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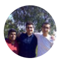

Muhammed Ernur Akiner
Akdeniz University

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Managing Saltwater Intrusion and Agricultural Practices along the Boğaçay River, Turkey: Effects from Excavation and Land Source Pollution

Muhammed Ernur Akiner[†]* and Časlav Lačnjevac[‡]

[†]Vocational School of Technical Sciences
Department of Environmental Protection Technologies
Akdeniz University
Antalya 07058, Turkey

[‡]Faculty of Agriculture
University of Belgrade
Belgrade 11080, Serbia

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ABSTRACT

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The Boğaçay is a river situated in the Konyaaltı district of Antalya. In 2017, Antalya Metropolitan Municipality implemented a large project in which the river bed was excavated to 1.5 m below sea level. The aquifer is vital for meeting the drinking water needs of the city of Antalya. The goal of this research is to discover the applications that may be made to combat seawater intrusion and nutrient contamination, both of which were brought to the forefront by the Boğaçay Project. In this work, modeling was used to estimate the extent to which agricultural best management practices (BMPs) will be efficient in reducing pollutant load. In BMP modeling with the soil and water assessment tool (SWAT), a decrease of 39%, 38%, and 38% is anticipated in the 5-day biochemical oxygen demand (BOD_5), total phosphorus, and total Kjeldahl nitrogen loads, respectively. Sediment accumulated in the channel, and sediment transport occurred on the beach due to coastal erosion. Coastal erosion of up to 25 m was observed from the project's beginning to the present. Substantial land base pollution because of the diffused sources was found. Saltwater intrusion in the Boğaçay River estuary functions as a catalyst in the production of poor odor and appearance, as well as the rapid expansion of algae. The municipality is attempting to remedy this problem by periodic harvesting, which is an overly expensive and ineffective option. Instead, the elevation of the riverbed should be restored to preproject levels to prevent additional environmental and geographic damages.

ADDITIONAL INDEX WORDS: *Agricultural best management practices, nutrients, seawater wedge, sediment transport.*

INTRODUCTION

Antalya Metropolitan Municipality started implementing a high-cost project on the Boğaçay River in 2017 (Dipova, 2019). First, the riverbed was lowered to 1.5 m below sea level by excavation. Then, the sea entered 750 m toward the land (UCTEA-CGE, 2018). The freshwater is less dense and floats on the saltwater. The incoming marine tide lifted the outgoing freshwater in the Boğaçay River's estuary because of a salt wedge phenomenon. The municipality planned construction of a marina at the river estuary, as well as various activities (movie sets, entertainment centers, living areas) along the marina's Boğaçay riverbed. They started this project, called "Crazy Project," despite all objections of stakeholders and scientists. The project is ongoing, and it is not fully completed yet. The project poses a severe threat to the Boğaçay alluvial aquifer and Konyaaltı Beach. This research has two aims. The first is to determine the new Boğaçay Project's possible environmentally adverse effects. The second is to determine what should be done to counteract these adverse effects. Systematic incorporation of agricultural management activities is needed to prevent diffuse source pollution from entering receiving water bodies. Agricultural best management practices (BMPs) are primarily the most convenient way to reduce nutrient load. Infrastructural disposal of diffuse agricultural pollution is extremely difficult and costly. It is not economical per the engineering approach. The primary purpose of this research is to compare the project's main construction phase before and after in light of scientific data. Although the project has not been fully accomplished as planned, the main construction phase and the excavation, concrete works such as retaining walls, channel stabilization, and harvesting the natural plantation in the estuary are complete. Another motivation is to determine the environmental impact of the project on the raw water source. Ecological sensitivities should not be ignored in the development process. In 2018, the excavation and harvesting phases of the project were complete. According to the Republic of Turkey Governorship of Antalya (2020), agricultural pollution in the region is clearly from nonpoint sources. Agricultural fertilizers used in greenhouse and garden cultivation are a significant source of nutrients in the Boğaçay River watershed.

Furthermore, the soil structure of agricultural lands has low infiltration capacity and a poor ability to retain nutrients. The impact of agricultural pollution on the river is clear. The outlet of the river is filled with sediment. The sediment transported along the watershed brought with it a large nutrient load. Hence, the concentration of pollutants increased. Riparian

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*Corresponding author: ernurakiner@akdeniz.edu.tr

buffers could be established to overcome the issue. A project that concerns the community should not be carried out without the consent of the stakeholders. Agricultural practices lagged behind developed countries, especially land use for agriculture. With agricultural BMPs to be applied, reducing nutrients and pesticides in the receiving water environment is possible.

Previously, river estuary water was all fresh. After the project implementation, salinity became a problem in the Boğaçay aquifer and wells because of the arrested salt wedge. The Boğaçay River has two endemic freshwater fish species: *Capoeta antalyensis* (Antalya barb) and *Alburnus baliki* (Antalya bleak) (Küçük and İkiz, 2004). These are at risk of disappearing because of the threat of saltwater intrusion. The freshwater source of Konyaaltı, groundwater, is open to pollution. The Boğaçay River prevents Konyaaltı Beach from negatively affecting littoral transport by continuously discharging the sediments to the Mediterranean Sea. As a result of this project, the river was prevented from meeting with the coast, and the shoreline eroded rapidly. The coastal line receded up to 25 m due to wave erosion. The eroding shoreline between October 2017 and August 2019 was detected through satellite photography.

The excess nutrients in the water, including nitrogen (N) as well as phosphorus (P), create a significant water quality issue (Bhagowati and Ahamad, 2019). Toxic algal blooms, oxygen depletion, fish mortality, biodiversity loss, and the extinction of aquatic plant beds are consequences of these nutrients (Carpenter *et al*., 1998). Nutrients are produced by diffused source contamination because they are due mainly to agricultural practices, and it is impossible to determine the accurate source position. Nitrogen occurs in soils as organic and mineral (inorganic) forms. It is reactive and mobile because of its chemical character, making it harder to predict its movement through soil and water processes. The other vital nutrient, P, is more stable than N, whose campaign is associated with soil erosion (Shi and Schulin, 2018). Runoff may produce a more significant amount of pollutants and sedimentation in areas where rainfall frequency and intensity have risen. Nonpoint nutrient pollutants, heavy metals, and chemicals are also transferred with soil particles, resulting in greater sediment levels and, ultimately, water eutrophication and disruption of vulnerable aquatic ecosystems (Bing *et al*., 2013; Chen *et al*., 2011). As the region receives extreme rainfall, more soil in the watershed is transported to the Boğaçay River by erosion. Hence, the river will bring more pollutants and increase pollution concentration. Plant uptake has a very significant function in eliminating P from the soil. The leading cause of P in the ground is fertilizer, manure, or crop residue.

One of the postproject articles in the literature sought to discover recreational changes and assess people's satisfaction following the study (Yılmaz, Olgun, and Gül, 2020). Another study focused on the flood risk associated with the quick transformation of the river's morphology due to the project (Özcan and Özcan, 2020). Moreover, studies on visible postproject coastal erosion have been published (Dipova, 2019; Tur, Uzunsakal, and Mehr, 2020). Furthermore, the threat of salinity is mentioned in specific project reports (UCTEA-CGE, 2018). However, the current study is unique in that it clearly shows that nutrients derived primarily from agriculture might create pollution due to the project's changing topographic structure. Recent findings also demonstrate that nutrient overload, which was seen within the scope of this research, caused the water in the Boğaçay River's estuary to lose quality as the topographic structure changed, and excessive algae appeared as a result of the deterioration of water quality.

Effect of Soil Properties on Nutrient Export

The export of nutrients from a specific land use type can be represented in nutrient load per area per time. Land use maps can be used as an indirect indication of the estimated nutrient loads. A drilled well in the Boğaçay riverbed with a total depth of 15.00 m shows that clayey, sandy, and gravelly levels of Quaternary Boğaçay River alluviums are between 0.50 and 15.00 m. There is organic soil between 0 and 0.5 m. In the well, close to the surface, grayish-brown silty sandy clay is between 0.50 and 3.90 m, fine–medium grained grayish sand is between 3.90 and 4.70 m. In the lower parts, semi-hard–soft silty sandy clay with bluish-gray colored sand is between 4.70 and 11.20 m, and light-colored coarse gravel is between 11.20 and 15.00 m (Camlilar, 2010). Thus, the Boğaçay riverbed has clay soil with high cation content, low adsorption capacity, low infiltration capacity, and high erodibility. The Boğaçay riverbed has predominantly sandy/gravelly deep layers, low cation content, low abrasion, and high seepage capacity. Dissolved nutrient inputs from circulating offshore water, river runoff, and groundwater seepage affect coastal marine ecosystems, and nutrient flux *via* groundwater seepage is considered a minor component of primary productivity, also causing the intrusion of the saltwater wedge beneath the freshwater aquifer along the marine coastline (Uchiyama *et al*., 2000). There is a limited organic soil layer at the top of the riverbed. The agricultural lands' soil structure outside the riverbed can be considered organic soil within the watershed area. It has substantial nutrient value, low infiltration capacity, and minimal ability to retain nutrients. Interpretation of the soil nutrient properties given by Beaulac and Reckhow (1982) shows that the nutrients exported from organic soil, commonly used for cultivation, are higher than from other soils. Organic soils decompose rapidly and produce high export rates (Saint-Laurent, 2020; Wadnerkar *et al*., 2019).

Nutrient Retention Phenomenon

Owing to the nutrient retention cycle, the abundance of nutrients in the river system is typically lower than the nutrient load upstream of the river (Dalu *et al*., 2019; Ye, Sivapalan, and Ran 2020). An awareness of this phenomenon is essential for avoiding overloading the channel and the lake network and preventing subsequent eutrophication (Dalu *et al*., 2019). As a result, having an ecological buffer zone along the canal is crucial. The project's urbanization may disrupt the nutrient retention cycle.

Retention of nitrogen is attributed to biochemical mechanisms, such as denitrification (Pozdnyakov *et al*., 2019; Putz *et al*., 2018; Zhou *et al*., 2018). Phosphorus retention is further affected by physicochemical means, such as sediment sorption/desorption reactions (Bai *et al*., 2017; Canga, Heckrath, and Kjaergaard, 2016). Chemical adsorption to sediment after the flood and the dry season enhances phosphorus retention

(Barletta, Lima, and Costa, 2019; Li *et al*., 2017). Net sedimentation occurs in shallow waters with little flow (Horvatinčić *et al*., 2018). The particulate P fraction in the water column is more critical than the dissolved P fraction (Williams *et al*., 2018). A significant decrease in the water column's nitrogen amounts is found during the growing season of aquatic macrophytes and algae (Hussian and Haroon, 2019). Mineralized biomass releases nutrients during autumn (Nikolakopoulou *et al*., 2020).

By harvesting the aquatic plants, nitrogen retention can be improved (Lu *et al*., 2018; Verhofstad *et al*., 2017). Nutrient absorption of macrophytes (*Potamogeton pectinatus*, *Potamogeton perfoliatus*, *Potamogeton crispus*) and algal biomass is limited to 1% for nitrogen and 0.1% for phosphorus (Zhou *et al*., 2018). Denitrification is the primary mechanism by which nitrogen is depleted in the aquatic system (Hellemann *et al*., 2017; Pozdnyakov *et al*., 2019). Phosphorus retention happens during low flow levels and in flooding when the water runs partially beyond its bank. Further nutrient intake by benthic species such as emergent macrophytes (Ranunculus, Sagittaria, Alisma, and Butomus), submerged macrophytes (*Stuckenia pectinata*, *Potamogeton pectinatus*, *Potamogeton perfoliatus*, *Potamogeton crispus*), and mussels (*Contradens contradens*, *Monodontina vondembuschiana*, *Sinanodonta woodiana*) can effectively lead to nutrient retention (Zieritz *et al*., 2019). Riparian buffers may improve the in-stream processes that eliminate stream-borne contaminants. Plant debris promotes denitrification and deterioration of pesticides, while large woody debris facilitates sediment deposition (Shelley *et al*., 2017). Unfortunately, there are insufficient buffer zones around the Boğaçay River watershed. Areas up to the canal's edge will be open to settlement after the municipality's zoning plan.

Improvement of the Water Quality by Dilution

The dilution principle applies when the natural environment and aquatic ecosystems can absorb and disrupt certain pollutants. Absorption capacity for a river or lake requires more than a simple dilution of the pollutant flow to reduce its concentration. The function of the water body to receive pollutants depends on many other processes. Effective processes are precipitation, volatilization, chemical disintegration, microbial disintegration/conversion, and aquatic plants' uptake.

Savenije (2005) classifies estuaries according to their salinity, form, geology, tidal, and water roles. The Boğaçay River shape is known as the funnel or trumpet type. The banks approach each other upstream. Deeper areas near the ocean have an immense tidal influence, but shallow canals and creeks do not have the same tidal effect (Dike and Agunwamba, 2012). As a result, assessing the tidal influence on the Boğaçay River estuary was difficult, although this natural cycle was significantly disrupted following the riverbed excavations. The saltwater intrusion is caused because of the decrease in riverbed elevation. The Boğaçay River may be categorized as alluvial in a coastal plain based on its geology. The sediments may be accumulated by flowing in the estuary. The alluvial estuaries' structure is highly reliant upon the discharge, in other words, the rainfall obtained from the drainage catchment area.

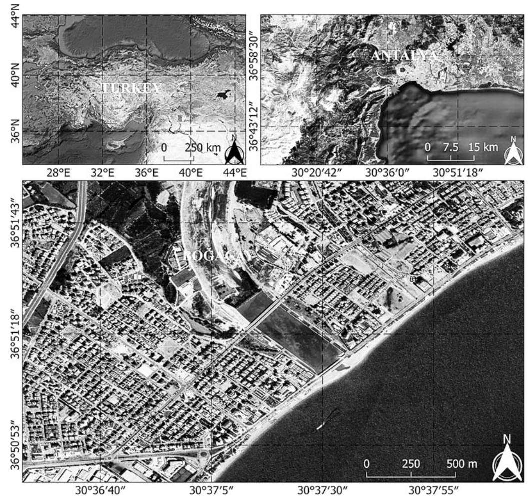

Figure 1. The geographical coordinates of the Boğaçay River watershed, which is located in southern Turkey on the Mediterranean Sea's coast (ESRI, 2021).

Water in the Mediterranean Sea is salty, but, before the project, neither Boğaçay River water nor Boğaçay River estuary was salty. The River Boğaçay was known to be fresh water. Currently, the saline Mediterranean seawater intrusion is suspended. The habitat in the estuary is going to be under threat soon. However, the river's salinity may not be precisely observable until the seawater fills the wells in the watershed's estuary region.

METHODS

The Crazy Project transforms the river estuary into a water storage reservoir. The water that cannot be released into the sea stagnates, and the water quality deteriorates as the nutrient load through the sedimentation increases. Agricultural BMPs are tools that will help to mitigate the potential contamination caused by the Boğaçay Project. The extent to which BMPs will be beneficial in reducing the pollution load was determined through modeling in this study. The soil water assessment tool (SWAT) model was used for the investigation because it has a solid mathematical modeling foundation.

Study Area

The Boğaçay River is located in Konyaaltı, Antalya, Turkey, as shown in Figure 1. The Boğaçay River watershed has a drainage area of 850 km^2 (Tur, Uzunsakal, and Mehr, 2020). The river discharges into the Mediterranean Sea from the coast of Konyaaltı. Today, the watershed is irregular and causes periodic floods depending on the precipitation regime (Cengiz *et al*., 2017). In addition, there is intensive agricultural production in the lands around the Boğaçay River, both greenhouse and garden cultivation. There is also a significant increase in housing for residential purposes because of the open areas (Leventeli, Yalcin, and Kilic, 2019). There is a lack of

Table 1. *Water quality classes (MFWA 2012).*

Parameter (mg/L)	Water quality class 1	2	3	4
Nitrate nitrogen	<5	<10	<20	>20
Total Kjeldahl nitrogen	<0.5	<1.5	<5	>5
Total phosphorus	<0.02	<0.16	<0.65	>0.65
BOD_5	<4	<8	<20	>20
Chlorine	<25	<200	<400	>400
Sodium	<125	<125	<250	>250

infrastructure throughout the whole watershed except in a minimal area in the city center located at the watershed's seashore (Yazıcı and Karagül, 2014). There is no treatment plant working efficiently in this watershed. Hence, the watershed outlet's average load is diffused. Substantial land base pollution because of the diffused sources was found. The point load effect is minimal and ignorable for this watershed. Generally, pollution loads are infiltrated underground, mix with the groundwater, find a way into an aquifer, and finally reach the creeks. All pollutants finally reach the Mediterranean Sea as an integrated diffused pollution source through the Boğaçay River. The beach is indispensable for city tourism and landscape. The aquifer is also vital for meeting the drinking water needs of the city of Antalya. This natural river was subjected to a series of irreversible human interventions because of a municipal project.

Materials and Techniques

Campbell *et al*. (2004) described dispersed emissions from rural areas as enhanced soil degradation, soil depletion, environmental waste, drainage, and poultry. Turkish water quality management regulations state that pollutants' origins are fertilizers, agricultural litter, decaying organic compounds, manufacturing, contaminated groundwater, sewage, soil degradation, and phosphate-based cleaning products (Official Gazette, 2004). Nitrates and phosphates are contaminants linked to fertilizers, compost, and waste. There is intensive agriculture in the Boğaçay River watershed. Therefore, the primary nutrient source is agricultural fertilizers. The Boğaçay Project enables the river estuary to act as a water retention dam. The water that cannot be discharged into the sea stagnates, and the water quality deteriorates with the sediment's nutrient load. In addition, with the saline seawater ingress, the habitat that can consume the accumulated nutrients, namely flora and fauna, was destroyed.

Since the rough construction, excavation works, and stream rehabilitation, which is the first phase of the project, was completed, those steps cannot be undone. Therefore, to reduce the pollution that may occur in the river outlet section mentioned in the study, the agricultural BMPs approach, which is not applied in the basin in any way, is presented as a proposal. The two issues addressed in this research, the project and the BMPs, are closely related to each other. Agricultural BMPs are the application that will alleviate the potential pollution caused by the Boğaçay Project. Their benefits are revealed numerically. The SWAT model was used for the analysis, since it has an excellent mathematical modeling infrastructure.

Figure 2. Two sampling locations, No. 1 and No. 2, were chosen based on the seawater reaches 700 m from the beach, with No. 1 being at the channel outflow and No. 2 being beyond the reach of the seawater (No. 1, 36°51′14″N, 30°37′34″E; No. 2, 36°51′28″N, 30°37′14″E).

Measured data for this research were obtained from the State Hydraulic Works (DSI) monitoring program for the Boğaçay stream discharging into the Mediterranean sea (DSI, 2019). Samples were transported in a cold box (4°C) and analyzed within 24 hours (ISO 5667-2, 1991; ISO 5667-3, 1994; ISO 5667-6, 1990). Then each parameter was tested in the laboratory. Applied test methods were ion chromatography for TKN and nitrate nitrogen; the stannous chloride method for total P; and 5-day incubation for 5-day biochemical oxygen demand (BOD_5). According to Turkey's surface water quality management regulations (SWQMR) (MFWA, 2012), water quality classes are shown in Table 1. Samples were collected at two measuring points. The measuring points were selected considering the seawater entering 700 m from the shore. Point number 1 was at the outlet from the channel, and point number 2 was chosen from beyond the seawater's reach (Figure 2).

The measurements, covering the years 2016, 2017, and 2018, are the annual average of monthly values. Data gathered from the State Hydraulic Works of Turkey (DSI, 2019) and the Republic of Turkey Governorship of Antalya (2017, 2018, 2019, 2020) mainly cover crucial information about the historical trend (2016–2018) of the pollution in the Boğaçay. The authors had a certain amount of data measured by DSI (2019) and the Republic of Turkey Governorship of Antalya (2017, 2018, 2019, 2020). Also, all data were supported by field measurements in Boğaçay conducted once a week, sometimes daily, as long as the weather conditions allow, or semimonthly. Thus, the monthly average data were obtained using the mean value of the absolute measured values. In local data deprivation, the published water quality data and the runoff models were chosen to approximate the possible interval of diffuse pollution loads produced by the catchment region. Various comparisons were taken into account, along with field experiments, to analyze spatial and temporal statistics (DSI, 2018, 2019; ISO 5667-6, 1990; Republic of Turkey Governorship of Antalya, 2017, 2018, 2019, 2020).

SWAT was used as a dynamic, empirical, hydrological tool for modeling the Boğaçay River watershed water quality (Arnold

Figure 3. Satellite imagery from October 2017 (upper figure) and August 2019 (lower figure) reveals coastal erosion that occurred since the dates fall between the before and after the river bed excavation within the scope of the Boğaçay project implementation.

et al., 1998). Early studies are recommendations for establishing an acceptable study methodology (Wickham *et al.*, 2005).

SWAT monitored the flow and nutrient transfer introduced to the main river channel and transported downstream (Neitsch *et al.*, 2002). ArcSWAT facilitates computational models of the SWAT in the ArcGIS system (Čerkasova, Umgiesser, and Ertürk, 2018; Lotz, Opp, and He, 2018; Malagó *et al.*, 2018). Under this program, ArcGIS includes the GIS source along with the typical windows oriented computing interface.

Many researchers have investigated the usefulness of BMPs to alleviate nutrient outputs (Himanshu *et al.*, 2019; Ni and Parajuli, 2018; Pearce and Yates, 2017; Risal *et al.*, 2020; Wang *et al.*, 2018). Numerous field-scale simulations are required to test the efficacy of BMPs using the SWAT technique (Almendinger and Ulrich, 2017; Aulenbach *et al.*, 2017; Jiang *et al.*, 2014; Rittenburg *et al.*, 2015). Feasible approaches for minimizing nonpoint source contaminant loads include strip and contour croppings, parallel terraces, buffer filter strips, slope stabilization systems, residue control, and grassy wetlands.

Implementing BMPs in SWAT requires calibrating parameters within the model. The model simulates an issue by fine-tuning the latest parameters depending on each management practice. One of the BMP parameters is the FILTERW, and this function concerns filter strips through the edge of the region. It is the side diameter of the filter band. The study of Arabi *et al.* (2007) is an indispensable guide for modifying parameters to simulate BMPs in the SWAT model.

RESULTS

The potential reduction in pollution loads with some agricultural BMP applications was revealed using the SWAT model. Also, the project was shown to inhibit sediments' ability to reach the Konyaaltı coast. According to the Union of Chambers of Turkish Engineers and Architects—Chamber of Geological Engineers (UCTEA-CGE), it was calculated that more than $1.6 billion USD should be spent for river rehabilitation alone (UCTEA-CGE, 2018). A second marina construction plan and groin construction to prevent coastal erosion on the shore require additional expenditure.

Sediment Transport

It is estimated that 250,000 m^3/y sediment is transported to the sea from the Boğaçay River watershed with an area of 850 km^2 (UCTEA-CGE, 2018). Sediment entering the channel with the project will not reach the sea. The Boğaçay riverbed was excavated on average 6 m and lowered to 1.5 m below sea level. Therefore, the sediment cycle between the river and the shore was interrupted. The channel will be filled with approximately 250,000 m^3 sediment each year. Cleaning it will be quite costly. Due to wave erosion, the coastal line's maximum recession was 25 m, according to the satellite imagery (Figure 3). The eroded shoreline between October 2017 (upper figure) and August 2019 (lower figure) is shown in Figure 3. Restoring the lost sediment with natural processes is no longer possible due to the so-called Crazy Project.

The reported water quality state of the Boğaçay River is displayed in Table 2. The river's water quality condition was set out through Turkey's SWQMR (MFWA, 2012). In Table 2, the numbers within brackets are prescribed water quality levels out of four, according to Turkey's SWQMR (MFWA, 2012).

Table 2. *Water quality classes are in parentheses for the sampling points between the years 2016 and 2018.*

Year	Point	Discharge (m^3/s)	Nitrate nitrogen (mg/L)	TKN (mg/L)	Total phosphorus (mg/L)	BOD_5 (mg/L)	Chlorine (mg/L)	Sodium (mg/L)
2016	1	7.05	1.18 (1)	19.02 (4)	0.22 (3)	6.20 (2)	25.90 (2)	22.02 (1)
2016	2	8.32	1.80 (1)	15.80 (4)	0.37 (3)	6.10 (2)	26.27 (2)	18.63 (1)
2017	1	8.63	1.08 (1)	14.42 (4)	0.015 (1)	0.75 (1)	18.55 (1)	14.10 (1)
2017	2	9.45	1.69 (1)	13.41 (4)	0.02 (1)	0.68 (1)	21.60 (1)	13.56 (1)
2018	1	10.50	0.98 (1)	7.42 (4)	0.38 (3)	4.80 (2)	22.56 (1)	16.70 (1)
2018	2	11.20	1.30 (1)	7.20 (4)	0.46 (3)	4.40 (2)	22.50 (1)	16.30 (1)

Table 3. *BMP representation in the SWAT model (adapted from Lee et al. 2010).*

BMP	SWAT Representation
Terrace	For all croplands with a slope $\geq$ 2%, USLE_P changed to 0.5, and CN2 was reduced by 6
Contour farming	For all croplands with slope $\geq$ 2%, USLE_P changed to 0.5, and CN2 was reduced by 3
Filler strips	15 for FillerW in .mgt
Critical pasture planting	Manning's *n* of a channel on *.sub changed from 0.014 to 0.15
Prescribed grazing	USLE_C in crop.dat is changed from 0.007 to 0.003
Cropland to pasture	CN2 changed appropriately from cropland depending on the soil class appropriate to pastureland (roughly −5), NROT changed to 2 and husc in mgt1.dbf changed to 0 for scheduling by heat units
Riparian buffer strips	Channel cover factor changed for channels above 0.1 to 0.1
Graded stabilization structures	HRUs with a slope greater than 3% were changed to 3%
Pasture planting	USLE_C in crop.dat is changed from 0.007 to 0.003
2000 ft buffer around the lake	No fertilizer in the sub-watersheds around the lake
WWTP level II	Replaced point source inputs with WWTP level II data

CN2, moisture condition II curve number; NROT, number of years of rotation; HRUs, hydrologic response units; WWTP, wastewater treatment plant

Implementation of BMPs

The analysis determines the effect of environmental activities on river water quality. SWAT simulates most environmental procedures with necessary modifications to the parameters (Brouziyne *et al*., 2017; Ha *et al*., 2018). See Table 3 for BMP projections on SWAT. The numbers given in Table 4 can alter within varying flow regimes, soil characteristics, and slopes. Arabi *et al*. (2008) offers an essential source of knowledge on interpreting BMP implementations and modifying variables for that purpose (Arabi *et al*., 2008).

Model Calibration

In this study, the paper written by Neitsch *et al*. (2002) was taken as an example of the SWAT model's calibration. Neitsch *et al*. (2002) proposed a three-phase calibration method in water quality modeling, beginning with streamflow and water balance preceded by sediment and nutrient sequence. The parameters below were used to calibrate the Boğaçay River watershed's SWAT configuration (Table 4). The sensitivity analysis variables in Table 4 are the mean quantities for the entire watershed.

The use of parallel terraces in a region would decrease the amount of surface runoff. The maximum runoff intensity is often reduced by lowering the hillside slope. It decreases sheet erosion and rilling by increasing sediment deposition in surface runoff (Feng, Wei, and Pan, 2020). It also reduces river erosion and stops rills and gullies from developing (Arabi *et al*., 2007). Diminishing the curve number (CN) value by seven units out of its calibrated amount (82) reflects the parallel terraces' effect on the amount of surface runoff. In addition, CN has a scale between 36 and 100 at SWAT; smaller values suggest reduced runoff potential, whereas more significant numbers imply

Table 4. *Parameters for calibration in the SWAT Model.*

Parameter	Description	Optimized value
Parameters from sensitivity analysis		
CN2	Curve number	82 (71–86)
Ch_K2	Effective hydraulic conductivity in the main channel (mm/h)	6–25
Sol_Awc	Available soil water capacity (mm H_2O/mm soil)	0.22
Ch_N2	Manning's *n* value for the main channels	0.05
Sol_Z(MX)	Maximum rooting depth of soil profile (mm)	500
Sol_K	Soil hydraulic conductivity (mm/h)	460
Surlag	Surface runoff lag coefficient	4
Usle_P	USLE equation soil erodibility factor	0.7
Usle_C	Minimal value of USLE equation cover and management factor	0.001–0.03
Nperco	Nitrate percolation coefficient	0.9
Ch_Cov	Channel cover factor	0.595–0.95
Additional parameters adjusted for calibration		
ESCO	Soil evaporation compensation factor	0.95
GW_Delay	Groundwater delay time (days)	54

enhanced runoff potential. A universal soil loss equation (USLE) is frequently used to define soil erosion (Kılıç, 2021). The modified USLE_P value was 0.12; on the other hand, the measured value was 0.7. Thirty-meter-long filter strips were used to limit the FILTERW value to 30. Specific potential BMPs to be included were contour crops and riparian buffer areas.

Nevertheless, the CN and USLE_P quantity shifts are, more importantly, related to BMP terracing expectations. This condition does not enable one to see the consequences of all three BMPs by arranging SWAT variables. Three units from the measured quantity could decrease the number of curves needed to understand the impact of riparian buffer strips or contour farming. However, terracing BMPs requires an increase of seven units. There is a typical case for the USLE_P change. It is vital for land slopes between 1% or 2% to reduce USLE_P to 0.3 for riparian buffer strips and 0.6 for contour farming. Table 5 depicts the BMP simulations. Table 6 indicates the results of BMPs, where TKN and total P stand for total Kjeldahl nitrogen and total phosphorus, respectively. Nonpoint source nitrogen and phosphorus concentrations can be managed to use the best management techniques. Filter strips are used to reduce the amount of suspended particulates and particles in runoff water. Parallel terraces are an agronomic conservation approach that prevent sedimentation by reducing soil erosion down the slope by generating crop row ridges that act as barriers to surface runoff. As a result, sediment transport is limited by these two applications. As shown in Table 6, model findings reveal a decrease in TKN, total P, and BOD_5 concentrations, resulting in water being rated as higher quality.

The SWAT model takes into account processes such as denitrification and plant uptake while making calculations. For this reason, deviation in a decrease in TKN, total P, and

Table 5. *List of BMPs simulated.*

Background	Up and downhill planting with conventional tillage
BMPs	Parallel terraces with conventional tillage, 30 m filter strips

Table 6. *Water quality class at the outlet of the watershed (point No. 1) based on BMP implementation.*

Year	Pollution parameter	Discharge (m^3/s)	Average annual pollution load (kg)	After best management practices (kg)	Concentration (mg/L)	Water quality class (before/after) BMP
2016	TKN	7.05	4,231,503	2,623,108	11.79	(4/4)
2017	TKN	8.63	3,927,092	2,434,404	8.94	(4/4)
2018	TKN	10.50	2,458,602	1,524,087	4.60	(4/3)
	% reduction		38			
2016	Total P	7.05	48,944	30,340	0.14	(3/2)
2017	Total P	8.63	4085	2532	0.01	(1/1)
2018	Total P	10.50	125,912	78,052	0.23	(3/3)
	% reduction		38			
2016	BOD_5	7.05	1,379,354	841,268	3.78	(2/1)
2017	BOD_5	8.63	204,252	124,573	0.46	(1/1)
2018	BOD_5	10.50	1,590,470	970,027	2.92	(2/1)
	% reduction		39			

BOD_5 loads as a result of BMP application is quite natural. In addition, beyond the SWAT analysis, the effect of the pollution parameters was interpreted following Turkey's SWQMR (MFWA, 2012), which quality class they correspond to in terms of the measured concentrations; in other words, this study demonstrated which variable is needed to create the potential threat.

Current Status of Boğaçay

Boğaçay, where the waters coming from the karstic structure of the Taurus Mountains in Antalya merge at Konyaaltı Beach and pour into the Mediterranean, is covered with moss. The water coming to Boğaçay, where the bed elevation level was lowered, mixes with the fertilizers left from the surrounding agricultural areas, and algae occur in the freshwater that cannot reach the sea as easily as before the Crazy Project. The global warming that is threatening water resources today, as well as the observed global climate change, causes an increase in the seasonal average temperature, a change in the water level, and a decrease in the oxygen level in the water, which negatively affects the life in the water. Current studies in the literature indicate that global warming will be one of the most significant negative factors affecting global water quality in the future (Radhapyari *et al*., 2021; Valipour, Bateni, and Jun, 2021). Saltwater intrusion acts as a catalyst in the formation of bad odors and appearance of algae with the warming of the water with hot air. When the saltwater, which enters from the sea and stratifies at the bottom due to the density difference, meets the algae growing in freshwater, decay begins. Negative results of the project are seen in Boğaçay as of May 2021. As a temporary solution, growing grass is cut from the bottom and harvested (see Figure 4). Despite the costly cleaning efforts, human intervention has caused the ecological balance to deteriorate and the water quality to decrease. In short, expensive systems such as mobile ventilation systems may be required to increase oxygen and maintain the ecosystem.

In the study area, water temperature is significantly related to total phytoplankton biomass. However, there is still considerable uncertainty about the magnitude of temperature changes and how they will drive eutrophication in water bodies in different regions and climates beyond the effect of human activities. Warmer water temperature, on the other hand, is associated with higher relative cyanobacteria biomass. Warmer spring and summer temperatures may also cause significant changes in plankton population dynamics in small eutrophic water bodies (Dupuis and Hann, 2009).

DISCUSSION

Land usage has a significant impact on hydrological systems. The Boğaçay River watershed region has unique soil characteristics and land use. Best management practices (BMPs) are strategies intended to minimize emissions. If the land-use type is agricultural, nutrient emission transported by hydrological processes can be avoided via BMPs. A variety of BMPs may be tested through the SWAT model to identify the correct BMP against growing nitrogen loads in the watershed. The current BMP in the watershed was recognized to be up and down for traditional tillage.

The BMP scenario designed through SWAT was parallel terraces within this research, including traditional tilling and 30-m-long filter strips. Computational model findings were tested in compliance with Turkey's Surface Water Quality Management Regulations (SWQMR) (MFWA, 2012). Results show that a decrease in TKN, total P, and BOD_5 loads of up to 38%, 38%, and 39% are expected. Hence, there is a significant reduction in nutrient pollution discharged to canal water from agricultural areas. Also, the water quality of the river is expected to be improved through the proposed BMPs.

Three critical parameters were reduced to the rates corresponding to the upper level of the quality range. For instance, if the 2018 BOD_5 value is considered, water quality will rise from class two to class one as long as the suggested BMP is implemented. Similarly, the TKN and total P load were lowered sufficiently to shift the water quality to the upper level.

The most damaging impact of the so-called Crazy Project was visible at the world-famous Konyaaltı Beach. The project causes the river estuary to act as an artificial dam. Within two years, the sediment cycle was interrupted. According to the results of this research, the shoreline was retracted up to 25 m.

The saline wedge takes on different shapes depending on parameters, such as the aquifer's hydraulic conductivity, the amount of discharge from the aquifer up to the sea, the hydraulic gradient, and the density difference of freshwater and saltwater. Groundwater becomes salinized and unusable for the phenomenon called seawater interference or intrusion in coastal aquifers.

Figure 4. Periodic harvesting activity by the municipality to remove excessive moss that produces odor and unpleasant visual pollution owing to the deteriorating water quality caused by the Boğaçay project.

As was done in the Crazy Project, excavation of the river bed can cause downstream siltation, and river bed clogging causes a decrease in riverbed hydraulic conductivity. Alluvial materials that cannot reach the beach are prevented from compensating those transported due to coastal erosion. Coastal erosion causes the shoreline to retreat and the saltwater–freshwater interface to move inward.

Lowering the channel to 1.5 m below sea level will cause seawater wedge and faster salinization of groundwater. Salinity is also the main driver for species distribution. Salinization will pose a threat to the species diversity and habitats in the Boğaçay River in the future.

Over time, this chain of events destroys the beach, which is the asset that primarily attracts visitors. A comprehensive and long-term beach protection strategy will make a significant contribution to the economic system. Making beaches unhealthy places for tourism does not make sense in the economy beyond environmental terms.

Although statistical methods and modeling studies assume a complete data set for analysis, missing values are common in water quality investigations. Missing value handling can be complex, since determining the type and pattern of missingness and completely grasping the most effective imputation approach requires a thorough evaluation of the data. Gaps in water quality data sets can occur for various reasons, including poor data input, equipment failure, sample loss before analysis, and inaccurate readings. Missing values make data processing more difficult, impair statistical efficiency, and lower statistical estimating power. Repeating the experiment and producing a complete data set is the best strategy to estimate missing values. This alternative, however, was not viable due to the retrospective nature of the study and the reliance on past data. Where resampling was not possible, various sources were used to fill in the missing values, which could reduce inaccuracy of results owing to missing data.

In future investigations, a more extensive spatial and temporal data set can be examined, as a few missing data in a large data set has little effect on the analysis results compared to a collection of limited spatial and temporal data. For future research, the study could be expanded to include salinity analysis and total suspended sediments (TSS) observation. In addition, in future studies, temporal datasets can be used to investigate changes in land use land cover (LULC), as well as soil parameters and geomorphological units.

CONCLUSIONS

This project is a catastrophic example of demolishing natural beauty by human intervention. The sediment transported by the Boğaçay River will accumulate at the outlet of the estuary. Hence, periodic cleaning of sediment accumulated in the channel is now necessary. With the so-called Crazy Project, the municipality has inherited a complex environmental problem and recurrent rehabilitation costs for future generations. Transported sediments that come with the floods will fill the excavated area at the Boğaçay River's outlet. The facilities to be built along the Boğaçay River and its branches will be in danger of flooding.

This situation also causes the accumulation of nutrients due to sediment transport. On the other hand, in 2017, there was significant nutrient retention due to the harvesting work carried out for the project. Therefore, pollution concentrations in 2017 decreased. In 2018, the excavation and harvesting phases of the project had already been completed. The impact of agricultural pollution on the river is visible again. The outlet of the river is filled with sediment. The sediment transported along the watershed brought with it a large nutrient load. Hence, the concentration of pollutants increased.

If motor-driven submerged or floating jet aerators are used in the summer and withdrawn in the winter, the system will help to reduce problems such as bottom mud formation, odor, and visual pollution in Boğaçay. Furthermore, predatory fish species can be employed for biological control in eutrophic freshwater habitats, and making compost from the plants and algae collected will be appropriate. Construction in the floodplain should be avoided, and stream beds should be cleaned through harvesting regularly.

Biogeochemical parameters and hydromorphological characteristics of receiving waters are vital for nutrient retention. Land management of riparian and marine ecosystems in watersheds will be the leading challenging environment for integrating ecological and socio-environmental connections.

Initiatives to preserve the Boğaçay River watershed will help policymakers safeguard the ecosystem while increasing people's living standards.

The Crazy Project is a high-cost project, but unfortunately, it has disturbed the geological balance in the Boğaçay area. Environmental damage caused by the project requires higher environmental rehabilitation and maintenance costs. This study reveals the current and possible future negative consequences. Consequently, the river's elevation should be returned to a preproject level so that the environmental and geographic damage does not increase further.

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