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An Integrated Modeling Approach to Assess Best Management Practices (BMPs) for Improving Stream Water Quality Using the MapShed and WASP8 Models

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Abstract

Diffuse pollution control through the implementation of best management practices (BMPs) is essential for integrated water management. This study presents a comprehensive approach that integrates monitoring and deterministic water quality modeling to assess the effectiveness of various BMPs and point pollution control scenarios for improving water quality. The pilot study area (PSA) is the *Acısu Creek* watershed in the south of Turkiye. The hydrological model MapShed was employed to estimate sediment and nutrient load reductions by BMPs and these estimates were used as inputs to the Water Quality Analysis Simulation Program (WASP8) for water quality simulations. The MapShed model was calibrated in the Lower Aksu Stream basin from 2013 to 2019, achieving satisfactory results. Calibration and verification of the WASP8 model were performed using one year of monthly water quality monitoring results, showing good agreement between measurements and predictions. Diffuse pollution control scenarios were effective in decreasing pollutant concentrations. The BMP scenario for management of pastureland and livestock wastes led to total nitrogen (TN) and total phosphorus (TP) load reductions of 43% and 34% from pastureland, and 61.5% and 57.9% from farm animals, respectively, but the watershed annual loads decreased only by 4%. The combined BMP scenario targeting agricultural practices, pasture management and animal waste control provided the maximum reduction in total annual diffuse pollution loads by 35% for TN and 29% for TP. The holistic nature of this study contributes to the advancement of water quality modeling and provides valuable insights for sustainable water resources planning and decision-making.

Keywords BMPs · MapShed · Modeling · Simulation · WASP8 · Water quality

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1 Introduction

The depletion of water resources due to climate change, population increase, agricultural expansion, and water pollution necessitates the implementation of a comprehensive policy for sustainable water management. River basin management, which encompasses social, economic, and environmental perspectives, plays a vital role in this policy. Models are widely used for the assessment and management of water quality under the influence of various anthropogenic activities and changing environmental conditions (Bai et al. 2022), decision-making processes and strategy development to enhance water quality across diverse water bodies (Tsakiris and Alexakis 2012) and sustainable agricultural water management (Cetin et al. 2023).

With the advancements in computational technologies, several surface water quality simulation models, like EFDC, MIKE, BASINS, QUAL2E/K, CE-QUAL/W2, AQUA-TOX, Delft3D, and WASP, have been developed and continually updated. Among these, the Water Quality Analysis and Simulation Program (WASP) has been widely utilized in the literature, offering valuable insights into phytoplankton and nutrient cycles. Recent applications of WASP include surface water quality simulation (Iqbal et al. 2018), eutrophication control (Wang et al. 2018), Total Maximum Daily Load studies (Camacho et al. 2018) and assessment of climate change impacts on lakes (Park et al. 2013). Research studies conducted in diverse locations of the world have demonstrated the effectiveness of the WASP model in addressing water quality challenges.

Accurate estimation of diffuse pollution is critical for the effective protection and management of water resources, ensuring ecological balance, public health, and economic vitality. In recent decades, numerous tools have been developed to quantify nutrient losses in river basins both in Europe (Arheimer and Brandt 1998; Behrendt 1999; Kronvang et al. 1999) and beyond (Gull and Shah 2020). These tools, tailored for various regions, differ in complexity, temporal and spatial resolutions, and data requirements (Clark et al. 2017). Process-based dynamic quantitative tools, such as SWAT (The Soil & Water Assessment Tool), INCA (Integrated Catchments) and HSPF (Hydrological Simulation Program), typically demand comprehensive input data on a temporal and spatial scale. When such detailed data is lacking, empirical, semi-empirical, or statistical models serve as suitable alternatives (Bouraoui and Grizzetti 2014). The MapShed model, with its user-friendly interface and simplified input datasets, is distinct from other models like HSPF and SWAT and has received approval from the United States Environmental Protection Agency (US-EPA) as an intermediate model that incorporates algorithms capable of simulating essential mechanisms governing nutrient and sediment movement within a watershed (Evans and Corradini 2016).

The control of diffuse source pollution using Best Management Practices (BMPs) holds significant importance for various reasons, such as improved water quality, eutrophication prevention, habitat protection, flood mitigation and conservation of human health. BMPs could be categorized as structural (e.g., terracing, constructed wetlands, sediment control ponds), product-focused (e.g., crop rotation, reduced tillage, filter strips), and non-structural (e.g., floodplain restoration, sustainable irrigation, fertilizer management) approaches (Novotny 2002). The effectiveness of BMPs was investigated by modeling studies for the hydrological performance of low-impact BMPs (Gulbaz and Alhan 2017), control of nitrogen loads in irrigation return flow (Cavero et al. 2012; Karnez et al. 2017) and evaluation of parameter uncertainties (Chen et al. 2022).

This study aims to present a combined modeling approach for comprehensive water quality assessment. The novelty of this research is the integrated use of the MapShed hydrological model and the WASP8 water quality model to evaluate: i) the effectiveness of various BMPs in reducing sediment, nitrogen (N), and phosphorus (P) loads and, ii) the impacts of several scenario conditions on point discharges. The study area is the *Acısu Creek* watershed, in the south of Turkiye, where agriculture and urbanization adversely impacted its natural flow regime and impaired the water quality. The holistic nature of this study contributes to the advancement of water quality modeling and provides valuable insights for sustainable water resources planning and decision-making.

2 Materials and Methods

2.1 Study Area

The pilot study area (PSA) is the Acısu Creek watershed, located within the Antalya River Basin of Turkiye, and spans 46 km from the upstream to its discharge point to the Mediterranean Sea (Fig. 1). The creek plays a vital role in the regional hydrological system with its complex network of interconnected tributaries and channels. The PSA covers 37,818 hectares (ha) and includes various land uses (Fig. 2a): agricultural land (26,710 ha, 71%), forests (7,891 ha, 21%), disturbed/open land (311 ha), pastures (1,278 ha), and residential areas (1,628 ha). The southern coastal part of the PSA is characterized by intense tourism activities, while the inland areas are dominated by agricultural practices. Elevations range from sea level to 1,464 m above mean sea level, with higher elevations in the forested northern part.

The PSA experiences a Mediterranean climate with hot summers and mild winters, creating favorable conditions for agriculture and tourism. In 2021, the yearly average air temperature, total annual precipitation and open-pan evaporation were 19.6 °C, 745 mm and 1392 mm, respectively. In the PSA, water quality is influenced by both point and
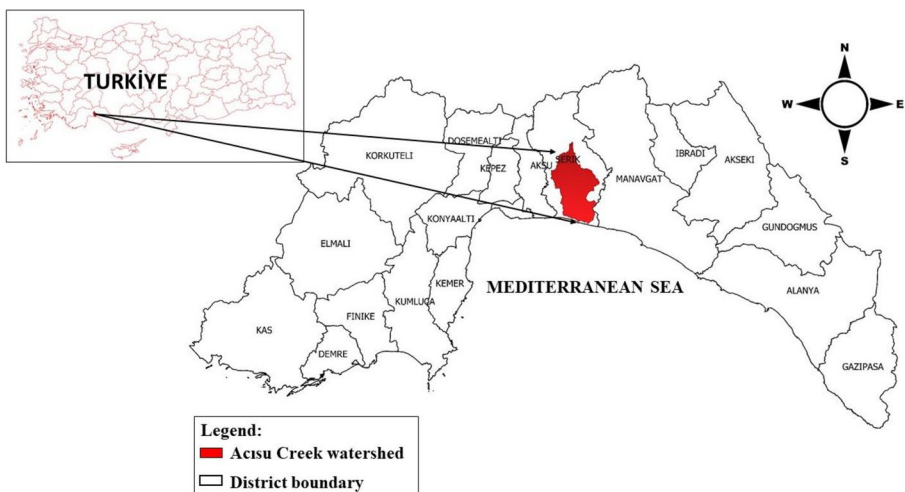
Fig. 1 Location of the study area in Turkiye, Antalya province, and the districts
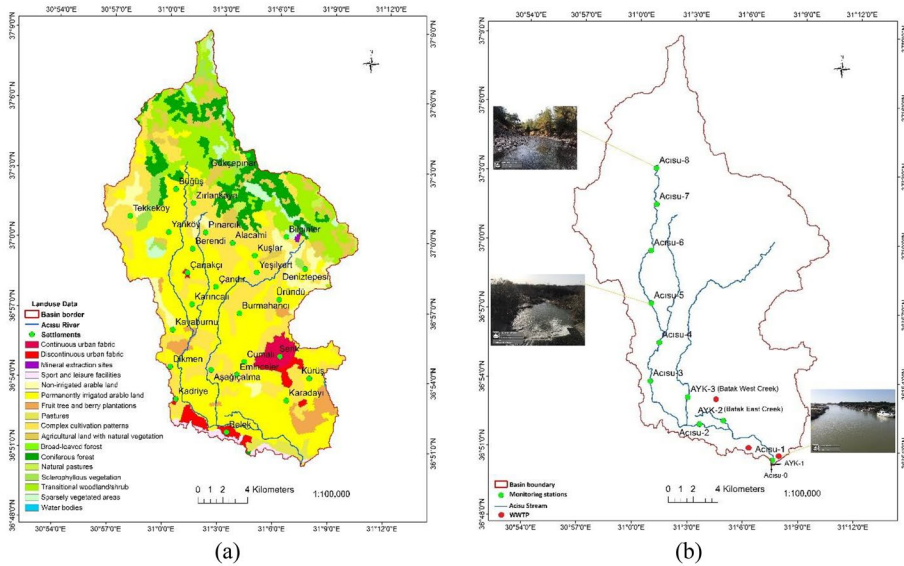
Fig. 2 **a** Land-use/cover in the Acısu Creek watershed and **b** locations of the water quality monitoring stations

diffuse pollution sources where three wastewater treatment plants (WWTPs) (Bogazkent, Belek-2, and Serik) are the primary point sources. Effluents from the Belek-2 and Bogazkent WWTPs are released into the Acısu Creek, while the Serik WWTP discharges into a tributary. In 2022, two WWTPs (Belek-2 and Serik) were closed, and a new one (Serik-2 WWTP) started operation.

2.2 Monitoring Studies

For a comprehensive assessment of water quality in Acısu Creek, monitoring stations were selected based on land use/cover, point and diffuse pollution sources. Nine monitoring stations were established along the mainstem of Acısu Creek, while an additional three monitoring stations were at the tributaries. The locations of all monitoring stations are depicted in Fig. 2b.

Monthly water quality monitoring was conducted for a duration of one year (from Sept. 2020 till Sept. 2021) which involved measurements and analysis of many physicochemical and bacteriological parameters. Water samples were manually collected using a cross-sectional composite sampling method. Measurements of temperature, pH, electrical conductivity, salinity, dissolved oxygen (DO) concentration and saturation percentage, and chlorophyll-a parameters were performed in-situ using a multiparametric probe. Total Suspended Solids (TSS), COD (Chemical Oxygen Demand) and BOD_5 (Biochemical Oxygen Demand) analyses were carried out using standard methods (APHA 1998). Anion and cation groups were analyzed with an Ion Chromatography system. Total Organic Carbon (TOC) and Total N (TN) parameters were analyzed simultaneously using a TOC/TN equipment. Total P (TP) was determined spectrophotometrically by applying the ascorbic acid method and persulfate digestion (APHA 1998).

Total coliform, fecal coliform (FC), Escherichia coli (E.coli), and fecal streptococcus analyzes were conducted by membrane filtration method (APHA 1998; Myers and Sylvester 1997). Flow measurements were carried out by the State Hydraulic Works Regional Directorate.

2.3 Integrated and Deterministic Modeling Scheme

The implementation scheme of the integrated and deterministic modeling study is illustrated in Fig. 3. Data collection and monitoring studies facilitated the identification of input data required for modeling purposes. The modeling study was carried out by integrating the MapShed Version 1.5 (Evans and Corradini 2016), an open-access hydrological and diffuse pollution load simulation model, and the WASP8 model (US-EPA 2020) of the US-EPA. The MapShed model was used to estimate daily surface runoff and concentrations of TSS, TN, and TP from the watershed. These estimates were directly defined as input data for the WASP8 model. The Advanced Eutrophication module of the WASP8 model was used to perform water quality simulations and provide predictions of flow and water quality parameters. Analyses of various scenarios were undertaken, and recommendations were put forth to improve the water quality in the PSA based on the simulation results.
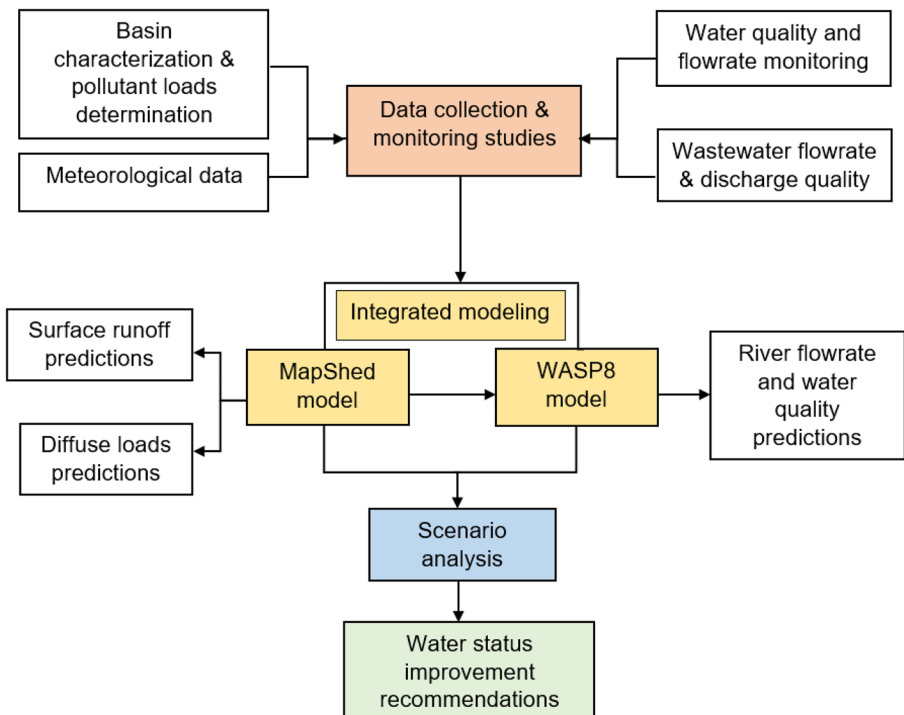

Fig. 3 Implementation scheme of the integrated and deterministic modeling study

2.3.1 The MapShed Model

The MapShed model, a GIS-based watershed simulation tool, replicates the functionality of the AVGWLF software (Evans and Corradini 2016). Its hydrological component uses the SCS Curve Number method for precipitation-flow correlation and employs the Universal Soil Loss Equation for soil erosion calculations. Key model inputs include transport, nutrients, and animals, with GIS shape files delineating meteorological station locations, basin boundaries, stream networks, and soil distribution. Furthermore, GIS grid files of land use/cover and digital elevation maps are required. In this research, the MapShed model was initially calibrated at the *Küçükaksu Gebiz* sub-basin of the Aksu Stream (adjacent to the PSA) which has extended daily flow rate data. Meteorological data sets of daily minimum and maximum air temperatures, and daily precipitation rates from 2010–2021 were collected from eight stations within and around the watershed (Table S1 and Fig. S1 in Supplementary Material), in addition to population and livestock data. Quality control of meteorological data was manually conducted with expert judgment through gross error checks. The calibration period spanned from January 1, 2013 to December 31, 2015, while verification period spanned from November 1, 2017 to December 31, 2019, yielding satisfactory results (Nash–Sutcliffe efficiency value > 0.50, RMSE = 4.95 m^3/s, MAE = 2.75 m^3/s and R^2 = 0.74) (Muhammetoglu 2022).

2.3.2 The WASP8 Model

The latest version of the WASP model (v8.32) was utilized for hydrodynamic and water quality simulations. WASP is a structured mass balance and transport framework, enabling spatiotemporal water quality analyses in surface waters and sediments (Wool et al. 2001). It employs a flexible compartmental approach, accounting for advective and dispersive transports across segments, and utilizes the kinematic wave equation for hydrodynamics (Ambrose and Wool 2017). The model comprehensively represents processes like nutrient enrichment, eutrophication, and DO depletion, integrating all point, diffuse sources, and various transformations. Acısu Creek was divided into 12 segments (S1-S12), based on factors like tributary inputs, WWTP discharges, pollution sources, and land use/cover. Segment lengths varied between 0.3 to 8.0 km. Figure 4 illustrates the Acısu Creek segment network with the locations of monitoring stations and load inputs. Monitoring stations Acısu-6 (most upstream) and Acısu-0 (most downstream) served as model boundaries and tributaries YK3 and YK-2 were connected to segments S7 and S6, respectively. YK-1 tributary and the effluents from two WWTPs (Bogazkent and Belek-2) were defined as point loads to segments S2 and S3, respectively.

The MapShed model estimated daily surface runoff, TSS, total/dissolved N and P loads, and concentrations for the five sub-watersheds. These were supplied as input to the WASP8 model at connection points MS0-MS4 on the stream network. The sub-watershed delineations and connections to Acısu Creek were derived using the MapShed model. The WASP8 model application comprised two stages: calibration (September 2020–March 2021) and verification (March 2021–October 2021). Model predictive accuracy was assessed by Root Mean Square Error (RMSE) and coefficient of determination (R^2). Meteorological data sets required for the WASP8 model were obtained from the Antalya Regional Meteorological Station as hourly data sets (air temperature, wind speed, solar radiation, cloud cover and relative humidity). Segment specifications (average widths and depths, bottom slopes,
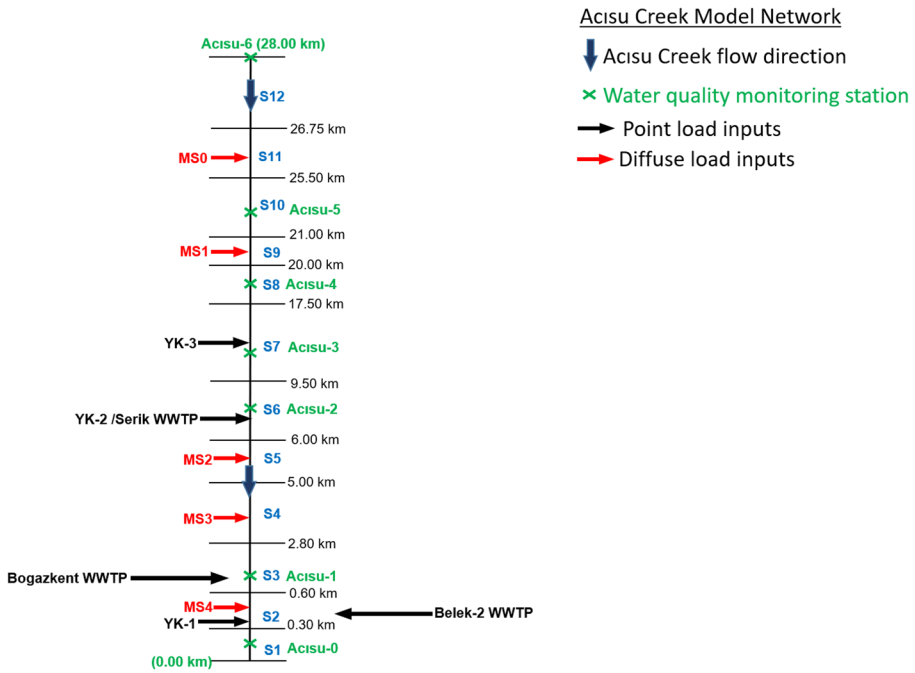
Fig. 4 WASP8 model segmentation for the Acısu Creek application

minimum water depths, Manning's friction coefficients) were determined from related reports and field observations.

2.3.3 Management Scenarios

To enhance the water quality of Acısu Creek, control options targeting diffuse pollution from agriculture and pasturelands were simulated using the MapShed and WASP8 models through Scenarios S1, S2, and S3. S1 employed BMP7 of the MapShed model, encompassing pasture management, livestock waste management system (WMS), surface flow controls, and poultry phytase feed. S2 integrated BMP1 (cover crops), BMP2 (conservation tillage), BMP3 (contour farming), and BMP6 (nutrient management) of the MapShed model. S3 combined both the S1 and S2 approaches. Scenario S0 was established as the baseline condition.

For point source discharge control within the PSA, two management scenarios were evaluated concerning urban WWTPs. Scenario S4 proposed a 25% reduction in wastewater discharge from Belek-2 and Bogazkent WWTPs, aligning with plans for agricultural reuse. Scenario S5 examined the latest WWTP operational framework in 2022 which involved the closure of two WWTPS (Belek-2 and Serik) and the operation of a new one (Serik-2) with effluent discharge into a tributary of the Acısu Creek. The effluent quality and discharge flow rates of the new WWTP were obtained from local authorities. An overview of management scenarios and BMP pollutant reduction efficiencies (Evans et al. 2008) are presented in Table 1.

Table 1 Descriptions of management scenarios and pollutant reduction efficiencies of BMPs

Scenario	Description of scenario	Pollutant reduction efficiency (%)		
		N	P	Sediment
S1	Pasture management	43	34	13
	Livestock WMS	75	75	75
	Poultry WMS	14	14	14
	Flow control in confined feeding areas	15	15	15
	Phytase feed for poultry (BMP7)	-	21	-
S2	Crop rotation and cover crops (BMP1)	25	36	35
	Conservation tillage (BMP2)	50	38	64
	Contour farming (BMP3)	23	40	41
	Fertilizer management (BMP6)	70	28	-
S3	Combination of S1 & S2	same as above		
S4	25% reduction in the discharge of treated wastewater from two WWTPs due to reuse of treated wastewater for agriculture			
S5	Recent operation and discharge scheme of the WWTPs			

Environmental quality standards (EQS), derived from the Turkish Regulation on Surface Water Quality (SWQR 2012), were used to evaluate in-stream water quality and BMP effectiveness in diffuse pollution control. The EQS classify surface water quality into three categories: Class-I (very good), Class-II (good), and Class-III (moderate) based on physicochemical parameters as presented in Table S2 (Supplementary Material).

3 Results and Discussion

3.1 Monitoring Results

Water quality monitoring results for continuously flowing upstream (Acısu-6) and downstream (Acısu-0) stations are summarized in Table S3 (Supplementary Material). While upstream stations (Acısu-8, Acısu-7 and Acısu-6) exhibited good water quality due to limited impacts from pollution sources, significant impairments were observed in the downstream section. Annual average monitoring results categorized water quality as Class III (moderate) for Acısu-0, Acısu-1, Acısu-2, and two tributaries (YK1 and YK2), and Class II (good) for the other stations. Particularly, the deteriorated water quality at the discharge point of the creek to the Mediterranean Sea (Acısu-0), poses substantial environmental concerns for the coastal area, tourism, and aquatic life. In the PSA, BOD_5, NH_4-N, PO_4-P, and TP were the most significant parameters contributing to pollution and they were attributed to effluent discharges from three WWTPs and diffuse sources. The intense agricultural activities in the PSA, with over 5,000 tons of fertilizer applied in 2020, played a key role (Muhammetoglu et al. 2022).

3.2 The MapShed Model Application

The MapShed model was applied for a simulation period of three years (from January 1, 2019, to October 15, 2021) to estimate surface runoff and diffuse pollution loads of TN,

TP, and sediments across five sub-watersheds and the whole PSA (Muhammetoglu 2022; Muhammetoglu et al. 2022). For 2021, annual TN and TP loads were estimated at 627 and 136 tons/year, respectively, with areal loads of 16.6 and 3.6 kg/ha/year (presented as base condition at Table S4 in the Supplementary Material). The predicted surface flow rates at the outlet of the PSA for 2021, along with the measured daily precipitation, are illustrated in Fig. S2 (Supplementary Material).

In 2021, diffuse TN loads were sourced mainly from agricultural areas (72%), septic tanks (17%), livestock (7%), and pasture lands (1.51%), with other land uses contributing 2.09%. TP loads exhibited a similar distribution: 82% from agriculture, 8% from septic tanks, 6% from livestock, 1.98% from pasture lands, and 1.72% from other land uses. Septic tanks are often overlooked as a potentially significant source of water pollution (Withers et al. 2014), but agricultural lands and septic tanks were significant sources of TN and TP in the PSA. In 2021, precipitation was highest in November and December whereas maximum evapotranspiration was observed between May and July. Correspondingly, the highest nutrient loads were predicted for November 2021 due to increased surface runoff (Muhammetoglu 2022; Muhammetoglu et al. 2022).

3.3 WASP8 Model Calibration and Verification

Key kinetic constants and coefficients determined through WASP8 model calibration for Acısu Creek are detailed in Table 2 where default values were assigned for the remaining constants and coefficients. Figures 5, 6 and 7 display the WASP8 model predictions for flow and water quality variables for calibration and verification periods. The comparison of flow measurements and predictions, limited to measurements from Acısu-1, Acısu-3, and Acısu-6, is shown in Fig. 5. Water quality predictions for Acısu-1

Table 2 Kinetic constants and coefficients determined through WASP8 model calibration

Kinetic constant name	Calibrated value
Nitrification rate (1/day)	0.05
Temperature correction coefficient for nitrification	1.07
Denitrification rate (1/day)	0.03
Temperature correction coefficient for denitrification	1.04
BOD deoxygenation rate (1/day)	0.1
Temperature correction coefficient for BOD deoxygenation rate	1.07
Dissolved organic N mineralization rate (1/day)	0.01
Temperature correction coefficient for dissolved organic N mineralization rate	1.08
Dissolved organic P mineralization rate (1/day)	0.01
Temperature correction coefficient for dissolved organic P mineralization rate	1.08
Oxygen to carbon stoichiometrically ratio in periphyton	2.667
Temperature correction coefficient for reaeration rate	1.024
Phytoplankton maximum growth rate (1/day)	0.4
Temperature correction coefficient for phytoplankton maximum growth rate	1.07
Phytoplankton respiration rate (1/day)	0.1
Temperature correction coefficient for phytoplankton respiration rate	1.07
Phytoplankton death rate (1/day)	0.1

(a) Segment Acısu-6

(b) Segment Acısu-3

(c) Segment Acısu-1
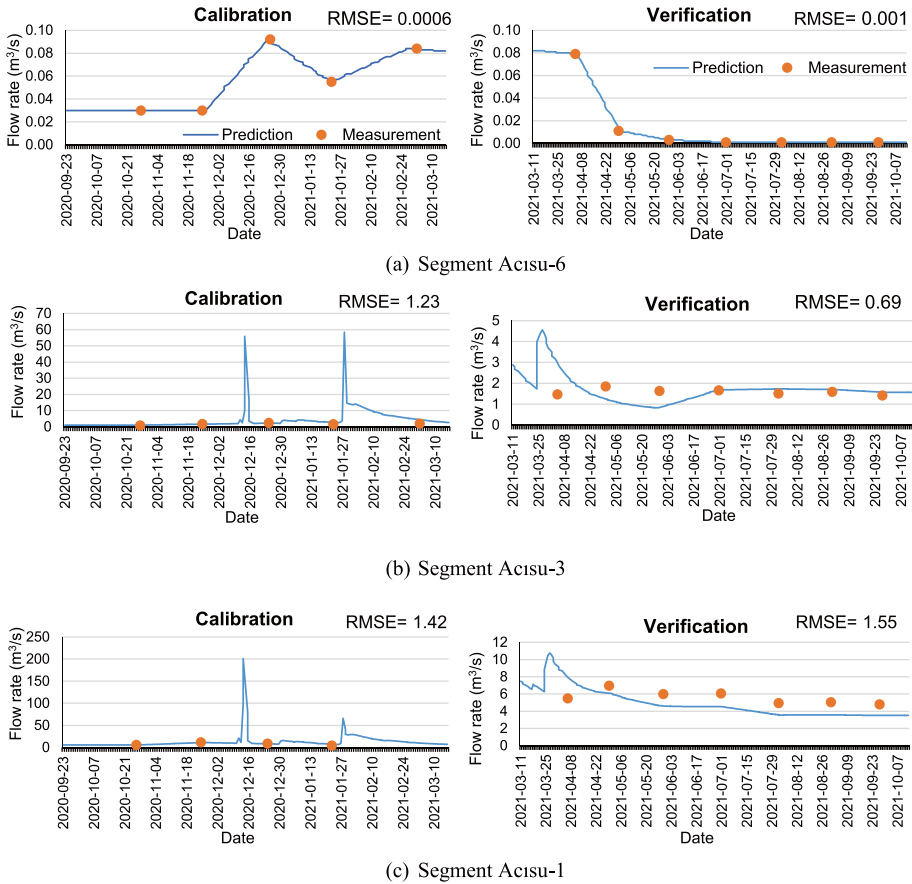
Fig. 5 Flow rate prediction for segments **a** Acısu-6, **b** Acısu-3, and **c** Acısu-1 for calibration and verification periods

are given in Figs. 6 and 7, while Figs. S3–S4 (Supplementary Material) depict the predictions for other stations.

The MapShed model predicted considerable surface runoff rates between Acısu-5 and Acısu-0, leading to extreme increases in flow rate during heavy rainfall and flooding events in December 2020, January and November 2021. Conversely, flow rates at the upstream Acısu-6 station were very low and even approaching zero from May to October 2021 due to dry conditions. Monitoring stations Acısu-8 and Acısu-7 were excluded from the modeling study due to recurrent seasonal droughts and model prediction errors were computed for the other stations on the Acısu Creek mainstem (Table S5 in Supplementary Material). Predictions of the WASP8 model for calibration and verification periods were generally in good agreement with measurements, as indicated by low RMSE values and high R^2 coefficients. RMSE ranged: 0.26–2.84 °C for temperature, 0.04–2.90 mg/L for BOD_5, 0.46–1.07 mg/L for DO, 0.004–0.53 mg/L for NH_4-N,
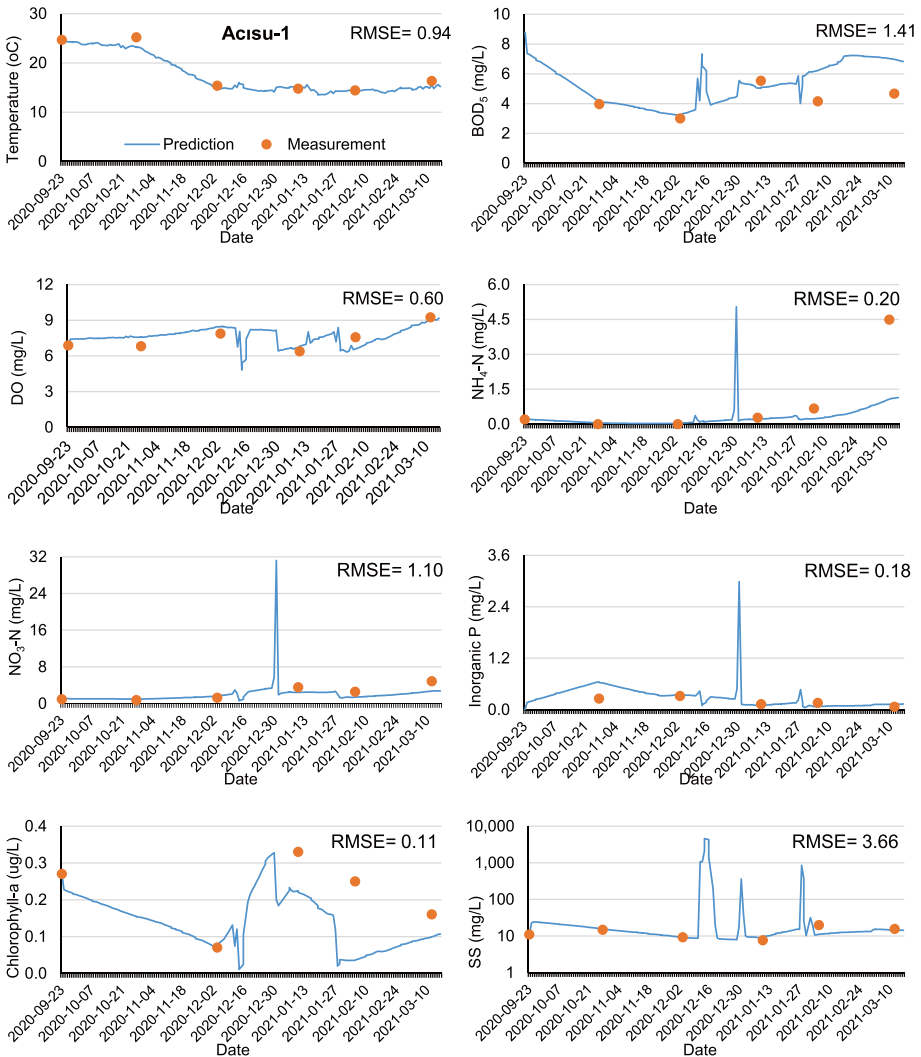
Fig. 6 Model calibration results for Segment Acısu-1

0.01–1.78 mg/L for NO_3-N, 0.0003–0.69 mg/L for inorganic-P, 0.01–1.47 µg/L for chlorophyll-a, and 0.05–17.26 mg/L for SS.

Predictions of water temperature were in good agreement with the measurements, showing typical seasonal variations. Variations in BOD_5 predictions reflected pollution inputs from tributaries and downstream WWTP discharges. High concentrations of NH_4-N, NO_3-N, inorganic-P and TSS coincided with increased surface runoff. During the verification period, the scarcity of rainfall and runoff resulted in reduced flow rates and dilution capacity, leading to increased TSS concentrations in the mid-section.
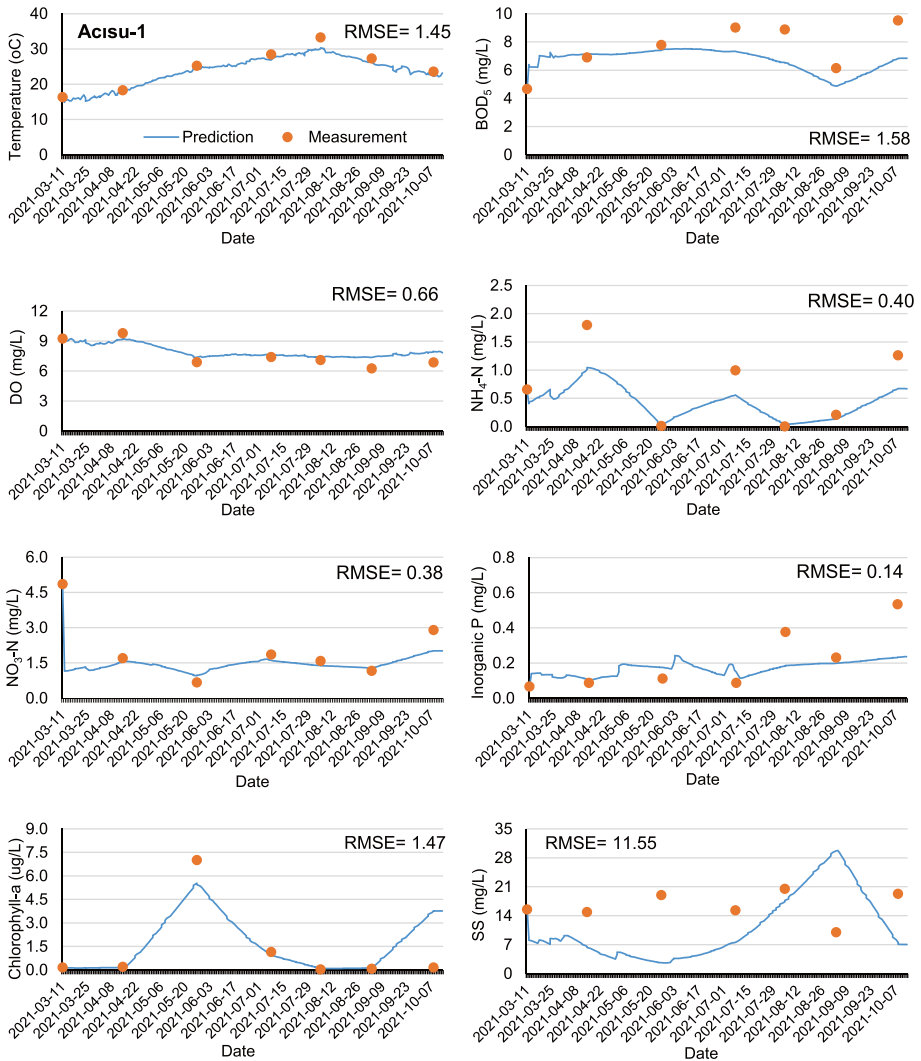
Fig. 7 Model verification results for Segment Acısu-1

3.4 Results of Management Scenarios

Several management scenarios were developed to assess BMPs' efficiency in reducing diffuse pollution and improving water status of Acısu Creek. Figure 8 presents results for Acısu-1 segment, focusing on parameters most influenced by diffuse pollution control (S0 denotes the baseline condition for 2021).

Water quality variations related to diffuse pollution were significant for NH_4-N, NO_3-N, inorganic-P, and SS during high precipitation periods and peak flows in January and November 2021. The S1 scenario, addressing pollution from pasturelands and farm animals, showed minimal improvement over the baseline condition. Conversely, the S2
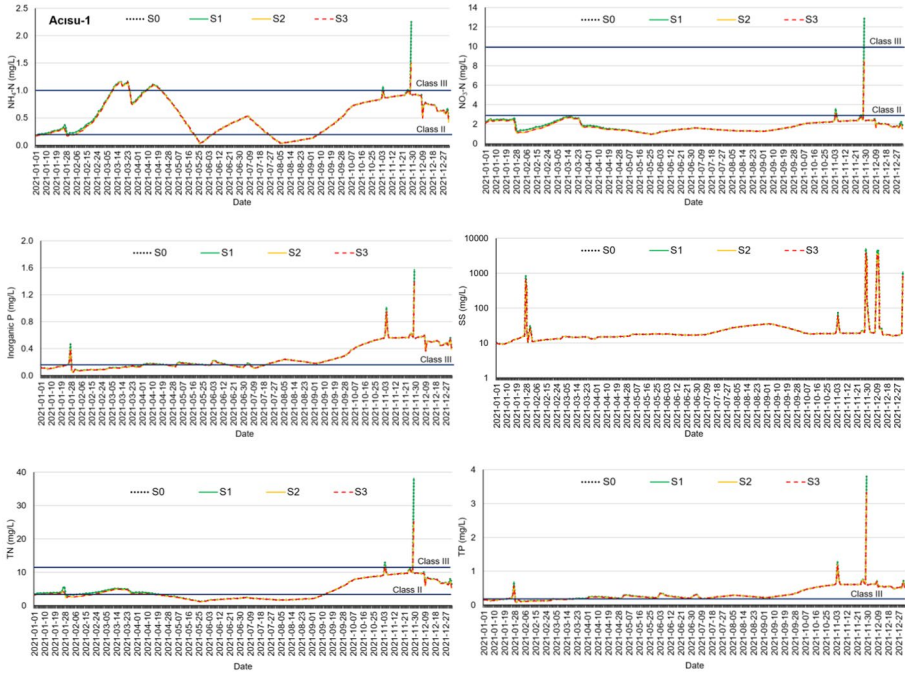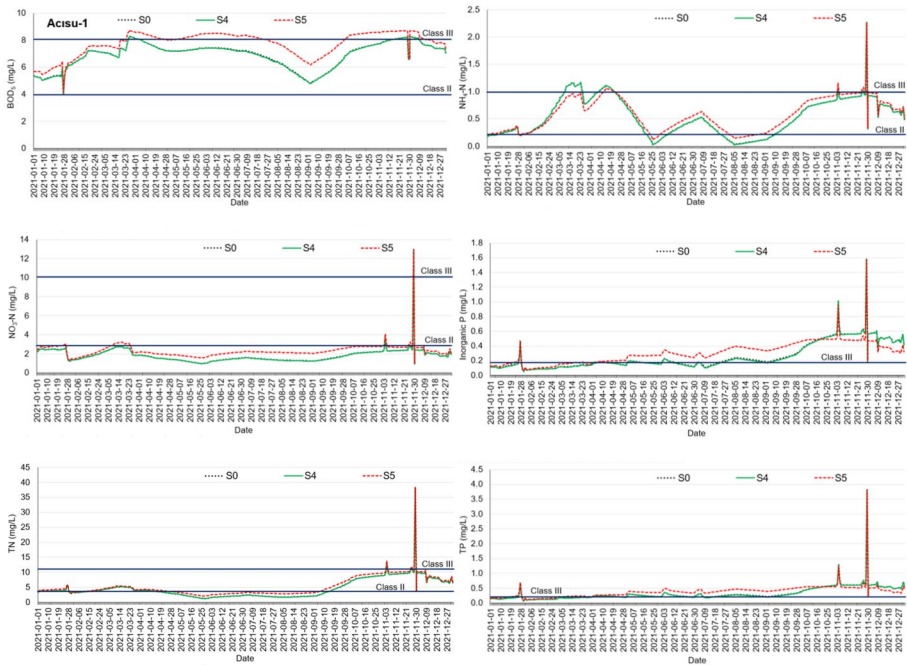
Fig. 8 Model predictions of the Scenarios S1, S2 and S3 for segment Acısu-1

scenario, targeting agricultural land pollution, led to significant decreases in pollutant concentrations, especially during high precipitation periods. Combining both scenarios (S3) yielded the most substantial reductions in concentrations of SS, N and P groups, particularly during peak flow events.

Scenario S4, entailing a 25% pollutant discharge reduction from two WWTPs, showed minor changes in BOD_5, inorganic-P, TN, and TP concentrations compared to the base condition. For Scenario S5, the increase in point source pollution from the newly operational WWTP resulted in significant increases in concentrations of BOD_5, N and P groups (Fig. 9).

4 Discussion

Diffuse pollution control scenarios were effective in decreasing pollutant concentrations where the S1 scenario led to TN and TP load reductions of 43% and 34% from pastureland, and 61.5% and 57.9% from farm animals, respectively, but the watershed annual loads decreased only by 4% (Table S6 in Supplementary Material). The S2 scenario reduced cropland TN and TP loads by approximately 46% and 30%, yielding watershed reductions of 31.2% and 24.8%, respectively, highlighting a significant impact. The combined scenario (S3) provided the maximum reduction in total annual diffuse pollution loads with around 35% for TN and 29% for TP. Peak flow periods in S2 and S3 scenario conditions revealed remarkable reductions in NH_4-N, NO_3-N, inorganic-P, SS, TN, and TP concentrations, while S1 scenario showed marginal improvement in comparison to the baseline condition. The elevated N and P concentrations degraded water quality to Class III in mid

Fig. 9 Model predictions of the Scenarios S4 and S5 for segment Acısu-1

and downstream sections during winter peak flows in January and December 2021 and low flows in March 2021 (Fig. S5 in Supplementary Material).

In this study, the integrated use of the MapShed and WASP8 models was successful in simulating flow dynamics and water quality variations in the PSA. The simulation also covered diverse management strategies, including BMPs for diffuse pollution and point source discharges. The WASP8 model has been successfully applied in many research studies: i) to simulate and analyze surface water quality (Akomeah et al. 2015), eutrophication (Li et al. 2018), transport of pollutants in water bodies (Bouchard et al. 2017; Quijano et al. 2017), ii) to predict management strategy impacts on ecosystems (Srinivas and Singh 2018), iii) to examine the impacts of point and diffuse pollution sources by risk assessment (Yao et al. 2015). Nevertheless, this research offers a novel contribution to the literature by integrating the MapShed and WASP8 models in assessing the efficiency of various BMPs for diffuse pollution control.

5 Conclusions

Diffuse and point pollution sources have a major impact on the impairment of water quality that need to be managed with a comprehensive approach. There is a wide range of potential BMPs available, with varying costs and efficiencies in reducing diffuse pollution. While implementing the most cost-effective BMP at the farm scale is crucial, when addressing overall water quality issues in a watershed, the precise location for implementing BMPs may be less critical during the general planning phase. Therefore, it is essential to have

a good understanding of whether general types of BMPs might be potentially useful in reducing pollutant loads within a watershed where diffuse source pollution is a significant concern. Consequently, the application of deterministic models in an integrated manner is very helpful to investigate the effectiveness of several BMP options for reducing diffuse pollution within a watershed. In the presented study, the results of model calibration and verification showed good agreement with measurements, indicating the reliability of the integrated use of the MapShed and WASP8 models in simulating flow dynamics and water quality variations. Additionally, the most effective BMPs were identified to reduce diffuse pollution, promote sustainable agricultural practices and improve water quality in the study area. However, there is a need for a future study to investigate the potential impacts of the current point and diffuse pollution loads on the coastal ecosystem and to carry out a cost analysis for the recommended BMP options. The integrated use of the MapShed and WASP8 models could be extended to simulate the impacts of climate change on flow dynamics and the water quality of the receiving environment.

Author Contributions The authors confirm contribution to the paper as follows: study conception and design: Ayse Muhammetoglu and Habib Muhammetoglu; data collection: Pelin Orhan and Secil Tuzun Dugan; MapShed model application: Ozgun Akdegirmen, WASP model application: Pelin Orhan; analysis and interpretation of results: all authors. All authors reviewed the results and approved the final version of the manuscript.

Declarations

Competing Interests The authors have no competing interests to declare.

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