Determination of Non-point Pollution Critical Areas to Provide Sustainable River Basin Management, Gördes Dam Basin, Turkey

A Özdemir

1 Republic of Turkey Ministry of Agriculture and Forestry, General Directorate of Water Management
E-mail: ozdemir.ayfer@gmail.com

Abstract. Non-point source (NPS) pollution is the main factor cause of various water quality problems across river basins in Turkey. The determination of critical source areas (CSAs) is necessary to control non-point source (NPS) pollution at a basin scale, especially when there are limited resources in the areas. The aim of this study is to determine the spatial and temporal distribution of NPS pollution loads in the Gördes dam basin, Turkey. CSAs were identified based on the Soil and Water Assessment Tool (SWAT). Fact and Fully Calibration Tool (FACT) were used to calibrate the model. The distribution of total nitrogen and phosphorus load in the basin was determined based on the subbasins level. The results based on the calibrated model showed that the sub-basins heavily and seriously polluted by agricultural and forest areas. Higher TN and TP loads occurred mainly in the downstream areas of the Gördes dam basin. Furthermore, the central zone of the Gördes dam basin was identified as the major source of TN and TP loads owing to the flow direction.

1. Introduction
In river basins, human activities such as increase in population rate, agricultural and industrial activities have degraded water quality and quantity day by day. Although point pollution can be controlled by taking some measurements, non-point source (NPS) pollution loads are still a serious challenge for water management. NPS pollution loads have not been understood well since it is a complex process including agriculture, forestry, meteorology, hydrology, etc. Since NPS pollution loads contain complex mechanisms and uncertain character, assessment and controlling of non-point pollution is difficult to issue for decision-makers and planners about water management. Mathematical modelling has been widely used for understanding the spatial and temporal distribution of NPS pollution loads. The Soil and Water Assessment Tool (SWAT) is the most popular mathematical model to predict the impact of land management practices on water, sediment and agrochemical yields in large watersheds with varying soils, land use and agricultural conditions over extended periods [1]. The model is a physically based and simulates hydrologic processes at sub-basin level. Many researchers have performed the SWAT to estimate and analyse the spatial and temporal distribution of NPS pollution loads since these pollutants have threatened water quality and created serious water management problems in the watershed [2, 3]. These studies show that NPS pollution loads caused by distinct land use types have significant differences. For example, while the most TN and TP load per unit area results from agricultural land, forest lands have the least pollution load per unit area. Scenarios with different combinations of pollution sources have been applied to assess the contributions of natural sources, cultivation, industry, households, craft villages, and livestock by using the SWAT [4, 5]. Thus, Critical Pollution Source
Areas (CSAs), and Best Management Practices (BMPs) in basins have been determined by the evaluation of results of the SWAT. CSAs are necessary to the NPS pollution control at a basin scale, especially when there are limited resources in areas.

In this study, the spatial and temporal distribution of NPS pollution loads in the Gördes dam basin Turkey were estimated and analysed to determine critical source areas (CSAs) by using the SWAT.

2. Materials and method

2.1. Study area

The Gördes Dam was located between 39° 10' - 38° 40' north longitude and 28° 05' and 28° 30' east latitude in the Aegean region, Turkey (Figure 1). The dam was constructed on the Gördes river to provide irrigation water supply to agricultural areas around the dam and drinking water supply to the Izmir province. The area of the basin is 1049.93 km². The active storage volume of the dam is designed to be 5,500,000 m³ and the surface area of the dam is 14.05 km² at the normal water level of the dam. The land in the basin is predominantly used for agriculture, and land cover in the basin is the mostly coniferous forests. The recorded mean annual rainfall, evaporation, maximum and minimum temperature values are 613 mm/year, 744.3 mm/year, 21.07 °C and 8.42 °C, respectively. The mean annual flow rate of the Gördes river is measured as 2.64 m³/sec.

2.2. Model description

The SWAT model is the most popular model that is used by hydrologists and decision makers about water management due to having advantages. Ungauged watersheds can be modelled accurately by the SWAT [1]. Alternative input data changes in land use, land management practices, and climate can be performed during the simulation of the model [6]. The definition of watershed hydrologic features and storage, as well as the organization and manipulation of the related spatial and tabular data, can be carried out by the interface in Geographical Information System (GIS) [7]. The SWAT offers the flexibility of simulating with insufficient input data. Moreover, the SWAT simulates long-term impacts of land use, land management practices, and build-up of pollutants with a continuous-time model [6].

Figure 1. Location of the Gördes dam basin
Therefore, the SWAT model was applied to the Gördes dam basin to determine vulnerable areas to non-point pollution due to advantages of the SWAT model.

2.3. FACT
A software package called Fast Automatic Calibration Tool (FACT) was applied for the calibrate processes of the model. The FACT was developed for the SWAT to reduce the calculation complexity and improve the performance of the calibration procedure [8]. The Sequential Uncertainty Conformity Algorithm (SUFI-2) is used in the FACT since a large number of parameters in conjunction with uncertainty analysis can be performed by the SUFI-2. During the calibration processes, sixteen parameters defining the related processes of the system, such as surface runoff, baseflow, and lateral flow, were used (Table 1). The Hachhü river stream gauge station on the Gördes river was utilized for the comparison between observed and the simulated flow values. Although observed flow values at the station were between 1979 and 2013, there are missing data between 1997 and 2013. Therefore, the model was performed from 1981 to 1996 with 2 years warm period. The calibration period was considered from 1979 to 1996 periods, and the validation period was determined from 1979 to 1981 periods.

| Parameters                  | Min-Max | Model-Calibration | Definition                                                                 |
|-----------------------------|---------|-------------------|-----------------------------------------------------------------------------|
| r__CN2.mgt                  | -0.2-0.2| 75-72             | Initial SCS runoff curve number                                            |
| r__SOL_AWC().sol            | -0.2-0.1| 0.14-0.18         | Surface runoff lag time.                                                    |
| r__SOL_K().sol              | -0.8-0.8| 85-33             | Available water capacity of the soil layer                                 |
| r__SOL_BD().sol             | -0.5-0.6| 1.45-1.57         | Saturated hydraulic conductivity (mm/hr)                                   |
| a__GWQMN.gw                 | 0-25    | 1000-1013.80      | Moist bulk density (Mg/m$^3$ or g/cm$^3$)                                  |
| a__GW_REVAP.gw              | -0.1-0  | 0.02-0.02         | Threshold depth of water in the shallow aquifer required for return flow to occur (mm H$_2$O) |
| v__REVAPMNX.gw              | 0-500   | 750-155.63        | Groundwater “revap” coefficient                                            |
| v__ALPHA_BF.gw              | 0-1     | 0.48-0.6          | Threshold depth of water in the shallow aquifer for “revap” or percolation to the deep aquifer to occur (mm H$_2$O) |
| v__GW_DELAY.gw              | 30-450  | 31-234.60         | Baseflow alpha factor (days)                                               |
| v__ESCO.hru                 | 0.8-1   | 0.95-0.8          | Groundwater delay time (days)                                              |
| v__SFTMP.bsn                | -5.0-5.0| 1-1.37            | Soil evaporation compensation factor                                       |
| v__SMTMP.bsn                | -5.0-5.0| 0.5-4.8           | Snowfall temperature (°C)                                                  |
| v__SMFMX.bsn                | 1.7-6.5 | 4.5-6.12          | Snowmelt base temperature (°C)                                             |
| v__SMFMMN.bsn               | 1.7-6.5 | 4.5-1.61          | Melt factor for snow on June 21 (mm H$_2$O/°C-day)                          |
| v__TIMP.bsn                 | 0.01-1  | 1-0.43            | Melt factor for snow on December 21 (mm H$_2$O/°C-day)                      |
| v__SURLAG.bsn               | 0.05-24 | 4-18.19           | Snow pack temperature lag factor.                                          |

2.4. Data preparation
The data prepared for the model are divided into two different types, time series and spatial inputs. The hydrologic cycle of the basin is simulated in daily and monthly time steps by the model. Meteorological data sets, minimum and maximum temperatures, rainfall, average relative humidity, average wind speed, average solar radiation, are used as time series type inputs whereas land use and soil layers are spatial data type inputs.
Daily time steps were used in this study. The data used for the construction of the SWAT and their properties were shown in Table 2. A Digital Elevation Model (DEM) was produced from 1:25 000 scale topographic maps. The resolution of DEM is 30×30 meters. Universal Transverse Mercator (UTM) projection system and ED 1950_UKM_Zone 35N geographic coordinate was assigned to the DEM. Sub-basins of the basin from the DEM were produced based on minimum, maximum, and suggested sub-watershed area in hectares. They were calculated as 190, 1448, and 700 hectares, respectively. Stream and outlet of sub-basins were defined at the end of the pre-processing of the DEM. Thus, 29 sub-basins were obtained from the DEM (Figure 2a). NPS pollutants were assigned based on the fertilizer and pesticide amount used in agricultural areas whose data were obtained from the Ministry of Agriculture and Forestry.

Table 2. Data preparation

| Data       | Description                                                                 | Data Source                                                                 | Year              | Scale |
|------------|------------------------------------------------------------------------------|------------------------------------------------------------------------------|-------------------|-------|
| Hydrological | flow                                                                         | DSI monitoring station                                                     | 1979-2018         | daily |
|            |                                                                              |                                                                              | 1997-2013 (missing data)                                      |                   |
| Meteorological | Precipitation, temperature, humidity, solar radiation, wind             | NCEP/CFSR (The National Centers for Environmental Prediction/Climate Forecast System Reanalysis) | 1974-2014         | daily |
| Slope surface | validated DEM                                                                |                                                                              | 1/25.000 topographic map                                      | 30 m              |
| DEM        | Delineation of cells and generation of stream network                       |                                                                              |                   |       |
| Land use map | Land use types                                                              | Corine 2018                                                                 | 2018              | 30 m  |
| Soil map   | Soil types and properties                                                   | Ministry of Agriculture and Forestry, shape files                           |                   | 30 m  |

Moreover, the soil map of the study area (Scale: 1/25,000) was obtained from the Republic of Turkey the Ministry of Agriculture and Forestry. There are mostly limeless brown forest and limeless brown soil types, which cover %32.05 and %20.25 of the study area (Figure 2b). The soil properties that are required for the SWAT model were determined based on Guidelines for Soil Description [9, 10]. Corine 2018 was used to produce land use/land cover map of the study area, and the map resolution was determined as 30×30 meters. There are twenty-three land use/land cover class in the study area and, the most dominant type of land use is forest-deciduous and agricultural areas, which cover %28.39 and %26.77 of the basin, respectively (Figure 2c). NCEP/CFSR (The National Centers for Environmental Prediction/Climate Forecast System Reanalysis) data were used to obtain meteorological data of the study area due to advantages such that the data is available along with in situ measurements from several ground stations. Meteorological data handled from the station near the study area is between 1979 and 2014 years in the daily time step.

2.5. Definition of hydrological response units
Sub-basins in the basin are divided into hydrologic response units (HRUs) that are unique combinations of land use, soil and slope properties in the SWAT. Hydrological, sedimentological, and land management processes are calculated based on HRUs into sub-basins. In this study, the total number of 30 HRUs were generated by using %40/%40/%20 threshold values for land use/soil/slope combination.
2.6. Definition of pollution loads to basin
The main products in the Gördes dam basin are tobacco and cereals. Cereals in %40, tobacco in %28, and other field crops in %32 of agricultural areas are produced. TN and TP coming from the agricultural areas were calculated as 155604 and 13628 kg/year, respectively. Although there are many points pollution source (PPS) loads such as chicken farms in the basin, in this scope of work, data input of PPS was not defined in the model. In future studies, all point sources will be defined in the model.

![Figure 2. a. DEM and subbasins b. landuse/landcover map of the study area c. soil map of the study area](image)

3. Result and discussion
3.1. Model performance
The model was simulated from 1981 to 1996 with 2 years warm period. Flow rate data obtained from the Hacihıdır stream gauge station were used for the comparison between observed and simulated flow data. Nash-Sutcliffe efficiency (NSE) and coefficient determination ($R^2$) were used to represent model accuracy. According to the comparison between simulated and observed flow rate values on the station on the Gördes river, NSE and $R^2$ are -0.013 and 0.74, respectively. Although the results of the model
accuracy value didn’t enough to reflect the real world, the graphical representation of the model results showed that characteristics of the simulated flow rate were similar to the observed flow rate (Figure 3). 1981-1996 period was utilized for the model calibration. Similarly, 1979-1981 period was used for the validation. The initial model results were improved to $R^2=0.82$, NSE=0.68 after the calibration by using the FACT with 250 simulation number (Figure 4). The model had $R^2=0.89$, NSE = 0.77 after the validation period between 1979 and 1981 years (Figure 5).

![Figure 3. The simulated and observed flow rates of the Gördes river (1981-1996).](image)

![Figure 4. The results of calibration processes; the simulated and observed flow rates of the Gördes river (1981-1996).](image)

![Figure 5. The results of validation processes; the simulated and observed flow rate of the Gördes river (1979-1981).](image)
3.2. Non-point source pollution critical areas

After the calibration and validation processes, the SWAT model was performed to simulate the TN and TP loads from NPS pollutions in the Gördes dam basin. In this study, only hydrological calibration was done because there is no water quality monitoring station in the basin. However, studies indicate that the SWAT shows good results when limited data and missing data conditions. Therefore, CSAs determined by the model can point areas that have to be under control that by applying land and water management policies.

The spatial distribution of NPS pollution loads from 1981-1996 was shown in figure 5. Land use type has a significant impact on streamflow and NPS pollution loads. NPS loads were primarily caused by agricultural and forest areas. Higher TN and TP loads occurred mainly in the downstream areas of the Gördes dam basin. Furthermore, the spatial distribution of TN and TP loads are dense around the dam due to the flow direction (Figure 6).

![Figure 6. Spatial distribution of TN and TP loads in the study area.](image)

4. Conclusions

NPS pollution loads in the basin were calculated by using the SWAT to define CSAs. TP and TN loads in the basin were distributed mainly on the downstream areas of the Gördes river. Agricultural and forest areas have a great impact on NPS pollution loads. CSAs should be defined based on the major source areas of TN and TP loads in basins to provide controlling NPS pollution loads. Although there are many points and nonpoint source pollution loads in the basin, NPS pollution loads caused by land-use types were examined in this study. In future studies, by defining all pollution types to the model, climate change impact on hydrological processes and pollution loads in the basin are planned to study.

5. References

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