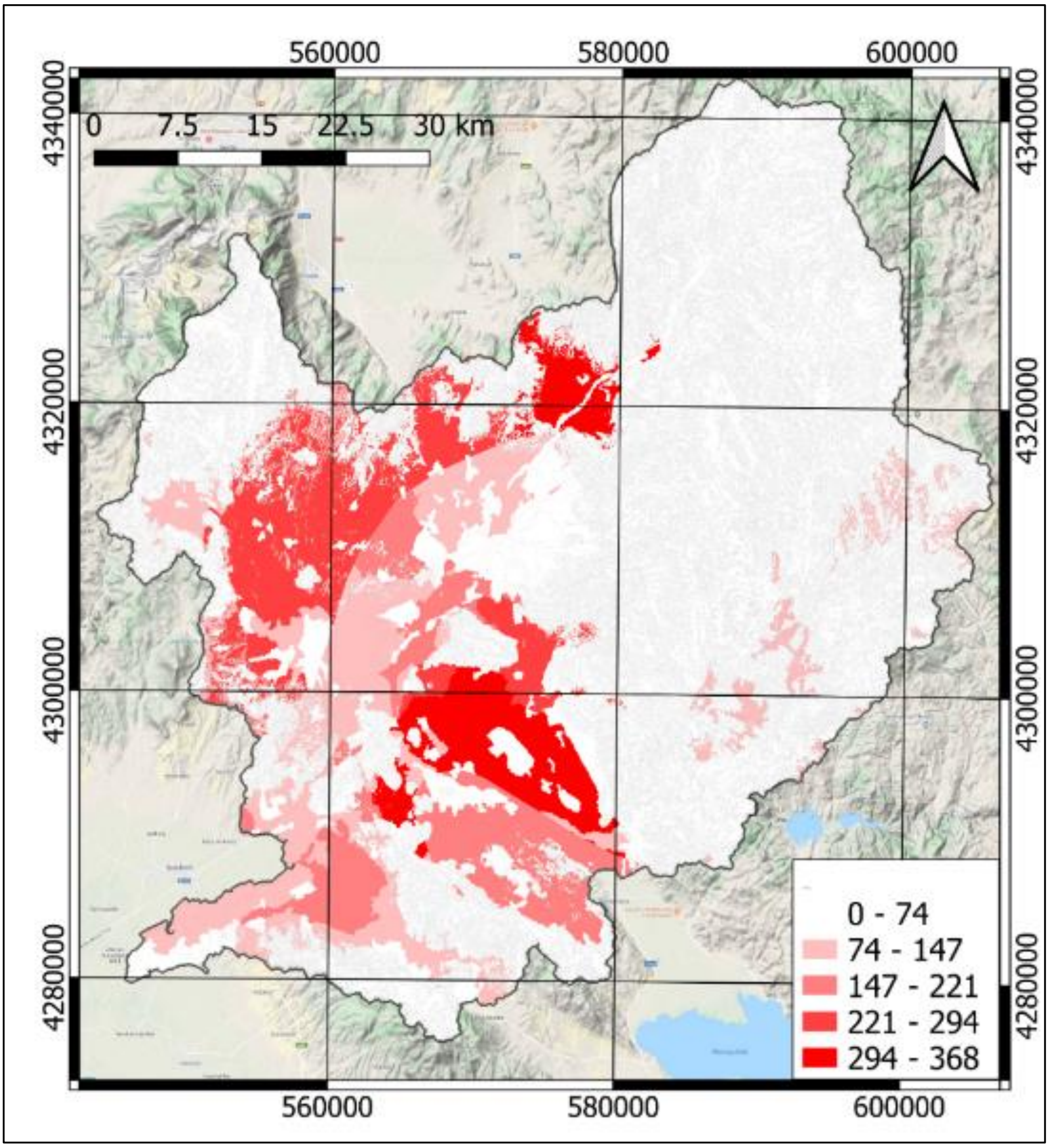

Figure 4.15. Annual TN intake from Fertilizers (tonnes/year) in Gurduk Watershed

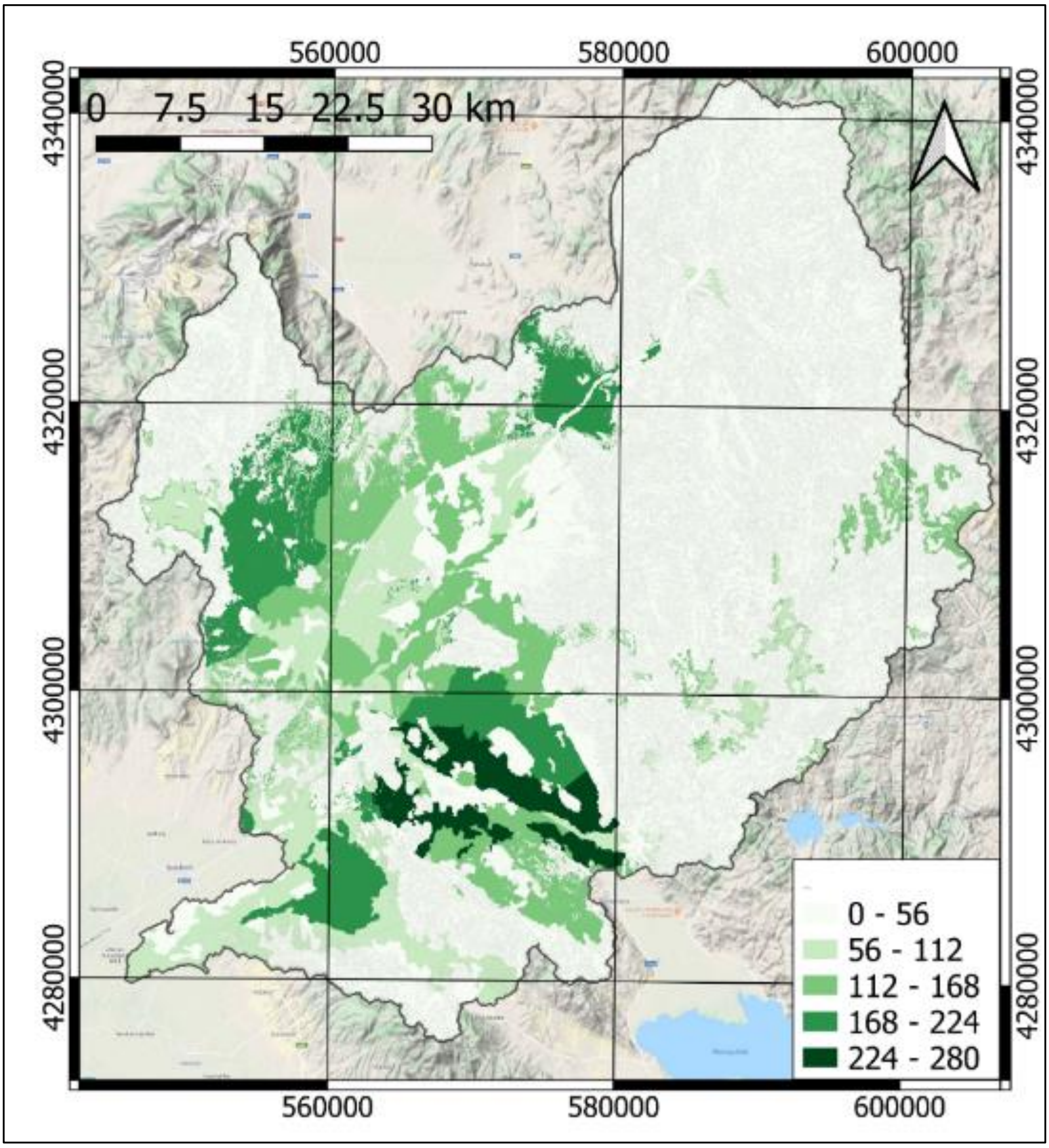

Figure 4.16. Annual TP intake from Fertilizers (tonnes/year) in Gurduk Watershed

Summary of agricultural practices for each HRU is presented in Appendix-A.

4.2. Calibration and Validation

The SWAT model needs to be calibrated and validated to give accurate results. SWAT-CUP is the interface program for the calibration of the SWAT model. In this study, SWAT-CUP interface is used for calibration stage.

4.2.1. Stream Flow Calibration & Validation

The stream flow values generated by running the SWAT hydrological model were calibrated using SWAT-CUP. During the calibration phase, SUFI-2 algorithm was used among 5 defined parameter optimization algorithms.

Stream flow calibration & validation processes were done for three different sub-basins with three different stations' long term flow rate data. Table 4-11 shows, information on stream flow monitoring station used for each sub-basin and available years of each station.

Table 4-11. Stream Flow Calibration & Validation Information

Station	**Sub-basin**	**Available Years**
E05A009	14	2007-2015
E05A010	26	2007-2012
E05A018	28	2007-2010

Calibration of the watershed was done for Sub-basin-14, Sub-basin-16 and Sub-basin 28 stream flow values which were observed in the E05A009, E05A010 and E05A018 respectively were used (Figure 4.17).

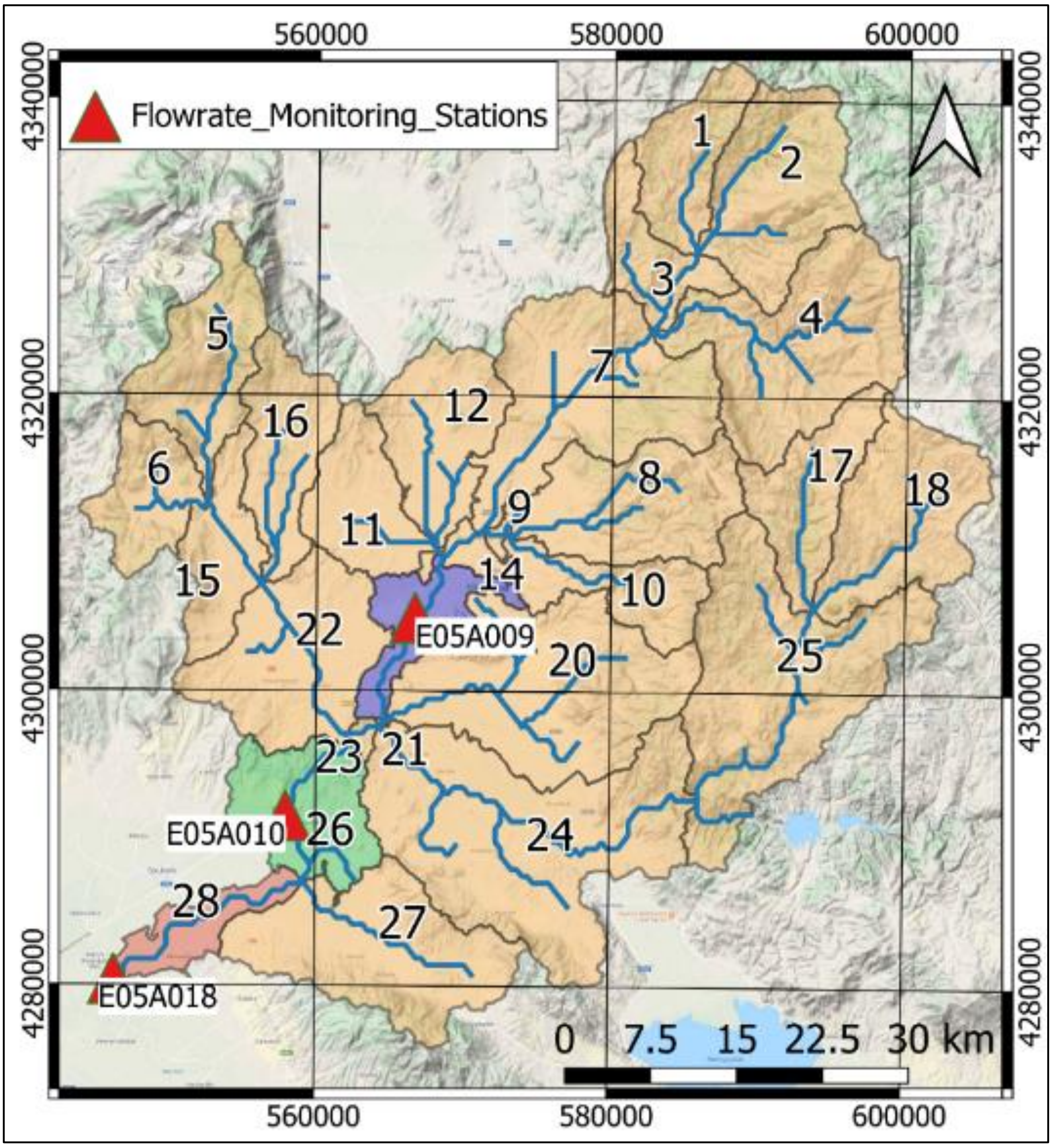

Figure 4.17. Locations of the Stream Flow Monitoring Stations

When the previous studies regarding the most sensitive parameters were examined , it was seen that, CN2, ALPHA_BF, ESCO and GWQMN parameters are directly affecting the hydrological process of surface flow (Qiu, 2012). On the other hand, Kannan (2006) stated that GW_REVAP and REVAPMN are the most sensitive parameters related to groundwater and affect surface flow. The parameters listed below were selected for stream flow calibration.

Table 4-12. Calibration Parameters Descriptions for Stream Flow

No	Parameter Name	Ext.	Description
1	CN2	.mgt	SCS runoff curve number for moisture condition
2	ALPHA_BF	.gw	Baseflow alpha factor
3	RCHRG_DP	.gw	Deep aquifer percolation fraction.
4	GW_REVAP	.gw	Groundwater "revap" coefficient
5	GWQMN	.gw	Threshold depth of water in the shallow aquifer required for return flow to occur
6	REVAPMN	.gw	Threshold depth of water in the shallow aquifer for "revap" to occur.
7	GW_DELAY	.gw	Groundwater delay
8	EPCO	.hru	Plant uptake compensation factor
9	ESCO	.hru	Soil evaporation compensation factor
10	SURLAG	.bsn	Surface runoff lag time
11	SMFMX	.bsn	Maximum melt rate for snow during year (occurs on summer solstice)
12	SMFMN	.bsn	Minimum melt rate for snow during the year (occurs on winter solstice)
13	SFTMP	.bsn	Snowfall temperature
14	SMTMP	.bsn	Snow melt base temperature
15	TIMP	.bsn	Snow pack temperature lag factor
16	SNOCOVMX	.bsn	Minimum snow water content that corresponds to 100% snow cover
17	SNO50COV	.bsn	Snow water equivalent that corresponds to 50% snow cover
18	SOL_AWC	.sol	Available water capacity of the soil layer
19	CH_N1	.sub	Manning's "n" value for the tributary channels
20	CH_N2	.rte	Manning's "n" value for the main channel

As shown in Table 4-13, 20 parameters affecting the hydrological processes of the watershed were assessed. With these parameters, SWAT-CUP program was run and at the end of 1500 simulations for each sub-basin were performed and optimum fitted parameter values were obtained.

Table 4-13. Calibration Parameters and Fitted Values for Stream Flow

Nº	Parameter Name	File Extension	Method	Min Value	Max Value	Fitted Value
1	CN2	.mgt	relative	-0.1	0.1	-0.093
2	ALPHA_BF	.gw	replace	0	1	0.957
3	RCHRG_DP	.gw	replace	0	1	0.170
4	GW_REVAP	.gw	replace	0.02	0.2	0.154
5	GWQMN	.gw	replace	0	5000	326.250
6	REVAPMN	.gw	replace	0	500	314.375
7	GW_DELAY	.gw	replace	0	500	92.375
8	EPCO	.hru	replace	0.01	1	0.512
9	ESCO	.hru	replace	0	1	0.884
10	SURLAG	.bsn	replace	1	24	14.829
11	SMFMX	.bsn	replace	0	9	3.436
12	SMFMN	.bsn	replace	0	9	1.645
13	SFTMP	.bsn	replace	-5	5	-3.458
14	SMTMP	.bsn	replace	-5	5	-3.258
15	TIMP	.bsn	replace	0	0.9	0.002
16	SNOCOVMX	.bsn	replace	0	500	200.125
17	SNO50COV	.bsn	replace	0	0.9	0.604
18	SOL_AWC	.sol	relative	-0.1	0.1	0.062
19	CH_N1	.sub	replace	0.01	1	0.814
20	CH_N2	.rte	replace	0	0.3	0.260

The statistical values showing the performance of the model obtained at the end of the calibration process are presented in Table 4-14. Best calibration performance is seen for Sub-basin-14. Accordingly, for sub-basin-14, while the 0.803 value of R^2 is in the range of 0.75-0.85, the NSE statistic that takes the value of 0.791 is in the range of 0.70-0.80 and the PBIAS statistic is in the range of -15 and -25 with the value of -13.047. According to the model performance statistics evaluation table, it is concluded that there is a good correlation between the simulation values obtained during the calibration process and the observed values.

Similarly, for sub-basin-14 the performance of the model was evaluated in the validation process for the years 2012-2015. As it can be seen from Table 4-14, the coefficient of determination is $R^2 = 0.660$, the NSE efficiency coefficient is 0.545 and the percentage error statistics PBIAS = -13.107. When the performance statistics of the model are compared with Table 2-9, it is understood that the model gives satisfactory results in the validation process. When the graph generated by SWAT-CUP at the end of the calibration process (Figure 4.18) is examined, it is observed that there is a good correlation between the observed and simulation values in general. Performance evaluation for the Subbasin-14, Subbasin-26 and Subbasin-28 is given in Table 4-23.

Table 4-14. Performance Evaluation of Model's Calibration and Validation Processes for Streamflow

	Parameter	Calibration (2007-2008)	Validation (2009-2010)
Subbasin-28	R^2	0.801	0.888
	NSE	0.792	0.819
	PBIAS	-4.06856112	24.97091
	Parameter	**Calibration (2007-2009)**	**Validation (2010-2012)**
Subbasin-26	R^2	0.6	0.571
	NSE	0.339	0.543
	PBIAS	-65.33	-13.564
	Parameter	**Calibration (2007-2011)**	**Validation (2012-2015)**
Subbasin-14	R^2	0.803	0.66
	NSE	0.791	0.545
	PBIAS	-13.047	-13.107

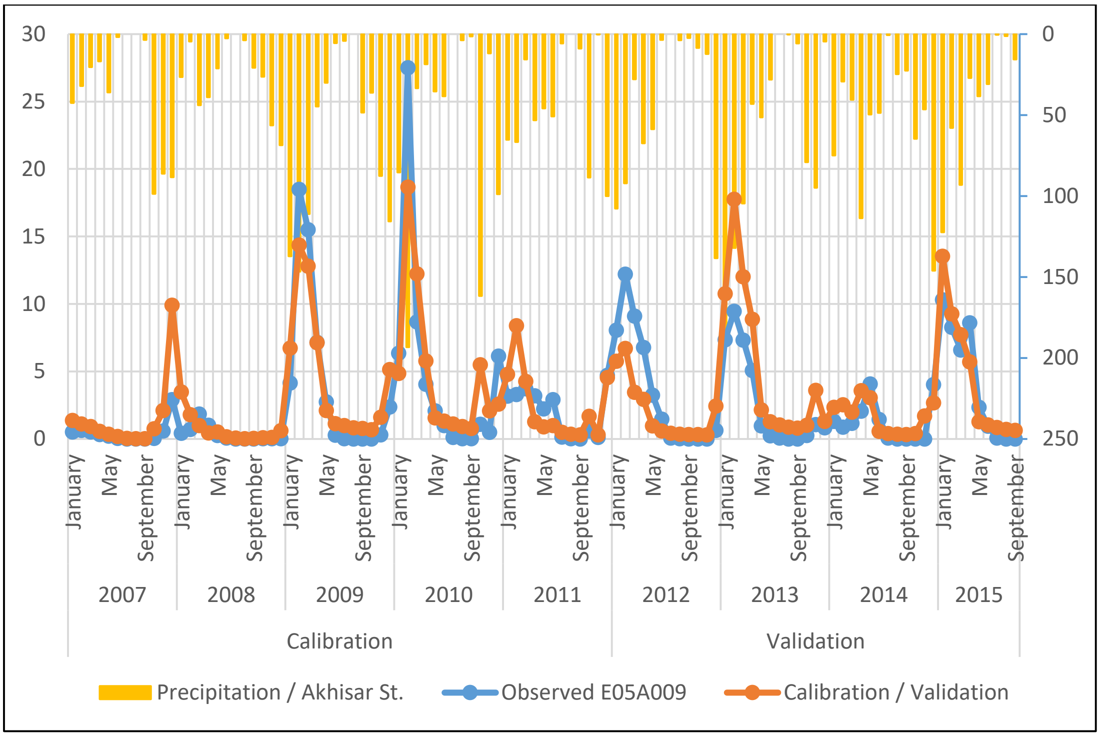

Figure 4.18. Hydrograph of the Model's Calibration and Validation Processes (Sub-basin 14)

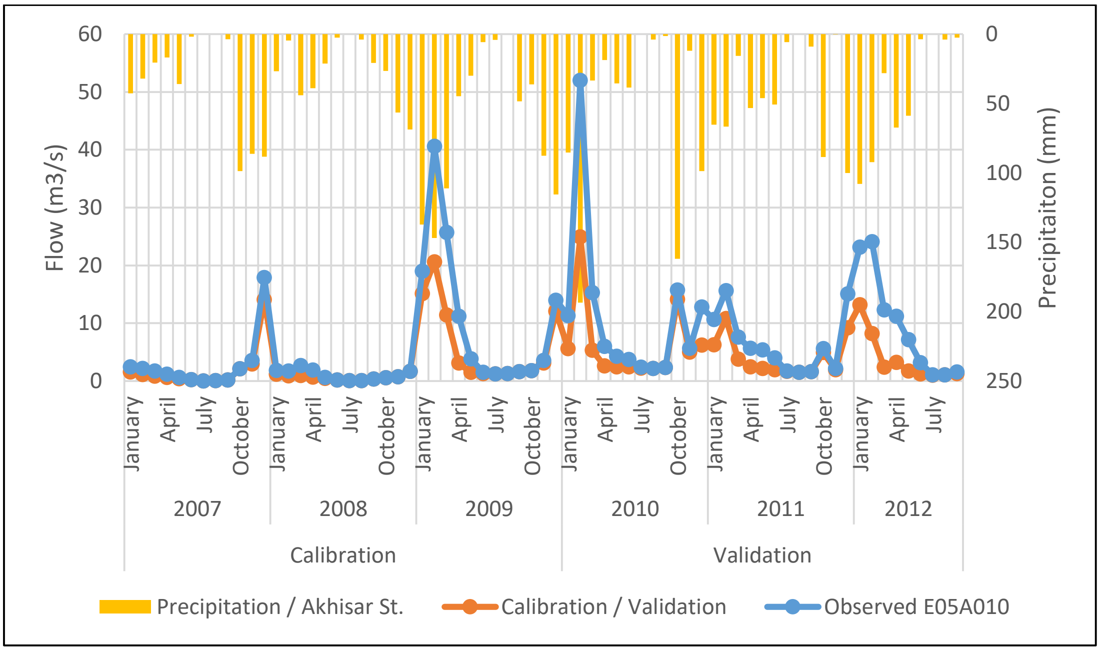

Figure 4.19. Hydrograph of the Model's Calibration and Validation Processes (Sub-basin 26)

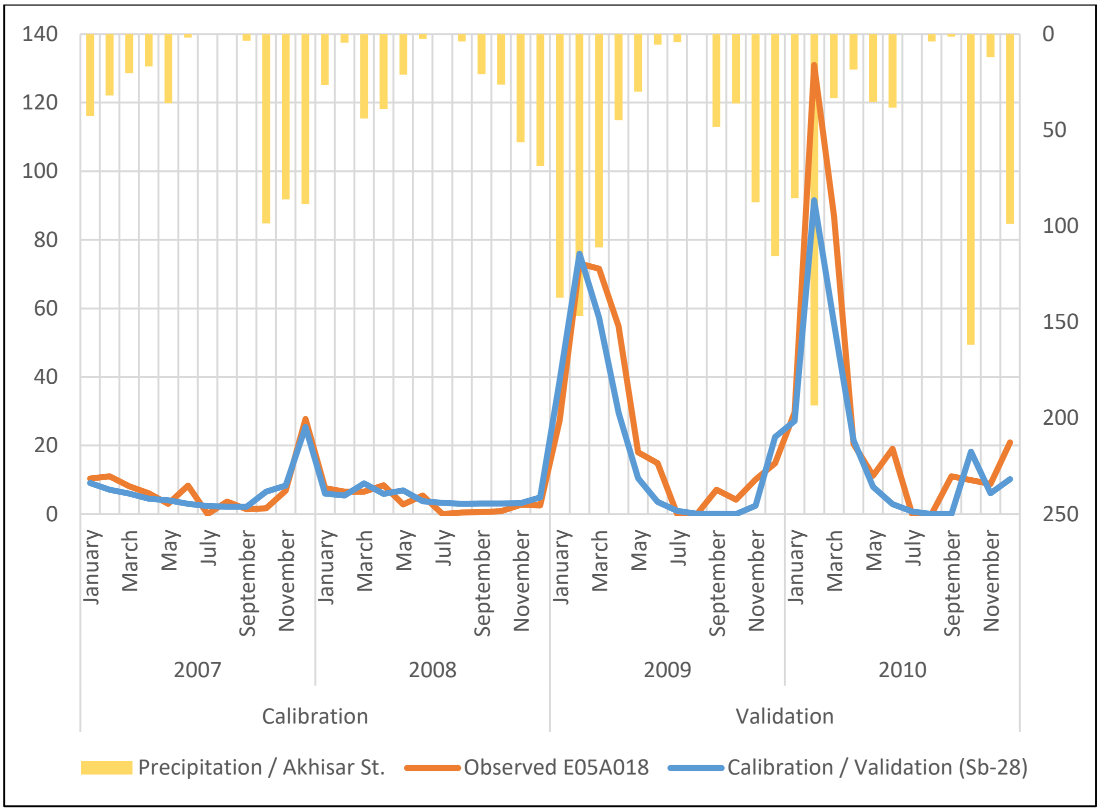

Figure 4.20. Hydrograph of the Model's Calibration and Validation Processes (Sub-basin 28)

One thing to consider in the calibration process is whether the parameter ranges in the SWAT-CUP program are in the same range as those in the SWAT model. If this is not taken into account, it is not possible to reach sensitive parameters that affect the flow values of the basin. In this study, this issue is taken into consideration; the calibration process has been completed by taking into account the ranges of the sensitive parameters in SWAT and SWAT-CUP.

After this process, the revised parameter values were entered into SWAT model and the model was run again. The simulated current values obtained for the validation period and the observed values are shown together for Sub-basin 14, Sub-basin 26 and Sub-basin 28 in Figure 4.18, Figure 4.19 and Figure 4.20 respectively.

When the statistical values obtained as a result of the calibration and validation processes were compared, the predictive capacity of the model observed to be weakened as R^2 values are decreased in the validation periods for all the sub-basins. This decrease indicates that the correlation between the observed values and the simulation values during the validation process has changed. The change in the NSE value indicating the model estimation capacity means that the estimation capacity in the calibration process is reduced during the verification process. The negative performance of PBIAS, another performance statistic, means that the model generates higher flow values than the observed values during the validation period.

It is a natural result that simulation values and actual values do not show parallel trend to the extent desired. Because, human error should always be expected at every stage of research. In addition, it should not be forgotten that the studied basin is not a natural basin and is under intense pressure from human activities. This is because the research area is the agricultural basin and human-induced interventions are ongoing at all times of the year.

4.2.2. Sediment Calibration & Validation

Similar to the streamflow calibration, sediment values were calibrated using SWAT-CUP, SUFI-2 Algorithm. The SWAT-CUP program was used the years 2012-2013 for this process. Calibration of the watershed was done for Subbasin-7 and Subbasin-24 and sediment values which were observed in the 05-02-00-061 and 05-02-00-003 were used (Table 4-11, Figure 4.21).

Table 4-15. Water Quality Calibration & Validation Information

Station	**Sub-basin**	**Available Years**
05-02-00-061	7	2012-2014
05-02-00-003	24	2018

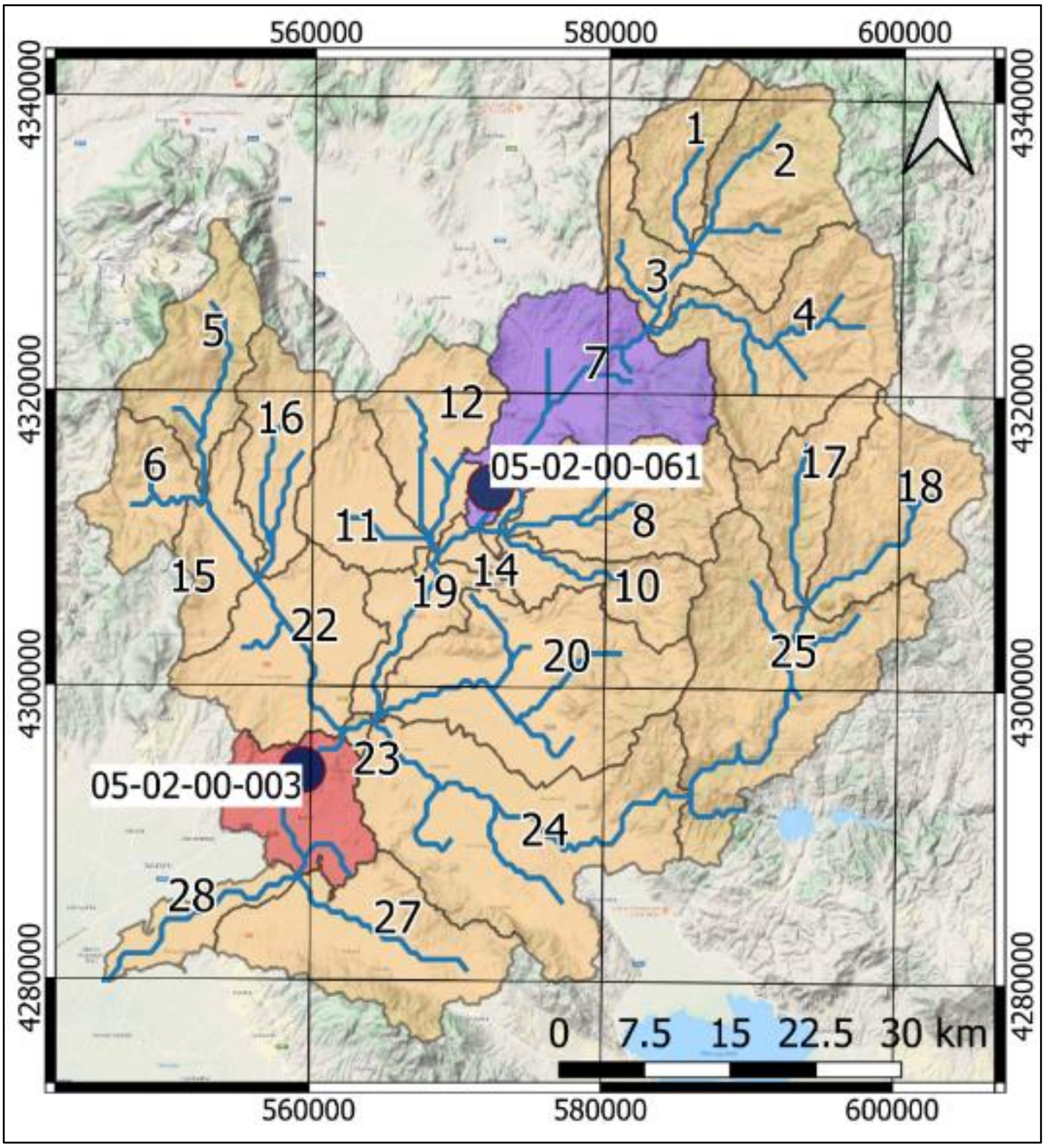

Figure 4.21. Location of Quality Monitoring Stations

Sediment parameters were calibrated following streamflow calibration. Calibration of sediment loading focused on parameters controlling landscape erosion and channel routing. Like streamflow calibration, sediment calibration consisted of an initial manual calibration step to match predicted and observed sediment loads followed by automated calibration with SWAT-CUP software to fine-tune parameter estimates and further manual calibration based on SWAT-CUP results (Wisconsin Department of Natural Resources, 2018).

USLE_P, LAT_SAD, SURLAG, CH_EROD, USLE_K, CH_N2, CH_COV, SPCON, HRU_SLP, are among the most sensitive parameters while considering, sediment calibration (Eldho T.I, 2018). The parameters listed in Table 4-16 were selected for sediment calibration.

Table 4-16. Calibration Parameters Descriptions for Sediment Yield

No	Parameter Name	File Ext.	Description
1	SPEXP	.bsn	Exponent parameter for calculating sediment re-entrained in channel sediment routing
2	SPCON	.bsn	Linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing
3	CH-ERODMO	.rte	Monthly channel erodability factor (Kch, monthly)
4	CH_COV1	.rte	Channel erodibility factor
5	CH_COV2	.rte	Channel cover factor
6	ADJ_PKR	.bsn	Peak rate adjustment factor for sediment routing in the subbasin (tributary channels) - $prf_{tributary}$
7	C_FACTOR	.bsn	Scaling parameter for Cover and management factor in ANSWERS erosion model
8	USLE_P	.mgt	USLE equation support practice
9	USLE_K	.sol	USLE equation soil erodibility (K) factor
10	RSDCO	.bsn	Residue decomposition coefficient.
11	BIOMIX	.mgt	Biological mixing efficient
12	CH_WDR	.rte	Channel width-depth ratio.
13	CH_BED_KD	.rte	Erodibility of channel bed sediment by jet test (cm3/N-s)
14	CH_BNK_KD	.rte	Erodibility of channel bank sediment by jet test (cm3/N-s)
15	CH_BNK_D50	.rte	D50 Median particle size diameter of channel bank sediment (μm)
16	CH_BNK_TC	.rte	Critical shear stress of channel bank (N/m2)
17	CH_BNK_BD	.rte	Bulk density of channel bank sediment (g/cc)
18	CH_BED_BD	.rte	Bulk density of channel bed sediment (g/cc)
19	CH_BED_D50	.rte	D50 Median particle size diameter of channel bed sediment (μm)

As shown in Table 4-17, 19 parameters affecting the sediment yield of the watershed were assessed. With these parameters, SWAT-CUP program was run and at the end of 20 iterations, 1500 simulations were performed and optimum fitted parameter values were obtained.

Table 4-17. Calibration Parameters and Fitted Values for Sediment

No	Parameter Name	File Ext.	Method	Min	Max	Fitted Values
1	SPEXP	.bsn	Replace	1	1.5	1.0025
2	SPCON	.bsn	Replace	0.001	0.01	0.003295
3	CH-ERODMO	.rte	Replace	0	1	0.405
4	CH_COV1	.rte	Replace	-0.05	0.6	0.55775
5	CH_COV2	.rte	Replace	-0.001	1	7.950205
6	ADJ_PKR	.bsn	Replace	0	2	1.71
7	C_FACTOR	.bsn	Replace	0.001	0.45	0.447755
8	USLE_P	.mgt	Replace	0	1	0.105
9	USLE_K	.sol	Replace	0	0.65	0.00325
10	RSDCO	.bsn	Replace	0.02	0.1	0.0916
11	BIOMIX	.mgt	Replace	0	1	0.715
12	CH_WDR	.rte	Relative	-0.1	0.1	0.031
13	CH_BED_KD	.rte	Replace	0.001	3.75	3.168905
14	CH_BNK_KD	.rte	Replace	0.001	3.75	2.081695
15	CH_BNK_D50	.rte	Replace	1	10000	4250.574707
16	CH_BNK_TC	.rte	Replace	0	400	130
17	CH_BNK_BD	.rte	Replace	1.1	1.9	1.48
18	CH_BED_BD	.rte	Replace	1.1	1.9	1.872
19	CH_BED_D50	.rte	Replace	1	10000	8150.185059

Fitted values for the calibration for sub-basin-26 was used for all the watershed as it was closer to the outlet of the basin and located at the downstream of the many of the point sources.

Performance of the sediment calibration was evaluated according to statistical values of R^2, NSE and PBIAS as in streamflow calibration (Table 4-18). Accordingly, value of R^2 was calculated as 0.575, in the unsatisfactory range of ≤ 0.60, whereas, NSE value was calculated as 0.496, in the unsatisfactory as it was below 0.50 and PBIAS statistic is in the range of -30 and -55 with the value of -32.916.

According to the model performance statistics evaluation table, it can be said that, calibration results could only be in satisfactory range for PBIAS, however, R^2 and NSE values have failed to give in the satisfactory results.

Similarly, validation process was conducted to assess the performance of the model for the year of 2015. As it can be seen from Table 4-18, the coefficient of determination is R^2 was calculated as 0.028, where the NSE efficiency coefficient is -0.105 and PBIAS statistic was calculated as -44.227. When the performance statistics of the model are compared with Table 2-9, it is understood that the model gives unsatisfactory results in the validation except for PBIAS process as well.

When the graph generated by SWAT-CUP at the end of the calibration process (Figure 4.22) is examined, it is observed that there is only a good correlation between the observed and simulated values for low sediment yields, on the other hand, model has failed to predict higher sediment yields accurately.

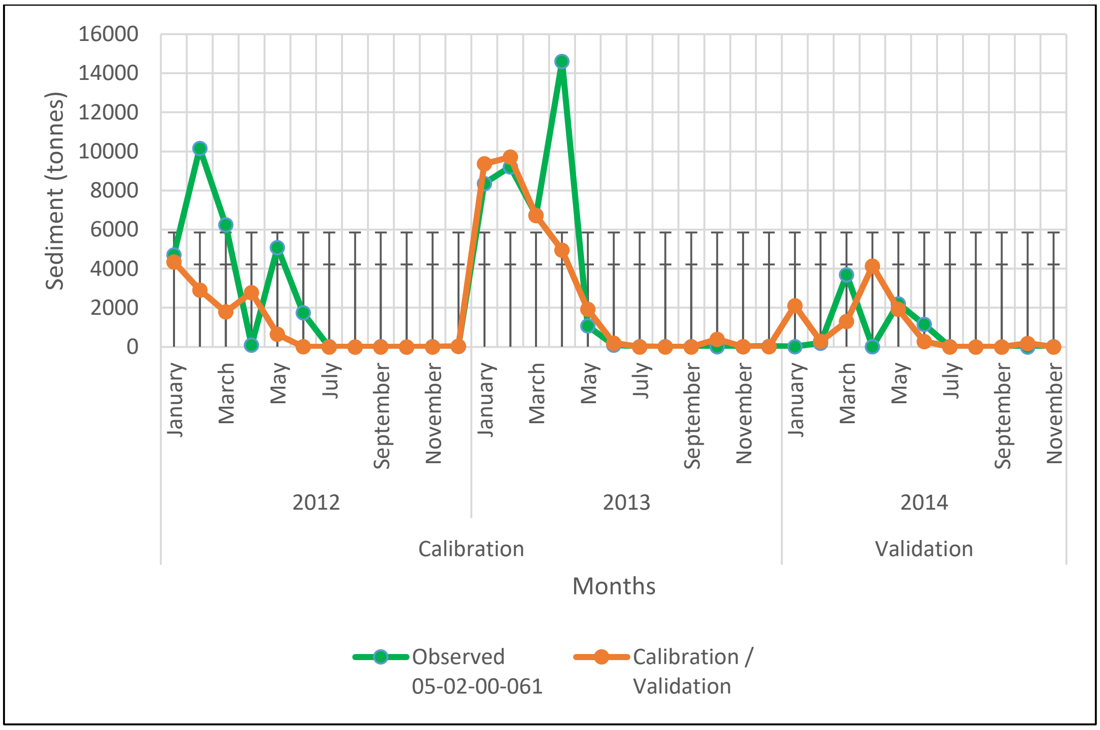

Figure 4.22. Results of Sediment Calibration and Validation Processes for Sub-basin 7

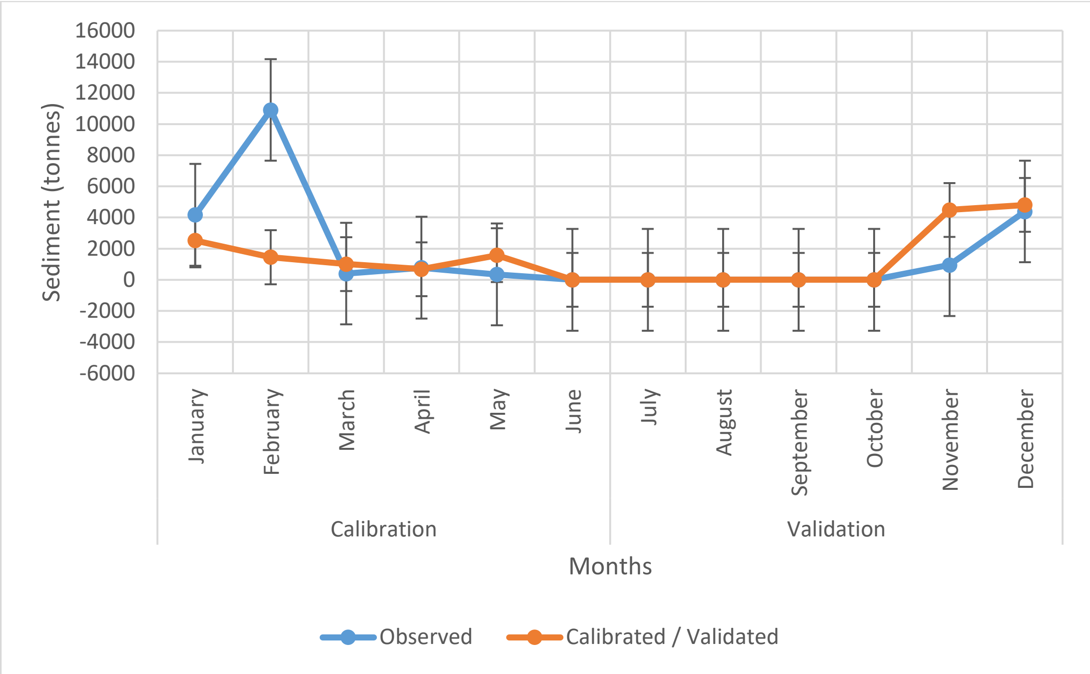

Figure 4.23. Results of Sediment Calibration and Validation Processes for Sub-basin 26

Table 4-18. Performance Evaluation of Model's Calibration and Validation Processes for Sediment Yield

	Parameter	**Calibration (2012-2013)**	**Validation (2014)**
Sub-basin 7	**R^2**	0.575	0.028
	NSE	0.496	-0.105
	PBIAS	32.916	-40.227
Sub-basin 26	**Parameter**	**Calibration (January-June 2018)**	**Validation (July-December 2018**
	R^2	0.178	0.656
	NSE	0.1	0.176
	PBIAS	56.29910464	-74.30591053

It should also be noted that, even though calibration results do not show desired performance values, standard deviations of the observed and calibrated & validated values for nutrient parameters are generally intersecting, which means with higher number of observed data, the model can show more accurate calibration performance.

4.2.3. Nutrient (NO_3, TN & TP) Calibration & Validation

Like sediment calibration, The SWAT-CUP program was used for this process. Calibration of the watershed was done for Nitrate, TN and TP values which were observed in the 05-02-00-003 and 05-02-00-061 Water Quality Stations.

Nutrient calibration was done with selected parameters given in Table 4-19. These parameters were selected considering previous studies on a global sensitivity analysis regarding nutrient calibration (Arnold J. M., 2012), (Me, 2015), (Haas, 2017), (Omani, 2012).

Table 4-19. Calibration Parameters Descriptions for Nutrient Calibration

#	Parameter Name	File Ext.	Description
1	SOL_ORGN	.chm	Initial organic N concentration in the soil layer
2	NPERCO	.bsn	Nitrogen percolation coefficient
3	BC1_BSN	.bsn	Rate constant for biological oxidation of NH3 (1/day)
4	BC2_BSN	.bsn	Rate constant for biological oxidation NO2 to NO3 (1/day)
5	BC3_BSN	.bsn	Rate constant for hydrolysis of organic nitrogen to ammonia (1/day)
6	CDN	.bsn	Denitrification exponential rate coefficient
7	SDNCO	.bsn	Denitrification threshold water content
8	SOL_NO3	.chm	Initial NO_3 concentration in the soil layer
9	ERORGN	.hru	Organic N enrichment ratio
10	SOL_ORGP	.chm	Initial organic P. concentration in the upper soil layer for a particular landuse
11	ERORGN	.hru	Organic nitrogen enrichment ratio
12	PHOSKD	.bsn	Phosphorus soil partitioning coefficient (m^3/Mg)
13	PSP	.bsn	Phosphorus Availability Index
14	RS5	.swq	Organic P settling rate
15	ERORGP	.hru	Organic Phosporus enrichment ratio

Fitted values for the calibration for sub-basin-26 was used for all the watershed as it was closer to the outlet of the basin and located at the downstream of the many of the point sources.

As shown in Table 4-20, 15 parameters affecting the nutrients of the watershed were assessed. With these parameters, SWAT-CUP program was run and at the end of 20 iterations, 1500 simulations were performed and optimum fitted parameter values were obtained.

Table 4-20. Calibration Parameters and Fitted Values for Nitrate

#	Parameter Name	File Name	File Ext.	Method	Min	Max	Fitted Value
1	SOL_ORGN		.chm	Replace	0	100	70.450005
2	NPERCO		.bsn	Replace	0	1	0.6205
3	BC1_BSN		.bsn	Replace	0.1	1	0.36055
4	BC2_BSN		.bsn	Replace	0.2	2	1.5221
5	BC3_BSN		.bsn	Replace	0.2	0.4	0.3859
6	BC4_BSN		.bsn	Replace	0.01	0.7	0.2159
7	CDN		.bsn	Replace	0	3	1.7385
8	SDNCO		.bsn	Replace	0	1	0.2405
9	SOL_NO3		.chm	Replace	0	100	41.450001
10	SOL_ORGP		.chm	Replace	0	100	51.4569
11	ERORGN		.hru	Replace	0	5	0.8425
12	PHOSKD		.bsn	Replace	100	200	134.456
13	PSP		.bsn	Replace	0.01	0.7	0.2359
14	RS5		.swq	Replace	0.001	0.1	0.0025
15	ERORGP		.hru	Replace	0	5	1.359

For sub-basin-7, performance of the nutrient values was again evaluated according to statistical values of R^2, NSE and PBIAS (Table 4-18). According to the model performance statistics evaluation table, it can be said that, calibration results were in generally satisfactory range for R^2 and PBIAS, on the other hand, NSE value has failed to give satisfactory results.

Similarly, validation process was conducted to assess the performance of the model. It can be said that the model gives unsatisfactory results in the validation process as well. When the graphs generated by SWAT-CUP at the end of the calibration process is examined, it is observed that there is a similar correlation between the observed and simulation values in general (Figure 4.24 to Figure 4.26).

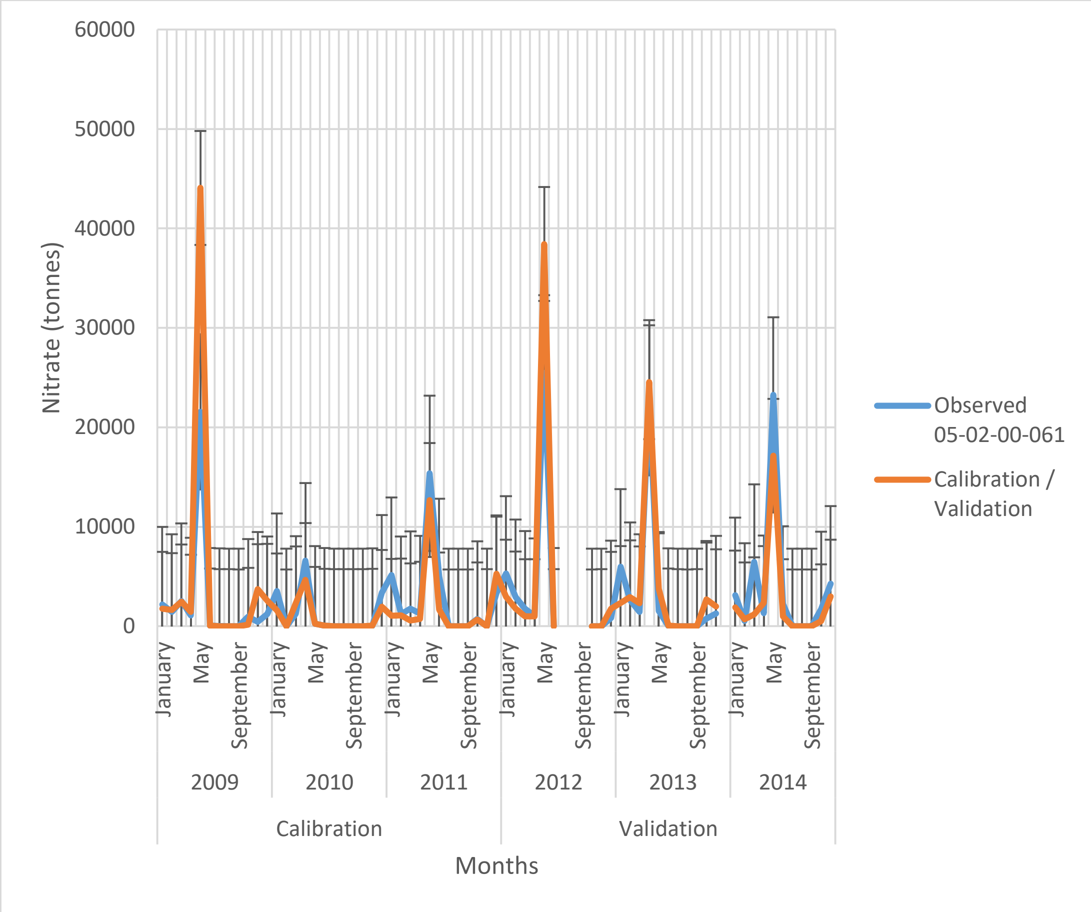

Figure 4.24. Results of Nitrate Calibration and Validation Processes for Sub-basin 7

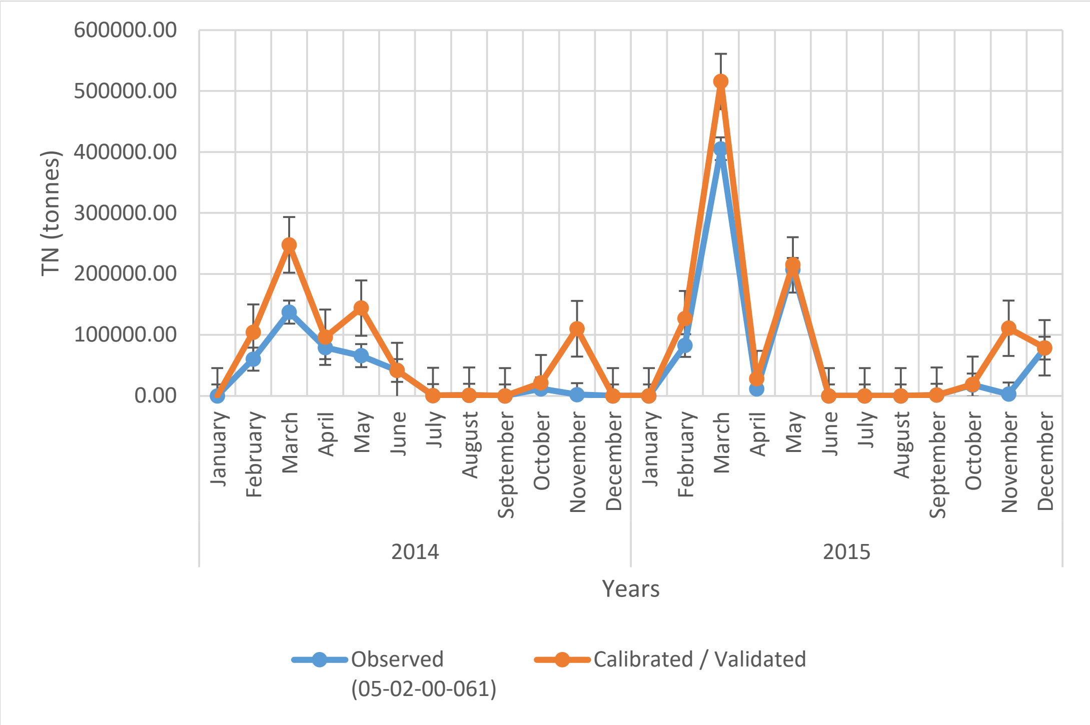

Figure 4.25. Results of Total Nitrogen Calibration and Validation Processes for Sub-basin 7

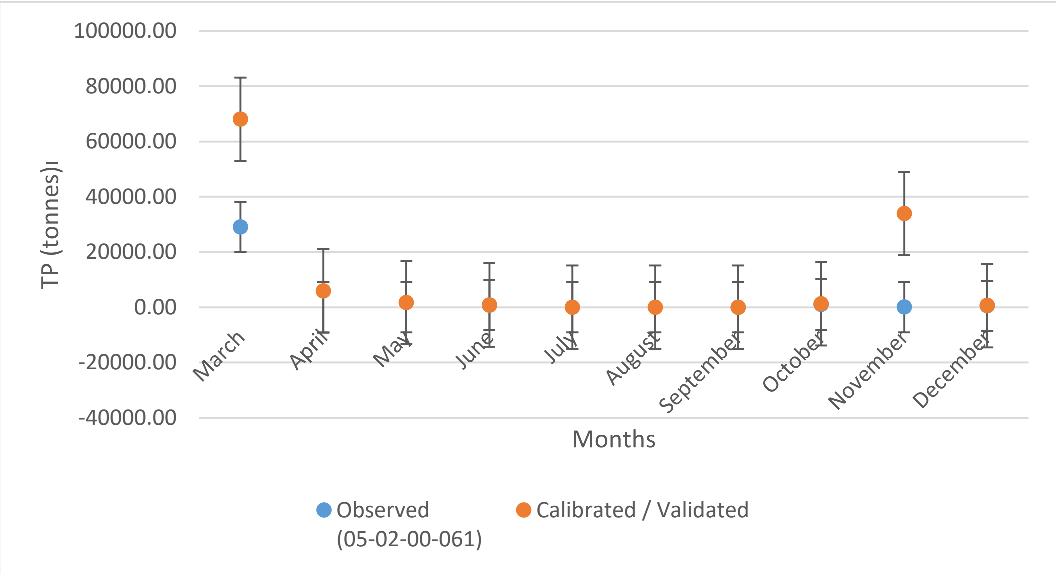

Figure 4.26. Results of Total Phosphorus Calibration and Validation Processes for Sub-basin 7

Table 4-21. Performance Evaluation of Model's Calibration and Validation Processes for Nutrient (Sub-basin 7)

	Parameter	Calibration (2007-2011)	Validation (2012-2015)
Nitrate	R^2	**0.81**	**0.625**
	NSE	0.149	-0.001
	PBIAS	**-14.92**	95.63
TN	**Parameter**	**Calibration (2014)**	**Validation (2015)**
	R^2	0.233	0.209
	NSE	0.149	0.12
	PBIAS	**7.88**	64.17
TP	**Parameter**	**Calibration (2015)**	**Validation (-)**
	R^2	**0.504**	**-**
	NSE	0.16	-
	PBIAS	-157.04	-

For sub-basin-26, performance of the nutrient values was again evaluated according to statistical values of R^2, NSE and PBIAS (Table 4-22). According to the model performance statistics evaluation table, it can be said that, calibration results were in generally satisfactory range for R^2 and PBIAS, on the other hand, NSE value has failed to give satisfactory results.

Similarly, validation process was conducted to assess the performance of the model. It can be said that the model gives unsatisfactory results in the validation process as well. When the graphs generated by SWAT-CUP at the end of the calibration process is examined, it is observed that there is a similar correlation between the observed and simulation values in general (Figure 4.27 to Figure 4.29).

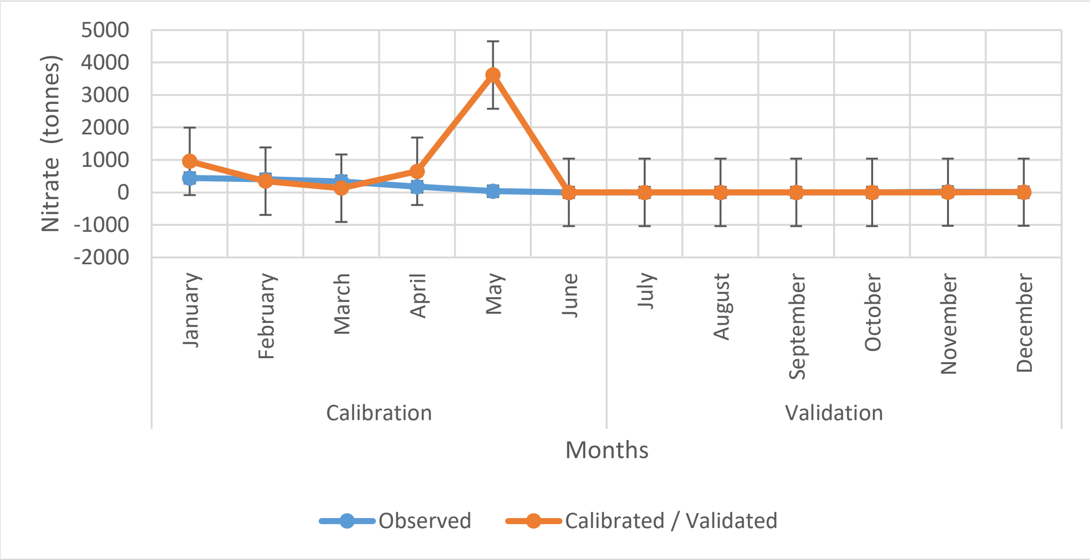

Figure 4.27. Results of Nitrate Calibration and Validation Processes for Sub-basin 26

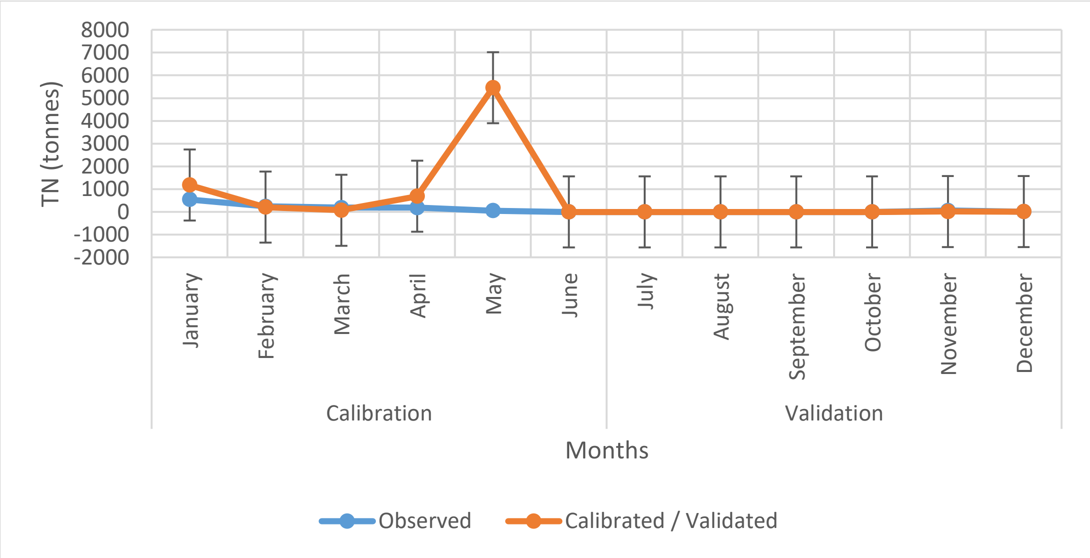

Figure 4.28. Results of Total Nitrogen Calibration and Validation Processes for Sub-basin 26

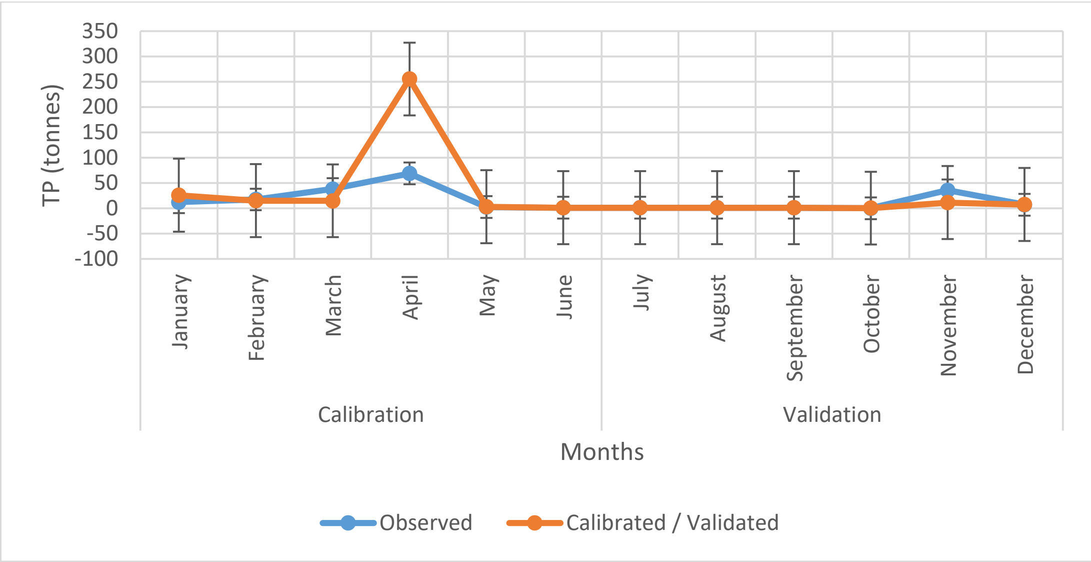

Figure 4.29. Results of Total Phosphorus Calibration and Validation Processes for Sub-basin 26

Table 4-22. Performance Evaluation of Model's Calibration and Validation Processes for Nutrient (Sub-basin 26)

	Parameter	**Calibration (January-June 2018)**	**Validation (July-December 2018)**
Nitrate	R^2	0.178	**0.656**
	NSE	0.1	0.176
	PBIAS	**56.29910464**	**-74.30591053**
TN	**Parameter**	**Calibration (January-June 2018)**	**Validation (July-December 2018)**
	R^2	0.137	**0.621**
	NSE	0.1	0.168
	PBIAS	-308.8515687	**46.62074065**
TP	**Parameter**	**Calibration (January-June 2018)**	**Validation (July-December 2018)**
	R^2	0.043	**0.798**
	NSE	0.15	0.201
	PBIAS	-524.601886	**53.57432297**

It should also be noted that, even though calibration results do not show desired performance values, standard deviations of the observed and calibrated & validated values for nutrient parameters are generally intersecting, which means with higher number of observed data, the model can show more accurate calibration performance.

4.3. Simulation Scenarios

Within the scope of this thesis, alternatives to improve water quality in Gürdük Watershed were examined in three different scenarios; i) decrease of fertilizers, ii) increase in waste water treatment efficiency and iii) changing the conventional tillage operations by conservational tillage. Thus, three different scenarios developed and presented in the Table 4-23.

Table 4-23. Scenarios Developed for Improving Water Quality in Gürdük Watershed

Scenario	Description
Baseline Scenario	Model simulation after streamflow, sediment, and nitrate load calibration
Scenario-1	Fertilizer application rates were decreased by 15%
Scenario-2	Increasing WWTP efficiency by 10 %
Scenario-3	Applying conservation tillage instead of conventional tillage
Scenario-4	Reducing the generated wastewater during industrial activities by 15 %
Scenario-5	Terracing (at the agricultural lands having a slope %10-%25)
Scenario-6	Fertilizer application rates were decreased by 30 %
Scenario-7	Increasing WWTP efficiency by 30 %
Scenario-8	Combination of Scenario-6 & Scenario-7

The efficiencies of these scenarios were evaluated by comparing them with the baseline scenarios. The evaluation was done regarding of reduced amount of sediment and nitrate loads of the subbasin-26 of the watershed which has the ultimate outlet of the basin (Figure 4.30).

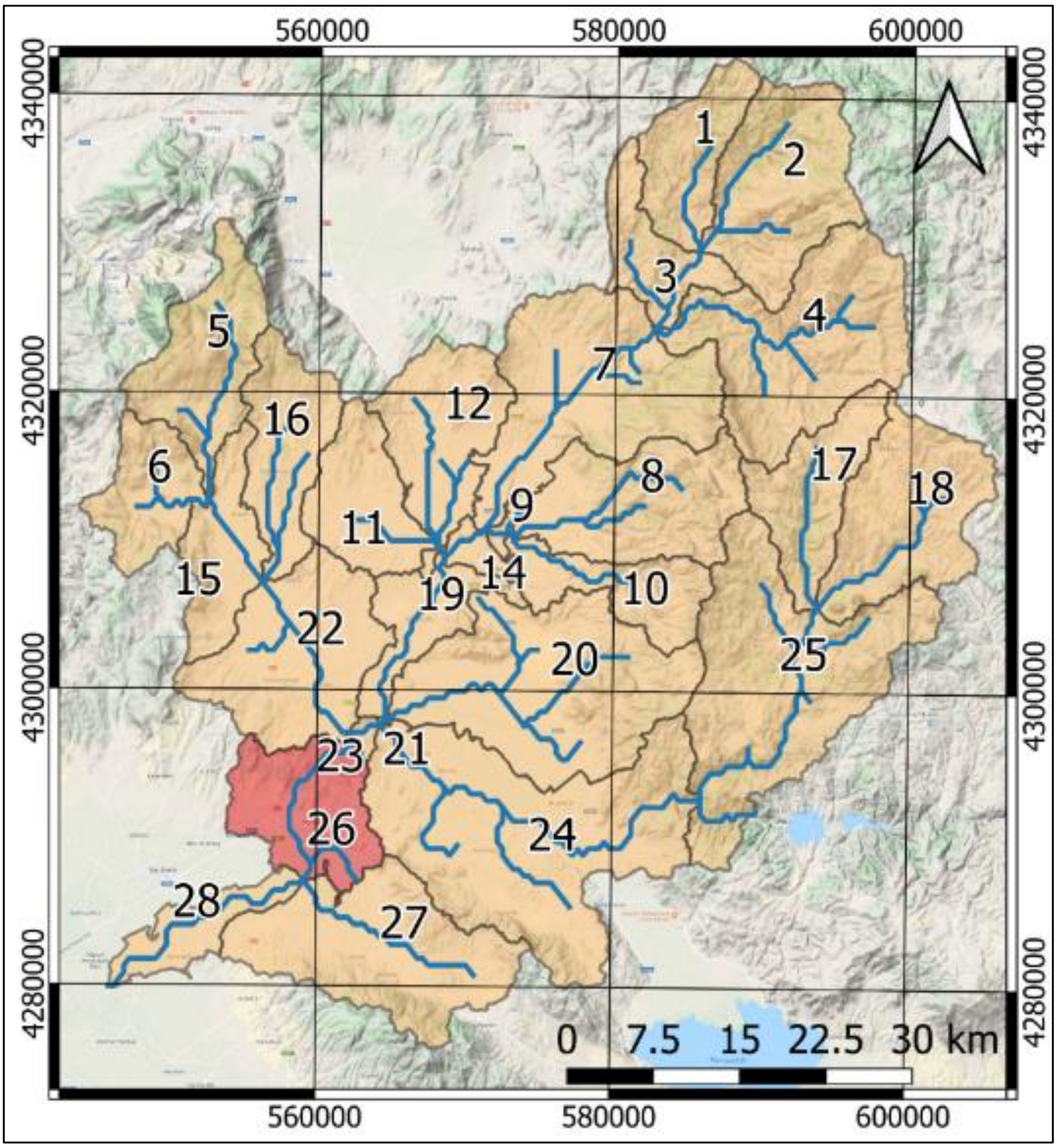

Figure 4.30. Location of Subbasin-26

4.3.1. Scenario-1

Amount of used fertilizer for each HRU were decreased by 15% and therefore; amount of nutrients applied which were specified in Appendix-A were decreased 15%. This scenario aims to decrease nutrient parameters in particular.

4.3.2. Scenario-2

Daily pollutant loads for each sub-basin which were specified in Table 4-9 were reduced by 10%. This scenario aims to decrease COD, nutrient and sediment parameters in particular.

4.3.3. Scenario-3

The goal of tillage application is to provide an environment for plant growing (Klute, 1982). A various types of tillage applications can be defined. Manipulation of soil can have serious impacts on crop yield, ether in bad or good ways (Ohiri, 1991). There is a variety of reasons why there is a high interest in conservation tillage all around the world. One of them is the fact that conservation tillage is considered as a good measure against erosion. Moreover, conservation tillage is and effective measure for water conservation as it prevents diffused sources of pollution (Unger, 1998). This scenario aims to decrease nutrient and sediment parameters in particular.

4.3.4. Scenario-4

By using proper pollution prevention methods decreasing the flowrate of each point source Table 4-9 were reduced by 15%. This scenario aims to decrease COD, nutrient and sediment parameters in particular.

4.3.5. Scenario-5

By having terracing applications in the agricultural areas having a slope between 10% and 25 %. This scenario aims to decrease nutrient and sediment parameters in particular.

4.3.6. Scenario-6

Amount of used fertilizer for each HRU were decreased by 30% and therefore; amount of nutrients applied which were specified in Appendix-A were decreased 30%. This scenario aims to decrease nutrient parameters in particular.

4.3.7. Scenario-7

Daily pollutant loads for each sub-basin which were specified in Table 4-9 were reduced by 30%. This scenario aims to decrease COD, nutrient and sediment parameters in particular.

4.3.8. Scenario-8

Applying the Scenario-6 and Scenario-7 simultaneously. This scenario aims to decrease COD, nutrient and sediment parameters in particular.

CHAPTER 5

RESULTS & DISCUSSION

5.1. Streamflow Calibration & Validation

Stream flow calibration & validation processes were done for three different sub-basins with three different stations' long term flow rate data. During the calibration phase, SUFI-2 algorithm was used via SWAT-CUP software.

There is a good correlation between the simulation values obtained during the calibration and validation processes and the observed values. Therefore; it can easily be said that SWAT Program can be used for various hydrological studies to be conducted in the Gürdük Basin.

5.2. Sediment Calibration & Validation

Calibration of the sediment values were also done using SWAT-CUP, SUFI-2 Algorithm. Sediment calibration of the watershed was performed for sub-basin-7 and sub-basin-26 and sediment values which were observed in the 05-02-00-061 and 05-02-00-003 respectively were used.

When evaluating the performance statistics, calibration results could only be in satisfactory range for PBIAS, however, R^2 and NSE values have failed to give in the satisfactory results. In addition, validation of sediment yield has failed to give satisfactory results as only PBIAS statistics was within the satisfactory range and R^2 and NSE were not.

These results can be explained as sediment calibration is generally hard to perform, as measurement are prone to have errors. Moreover, land use practices crucial in sediment formation, therefore; up-to-datedness of the land use data can have an important impact on the sediment formation calculations.

To have more accurate sediment calibration results, more accurate data on land use practices can be obtained from the site.

5.3. Nutrient (NO_3, TN & TP) Calibration & Validation

Calibration of the Nutrient (NO_3, TN & TP) values were also done using SWAT-CUP, SUFI-2 Algorithm. Nutrient (NO_3, TN & TP) calibration of the watershed was performed for sub-basin-7 and sub-basin-26 and sediment values which were observed in the 05-02-00-061and 05-02-00-061 respectively were used.

The performance statistics show that, calibration results were in satisfactory range for R^2 and PBIAS, on the other hand, NSE value has failed to give satisfactory results for R^2. Overall, total performance of Nutrient Calibration & Validation is unsatisfactory.

Even though there is a good correlation between the observed and simulated values in general, nutrient calibration can be improved. First of all, as it was stated in Chapter 3.3, there is only limited data on the number of the point sources (industrial and municipal wastewater discharges). Moreover, because the quality of the discharged treated waste water was unknown, it was assumed that, each treatment plant is discharging the treated waste water according to the related discharge limits for each sector specified in Water Pollution Control Regulation. (Chapter 4.1.8). This fact can cause miscalculating the pollutant loads. Therefore, obtaining actual data on the number and quality of the discharged wastewater can improve the nitrate calibration.

Furthermore, as in the case of sediment calibration, obtaining more accurate data on land use practices from the site and obtaining more detailed and up-to date information on agricultural practices can better the nutrient yield results.

5.4. Simulation Scenarios

Alternatives to improve the water quality of the Gürdük Basin needs to be identified via considering different types of pollution. Which means, the alternatives should include practices that affect point and non-point sources.

Table 5-1 shows the SWAT's calculated amounts of pollutant types emerged from point and diffused sources. Amount of annual loads of pollutants.

Table 5-1. Amount of Pollutant Types Emerged from Point and Diffused Sources (tonnes/year)

Pollutant Type	Point Sources	Diffused Sources
TN	158	1,148
TP	30	376
COD	2,323	-

Majority of the considered improvement alternatives were selected to cope with diffused sources since main pollutant source of the watershed is considered to be caused from agricultural management activities.

Different scenarios were selected to cope with the environmental stressors namely industrial and municipal wastewater discharges and agricultural activities.

To decrease the diffused pollution, two different alternatives for agricultural practices were recommended; decrease of fertilizers and changing the conventional tillage operations by conservational tillage.

Decrease percentage of average annual pollutant load calculated by comparing them with the baseline scenarios. Decrease percentage calculation was performed by the formula provided below:

$$Decrease\ Percentage\ (\%) = \frac{Pollutant_{\ i^{th}\ Scenario} - Pollutant_{\ BaselineScenario}}{Pollutant_{\ BaselineScenario}} \quad \text{Equation 12}$$

Decrease percentages of each scenarios regarding to sediment and nitrate loads were calculated and compared in Table 5-2.

Table 5-2. Evaluation of Scenarios for Improving Water Quality in Gürdük Watershed

Scenarios	**Sediment**	**NO_3**	**TN**	**TP**
Scenario-1 / Fertilizer application rates were decreased by 15%	3.50%	9.00%	4.50%	6.00%
Scenario-2 / Increasing WWTP efficiency by 10 %	5.00%	3.50%	5.00%	1.50%
Scenario-3 / Applying conservation tillage	8.00%	7.50%	5.50%	3.00%
Scenario-4 / Reducing the generated wastewater during industrial activities by 15 %	2.50%	2.00%	2.50%	3.50%
Scenario-5 / Terracing (at the agricultural lands having a slope %10-%25)	**13.00%**	2.50%	1.00%	3.00%
Scenario-6 / Fertilizer application rates were decreased by 30 %	6.50%	12.00%	7.00%	10.00%
Scenario-7 / Increasing WWTP efficiency by 30 %	6.50%	3.85%	5.25%	7.75%
Scenario-8 / Combination of Scenario-6 & Scenario-7	**3.50%**	**14.75%**	**12.50%**	**16.25%**

As it can be seen from Table 5-2, with different scenarios, significant improvements in the water quality can be reached. Scenario-2 (Increasing WWTP efficiency by 10 %) has been the least efficient alternative as the number of the sources are low, and quality of the discharged wastewater are assumed to be complying with Water Pollution Control Regulation.

Scenario-8 (Combination of Scenario-6 & Scenario-7) was the most efficient alternative for the water quality improvement as it has led to significant decreases in both the sediment and nitrate loads from both diffused and point sources.

Finally, Scenario-3 (Applying conservation tillage instead of conventional tillage) has also affected water quality status of the basin, especially in terms of sediment control. This should be noted as sediment control is not only in terms of water quality but also in terms of sediment control. Therefore, having more conservation tillage applications within the basin could also result in conservation the agricultural lands.

The effect of the most efficient scenario (Scenario-8) is evaluated considering the baseline status of sub-basin 26 and the updated status of the point regarding SWQR. Baseline and final status of the point is evaluated in Table 5-3.

Table 5-3. Evaluation of Scenario-8 regarding SWQR

Scenario	TN (mg/L)	SWQR Class	TP (mg/L)	SWQR Class
Baseline	15.3	Class-III	4.3	Class-IV
Scenario-8	10.94	Class-II	2.7	Class-IV

When Table 5-3 is examined it can be seen that, even though class of the monitoring point did not change according to TP, final value has significantly decreased. Moreover, class of the monitoring point has increased to Class II.

CHAPTER 6

CONCLUSION & RECOMMENDATIONS

Water quality in Gürdük Watershed was analysed to understand the current water pollution status and management strategies were developed via using SWAT model within the context of this study. Moreover, a water quality approach was tried to be established as WQIs were used to determine the before and after status of the watershed.

In order to evaluate the water quality status of Gürdük River Basin, long term of DSİ Quality Monitoring Stations numbered 05-02-00-061 and 05-02-00-003 was used. The evaluation of the water quality status of the watershed was performed with regards to Surface Water Quality Regulation and three different Water Quality Indices to understand the level of the water pollution in the watershed. Results of the evaluation have shown that water quality is in poor quality water for aquatic, potable and general usage.

Gürdük watershed currently includes many types agricultural activates and a wide range of manufacturing activities covering almost every kind of industry is being conducted in the watershed. Therefore; the watershed is rich in terms of point and diffused sources of pollution.

Therefore, a management strategy was introduced after analysing the point and diffused sources of pollution and evaluating the alternatives to improve water quality in Gürdük Watershed. SWAT model was used for understanding the effects of the point and diffused sources of pollution. Streamflow, sediment and nitrate loads were simulated in Gürdük Watershed and SWAT-CUP interface was used for calibration streamflow, sediment and nutrients.

Streamflow calibration & validation has shown good results in terms of R^2, NSE and PBIAS values and shown good correlation good correlation between the observed values. On the other hand, the sediment and water quality calibration has failed for giving satisfactory results.

The values NSE, PBIAS and R^2 have shown unsatisfactory performance for sediment and nitrate calibration. The main reason behind the failed sediment and water quality simulations is the limited data availability on land use. Obtaining more accurate data on land use practices from the site and obtaining more detailed and up-to date information on agricultural practices could improve the water quality calibration results. Even though, the water quality simulations did not give as good results as stream flow simulations gave, water quality improvement alternatives were still evaluated as modelling studies area considered to be useful for exploratory purposes even though accuracy of the modelling is not as high as desired levels.

As discussed in the water quality evaluation chapter, majority of the pollution is emerging from the diffused sources, especially from the agricultural activities. Therefore, water quality improvement alternatives were centred on agricultural management practices therefore nutrient removal.

Different alternatives were evaluated to improve water quality in Gürdük Watershed. The alternatives were introduced to deal with point and diffused pollution. Scenario-8 (Combination of Scenario-6 & Scenario-7) was the most efficient alternative for the water quality improvement as it has led to significant decreases in both the sediment and nitrate loads from both diffused and point sources.

The objective of this study was to help decision makers by evaluating different alternatives to improve the water quality in Gürdük Watershed along with other watersheds having similar characteristics. Therefore, as different alternatives were examined to cope with diffused and point sources of water pollution. So, performed activities within the scope of this thesis, can be effective to construct an integrated watershed management system and improve the water quality in Gürdük Watershed.

Recommendations

Considering the obstacles faced during this thesis, having more accurate data on land use practices from the watershed and obtaining more detailed and up-to date information on agricultural practices can result in better modelling studies. Moreover, number of water quality monitoring stations, and the frequency and the number of parameters monitored should be increased throughout the basin. Limited number of water quality parameter calibration could be performed in the watershed as there was a lack of adequate water quality data.

Water quality of the discharge locations of the point sources were assumed to be complying the water pollution control regulation. Therefore; obtaining actual data on the number and quality of the discharged waste water can improve the water quality calibration.

It is recommended that the effects of climate change to the watershed could also be analysed with SWAT model once there is enough data.

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APPENDICES

A. Agricultural Management Summary for HRUs

UNIQUECOMB	Product	NH_3-N	Org-N	NO_3-N	Total-N	P_2O_5-P	In-P	Total-P
1_AGRL_Lo91-2bc-3208_0-10	Wheat	14.037	7.427	3.678	25.141	8.854	3.896	27.170
1_AGRL_Lo91-2bc-3208_10-25	Wheat	15.877	8.401	4.160	28.438	10.014	4.406	19.517
1_AGRL_Lo91-2bc-3208_25-9999	Wheat	5.611	2.969	1.470	10.049	3.539	1.557	13.286
3_AGRL_I-Lc-E-2b-3114_0-10	Wheat	9.017	4.771	2.362	16.150	5.687	2.502	13.627
3_AGRL_I-Lc-E-2b-3114_10-25	Wheat	5.986	3.167	1.568	10.721	3.776	1.661	7.629
3_AGRL_I-Lc-E-2b-3114_25-9999	Wheat	2.413	1.277	0.632	4.323	1.522	0.670	13.872
3_AGRL_Lo91-2bc-3208_0-10	Wheat	12.859	6.804	3.369	23.033	8.111	3.569	20.079
3_AGRL_Lo91-2bc-3208_10-25	Wheat	9.247	4.893	2.423	16.563	5.833	2.566	64.470
6_OLIV_I-Lc-E-2b-3114_0-10	Olives	61.732	32.663	16.174	110.569	38.938	17.133	67.390
6_OLIV_I-Lc-E-2b-3114_10-25	Olives	12.462	6.594	3.265	22.321	7.860	3.459	161.175
7_OLIV_I-Lc-E-2b-3114_0-10	Olives	161.031	95.791	40.690	297.512	104.067	45.790	184.589
7_OLIV_I-Lc-E-2b-3114_10-25	Olives	37.030	22.830	9.243	69.103	24.120	10.613	94.348
7_OLIV_Jc49-1-3a-3139_0-10	Olives	65.635	34.728	17.196	117.559	41.399	18.216	69.077
7_OLIV_Jc49-1-3a-3139_10-25	Olives	10.417	5.512	2.729	18.659	6.571	2.891	17.836
9_OLIV_Jc49-1-3a-3139_0-10	Olives	9.220	4.878	2.416	16.513	5.815	2.559	135.656
11_OLIV_I-Lc-E-2b-3114_0-10	Olives	140.134	74.147	36.715	250.996	88.390	38.892	151.240
11_OLIV_I-Lc-E-2b-3114_10-25	Olives	26.377	13.957	6.911	47.245	16.638	7.321	100.036
11_OLIV_Jc49-1-3a-3139_0-10	Olives	83.760	44.319	21.945	150.024	52.832	23.246	79.447
12_AGRL_I-Lc-E-2b-3114_0-10	Wheat	3.709	1.962	0.972	6.643	2.339	1.029	5.709
12_AGRL_I-Lc-E-2b-3114_10-25	Wheat	2.577	1.363	0.675	4.615	1.625	0.715	44.528
12_AGRL_Jc49-1-3a-3139_0-10	Wheat	46.448	24.576	12.169	83.193	29.297	12.891	157.154
12_OLIV_I-Lc-E-2b-3114_0-10	Olives	126.574	66.972	33.163	226.709	79.837	35.129	145.834
12_OLIV_I-Lc-E-2b-3114_10-25	Olives	33.985	17.982	8.904	60.871	21.436	9.432	78.714
12_OLIV_Jc49-1-3a-3139_0-10	Olives	52.677	27.872	13.802	94.351	33.226	14.620	52.784
13_AGRL_Jc49-1-3a-3139_0-10	Wheat	5.436	2.876	1.424	9.737	3.429	1.509	6.762
13_OLIV_Jc49-1-3a-3139_0-10	Olives	2.008	1.063	0.526	3.597	1.267	0.557	2.490

UNIQUECOMB	Product	NH_3-N	Org-N	NO_3-N	Total-N	P_2O_5-P	In-P	Total-P
13_OLIV_Jc49-1-3a-3139_10-25	Olives	0.734	0.388	0.192	1.314	0.463	0.204	20.459
14_AGRL_Jc49-1-3a-3139_0-10	Wheat	21.792	11.530	5.709	39.031	13.745	6.048	29.378
14_OLIV_Jc49-1-3a-3139_0-10	Olives	10.552	5.583	2.765	18.900	6.656	2.929	143.993
15_OLIV_I-Lc-E-2b-3114_0-10	Olives	145.270	80.028	37.918	263.217	93.339	41.069	175.393
15_OLIV_I-Lc-E-2b-3114_10-25	Olives	41.863	25.957	10.796	78.615	28.462	12.523	188.928
16_OLIV_I-Lc-E-2b-3114_0-10	Olives	162.513	86.974	42.439	291.926	102.739	45.205	216.002
16_OLIV_I-Lc-E-2b-3114_10-25	Olives	73.758	42.163	18.880	134.801	47.263	20.796	79.406
17_AGRL_I-Lc-E-2b-3114_0-10	Wheat	12.494	6.611	3.273	22.378	7.880	3.467	33.151
17_AGRL_I-Lc-E-2b-3114_10-25	Wheat	24.005	12.701	6.289	42.996	15.141	6.662	32.071
17_AGRL_I-Lc-E-2b-3114_25-9999	Wheat	11.305	5.981	2.962	20.248	7.130	3.137	36.891
18_AGRL_I-Lc-E-2b-3114_0-10	Wheat	27.116	14.035	7.013	48.164	18.488	8.135	101.496
18_AGRL_I-Lc-E-2b-3114_10-25	Wheat	75.517	38.974	19.498	133.989	51.994	22.878	112.517
18_AGRL_I-Lc-E-2b-3114_25-9999	Wheat	36.856	18.849	9.466	65.171	26.142	11.503	129.266
19_AGRL_Jc49-1-3a-3139_0-10	Wheat	99.454	54.278	25.982	179.715	63.625	27.995	145.344
19_OLIV_Jc49-1-3a-3139_0-10	Olives	54.257	34.419	13.957	102.632	37.308	16.415	59.856
19_OLIV_Jc49-1-3a-3139_10-25	Olives	6.459	3.759	1.677	11.896	4.259	1.874	193.032
20_AGRC_Jc49-1-3a-3139_0-10	Tomatoes	205.322	109.163	53.771	368.256	129.791	57.108	206.014
20_AGRL_I-Lc-E-2b-3114_0-10	Wheat	21.045	11.135	5.514	37.695	13.274	5.841	36.431
20_AGRL_I-Lc-E-2b-3114_10-25	Wheat	19.064	10.087	4.995	34.146	12.025	5.291	145.308
20_AGRL_Jc49-1-3a-3139_0-10	Wheat	140.811	74.627	36.887	252.326	88.883	39.109	143.989
20_AGRL_Jc49-1-3a-3139_10-25	Wheat	17.613	9.319	4.615	31.547	11.109	4.888	17.324
21_AGRC_Jc49-1-3a-3139_0-10	Tomatoes	1.030	1.047	0.247	2.325	0.921	0.405	1.570
21_AGRC_Jc49-1-3a-3139_10-25	Tomatoes	0.190	0.193	0.045	0.428	0.169	0.075	29.639
22_AGRC_I-Lc-E-2b-3114_0-10	Tomatoes	27.683	20.112	7.006	54.801	20.413	8.982	108.803
22_AGRC_Jc49-1-3a-3139_0-10	Tomatoes	71.670	56.317	17.945	145.932	55.144	24.263	121.938
22_AGRL_I-Lc-E-2b-3114_0-10	Wheat	43.470	26.917	11.212	81.599	29.535	12.995	109.067
22_AGRL_Jc49-1-3a-3139_0-10	Wheat	57.932	48.544	14.369	120.844	46.206	20.331	84.037
22_AGRL_Jc49-1-3a-3139_10-25	Wheat	13.595	13.815	3.262	30.673	12.153	5.347	143.552
22_OLIV_I-Lc-E-2b-3114_0-10	Olives	123.266	83.335	31.476	238.077	87.536	38.516	168.409
22_OLIV_I-Lc-E-2b-3114_10-25	Olives	34.500	32.421	8.398	75.319	29.414	12.942	109.670

UNIQUECOMB	Product	NH_3-N	Org-N	NO_3-N	Total-N	P_2O_5-P	In-P	Total-P
22_OLIV_Jc49-1-3a-3139_0-10	Olives	70.045	41.808	18.137	129.990	46.745	20.568	69.986
23_GRAP_Jc49-1-3a-3139_0-10	Grapes	2.076	2.110	0.498	4.685	1.856	0.817	3.281
23_GRAP_Jc49-1-3a-3139_10-25	Grapes	0.473	0.480	0.113	1.067	0.423	0.186	91.546
24_AGRC_I-Lc-E-2b-3114_0-10	Tomatoes	82.319	62.289	23.093	167.701	63.152	27.786	273.659
24_AGRC_Jc49-1-3a-3139_0-10	Tomatoes	186.829	115.453	48.367	350.650	126.890	55.832	280.045
24_AGRL_I-Lc-E-2b-3114_0-10	Cotton	96.019	58.493	30.954	185.466	67.587	29.737	114.172
24_AGRL_I-Lc-E-2b-3114_10-25	Cotton	18.047	8.882	6.210	33.138	11.700	5.148	44.986
24_AGRL_Jc49-1-3a-3139_0-10	Wheat	28.591	17.172	8.260	54.022	19.540	8.598	37.058
24_AGRL_Jc49-1-3a-3139_10-25	Wheat	9.424	5.103	2.865	17.392	6.195	2.726	93.450
24_GRAP_I-Lc-E-2b-3114_0-10	Grapes	76.555	57.232	22.253	156.040	58.702	25.828	124.235
24_GRAP_Jc49-1-3a-3139_0-10	Grapes	38.344	25.694	10.803	74.840	27.573	12.132	85.510
25_AGRL_I-Lc-E-2b-3114_0-10	Wheat	48.103	25.048	12.573	85.725	31.809	13.996	107.703
25_AGRL_I-Lc-E-2b-3114_10-25	Wheat	64.528	33.599	16.782	114.909	42.985	18.914	83.547
25_AGRL_I-Lc-E-2b-3114_25-9999	Wheat	22.048	11.407	5.707	39.161	15.034	6.615	114.477
26_AGRC_Jc49-1-3a-3139_0-10	Tomatoes	72.118	73.282	17.306	162.705	64.464	28.364	169.041
26_AGRL_Jc49-1-3a-3139_0-10	Wheat	59.210	60.165	14.208	133.583	52.926	23.287	98.016
26_AGRL_Jc49-1-3a-3139_10-25	Wheat	16.938	17.212	4.065	38.215	15.141	6.662	83.632
26_GRAP_Jc49-1-3a-3139_0-10	Grapes	48.035	48.810	11.527	108.371	42.937	18.892	98.471
26_OLIV_Jc49-1-3a-3139_0-10	Olives	28.467	28.927	6.831	64.225	25.446	11.196	46.869
26_OLIV_Jc49-1-3a-3139_10-25	Olives	7.945	8.073	1.907	17.925	7.102	3.125	115.413
27_AGRC_Jc49-1-3a-3139_0-10	Tomatoes	81.719	83.038	19.610	184.366	73.046	32.140	186.541
27_AGRL_I-Lc-E-2b-3114_0-10	Wheat	63.204	64.224	15.167	142.595	56.496	24.858	106.402
27_AGRL_I-Lc-E-2b-3114_10-25	Wheat	19.459	19.773	4.669	43.901	17.394	7.653	104.983
27_AGRL_Jc49-1-3a-3139_0-10	Wheat	62.102	63.104	14.902	140.108	55.511	24.425	95.428
27_AGRL_Jc49-1-3a-3139_10-25	Wheat	12.036	12.230	2.888	27.155	10.759	4.734	82.802
28_AGRC_Jc49-1-3a-3139_0-10	Tomatoes	52.292	53.136	12.548	117.977	46.743	20.567	92.186
28_AGRL_Jc49-1-3a-3139_0-10	Wheat	19.327	19.639	4.638	43.603	17.276	7.601	67.850
28_GRAP_Jc49-1-3a-3139_0-10	Grapes	33.385	33.924	8.011	75.321	29.842	13.131	42.973

B. Observed vs Simulated Values (Streamflow and Water Quality)

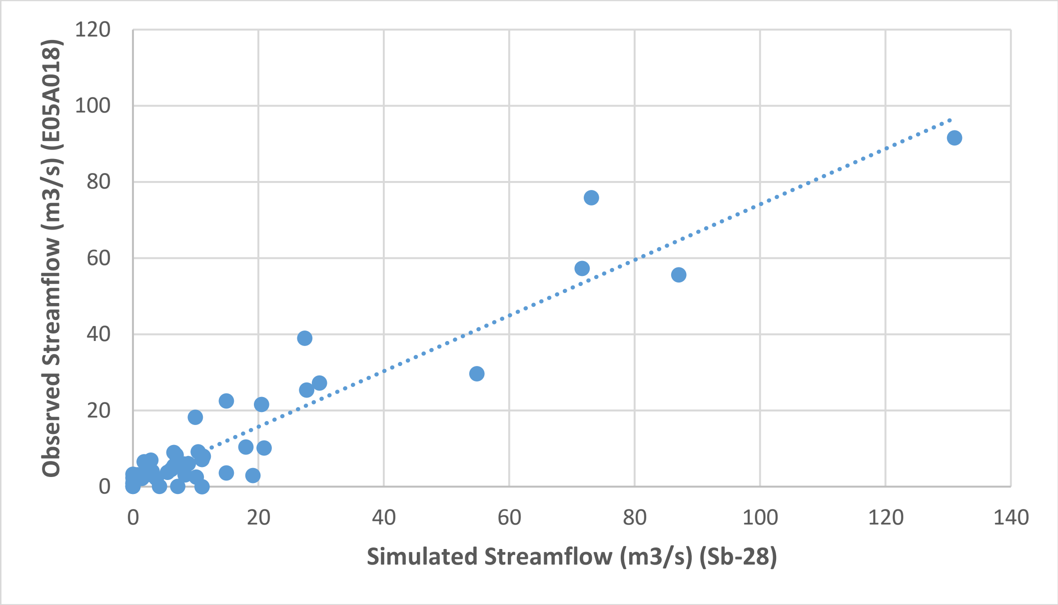

Figure B.1. Observed vs Simulated Values – Stream Flow (Sub-basin -28)

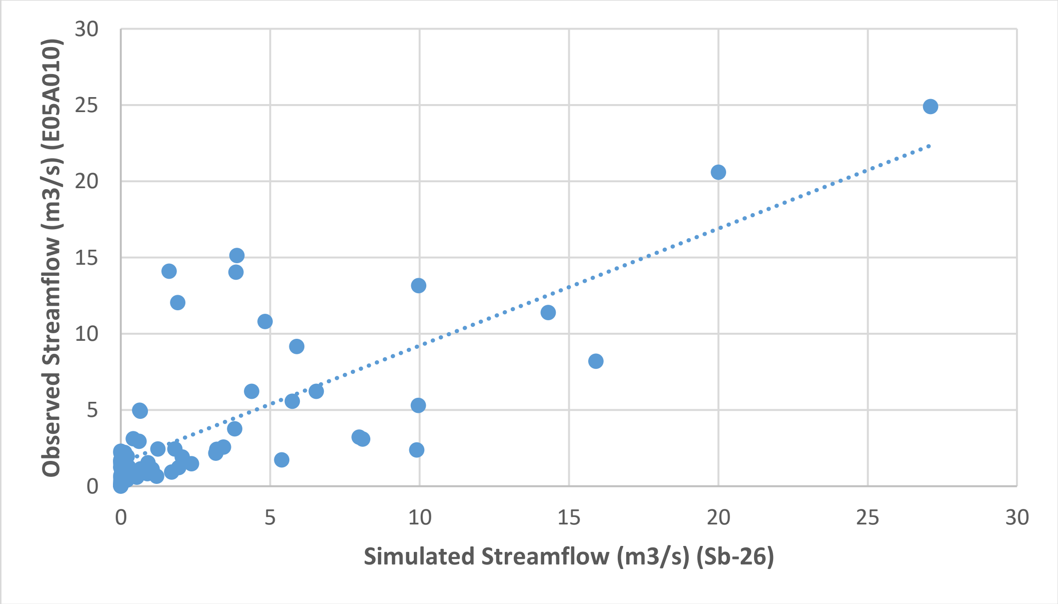

Figure B.2. Observed vs Simulated Values – Stream Flow (Sub-basin -26)

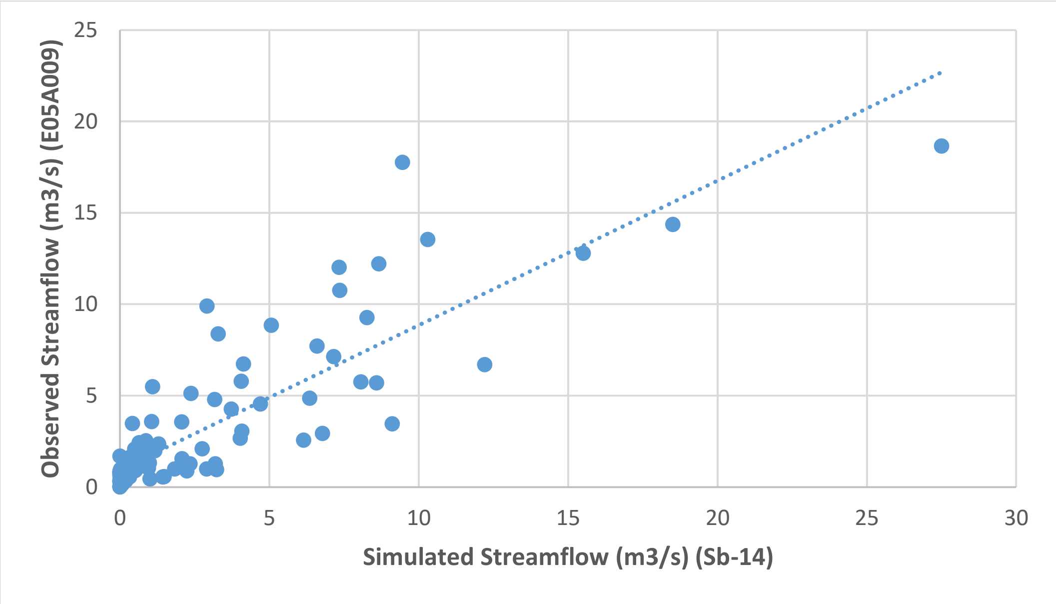

Figure B.3. Observed vs Simulated Values – Stream Flow (Sub-basin -14)

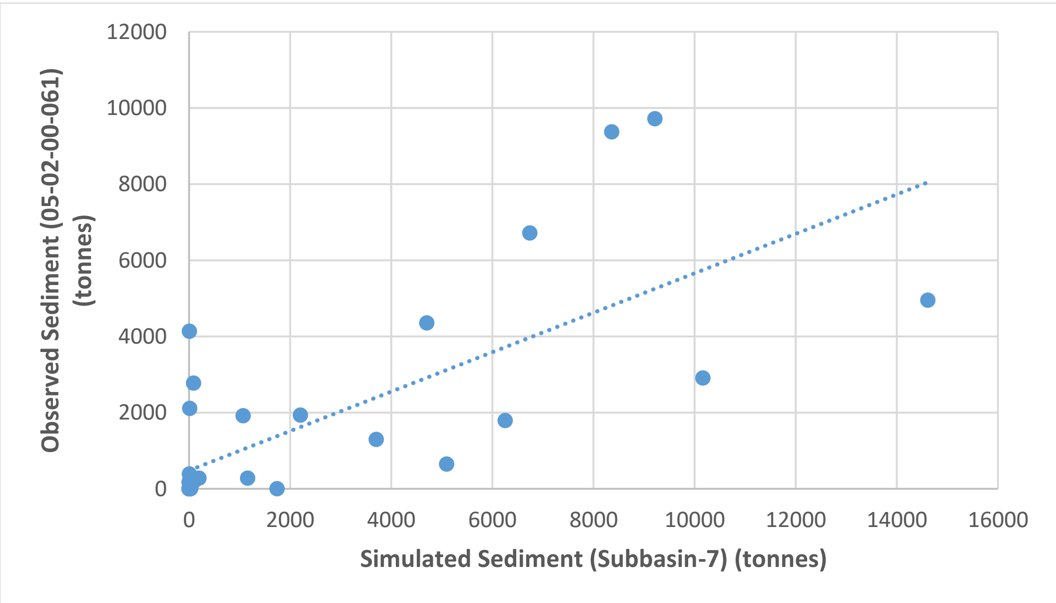

Figure B.4. Observed vs Simulated Values – Sediment (Sub-basin -7)

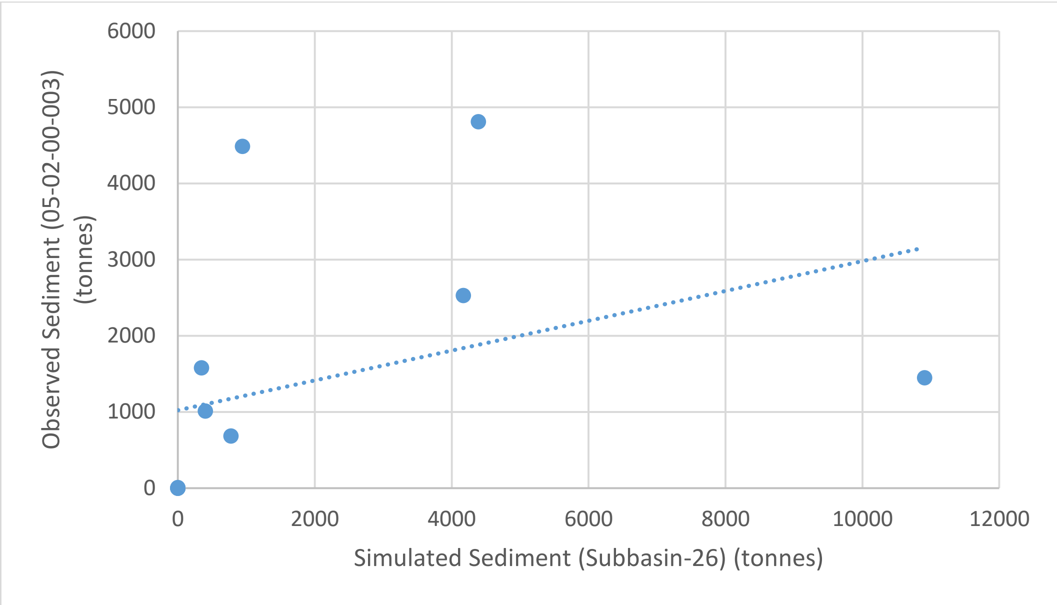

Figure B.5. Observed vs Simulated Values – Sediment (Sub-basin -26)

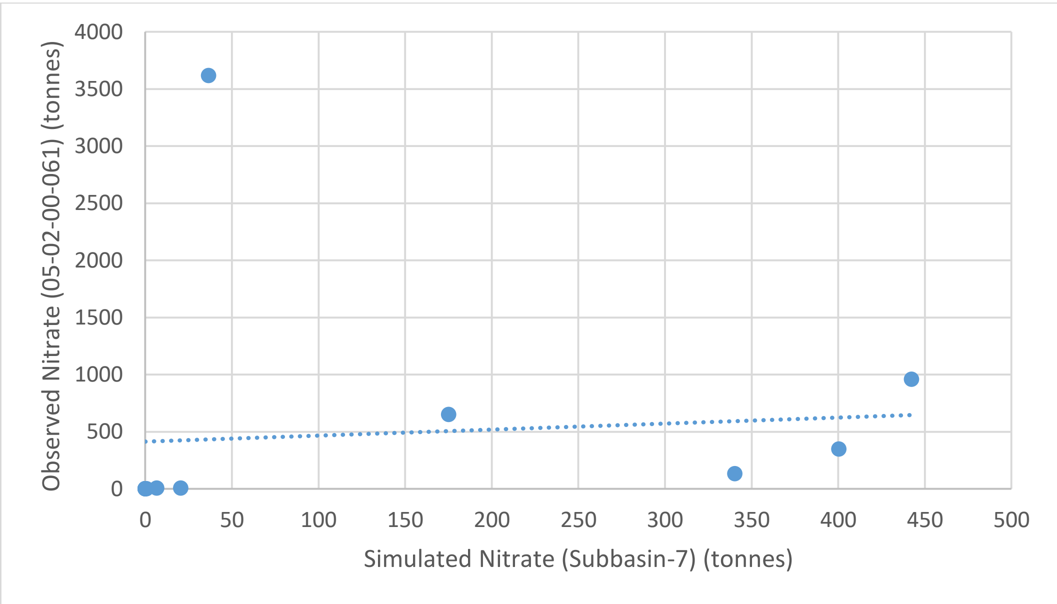

Figure B.6. Observed vs Simulated Values – Nitrate (Sub-basin -7)

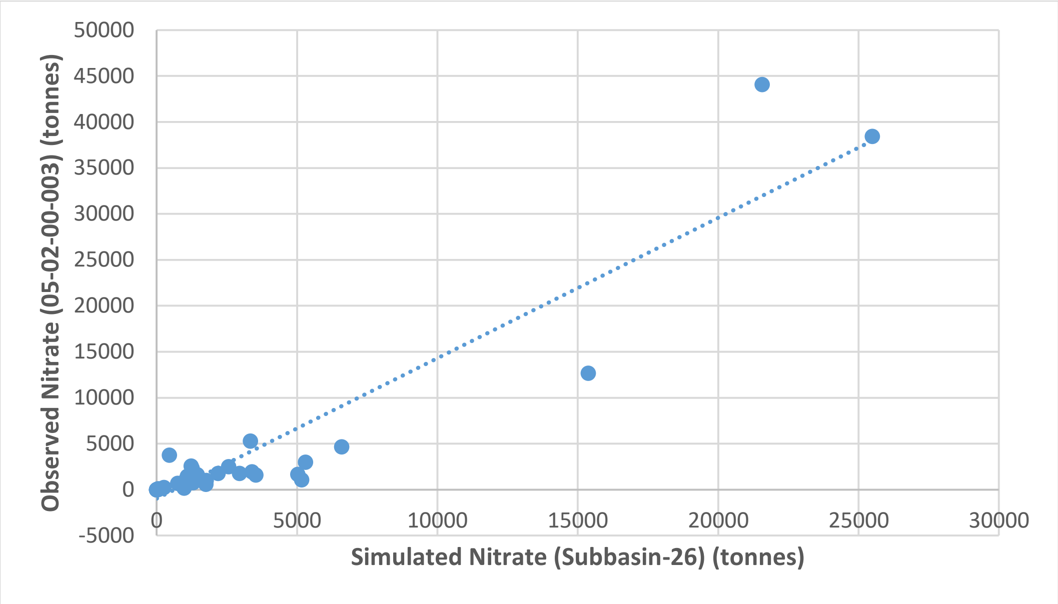

Figure B.7. Observed vs Simulated Values – Nitrate (Sub-basin -26)

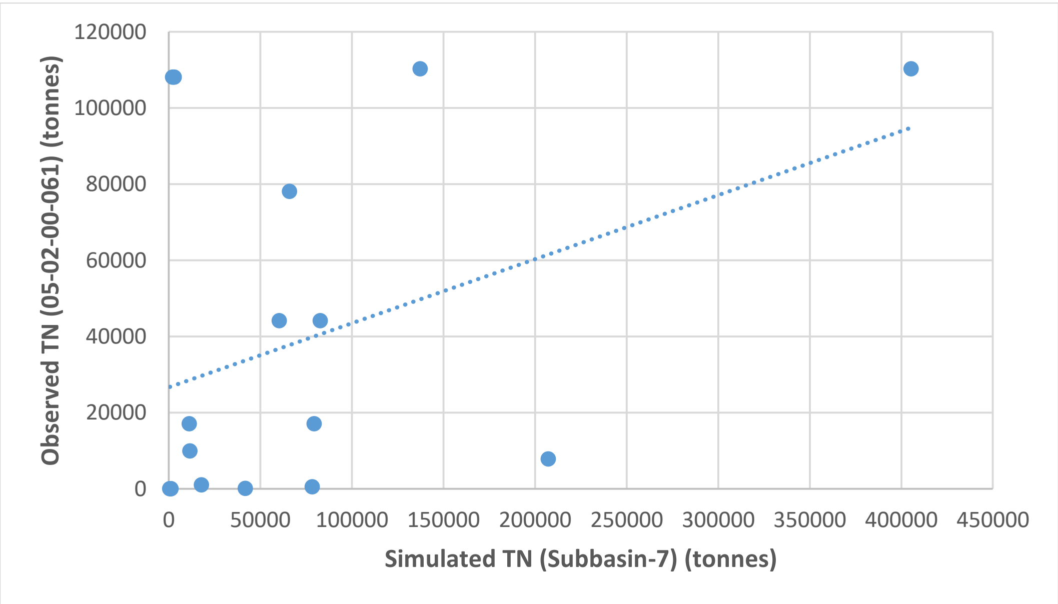

Figure B.8. Observed vs Simulated Values – TN (Sub-basin -7)

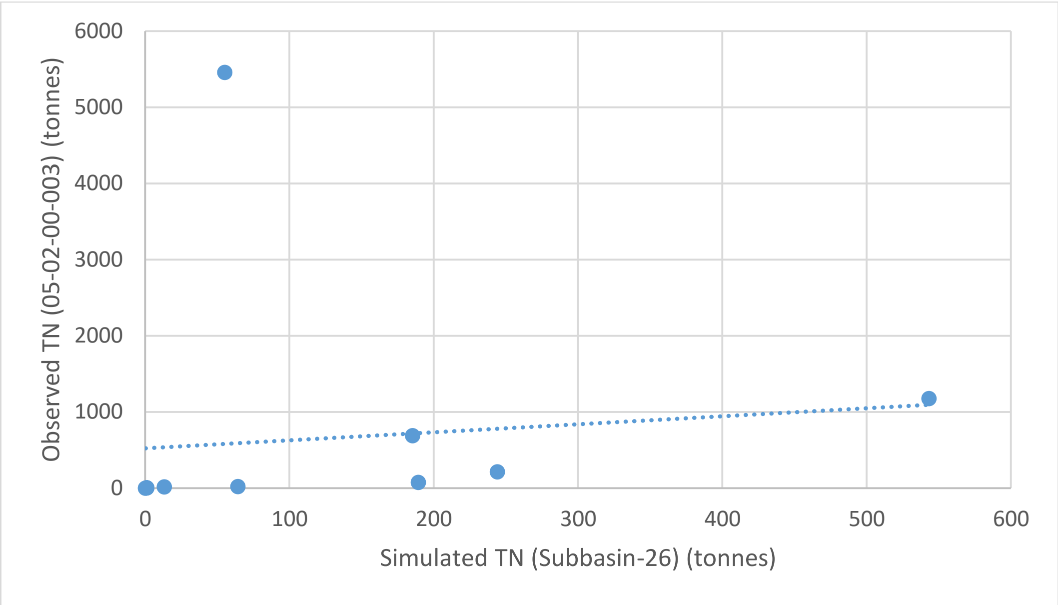

Figure B.9. Observed vs Simulated Values – TN (Sub-basin -26)

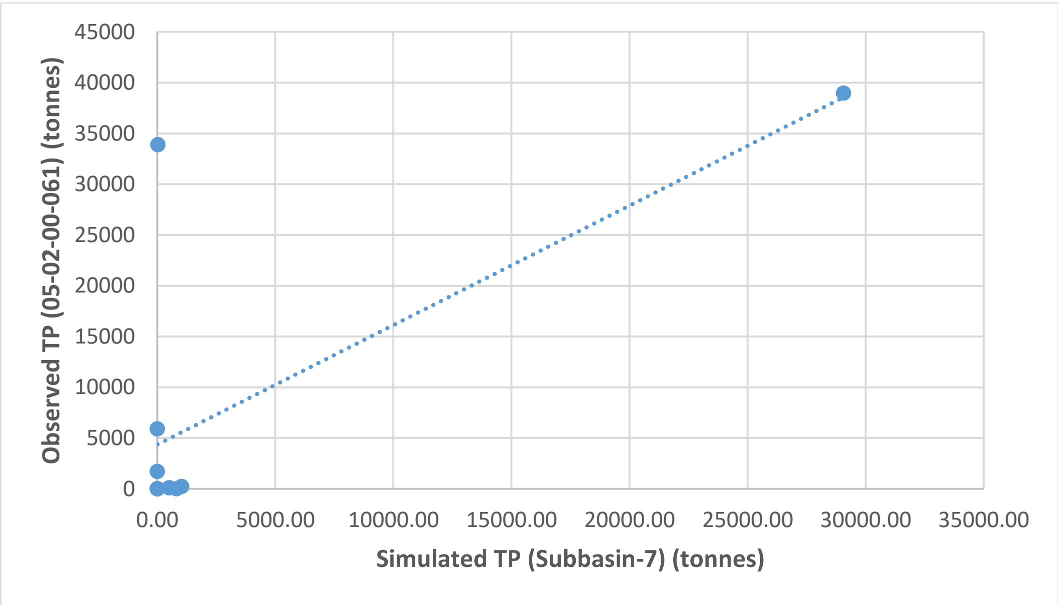

Figure B.10. Observed vs Simulated Values – TP (Sub-basin -7)

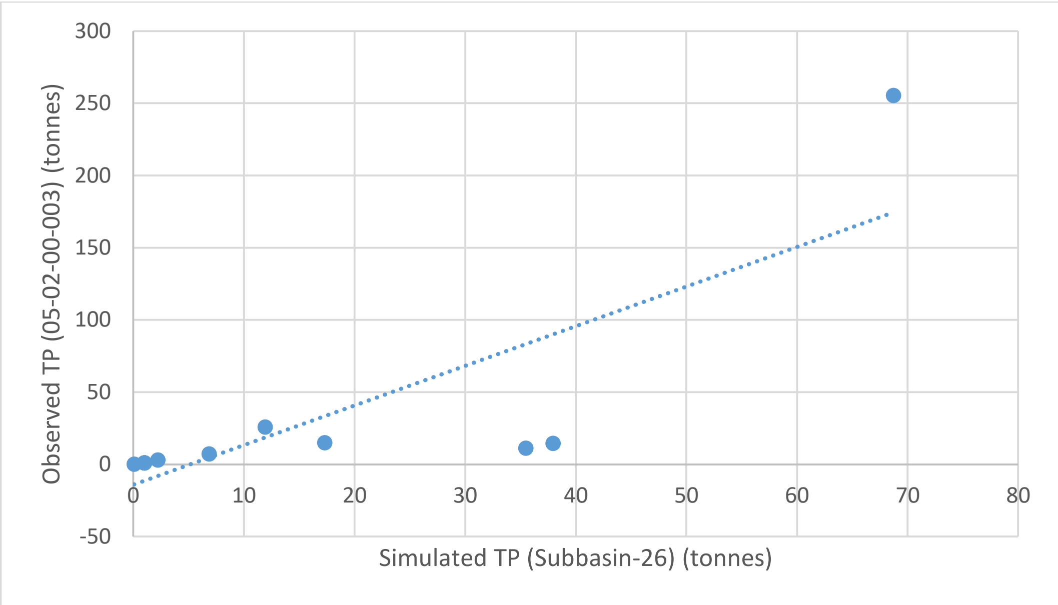

Figure B.11. Observed vs Simulated Values – TP (Sub-basin -26)