Agricultural Water Management 194 (2017) 160–171

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Research paper

Evaluation of the best management practices in a semi-arid region with high agricultural activity

Zeynep Özcan[a], Elçin Kentel[b], Emre Alp[a,*]

[a] Department of Environmental Engineering, Middle East Technical University, Ankara, Turkey
[b] Department of Civil Engineering, Middle East Technical University, Ankara, Turkey

ARTICLE INFO

Article history:
Received 6 February 2017
Received in revised form 29 June 2017
Accepted 10 September 2017
Available online 21 September 2017

Keywords:
Best management practices
Semi-arid regions
Lake Mogan
SWAT model
Diffuse pollution control
Non-irrigated agriculture

ABSTRACT

The arid and semi-arid regions with water scarcity are vulnerable to several stressors such as urbanization, high water demand created by agricultural and industrial activities, point and non-point pollution sources, and climate change. Hence, proactive policies and sustainable water management strategies that are based on decision support systems are crucial in arid and semi-arid regions. Because of large expenses and implementation difficulties associated with the diffuse pollution abatement plans, many authorities are hesitant to initiate, especially those that may present a financial burden on population. Lake Mogan, a shallow lake, is located in a semi-arid region dominated by dry agricultural activities and has been in eutrophic state for the past 20 years. There has been several management alternatives suggested to improve the water quality in Lake Mogan and one of the alternative is the application of BMPs that include fertilizer management, conservation/no tillage, contouring, and terracing to reduce the amount of diffuse source pollutants. In this study, Soil and Water Assessment Tool (SWAT) Model is applied to evaluate the effectiveness of agricultural best management practices (BMPs) in the Lake Mogan watershed located in a semi-arid region. The most effective BMP scenario was found as the one in which three individual BMP scenarios (30% fertilizer reduction, no tillage, and terracing) were combined. With this scenario average annual load reductions of 9.3%, 8.6%, 8.0%, and 11.1% were achieved in sediment, nitrate, total nitrogen, and total phosphorus, respectively. Even with the most effective BMP strategy, high levels of nutrient reduction will not be achieved since non-irrigated agriculture and intermittent low-flow streams accounts majority of the study area. The outcomes suggest integrated solutions should be developed to improve water quality in Lake Mogan. It is aimed that this study will aid decision makers to implement effective best management practices in watersheds showing similar characteristics (i.e. topographical, hydrologic processes, LULC (Land use land cover) characteristics, agricultural activities, meteorological etc.) with the study area.

1. Introduction

Nonpoint or diffuse source pollution is primarily related to land drainage and surface runoff (Hranova, 2006). Runoff, produced either due to rainfall or snowmelt, gathers and transports the pollutants to water bodies such as lakes and rivers. Contrary to point source pollution arising from industrial and sewage treatment plants, diffuse pollution originates from several dispersed and poorly defined sources (EPA, 2012). Diffuse pollution is affected by weather conditions, and land characteristics such as topography, soil type and land management (Ritter and Shirmohammadi, 2001). Return flow from irrigated agriculture, agricultural runoff and infiltration, wet and dry atmospheric deposition, runoff and snowmelt from roads and highways can be given as examples of diffuse pollution (Novotny, 2003). In rural areas, diffuse pollution is mainly associated with agricultural activities and animal operations. Application of fertilizers, pesticides and insecticides, irrigation return flow, irrigation with wastewater/sludge, and diffuse pollution from farmyards are some of the major cases of diffuse pollution in rural areas (Hranova, 2006).

Best management practices (BMPs) are defined as the soil and water conservation practices including social and cultural actions which have been recognized as the effective and practical ways for the environmental protection (Sharpley et al., 2006). BMPs are commonly designed with the purpose of ensuring the efficient use of agricultural chemicals; enhancing soil cover; reducing the veloc-

---

* Corresponding author.
E-mail address: emrealp@metu.edu.tr (E. Alp).

http://dx.doi.org/10.1016/j.agwat.2017.09.007

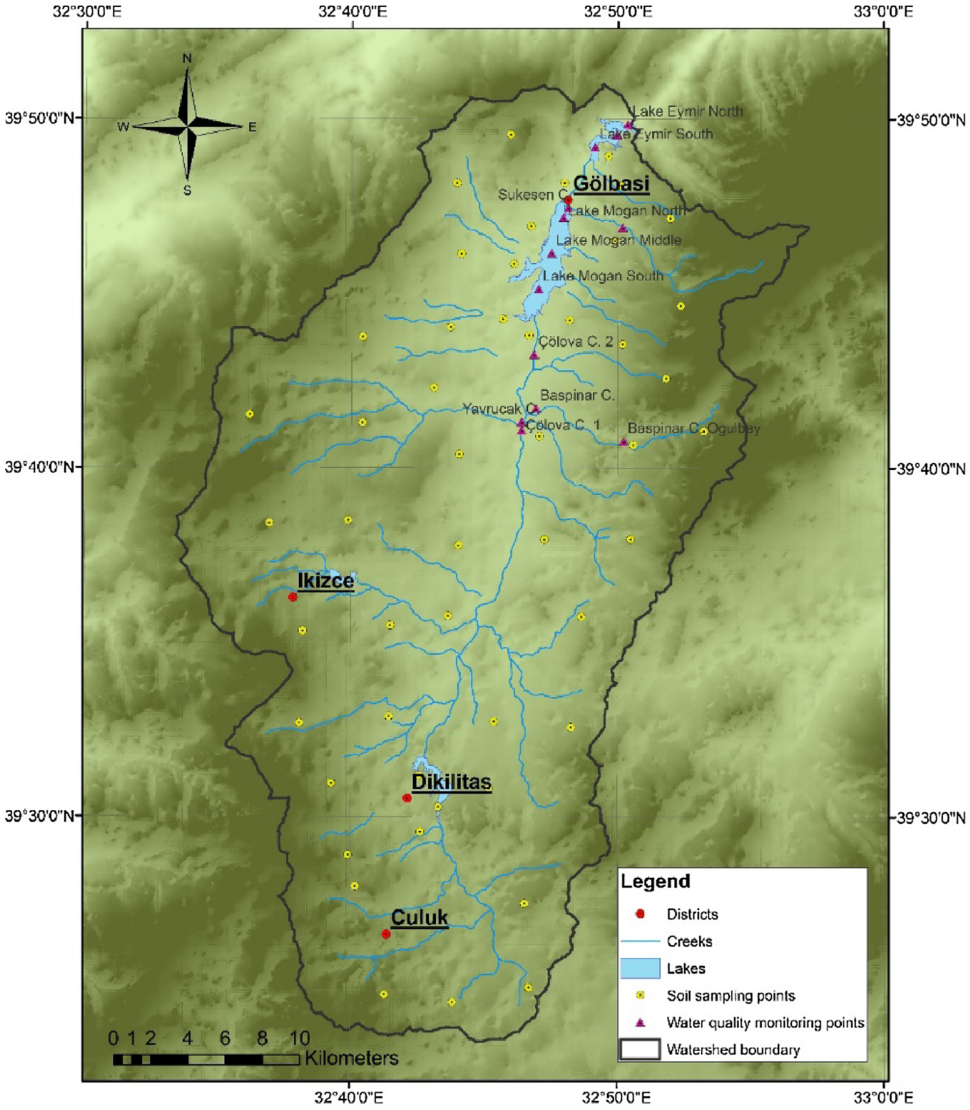


Fig. 1. Location of Lake Mogan watershed in 20 km south of Ankara, Turkey.

ity of surface runoff, and improving the management of livestock waste (Cestti et al., 2003). Troeh et al. (2004) stated that soil and water conservation methods are usually classified into two as vegetative and mechanical practices. Vegetative practices ensure denser vegetative cover for a longer period. Crop rotation, efficient use of fertilizers, and narrow row spacing can be given as examples of vegetative practices. These practices provide both improved product yield and erosion control. Mechanical practices are different from the vegetative ones in a way that they permit growing of plants which provide less soil protection but reducing the erosion at the same time. Contour tillage, no tillage, and terrace systems are some of the mechanical BMPs. Novotny (2003), on the other hand, categorized BMPs under three categories as structural, vegetative, and management. The author also added that the effectiveness of each BMP changes according to the pollutant specie in concern. Moreover, it was stated that the pollutants and the forms of them while they are transported should be taken into consideration in selecting the proper BMPs for the pollution removal. In the report prepared by Minnesota Department of Agriculture (Miller et al., 2012) the removal efficiencies of agricultural BMPs were discussed based mainly on the monitored research data but some modelling studies especially strong and practical ones were also taken into account. According to this report, the BMPs are classified as avoiding, controlling, and trapping BMPs. Avoiding BMPs aim at preventing the entry of pollutants into the environment while the controlling ones are used to control the risk of pollution if avoiding is not possible. Trapping BMPs are specified as the last step in order for catching the pollutants close to its source.

Evaluating the effectiveness of a specific BMP by field trials or by collecting monitoring data is both costly and time consuming. The amount of pollutant loads and removal rates are highly variable in every runoff event. The monitoring data should be collected repeatedly in order to successfully evaluate the performance of a BMP. Especially for large watersheds with varying land use classes and soil characteristics, intensive monitoring studies should be carried out to correctly assess the effects of a particular BMP. Consequently, such studies are not always possible at the watershed level. In this context, watershed models stand out as useful tools since they provide an inexpensive and time saving way for evaluating BMPs at the watershed level.

In this study, effectiveness of agricultural BMPs were assessed with Soil and Water Assessment Tool (SWAT), a physically based continuous-event hydrologic model, at Lake Mogan watershed dominated with agricultural lands. It is important to control the agricultural diffuse pollution to prevent deterioration of water quality in Lake Mogan. Within the scope of this study, the impacts

Table 1
Model inputs for Lake Mogan watershed: Sources and Descriptions.

Data Type	Source	Data Description/Properties
Topography	General Command of Mapping	Digital Elevation Model (DEM), 15 m x 15 m resolution
Soil	Field survey, soil analysis by the Central Research Institute of Soil Fertilizer and Water Resources Laboratory	Soil physical properties like bulk density, hydraulic conductivity, texture etc.
Agricultural Practices Information	Gölbaşı District Directorate of Food, Agriculture and Livestock Central Research Institute of Soil Fertilizer and Water Resources	Agricultural crops grown in the watershed, all types of agricultural practices
Land use	RAPIDEYE (May 7th 2013)	Land use classification
Meteorology	General Directorate of Meteorology	Precipitation, temperature, relative humidity, wind speed and solar radiation data

Table 2
Number of available monthly water quality data for the period 2008–2010.

Variable	Yavrucak (Calibration)	Sukesen (Validation)
Streamflow (m^3/sec)	33	33
Total Nitrogen (kg/month)	3	9
Nitrate (kg/month)	7	7
Total Phosphorus (kg/month)	10	16
Total Suspended Solids (tons/month)	10	16

of several BMPs on sediment, phosphorus, and nitrogen loads were evaluated with SWAT in two subbasins of Lake Mogan watershed located in Ankara, Turkey.

2. Materials and methods

2.1. Study area

The study area, Lake Mogan watershed (Fig. 1), is located in Gölbaşı County, 20 km south of Ankara, the capital city of Turkey. The lake provides aesthetic and recreational opportunities for the city, and a habitat for breeding of birds. It hosts numerous different types of birds including little grebe, red-necked grebe, mallard, and gadwall (Taşeli, 2006). The Ministry of Environment declared the area as a “Special Protection Area” in 1990.

Mogan is a shallow lake with an average depth of 4.5 m. It is the lake behind a natural alluvial dam covering an area of 6 km^2 (Özesmi, 1999). Groundwater contribution to the lake is very low. The main water entry is through rivers with irregular regimes. The lake is mainly fed by creeks which are usually dry during summer (DSİ, 1993). The lake is substantially fed by Sukesen creek from the northwest, by Çölova creek from the south and by the wetland named Çökek marsh which is formed by Yavrucak and Başpınar creeks.

Lake Mogan watershed has a total drainage area of 970 km^2. The lowest and highest points in the watershed are 960 m and 1700 m, respectively. Dry farming is practiced in approximately 31% of the watershed and 42% of the area is covered with pastures. Grain is the most widely grown crop in the area. Cultivation of vegetables is also carried out on a limited scale. The climate in the study area is continental. Summers are very dry, and water shortages are experienced in summer months.

Lake Mogan and its wetland ecosystem is under threat due to serious pollution. Uncontrolled urbanization, point and nonpoint pollution sources, and ineffective sewerage systems are some of the causes of the pollution. Sediment deposition due to substances entering via erosion, snowmelt and drainage have continued for many years. This deposition causes a decrease in the volume of the lake. Biological activities in the lake have accelerated through sediment deposition, wastewater discharge, and surface runoff. Therefore, eutrophication process has started in the lake (Özesmi, 1999). In addition, sometimes there are uncontrolled discharges to the lake from the industries located in the basin. Another important pressure threatening the water quality of the lake and the streams is the intensive agricultural activity carried out in the basin.

2.2. SWAT model description

In this study, ArcSWAT 2012 which is an ArcGIS extension (ArcGIS Desktop 10 Service Pack 5) was used for performing SWAT simulations. SWAT was developed by United States of Agriculture – Agricultural Research Service (USDA-ARS) with the purpose of predicting the impact of management practices on water, sediment and agricultural chemical yields in large ungauged basins. It is a conceptual model operating on a daily time step. SWAT is commonly used to model watersheds and simulate different agricultural conservation practices all over the world (Santhi et al., 2006; Bracmort et al., 2006; Lee et al., 2010; Güngör and Göncü, 2013; Liu and Lu, 2014). The model is able to simulate surface flow, subsurface flow, soil erosion, sediment deposition, and the movement of nutrients through watersheds. Major model components are hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Arnold et al., 1998).

In SWAT, a watershed is divided into a number of subbasins. These subbasins are then subdivided into hydrologic response units (HRUs) having unique soil and land use properties. HRUs are the smallest unit of the model where the hydrological processes are calculated (Arnold et al., 2012a). The required variables to simulate hydrological processes are precipitation, maximum and minimum air temperature, solar radiation, wind speed and relative humidity (Arnold et al., 1998). Depending on the evapotranspiration model used in the model, the required variables change. The available evapotranspiration models are Hargreaves (Society and Agricultural, 1985), Priestley and Taylor (1972), and Penman-Monteith (Monteith and Moss, 1977). The nitrogen (N) and phosphorus (P) processes are modeled by SWAT through transformation of nitrogen and phosphorus between organic and inorganic pools in the nutrient cycle (Tuppad et al., 2010). Nutrient loss processes modeled by SWAT from the soil are plant uptake, surface runoff, sediment transport, lateral flow and percolation (Lacewell et al., 2010). Nitrogen and phosphorus consumed by the plants are estimated by the supply and demand approach (Williams et al., 1984). QUAL2E model (Brown and Barnwell, 1987) kinetic routines are embedded in SWAT to simulate the changes in the in stream water quality (Arnold et al., 2012b).

Table 3
Description of BMPs simulated for the Lake Mogan watershed.

BMP Scenario	Descriptions
Baseline Scenario	Model simulation after streamflow, sediment, and nutrient load calibration was finalized.
Scenario-1	Fertilizer application rates were decreased by 10%.
Scenario-2	Fertilizer application rates were decreased by 20%.
Scenario-3	Fertilizer application rates were decreased by 30%.
Scenario-4	Conventional tillage operations were replaced by conservation tillage.
Scenario-5	Conventional tillage operations were replaced by no tillage.
Scenario-6	Conservation tillage was applied at low clay (<30%) agricultural lands.
Scenario-7	No tillage was applied at low clay (<30%) agricultural lands.
Scenario-8	Contouring was applied at agricultural lands.
Scenario-9	Terracing was applied at agricultural lands.
Scenario-10	Combination of Scenarios 3 and 5
Scenario-11	Combination of Scenarios 3, 5 and 9

2.3. Model setup

ArcSWAT extension of ArcGIS 10 (Service Pack 5) was used to setup the SWAT project. Five basic categories of data sets required to build a SWAT model are topography, land use, soil, climatic input files, and agricultural practices. Descriptions of the inputs used in this study are given in Table 1.

To generate the DEM, 30 sheets of vector maps in 1/25 000 scale were obtained from Turkish General Command of Mapping. These vector maps were used to obtain the DEM of the study area by using geostatistical interpolation methods. Forty-nine soil samples were collected in the field surveys to develop the soil map. The analysis of the soil samples were performed by the Central Research Institute of Soil Fertilizer and Water Resources Laboratory. Sixteen different parameters including pH, organic carbon, clay, sand, and silt were analyzed. The spatial soil map of Lake Mogan watershed was generated using Thiessen Polygons or Voronoi Polygons method.

Land use classification was carried out by using Rapid Eye satellite image. The image was obtained on May 7th, 2013 and it has five spectral bands. Orthorectified Rapid Eye data has a spatial resolution of 5 m. Total classification accuracy was 80%. The land use classes were determined as water bodies, forest, agriculture, road, settlement, mine site, fallowing land, rangeland, and bareland.

Information about the agricultural practices carried out in the watershed was obtained from Gölbaşı District Directorate of Food, Agriculture and Livestock. Wheat and barley are the most commonly cultivated crops in the watershed. In this study, it was assumed that in all agricultural lands winter wheat is cultivated, and the agricultural operations defined in SWAT are listed accordingly. Dry farming is carried out in the region but water is supplied from the wells when necessary. Four different types of fertilizers namely urea, ammonium nitrate, ammonium sulfate and diammoniumphosphate (DAP) are used in wheat cultivation. Cattle and sheep breeding is also performed in the watershed.

2.4. Model calibration and validation

Calibration of SWAT model for Lake Mogan watershed was carried out using 2007–2010 streamflow and water quality data from Yavrucak monitoring station. The model validation was performed using data from Sukesen monitoring station for the same period. The simulation period includes both dry and wet periods. Year 2007 was used as the warm-up period, while 2008 represents the dry and 2009–2010 represent the relatively wet period based on the evaluation of stream flow observations. Within this simulation period there are missing monthly water quality data. As it can be seen from Table 2, the number of monthly data available for water quality calibration and validation processes ranges between 3 and 16. The model was calibrated for streamflow, sediment, nitrogen and phosphorus with SWAT-CUP (SWAT Calibration and Uncertainty Procedures). SWAT-CUP, a public domain calibration program (Abbaspour et al., 2007) for SWAT model, was run using SUFI-2 uncertainty analysis. SUFI-2 method takes into consideration all sources of uncertainties, i.e. input data (e.g. precipitation), conceptual model, model parameters and observed data (Abbaspour et al., 2007).

Table 4
Fertilizer application rates.

	Application Rate (kg/ha)			
Fertilizer Type	Baseline Scenario	Scenario-1	Scenario-2	Scenario-3
Urea (46-00-00)	100	90	80	70
Amonium Nitrate (33-00-00)	150	135	120	105
Amonium Sulfate (21-00-00)	200	180	160	140
DAP (18-46-00)	250	225	200	175

Model performance was evaluated using time series graphics, and several statistical criteria including Nash-Sutcliffe simulation efficiency (NSE), coefficient of determination (R^2), and percent bias (PBIAS). After streamflow calibration, sediment and water quality calibration was performed. For sediment calibration monthly total suspended solids measurements, and for water quality, monthly total nitrogen, nitrate (NO_3), and total phosphorus measurements at Yavrucak monitoring station was utilized. Details of the calibration procedure can be found in Özcan (2016) and Alp et al. (2014).

2.5. BMP representation in SWAT

In this study, several management practices were evaluated with the calibrated and validated SWAT model in terms of their efficiencies in the reduction of the amount of transported sediment and nutrient loads. Changes in the amount of pollutants were evaluated at the Yavrucak and Sukesen subbasin outlets. To evaluate the results, the changes in the amount of pollutants were compared with a baseline scenario which represents current practices carried out in the watershed. The BMPs evaluated include nutrient management by reducing fertilizer amounts, land use management by replacing conventional tillage methods with conservation or no tillage, contouring, and terracing. Eleven scenarios composed of various BMPs are generated (Table 3) and evaluated at Lake Mogan watershed. Scenarios 1–9 include single BMP applications and Scenarios 10 and 11 are the combination of scenarios, which include several nutrient management, tillage and terracing applications.

2.5.1. Nutrient management

Nutrient management involves practices aiming to reduce the availability of excess nutrients by controlling the timing, the application rate, and the location for fertilizer placement. Availability of nutrients are most effectively limited through a lowered or precise fertilizer application rate. Three different nutrient management scenarios were developed by reducing the fertilizer amount by 10%, 20% and 30% compared to the current fertilizer application rates. In Table 4, the fertilizer application rates in the baseline scenario, and Scenario-1, Scenario-2, and Scenario-3 are shown.

2.5.2. Conservation tillage—no tillage

Land use management scenarios involving different tillage operations were developed and the impact on the sediment and nutrient

Table 5
Tillage parameters.

Tillage Operation Name	Mixing Efficiency (fraction)	Depth of mixing (mm)
Duckfoot Cultivator (Conventional Tillage)	0.55	150
Conservation Tillage	0.25	100
No Tillage	0.05	25

loads were assessed at Yavrucak and Sukesen subbasin outlets. In the current situation, the tillage operations are being carried out with duckfoot cultivator. In Scenario-4 and Scenario-5, conventional tillage operations with duckfoot cultivator were replaced with conservation tillage and no tillage, respectively. Conservation tillage is a tillage method that leaves at least 30% of the soil surface covered with crop residue after planting. In no tillage planting, on the other hand, planting is carried out by placing seeds in the soil without tillage and maintaining previous plant residues. The related tillage parameters for each tillage operation in SWAT are shown in Table 5. Troeh et al. (2004) stated that in order to select the appropriate implementation, conservation tillage has to be flexible. In other words, while in some cases it would be necessary to leave all residue in the surface, sometimes it may be required to integrate part of the residue. In fact, deciding on the proper implementation necessitates the knowledge on the amount of residues required to control erosion, the quantity of residue available, and the fraction of residue integrated with each tillage operation.

In this study, none of the parameters related to hydrological processes were modified to represent conservation and no-tillage practices. The adjusted parameters are the ones which are already defined in SWAT database for the conservation and no-tillage management schedules. As stated by Novotny (2003) conservation and no-tillage practices control erosion and sediment by decreasing soil detachment. These tillage parameters affect the amount of pollutants that tend to transfer to the surface runoff. Hence, in this study runoff generation parameters were just used to predict the amount of runoff. The same methodology was also followed in several other studies; e.g. Giri et al. (2014), Lam et al. (2011), Parajuli et al. (2016). In another study carried out by Wang et al. (2013), the impacts of tillage practices on hydrological processes were investigated. Wang et al. (2013) found that there was not a significant difference between conventional and no tillage practices based on the net mean changes in soil water content during a year.

The impact of conservation and no tillage scenarios were also tested on agricultural lands with low clay ratio (<%30) based on the suggestion of an expert from Soil, Fertilizer and Water Resources Central Research Institute (Scenario-6 and Scenario-7).

2.5.3. *Contouring—terracing*

Two managerial and structural best management practices were developed in Scenario-8 and Scenario-9 to evaluate their impacts on water quality and quantity. The former is the application of contouring, and the latter is the terracing at agricultural lands. Contour farming is farming in which plowing and crop rows follow field contours across the slope (Novotny, 2003). Contouring reduces soil erosion and increases infiltration. To simulate these effects, curve number (CN2) and the USLE Practice factor (USLE_P) are adjusted in SWAT (Arabi et al., 2008). The calibrated curve number was reduced by 3 units as suggested by Arabi et al. (2008). The USLE_P values were modified by multiplying with the suggested values given in Table 6 to represent contouring. These values for the corresponding percent slope were adapted from Wischmeier and Smith (1978).

Terrace is defined as an earthen embankment, channel, or a combination ridge and channel constructed across the slope to intercept runoff (Novotny, 2003). Terracing reduces soil erosion since it allows utilization of more intensive cropping systems. Terraces are also very effective in moisture conservation to increase crop production (Georgia Soil and Water Conservation Commission, 1994). In humid regions, terraces function as structures that improve the quality of water by reducing the rill erosion, avoiding the formation of gullies, and permitting the settling of sediment from the surface runoff. Terracing provides holding of surface runoff and, therefore the amount of water available for crops is enhanced in dry areas (Schwab et al., 1993). Contouring or the contour farming is plowing and the crops are planted so that field contours across the slope. Contouring is used for both erosion control in humid regions and for increasing soil moisture by decreasing runoff losses in subhumid regions (Novotny, 2003; Troeh et al., 2004).

Table 6
USLE_P values for contouring and terracing adapted from (Wischmeier and Smith, 1978).

Land Slope (%)	USLE_P	
	Contouring	Terracing
1–3	0.6	0.12
3–5	0.5	0.1
5–10	0.5	0.1

Table 7
Land use percentages of Yavrucak and Sukesen subbasins.

Land Use	Yavrucak Subbasin	Sukesen Subbasin
	Area (%)	Area (%)
Water	0.03	0.1
Forest	0.00	0.03
Agricultural land	47.00	11.13
Transportation	0.43	2.08
Residential area	11.48	21.56
Mining	0.05	0.01
Fallowing land	8.46	4.58
Pasture	30.91	55.22
Rangeland	1.64	5.31

There is no standard procedure to simulate impact of terracing. Reducing curve number by 5 units is one suggestion, while another is reducing it by 6 units (Arabi et al., 2008). In this study, terracing in SWAT is simulated by adjusting both erosion and runoff parameters (Arnold et al., 2012a). In order to simulate the impact of terracing, curve number was reduced by 5 units as suggested by Kaini et al. (2012), Strauch et al. (2013), Tuppad et al. (2010) and USLE_P was modified by multiplying with the suggested values given in Table 6. The parameters SLSUBBSN (i.e. the average slope length) was also adjusted to represent terracing in several studies (Arabi et al., 2008; Kaini et al., 2012; Shao et al., 2013) but SLSUBBSN was not modified in this study.

2.6. *Comparison of Yavrucak and Sukesen Subbasins*

Yavrucak and Sukesen subbasins differ from each other in terms of land use, soil, and slope. Land use percentages in Yavrucak and Sukesen subbasins are shown in Table 7. Land use map of the subbasins are shown in Fig. 2.

In Sukesen, more than 50% of the basin is covered with pastures. In addition, Sukesen subbasin is more urbanized compared to Yavrucak subbasin. Residential areas comprise nearly 22% of the total area in Sukesen (Table 7). Yavrucak subbasin, on the other hand, is mostly covered with agricultural lands (47%). Pastures also occupy a significant portion (31%) of the basin.

The dominant soil type in Sukesen subbasin is more clayey, and the percentage of rock is higher compared to the prevailing soil type in Yavrucak subbasin. Yavrucak is a more flat area. Only 2% of

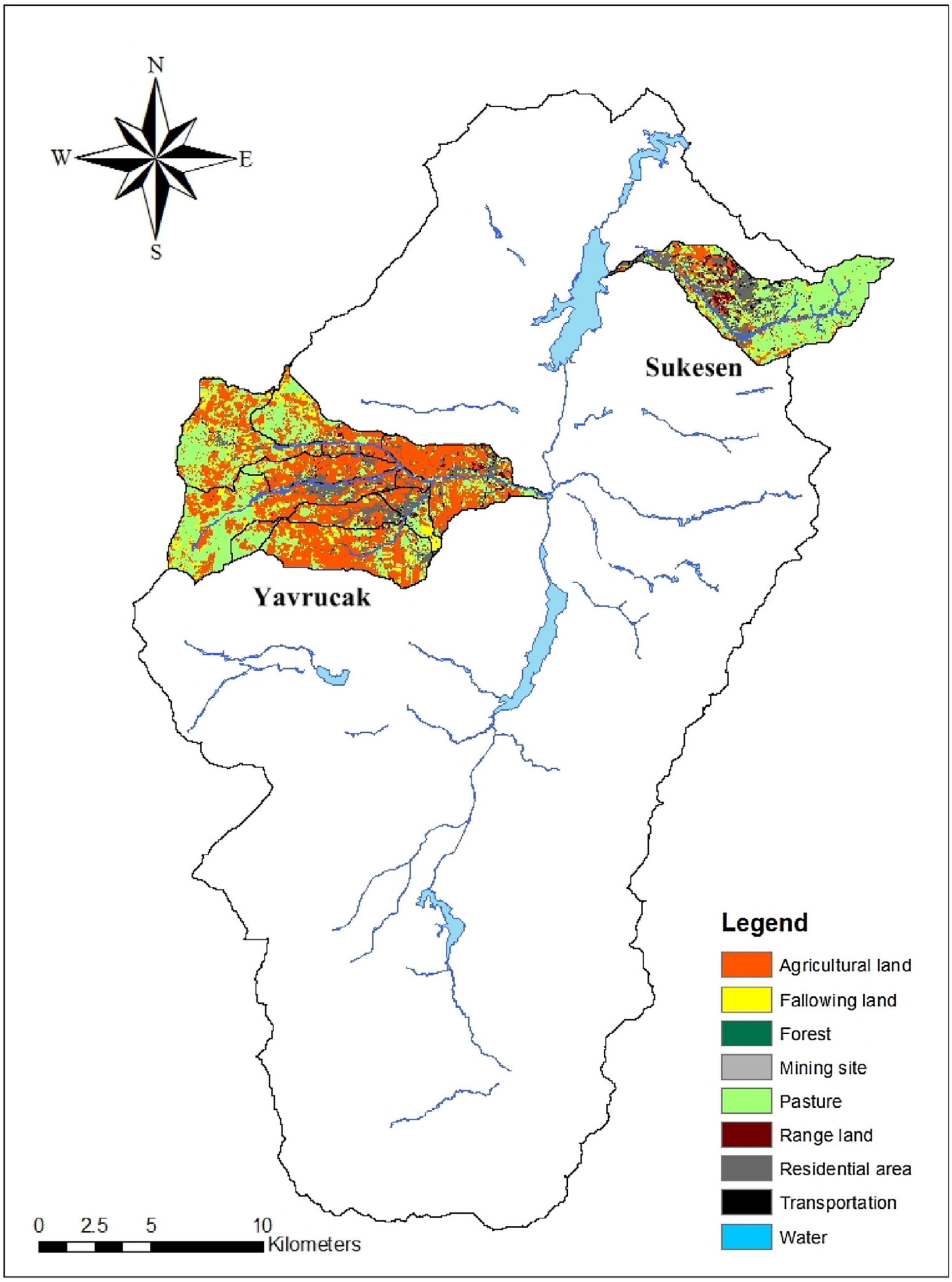


Fig. 2. Land use map of Yavrucak and Sukesen subbasins.

the total area has a slope higher than 10%. In contrast, nearly 55% of the area has slopes higher than 10% in Sukesen.

3. Results and discussion

3.1. Model calibration and validation

The SWAT model calibration was performed with SUFI-2 method through 1500 runs. The objective function was to minimize NSE, and the minimum value of objective threshold was chosen as 0.5. The results showed that parameters related to snow and groundwater processes are the most sensitive parameters in streamflow calibration. The calibration results indicate that the measured and simulated streamflow values are in good agreement on a monthly time step at Yavrucak monitoring station, (Fig. 3). For the best simulation, p-factor and r-factor values are 0.67 and 3.12, respectively while NSE, R^2 and PBIAS values are 0.74, 0.8 and -19.1, respectively. The statistical criteria show that the model performance is satisfactory to simulate hydrological processes (Moriasi et al., 2007). The complete discussion of the model results are given in Özcan (2016) and Alp et al. (2014).

Model sediment calibration was performed by fixing hydrology related calibration parameters, and adjusting sediment parameters. A total of 20 parameters were used and 1500 runs were performed. There is a reasonable agreement between the observed and simulated sediment loads (Fig. 4).

Water quality calibration was challenging due to limited data availability. A total of 1500 runs were performed with 15 parameters. NSE and PBIAS values for water quality calibration are calculated as -0.2 and 37.9 for NO_3, 0.64 and 11.7 for TN and 0.26 and -1.5 for TP. R^2 is only calculated for TP as 0.27. The results show that some peak loads, especially for NO_3, cannot be captured by the

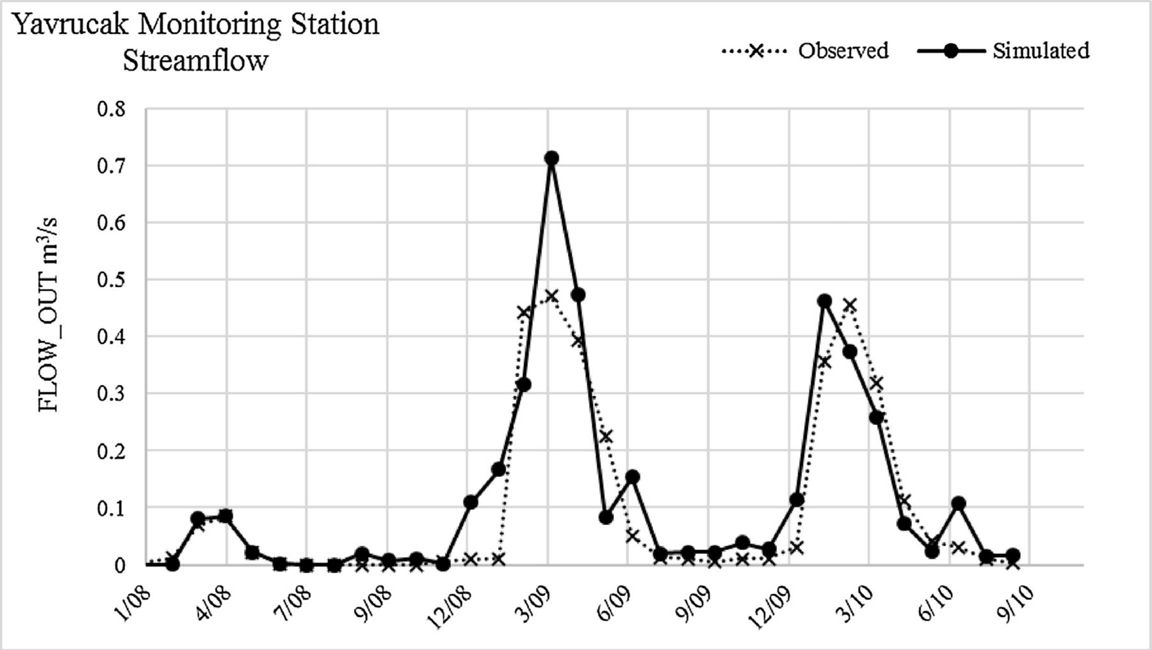


Fig. 3. Observed vs. simulated streamflow for Yavrucak monitoring station.

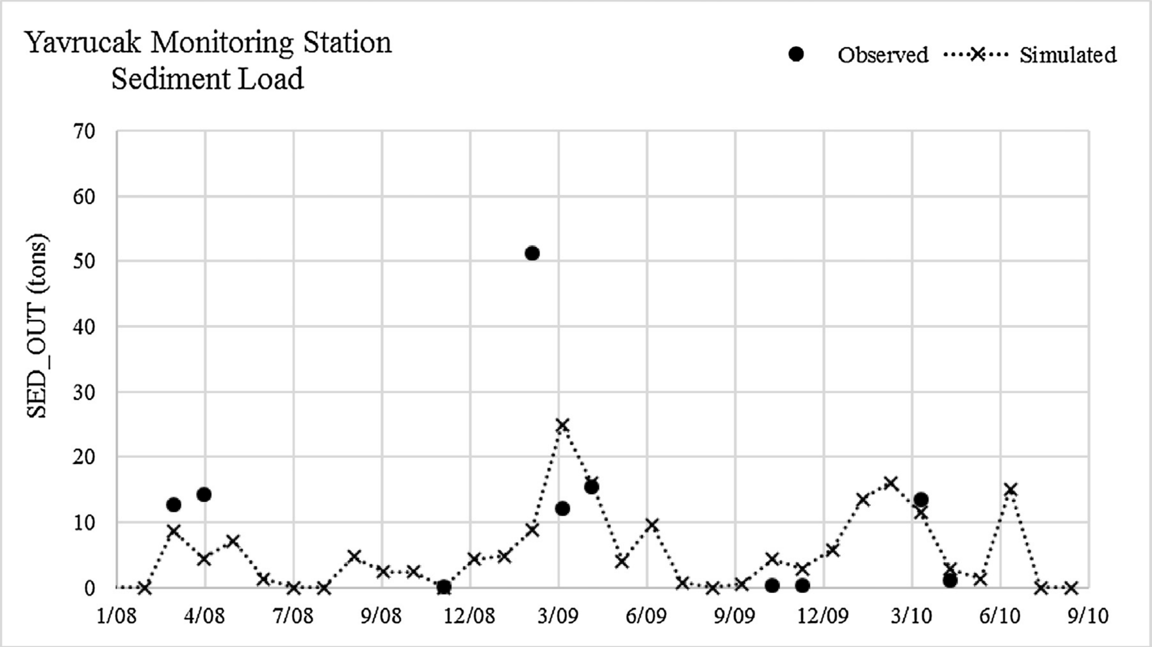


Fig. 4. Observed vs. simulated sediment load for Yavrucak monitoring station.

model. This problem might be due to lack of complete information about the point sources within the watershed. Total phosphorus loads, on the other hand, are overestimated in some months. The mean values of the simulated (calibrated) and observed loads in the long term from 2008 to 2010 are compared. The results show that when the long term averaged values are of concern, the model performance is satisfactory (Table 8).

Collection of additional water quality data in the study can further improve the power of the calibrated model to be used for development of a sustainable watershed plan. However, the performance of the SWAT model developed for Lake Mogan Watershed is acceptable to be used for the evaluation of the effectiveness of the agricultural best management practices as a preliminary assessment.

The model was validated at Sukesen monitoring station for the model calibration period. NSE, PBIAS and R^2 values of the streamflow validation simulation are 0.4, 62.4 and 0.35, respectively. The mean values of observed and simulated streamflow, and nutrient loads between 2008 and 2010 at Sukesen monitoring station are given in Table 9.

3.2. Evaluation of BMP scenarios

SWAT model simulations were performed over a three year period from 2008 to 2010 to evaluate and compare the effectiveness

Table 8
Summary of model calibration: Mean values of streamflow and nutrient loads for observed and calibrated model output at Yavrucak Monitoring Station.

	Calibration	
	Observed	Simulation
Streamflow (m^3/s)	0.10	0.12
Sediment (tons)	12.1	8.3
NO_3-N (kg)	1567.1	973.7
TN (kg)	369.4	326.1
TP (kg)	91.3	92.7

Table 9
Summary of model validation: Mean values of streamflow and nutrient loads for observed and calibrated model output at Sukesen Sampling Station.

	Validation	
	Observed	Simulation
Streamflow (m^3/s)	0.03	0.01
Sediment (tons)	23.9	1.8
NO_3-N (kg)	514.9	361.7
TN (kg)	55.3	112.9
TP (kg)	6.2	14.2

Table 10
Percent changes in annual average loads in the five most effective BMP scenarios at Yavrucak monitoring station.

Scenario	Sediment (%)	NO_3 (%)	TN (%)	TP (%)
Scenario-3: 30% reduction in fertilizer application rate	−0.35	−6.48	−6.02	−0.51
Scenario-5: No tillage scenario	−0.28	−1.46	−1.35	−4.50
Scenario-9: Terracing	−9.18	−1.00	−0.96	−6.63
Scenario-10: Combination of Scenarios 3 and 5	−0.60	−7.91	−7.35	−5.06
Scenario-11: Combination of Scenarios 3, 5 and 9	−9.27	−8.59	−8.02	−11.08

Table 11
Percent changes in annual average loads in five most effective BMP scenarios at Sukesen monitoring station.

Scenario	Sediment (%)	NO_3(%)	TN (%)	TP (%)
Scenario-3: 30% reduction in fertilizer application rate	0.37	−0.41	−0.37	0.09
Scenario-5: No tillage scenario	−0.03	−0.07	−0.06	−3.92
Scenario-9: Terracing	−0.93	−0.66	−0.62	−3.73
Scenario-10: Combination of Scenario 3 and 5	0.33	−0.48	−0.43	−3.85
Scenario-11: Combination of Scenario 3, 5 and 9	−0.84	−0.94	−0.88	−6.60

Table 12
Percentages of percent slopes in Yavrucak and Sukesen subbasins.

Slope (%)	Percentages of slopes	
	Yavrucak	Sukesen
1–3	30.3	5.5
3–5	37.1	12.2
5–10	26.0	27.6
>10	7.6	54.7

of BMP scenarios on water quality. The BMP Scenario simulations were carried on a yearly basis and the average annual loads for each pollutant (sediment, NO_3, TN and TP) were calculated at Yavrucak and Sukesen subbasin outlets. The percent changes in the amounts of average total annual pollutant loads (from 2008 to 2010) obtained for each scenario were compared with those simulated in the baseline scenario to evaluate the effectiveness of each BMP. The percent change was calculated as:

$$\text{percent change, } \% = \frac{(postBMP - preBMP)}{preBMP} * 100$$

where *preBMP* and *postBMP* are the average annual pollutant loads before and after BMP is applied, respectively. The results of the five most effective BMP scenarios in terms of average annual percent changes in sediment and nutrient loads at Yavrucak and Sukesen monitoring stations are given in Tables 10 and 11, respectively. A general overview of all the BMP scenarios are provided in the following paragraphs in 3 sub sections: i) Fertilizer Application Practices, ii) Land Management Practices iii) Combination of several BMPs

i) *Fertilizer Applications Practices*

In Scenario-1, Scenario-2 and Scenario-3, the reduction in fertilizer application rate led to reduction in NO_3 and TN loads. The sediment and TP loads were not affected significantly. The reason for the reductions in the nitrogen load being more pronounced is most probably due to the types of fertilizer used in the watershed. The fertilizers applied in the agricultural lands (ammonium sulfate, 21-00-00; ammonium nitrate, 33-00-00; urea, 46-00-00; diammonium phosphate (DAP), 18-46-00) are mainly nitrogen based. Furthermore, as the rate of reduction in the fertilizer application increased, the reduction in the amount of pollutants improved. In the Yavrucak subbasin, total NO_3 and TN loads were reduced more than 6% when the fertilizer application rate was decreased by 30%. A very similar study was carried out by Lam et al. (2011) in a watershed of 50 km^2 in Northern Germany. The study revealed that when the fertilizer application rate in arable lands were reduced by 20%, the simulated values of average annual loads for TN, NO_3, TP and sediment were decreased by 8.6%, 9.9%, 1.1% and 0.82%, respectively. Although the average annual nitrogen load reduction was slightly higher than the reductions obtained at the Yavrucak subbasin, TP and sediment loads were not affected significantly similar to what is observed at the Yavrucak subbasin. Park et al. (2015) in a watershed of 50 km^2 where 55% of the watershed was agricultural area performed another similar study. The authors found that reducing nutrient application resulted in 8.6%, 1.1% and 0.8% reductions in the annual TN, TP and sediment loads. Similar to the results obtained in Lake Mogan, TP and sediment load reductions were lower compared to TN.

ii) *Land Management Practices*

The two land use management scenarios, conservation tillage and no tillage, were simulated for Lake Mogan watershed. In Scenario-4, all tillage operations carried out with duck foot cultivator in agricultural lands were replaced by conservation tillage. Scenario-4 led to reduction in NO_3, TN and TP loads. However, conservation tillage did not affect the sediment load significantly. Annual average NO_3, TN and TP loads were decreased by 0.90%, 0.84% an 1.74%, respectively. Scenario-5, no tillage scenario, seems to be better than Scenario-4 since the calculated percent reductions were higher. Average annual percent reductions were calculated as 1.46%, 1.35% and 4.5% for NO_3, TN and TP loads, respectively. When Scenario-5 and Scenario-3 are compared, it is seen that the no tillage scenario is more effective in reducing the TP load. On the other hand, reduction in fertilizer application achieved higher percent reductions in NO_3 and TN loads. Similarly, Lam et al. (2011) reported that application of tillage scenarios did not result in considerable impacts on nitrogen load at the watershed outlet. Tuppad et al. (2010) assessed the impacts of several BMPs including conser-

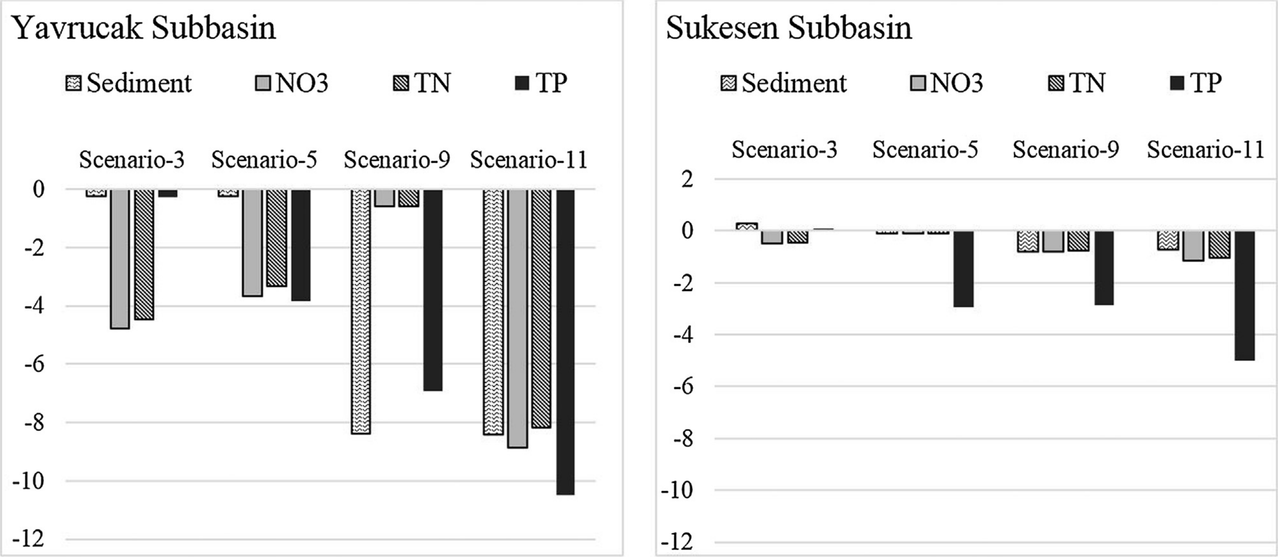


Fig. 5. Percent changes in annual average loads in the four most effective BMP scenarios.

vation tillage in the Bosque River watershed in Texas and concluded that the application of conservation tillage resulted in 3.6% reduction in the annual average TN load at the sub-watershed level which is close to the percent reduction calculated in the Lake Mogan watershed. In Scenario-6 and Scenario-7, the impacts of conservation tillage and no tillage operations were tested when they are applied on agricultural lands with low clay ratio. The implementation of these two scenarios did not have any impact on the average annual nutrient and sediment loads.

Scenario-9 is the simulation of terrace application over the whole agricultural lands. The results demonstrated that the terracing application reduced the TP and sediment loads more successfully compared to other scenarios. In Yavrucak subbasin, TP and sediment loads were decreased by 6.6% and 9.2%, respectively. The percent reductions in NO_3 and TN loads, on the other hand, were 1% and 0.96%, respectively. Strauch et al. (2013) used SWAT model to assess the impacts of BMPs including terracing on streamflow and sediment loads in the Pipiripau River Basin and found that the terracing scenario led to sediment load reductions of up to 31%. The authors reported that, the terraces were implemented in approximately 74% of the watershed area. Tuppad et al. (2010) stated that the long-term annual average sediment percent reduction at the watershed outlet was estimated as 17.2% when the terraces were implemented on 10% of the catchment area. Gassman et al. (2006) specified that terraces achieved the greatest sediment reduction among the simulated BMPs. Since it is possible to apply terracing in 47% of the total Yavrucak subbasin area, the predicted reduction in sediment loads is reasonable and inline with the previous studies. The average annual reductions achieved in Sukesen subbasin was comparably lower (Table 11). Since the percentage of agricultural lands in Yavrucak (47%) is more than 4 times that of Sukesen (11%), these results are reasonable. Moreover, adjustments of parameters to represent terracing were carried out according to percent slope (Table 6) which are significantly different in two subbasins (Table 12).

iii) Combination of several BMPs

The results demonstrated that each individual BMP scenario is effective in controlling certain types of pollutant. For instance, reducing fertilizer rate can play an important role in enhancing environmental quality by lowering NO_3 and TN loads in the river. The outcomes obtained from tillage scenarios show that replacing the conventional tillage operations by no tillage can reduce TP loads in addition to NO_3 and TN loads. Neither nutrient management scenarios nor changing tillage practices resulted in effective sediment control in the watershed. The highest percent reductions in sediment loads were simulated in the terracing scenario. Thus, combined effects of various BMP scenarios were tested. In Scenario-10, 30% fertilizer reduction and no tillage scenario were combined. Scenario-10 achieved 0.6%, 7.9%, 7.4%, and 5.1% reductions for sediment, NO_3, TN, and TP loads, respectively in Yavrucak. In Scenario-11, nutrient management and no tillage were combined with terracing. The highest reductions in pollutant loads among all BMP scenarios were obtained in this scenario. The annual average pollutant load reductions in Yavrucak subbasin were 9.3%, 8.6%, 8.0%, and 11.1% for sediment, NO_3, TN, and TP respectively.

3.3. *Overall assessment of the BMPs*

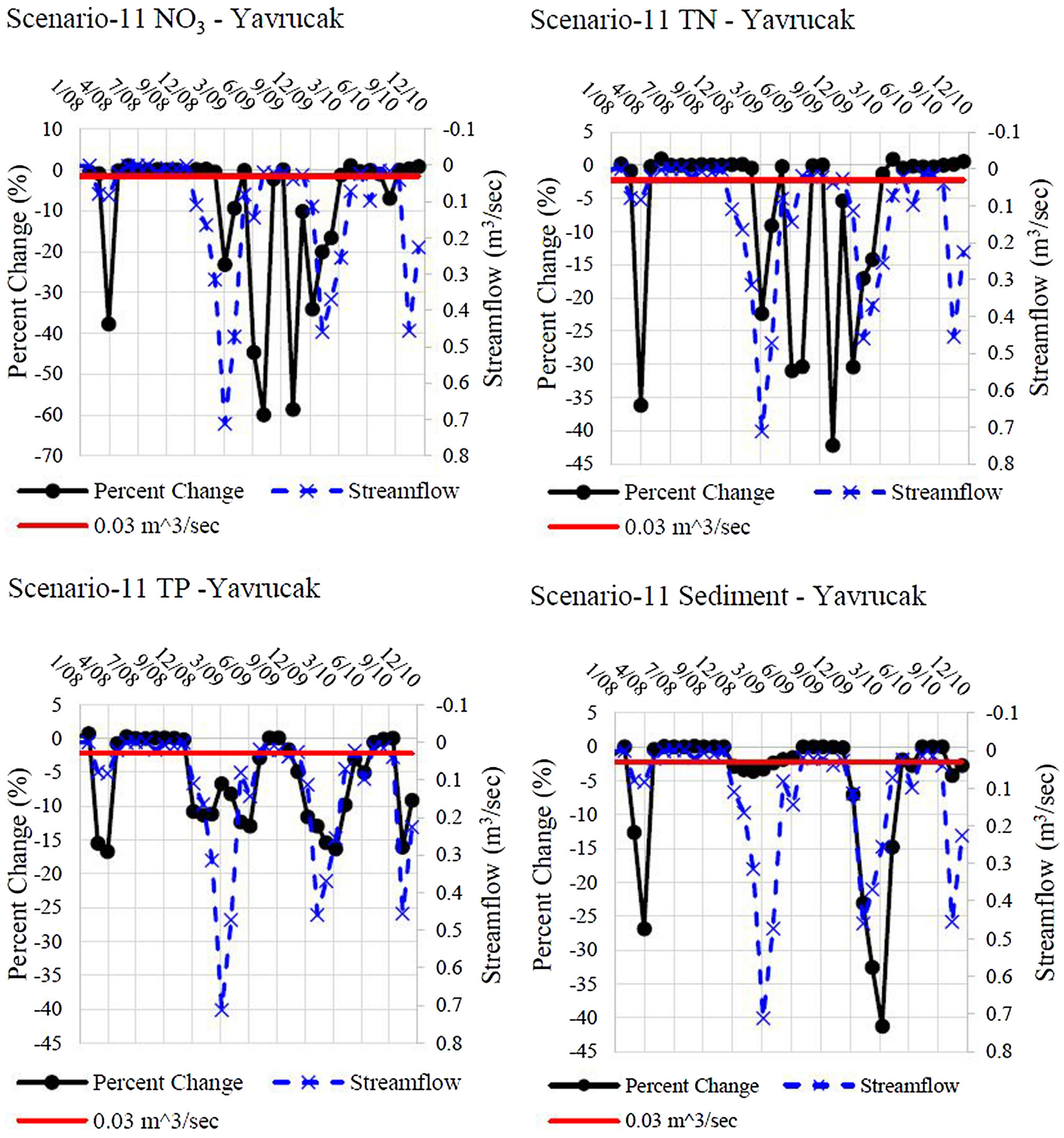
The results of the four most effective scenarios for each subbasin are graphically shown in Fig. 5. Even though, the combination scenario can be more than two times effective than the single BMP applications, the maximum reduction in pollution load is still under 11%. In this section the results are assessed in 3 categories that affects the performance of the BMPs: Land Use Land Cover (LULC) characteristics, agricultural practices, and wet/dry periods.

3.3.1. *Land use land cover (LULC) characteristic of the study area*

Pastures and agricultural lands occupy a significant part of Lake Mogan watershed, 31% and 42%, respectively. As expected, the impacts of agricultural BMP scenarios on pollutant loads at Yavrucak subbasin were higher compared to Sukesen subbasin. In Sukesen, even the most efficient BMP scenario achieved 0.84%, 0.94%, 0.88% and 6.6% reductions in sediment, NO_3, TN and TP loads, respectively. The reason is that the agricultural lands in Sukesen occupy only 11% of the total subbasin area. Therefore, different results obtained at the two subbasins were reasonable.

3.3.2. *Agricultural practice*

The highest percent reduction in average annual pollutant loads is 11.1%, which is calculated for sediment in Yavrucak subbasin. The results imply that combination of reducing fertilizer rate by 30%, changing tillage practice from duckfoot cultivator to no tillage and implementation of terraces in agricultural lands can achieve upmost 11.1% or lower reductions in average annual pollutant


Scenario-11 NO_3 - Yavrucak

Scenario-11 TN - Yavrucak

Scenario-11 TP -Yavrucak

Scenario-11 Sediment - Yavrucak

Fig. 6. Comparison of the percent changes in the pollutant loads with the baseline streamflow.

loads. There are several reasons why low pollution load reductions are achieved through application of these BMPs. Firstly, the model was constructed with the assumption that only winter wheat is produced in all agricultural lands. Even though, the crop pattern is highly homogenous through the whole watershed area, the impacts of crop rotation can also be evaluated as recommended in several studies (Merrill et al., 2011; Miller et al., 2012; Sharpley et al., 2006).

3.3.3. *The effects of wet/dry periods*

Moreover, it can be argued that the effectiveness of BMPs shows high variations under different flow regimes and BMPs perform better during high flows. The monthly percent changes in both sediment and nutrient loads and monthly average streamflow in Yavrucak subbasin for Scenario-11 are given in Fig. 6. As it can be seen, under low flow conditions (<0.03 m^3/s) the percent changes in pollutant loads are nearly negligible. Similar discussion was provided in a report prepared for Southwest Michigan Planning Commission (Kieser and Associates, 2008). Chaubey et al. (2010), likewise, mentioned that the performance of BMPs for a dry period will be different than for a wet period which has greater runoff, soil erosion, and transport.

Based on these discussions, the scenario results were also evaluated for relatively wet periods (>0.03 m^3/s) since the pollutant transport model may not be functioning properly when there is no or negligible flow in the rivers. The results showed that the percent reductions in the pollutant loads get a little higher when only wet period is considered. The percent reductions in annual average sediment, NO_3, TN and TP loads increased to 10.5%, 9.2%, 8.7% and 11.5%, respectively under wet conditions for the best simulation (Scenario-11) in Yavrucak.

4. Conclusions

The results indicate that each BMP is effective in controlling certain type of diffuse source pollutant. In addition, individual BMP scenarios are not very effective in reducing pollutant loads. Therefore, combined BMP scenarios were developed and simulated. The most successful scenario was the one in which the amount of fertilizers reduced by 30% together with no tillage and parallel terraces applied in agricultural lands.

The scenario results were also evaluated for wet periods. The results showed that the percent reductions in the pollutant loads show insignificant improvement when only wet period is considered. Since the study area is a semi-arid watershed dominated by dry agricultural activities and fed by seasonal creeks, the effectiveness of the BMPs are low due to the climatic and hydrodynamic characteristics of the region.

If the best scenario is considered as an alternative for pollution reduction in Lake Mogan watershed in practice, the following factors need to be taken into account. First of all, it is important to consider that the fertilizer (time and rate) and land management practices (tillage, terracing, etc.) may change depending on different soil characteristics, climate, and topography. Additionally, the cost-effectiveness of BMPs at the watershed scale should be evaluated in detail. Thus, the farmers and the decision-makers should take into account all the benefits and drawbacks before implementing the BMPs which seem to be as a possible solution for the pollution. Moreover, integrated solutions should be developed to improve water quality in Lake Mogan. It should be realized that representation of various BMP practices by changing model parameters bring additional uncertainties in the model results and the decision maker should be aware of these uncertainties and the need to conduct a detailed uncertainty analysis before the final decision on BMP practices is reached.

Evaluating the impacts of different management alternatives on pollution control is one of the steps of integrated watershed management plans, which is proposed by European Union Water Framework Directive. The goal of this study was to provide guidance for decision makers to implement the most effective best management practices to control agricultural diffuse pollution in Lake Mogan watershed, and in watersheds showing similar characteristics with Lake Mogan.

Acknowledgements

We would like to acknowledge the Scientific and Technological Research Council of Turkey (TÜBİTAK) for providing funding for this project entitled ‘Evaluation of Agricultural Diffuse Pollution and its Control Alternatives with SWAT model in Lake Mogan Watershed’ with project number 111Y284. We would also thank Prof. Dr. H. Şebnem Düzgün, Assoc. Prof. Dr. Oğuz Başkan and Aynur Hatipoğlu for their contributions. We also want to extend our thanks to METU Limnology Laboratory and General Directorate of Protection of Natural Assets for their help during the data acquisition stage of the project.

References

Abbaspour, K.C., Vejdani, M., Haghighat, S., Yang, J., 2007. SWAT-CUP calibration and uncertainty programs for SWAT. The Fourth International SWAT Conference, 1596–1602, http://dx.doi.org/10.1007/s00402-009-1032-4.

Alp, E., Özcan, Z., Hatipoğlu, A., Başkan, O., Düzgün, H.Ş., Kentel, E., 2014. Evaluation of Agricultural Diffuse Pollution and Its Control Alternatives with SWAT Model in Lake Mogan Watershed Ankara, Turkey.

Arabi, M., Frankenberger, J.R., Engel, B.A., Arnold, J.G., 2008. Representation of agricultural conservation practices with SWAT. Hydrol. Process. 22, 3042–3055, http://dx.doi.org/10.1002/hyp.6890.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large area hydrologic modeling and assessment part I: model development. Am. Water Resour. Assoc. 34 (1), 73–89, http://dx.doi.org/10.1111/j.1752-1688.1998.tb05961.x.

Arnold, J.G., Kiniry, J.R., Srinivasan, R., Williams, J.R., Haney, E.B., & Neitsch, S.L. (2012). Soil & Water Assessment Tool: Input/output documentation. Texas Water Resources Institute, *TR-439*. Retrieved from http://swat.tamu.edu/media/69296/SWAT-IO-Documentation-2012.pdf.

Arnold, J.G., Moriasi, D.N., Gassman, P.W., Abbaspour, K.C., White, M.J., Srinivasan, R., Jha, M.K., 2012b. SWAT: model use, calibration, and validation. ASABE 55, 1491–1508.

Bracmort, K.S., Arabi, M., Frankenberger, J.R., Engel, B.A., Arnold, J.G., 2006. Modeling long-term water quality impact of structural BMPs. Am. Soc. Agric. Biol. Eng. 49 (2), 367–374.

Brown, L., Barnwell, T., 1987. The Enhanced Water Quality Models: QUAL2E and QUAL2E-UNCAS Documentation and User Manual. National Service Center for Environmental Publications (NSCEP), Athens, Georgia.

Chaubey, I., Chiang, L., Gitau, M.W., Mohamed, S., 2010. Effectiveness of best management practices in improving water quality in a pasture-dominated watershed. J. Soil Water Conserv. 65, 424–437, http://dx.doi.org/10.2489/jswc.65.6.424.

DSİ, 1993. Mogan Gölü Kurtarma Projesi [Mogan Lake Rescue Project]. Ara takdim raporu, Ankara, Turkey.

EPA, 2012. What Is Nonpoint Source Pollution? (Retrieved August 6, 2015, from http://water.epa.gov/polwaste/nps/whatis.cfm.).

Güngör, Ö., Göncü, S., 2013. Application of the soil and water assessment tool model on the Lower Porsuk Stream Watershed. Hydrol. Process. 27 (March), 453–466, http://dx.doi.org/10.1002/hyp.9228.

Georgia Soil and Water Conservation Commission, 1994. Agricultural Best Management Practices to Control Water Quality in Georgia, Atlanta. Retrieved from http://infohouse.p2ric.org/ref/34/33252.pdf.

Giri, S., Nejadhashemi, A.P., Woznicki, S., Zhang, Z., 2014. Analysis of best management practice effectiveness and spatiotemporal variability based on different targeting strategies. Hydrol. Process. 28, 431–445, http://dx.doi.org/10.1002/hyp.9577.

Hranova, R., 2006. Diffuse Pollution of Water Resources. Taylor & Francis Group, London, Retrieved from http://archive.defra.gov.uk/environment/quality/water/waterquality/diffuse/.

Kaini, P., Artita, K., Nicklow, J., 2012. Optimizing structural best management practices using SWAT and genetic algorithm to improve water quality goals. Water Resour. Manage. 26 (7), 1827–1845, http://dx.doi.org/10.1007/s11269-012-9989-0.

Kieser & Associates, 2008. Modeling of Agricultural BMP Scenarios in the Paw River Watershed Using the Soil and Water Assessment Tool. SWAT), Michigan.

Lacewell, R., Harris, B., Tuppad, P., Ensor, M., Gibbs, M., Minzenmayer, R., Williams, J., 2010. Improving Water Management in Rainfed Agriculture: Issues and Options in WaterConstrained Production Systems, Retrieved from http://siteresources.worldbank.org/INTWAT/Resources/ESWWaterManagementRainfed_final.pdf.

Lam, Q.D., Schmalz, B., Fohrer, N., 2011. The impact of agricultural Best Management Practices on water quality in a North German lowland catchment. Environ. Monit. Assess. 183, 351–379, http://dx.doi.org/10.1007/s10661-011-1926-9.

Lee, M., Park, G., Park, M., Park, J., Lee, J., Kim, S., 2010. Evaluation of non-point source pollution reduction by applying Best Management Practices using a SWAT model and QuickBird high resolution satellite imagery. J. Environ. Sci. 22, 826–833, http://dx.doi.org/10.1016/S1001-0742(09)60184-4.

Liu, M., Lu, J., 2014. Predicting the impact of management practices on river water quality using SWAT in an agricultural watershed. Desalin. Water Treat. 1-114 (May), http://dx.doi.org/10.1080/19443994.2014.902332.

Merrill, L.S., Crawford, S.K., Hall, T., 2011. Manual of Best Management Practices (BMPs) for Agriculture in New Hampshire.

Miller, T., Peterson, J., Lenhart, C., Nomura, Y., 2012. The Agricultural BMP Handbook for Minnesota.

Monteith, J.L., Moss, C.J., 1977. Climate and the efficiency of crop production in britain [and discussion]. Phil. Trans. R. Soc. B : Biol. Sci., http://dx.doi.org/10.1098/rstb.1977.0140.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D., Veith, T.L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. Asabe 50 (3), 885–900, http://dx.doi.org/10.13031/2013.23153.

Novotny, V., 2003. Water Quality: Diffuse Pollution and Watershed Management, 2nd ed. John Wiley & Sons, Inc, New York.

Özcan, Z., 2016. Evaluation of the Best Management Practices to Control Agricultural Diffuse Pollution in Lake Mogan Watershed with SWAT Model. Middle East Technical University.

Özesmi, U., 1999. Ecology and politics of rehabilitation: mogan lake wetland ecosystem, ankara, Turkey. In: Streever, W. (Ed.), An International Perspective on Wetland Rehabilitation. Kluwer Academic Publishers, pp. 181–187.

Parajuli, P.B., Jayakody, P., Sassenrath, G.F., Ouyang, Y., 2016. Assessing the impacts of climate change and tillage practices on stream flow, crop and sediment yields from the Mississippi River Basin. Agric. Water Manage, http://dx.doi.org/10.1016/j.agwat.2016.02.005.

Priestley, C.H.B., Taylor, R.J., 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. Monthly Weather Rev. 100, 81–92, http://dx.doi.org/10.1175/1520-0493(1972)100<0081:OTAOSH>2.3.CO;2.

Ritter, W.F., Shirmohammadi, A., 2001. Agricultural Nonpoint Source Pollution: Watershed Management and Hyrdrology. CRC Press LLC.

Santhi, C., Srinivasan, R., Arnold, J.G., Williams, J.R., 2006. A modeling approach to evaluate the impacts of water quality management plans implemented in a watershed in Texas. Environ. Modell. Softw. 21 (8), 1141–1157, http://dx.doi.org/10.1016/j.envsoft.2005.05.013.

Shao, H., Baffaut, C., Gao, J.E., Nelson, N.O., Janssen, K.A., Pierzynski, G.M., Barnes, P.L., 2013. Development and application of algorithms for simulating terraces within SWAT. Trans. ASABE 56 (5), 1715–1730, http://dx.doi.org/10.13031/trans.56.10047.

Sharpley, A.N., Daniel, T., Gibson, G., Bundy, L., Cabrera, M., Sims, T., Stevens, R., Lemunyon, J., Kleinman, P., Parry, R., 2006. Best Management Practices To Minimize Agricultural Phosphorus Impacts on Water Quality AR S-163.

Society, A., Agricultural, O.F., 1985. Reference crop evapotranspiration from temperature. Appl. Eng. Agric. 1, 96–99, http://dx.doi.org/10.13031/2013.26773.

Strauch, M., Lima, J.E.F.W., Volk, M., Lorz, C., Makeschin, F., 2013. The impact of Best Management Practices on simulated streamflow and sediment load in a Central Brazilian catchment. J. Environ. Manage. 127, S24–S36, http://dx.doi.org/10.1016/j.jenvman.2013.01.014.

Taşeli, B.K., 2006. Influence of influent tributaries on water quality changes in Lake Mogan, Turkey. Lakes Reserv. Res. Manage., http://dx.doi.org/10.1111/j.1440-1770.2006.00302.x.

Tuppad, P., Kannan, N., Srinivasan, R., Rossi, C.G., Arnold, J.G., 2010. Simulation of agricultural management alternatives for watershed protection. Water Resour. Manage. 24, 3115–3144, http://dx.doi.org/10.1007/s11269-010-9598-8.

Wang, G., Barber, M.E., Chen, S., Wu, J.Q., 2013. SWAT modeling with uncertainty and cluster analyses of tillage impacts on hydrological processes. Stoch. Environ. Res. Risk Assess. 28, 225–238, http://dx.doi.org/10.1007/s00477-013-0743-9.

Williams, J.R., Jones, C.A., Dyke, P.T., 1984. A modelling approach to determining the relationship between erosion and soil productivity. Trans. Am. Soc. Agric. Eng. 27, 129–144, Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-0021644951&partnerID=40&md5=c2306c0c16b0a6db86ed12e70567a973.

Wischmeier, W.H., Smith, D.D., 1978. Predicting Rainfall Erosin Losses—A Guide to Conservation Planning. U.S. Department of Agriculture.