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Aims and Scope

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Case Study

The Feasibility Study to Improve the Efficiency of Municipal Water Supply

Kentsel Su Temininin Verimliliğinin Artırılmasına İlişkin Fizibilite Çalışması

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Abstract

The feasibility study was designed to assess water efficiency in municipal water supply systems. The total amount of produced and distributed water was 14,184,650 m^3 in 2018 for 79,296 people in Marmaris. Nonetheless, the volume of billed water was only 8,131,491 m^3; therefore, the non-revenue water percent was 42.7% involving unbilled authorized consumption (5.1%), physical losses (28.9%), and administrative losses (8.7%). According to projections, water demand including the losses was 14,184,650 m^3 in 2018, and is expected to increase to 22,204,429 m^3 in the without-project scenario whereas it would reach 19,852,469 m^3 in the with-project scenario by the year 2038. Consequently, five measures were proposed; establishing district metered areas and pressure management areas, infrastructure development, updating and extending Supervisory Control and Data Acquisition Systems, and other complementary measures to improve the efficiency of the water supply system.

* *Corresponding author*

Applying the proposed actions would reduce the total water losses from 37.6% to 24.7% (19.9% physical, 4.8% administrative) in 2023, and the value would reach 20.3% (18% physical, 2.3% administrative) in 2038. This study presents that the proposed investment's estimated total cost is € 2,956,739.26 and is foreseen to be implemented throughout 2021 and 2022. The Payback Period of the investment is 5.5 years (2027), and the Discounted Payback Period is 6.8 years (2028). The assessment shows that the unitary cost of water evolves from 1.31 €/m^3 in the current situation to 1.00 -1.30 €/m^3 in 2038, based on the scenario selection (with-/without- project scenario) and the investment distribution periods.

Keywords: *Municipal water supply, water use efficiency, water losses management, hydraulic modeling*

Öz

Bu fizibilite çalışması, kentsel su temini sistemlerindeki su verimliliğini değerlendirmek üzere hazırlanmıştır. Marmaris'te 2018 yılında 79.296 kişi için üretilip dağıtılan toplam su miktarı 14.184.650 m^3'tür. Öte yandan, faturalandırılan su miktarı yalnız 8.131.491 m^3 olduğundan gelir getirmeyen su oranı %42,7'dir. Gelir Getirmeyen Su; faturalandırılmayan izinli tüketimleri (%5,1), fiziki kayıpları (%28,9) ve idari kayıpları (%8,7) kapsamaktadır. Su kayıpları da dâhil olmak üzere toplam su ihtiyacına ilişkin değerlerin 2018 yılında yıllık 14.184.650 m^3 su üretimiyle başlayıp 2038 yılında projesiz senaryo için 22.204.429 m^3, projeli senaryo için ise 19.852.469 m^3 olacağı öngörülmektedir. Bu çalışmadan elde edilen bulgular neticesinde su kullanımındaki verimliliği artırmak için izole alt bölgelerin oluşturulması, basınç yönetimi alanlarının oluşturulması, altyapının iyileştirmesi, Veri Tabanlı Kontrol ve Gözetleme Sisteminin güncellenmesi, genişletilmesi ve diğer tamamlayıcı tedbirler olmak üzere 5 tedbir önerilmektedir. Bu tedbirlerin uygulanması sonucunda 2018 yılında %37,6 değerindeki toplam su kayıpları 2023 yılında %24,7 (fiziki kayıp %19,9 ve idari kayıp %4,8), 2038 yılında %20,3 değerine ulaşabilecektir (%18 fiziki kayıp ve %2,3 idari kayıp). Önerilen yatırımın tahmini toplam maliyeti 2.956.739,26 € olup yatırımın 2021 ve 2022 yıllarında yapılması öngörülmektedir. Yatırımın geri ödeme süresi 5,5 yıl (2027) ve iskontolu geri ödeme süresi 6,8 yıldır (2028). Sonuçlar mevcut durumda 1,31 €/m^3 olan suyun birim maliyetinin senaryo seçimi (projeli/projesiz senaryo) ve yatırım dağıtım periyotlarına göre 2038 yılında 1,00-1,30 €/m^3 aralığında değişeceğini göstermektedir.

Anahtar kelimeler: *Kentsel su temini, su kullanım verimliliği, su kayıplarının yönetimi, hidrolik modelleme*

Introduction

Socioeconomic developments and increasing climate change pressures negatively affect water resources and raise concerns about water scarcity (Kummu et al., 2016). Specifically, the Mediterranean region was pointed out as a threatened area for water scarcity in the near future. Therefore, water utilities should have a highly efficient process to sustain a sufficient water supply quantity (Muhammetoğlu et al., 2018). Hence, minimizing water losses especially in the water distribution system plays a key role in getting the maximum benefit from a unit of produced water in an efficient municipal water supply system. Getting attention to water loss may be difficult because it is mostly invisible, and it may negatively impact government budgets, environmental resources, and user's health. The varieties of impacts can help to increase attention on the importance of real costs associated with water losses from the municipal water supply system. For instance, water losses; 1) represent a lost opportunity to supply much water for a city, 2) increase the cost, 3) increase stress on aquatic ecosystems, 4) reduce the reliability of the water supply system, 5) increase pipe failures and 6) leaks in water pipes may reduce the water quality and threaten the user's health (Renzetti & Dupont, 2013). These possible impacts show that water loss must be controlled to prevent or reduce its negative impacts. Herewith water losses can be considered as one of the main problems in the water supply systems (Karadirek et al., 2012). Water leakage rates in the water distribution systems were found to be changed from 3-7% in well- maintained systems in the Netherlands to around 50% in some developing countries with less well-maintained systems, and the amount of leaked water depends on the type of leak, pressure, pipe material, water demand, and soil hydraulics (Puust et al., 2010). To illustrate, high pressures because of the hilly topography of Hong Kong, there are many difficulties to maintain the network sustainably. The replacement and rehabilitation of the aging pipelines and blocking the main leakages were some of the most useful ways to improve the efficiency of the system. After a water loss management program in Hong Kong, the leakage ratio was reduced from more than 25% in 2000 to about 15% in 2019 (WSD-Water Loss Management, n.d.). Leaks can occur in the storage (reservoirs and tanks), distribution systems, and service connections up to the point of metering.

The distribution leakages can be classified as background leaks, burst related leaks; which caused by many reasons; bad pipe connections, pipe corrosions, mechanical damages, ground conditions and movement, high system pressure, pipe age, defects in pipes, winter temperatures, damage due to excavation and poor workmanship (Khadam et al., 1991; Puust et al., 2010). Due to the difficulties of monitoring and projecting a real network system, simulation models are largely used to manage water distribution systems better. Therefore, several hydraulic models have been used either freeware (e.g., EPANET) or licensed software (e.g., WaterGEMs, WaterCAD) (Awe et al., 2019). EPANET is useful software for complex and conceptual studies; on the other hand, a licensed software usually has more user-friendly features. These simulators can be useful to reveal system requirements and do planning for improvements of the system's utilities (Terlumun & Robert, 2019). Modeling water quantity and quality using hydraulic models could improve the efficiency of municipal water supply.

District Metered Areas (DMAs) and Pressure Management Areas (PMAs) are one of the most advantageous and significant ways to reduce leakage in the water supply systems. The creation of the DMA in a complex water system consists of identifying areas that can be isolated by closing the corresponding valves. DMA allows detecting and monitoring possible leakages within its boundaries and it is a well-known and extensively used system to decrease physical losses in water networks. These establishments are guiding to understand water consumption and water losses in a network. Common practices recommend that a DMA should include 500 to 3,000 properties (service connections) in urban networks (Gomes et al., 2015). Besides, DMAs would substantially reduce leakage awareness time and are a prerequisite for effective prioritization of leak detection and repair activities. Pressure management through the creation of the PMAs is another significant way to reduce leakages in the system due to the relationship between pressure and leakage. The second benefit is the decrease in the number of bursts in the network, and an increase in the lifespans of assets. Excessive pressures and pressure fluctuations can be prevented by pressure management. Elevation deviations in topography have crucial impacts during establishing PMAs. PMAs aim at ensuring optimum pressures to the distribution network homogenously. In addition to the water quantity analyses, water quality analyses (i.e., water age and residual chlorine) could be done by using the aforementioned models. All these should be considered to control water losses and to reduce water quality concerns in municipal water supply systems.

This study focuses on a feasibility assessment on water efficiency in a municipal water system to provide technical assistance on the improvement of water efficiency in Turkey. The main objective of this study was to analyze in-depth the use of water at the municipal level in Marmaris to assess water use efficiency, the practices in water pricing (tariffs), and finally propose more appropriate measures to improve both the efficiency and the pricing. There are several problems in the Marmaris water supply system regarding leakages and operational difficulties. Thus, the system needs to be rehabilitated not to exceed the water loss limit determined by-law of "*Control of Water Losses in Drinking Water Supply and Distribution Systems*" published on 8th May 2014, Official Gazette of the Republic of Turkey No. 28994, which Article 9 was amended by the by-law of 31th August 2019 (Official Gazette of the Republic of Turkey, No. 30874). According to the by-law, total water losses [physical loss (real loss) and administrative loss (apparent loss)] in metropolitan municipalities should be less than 30% as of 2023 and less than 25% by 2028. This study assesses the current status of the municipal water supply system in Marmaris within the context of physical losses, administrative losses, and management of the system to build an implementation of an action plan for water efficiency. Within this purpose, the theoretical framework of this assessment consists of all municipal water system beginnings from water production to water reuse in the study area. Lastly, actions were identified as the program of measures to improve municipal water use efficiency, and the knowledge was used to develop action plans at the river basin level and to prepare methodological guidance documents.

Method

This study was conducted within the activity of the municipal sector feasibility study on water efficiency under the 3 RBMP project[1]. The target year of the project is 2038 and the planning cycles of the project are in line with the Water Framework Directive (WFD).

In this study, we assessed the current status of the municipal water supply system within the context of physical losses, administrative losses, and water system management to make an action plan for water efficiency. Figure 1 illustrates the main work packages of this study step-by-step. After assessing the current status, first, some measures were proposed in terms of physical losses by using a hydraulic model, i.e., district metered areas, pressure management areas, and infrastructure rehabilitation. Second, administrative loss reduction plans, integrated customer meter management, and illegal connection control plans were proposed to deal with administrative losses. Third, water system management was explored by the extension of the Supervisory Control and Data Acquisition (SCADA) Systems, developing the capacity building plans and saving water public awareness campaigns, and tariff-related measures. Finally, the findings from previous studies were used to implement an action plan.

Diagnosis of the Current Situation

Figure 2 depicts a summarizing diagram of the municipal water system of the study area. The total amount of water used in Marmaris comes from the Marmaris Atatürk Dam; a concrete faced rockfill dam with a total capacity of 25.56 Hm^3. The water is transmitted from the dam to a raw water pumping station by a diversion channel. After that point, water is conveyed by a DN1000 steel pipe to the valve chamber. Two valves discharge water to a creek and one valve diverts the water to the raw water pumping station. Then, the raw water is pumped to the drinking water treatment plant (DWTP). The DWTP process is conventional and no advanced processes are applied. Produced water is pumped to the Beldibi water storage tank with 5,000 m^3 for serving water to the Beldibi neighborhood and main storage tanks

[1] *Technical Assistance on Economic Analyses within River Basin Management Plans and Water Efficiency Aspects in 3 Pilot River Basins in Turkey (3 RBMP).*

(Marmaris with 5,000 m^3, Armutalan with 3,000 m^3, and İçmeler with 3,000 m^3). From storage tanks, the water is supplied mainly by gravity directly to final consumers or small deposits of certain neighborhoods. The total length of the transmission and distribution lines is around 270 km. When water is transferred, and used by final consumers, then wastewater is transferred to the wastewater treatment plant (WWTP).

Figure 1

The Content of the Feasibility Study

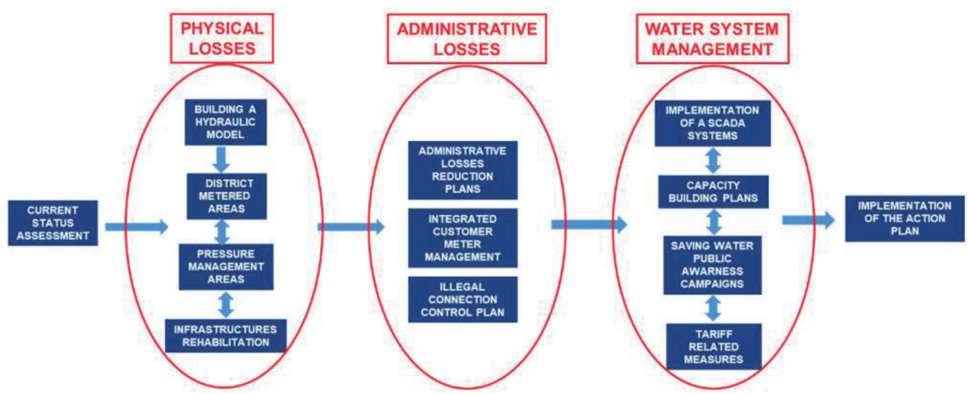
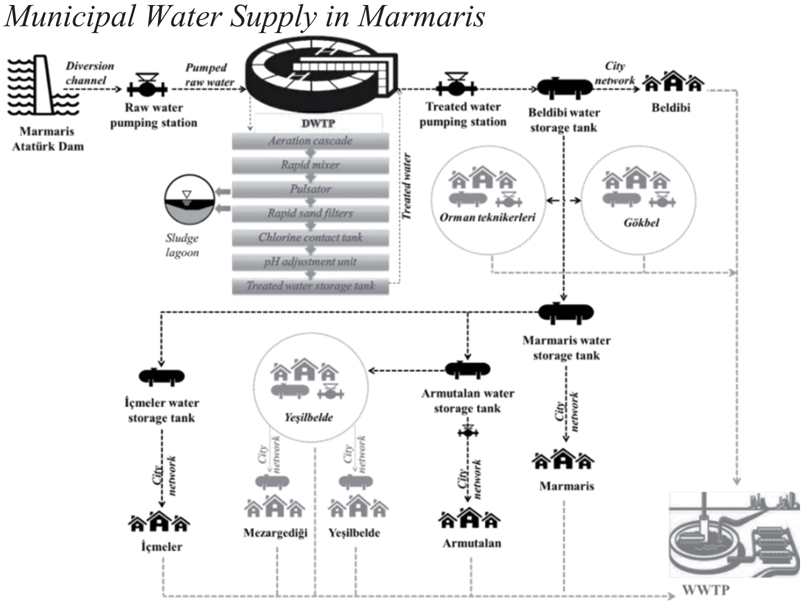


Figure 2

Municipal Water Supply in Marmaris



Throughout the study, the average yearly production of the DWTP was 56,160 m^3/day, but it sometimes reached 60,000 m^3/day in 2018. The water efficiency of the DWTP during water production was quite high (99.5%) due to the high quality of the raw water in 2018. The outlet pipe meter was not working; therefore, Muğla Water and Sewerage Administration (MUSKI) measured by subtracting the amount of backwashing and sludge removal from the amount of inlet water on a daily basis. All the components and parameters were identified to assess the current situation. Then, calibrated flow meters were installed on the outlet pipes of three main storage tanks (Marmaris, Armutalan, İçmeler) to evaluate the current status of the distribution network in terms of physical losses, daily and seasonal consumption patterns, and storage tank capacities. Measurements provided by these flow meters were very practical to evaluate the current status of the distribution. The data included maximum and minimum flows come from the storage tanks and average flow rates daily. Totalized volumes were also taken from June 1 to December 31 in 2018. Although the SCADA has been operated in the past, MUSKİ has only provided data since the calibration of flow meters and their connection to the provincial SCADA.

Efficiency Indexes and Ratios

An approach to assess the diagnosis of the water sector in the pilot area was to be a utilization of different well-known efficiency ratios and indexes. They allow us to compare those calculated values with similar systems at the international level. The water production index, non-revenue water (NRW) ratio assessment, administrative losses, physical losses were calculated. To be able to calculate all the ratios and indexes, a comprehensive data collection was done with the support of MUSKI responsible staff both in Marmaris and Muğla. The values of the main variables used for those calculations are; total water abstraction (m^3/year), system input volume (m^3/year), billed consumption (m^3/year), total physical losses (m^3/year), total administrative losses (m^3/year), the total length of water distribution (km), the total number of water connections, the average length of service connections (km), average operating pressure (mWC), total wastewater treated in the wastewater treatment plant (m^3/year), total reused treated wastewater (m^3/year). Accordingly, two main assessments (NRW and Physical loss) were done based on calculations. International NRW Assessment Matrix for the NRW assessment and Physical Loss Assessment Matrix for the physical loss assessment were used to determine the technical performance categories (Liemberger & McKenzie, 2005; Liemberger, 2010). Matrices and category definitions can be seen in the appendix (Table A1 and Table A2).

Infrastructure leakage index (ILI) is an index that was first introduced in 1999, and since then it has been used as a standard index to determine the performance efficiency within municipal water infrastructures in many countries (Liemberger & McKenzie, 2005). It is calculated by dividing the Current Annual Real Losses (CARL) and the Unavoidable Annual Real Losses (UARL) (equation 1). CARL is the actual loss happening in the system. UARL is the technically lowest achievable annual real losses for a well maintained and well-managed system. International Water Association (IWA) Task Forces have developed a 'user-friendly' pressure-dependent formula for predicting UARL values in a wide range of distribution systems (equation 2) (Lambert et al., 1999; Liemberger & McKenzie, 2005):

$$ILI = CARL/UARL \qquad (1)$$

where CARL is Current Annual Real Losses (lt/day); UARL is Unavoidable Annual Real Losses (lt/day).

$$UARL\ (lt/day) = (18 \times Lm + 0.8 \times Nc + 25 \times Lp) \times P \qquad (2)$$

where Lm is mains length (km); Nc is number of service connections; Lp is the total length of underground pipe between the edge of the street and customer meters (km); P is average operating pressure (mWC).

Model Building

WaterCAD (CONNECT Edition Update 2 [10.02.00.43]) licensed hydraulic model software was used as an analytical tool to simulate projections and to propose measures to improve efficiency in the system. The necessary input data was prepared to run simulations such as a digital map of the network, population projections, and water demands per the scenarios in this project.

To evaluate the water distribution network of Marmaris, various scenarios were used throughout modeling: 2018 Winter and 2038 Summer. Solutions for the network's problems were found according to the scenarios, which represent the behavior of the water network under different conditions. The main scenarios used are:

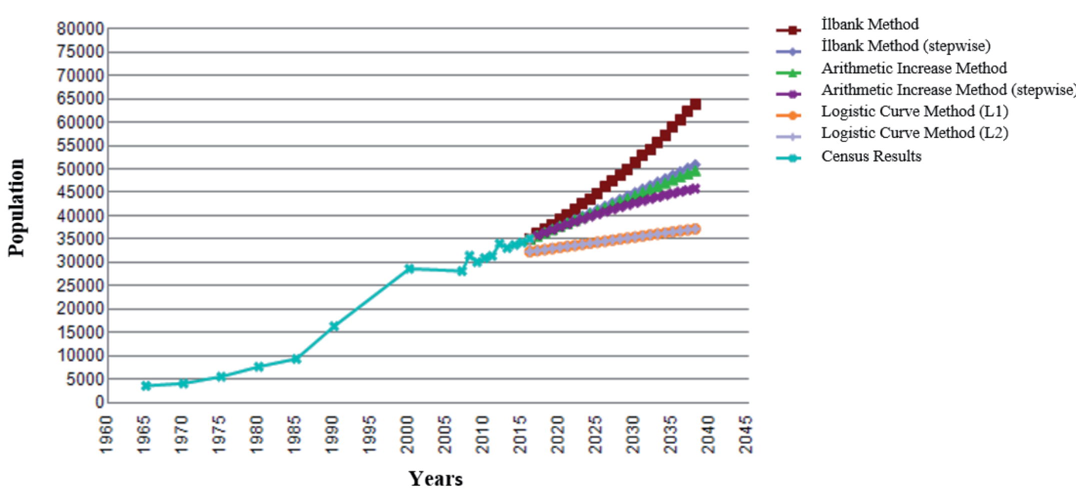
- The current situation, current water infrastructure and current demands (2018), used for calibration,
- Proposed measures related to the water infrastructure, current demands (2018),

- Proposed measures related to the water infrastructure, future demands (2038).

Population projections, water demands, water subscribers, and tariffs were evaluated to build a model for an efficient water supply. The population trend of the study area was evaluated from 2016 to 2038 for estimating the water demand until the target year of the 3 RBMP project. İlbank, arithmetic, and logistic-curve methods were used for population projections. Among these methods, the İlbank method showed the best fit for the previous trends, so the İlbank method with a constant increment rate (2.76) was selected for the population forecast for Marmaris city centre (Figure 3). Population forecasts of other neighborhoods can be seen in the appendix (Table A3). Then, water demands for different consumer types, and the impacts on the physical status of the municipal water supply system of the increasing population in the study area were estimated.

Figure 3

Population Projection Methods for Marmaris City Centre



The system in the selected area is expected to meet water demand until 2035 by the without-project scenario. In that year, water subscribers in the network would have less available water compared to their demand. Furthermore, water shortages in the high seasons might be seen, profoundly, even earlier than 2035. Implementing the project is favorable to reduce water losses and retain the present status of the system in the future as well. When the project is performed, the water supply in the selected area would meet future demands until 2038 by accomplishing the objective of physical water loss mitigation. To illustrate, gross water consumption is expected to be 465 liters per capita per day (lcd) in 2035 for the without-project scenario, while it is 411 lcd for the with-project scenario. DWTP and pumping stations do not require any investments for increasing the capacity; however, the rest of the water supply system excluding DWTP and pumping station requires an expansion to meet the connected subscriber ratio of 100%.

The creation of the DMA in a complex water system consists of identifying areas that can be isolated by closing the corresponding valves. It is also possible to precisely know the inflow rate and the served water by respectively metering the flow rate in the inlet point and reading the subscribers' meters. DMAs were established to detect and monitor possible leakages within their boundaries and it is a well-known and extensively used system to decrease physical losses in the water distribution network. In order to control the pressure in the network, PMAs were established. There are various Pressure Reduction Valves (PRV) in the market, and the model was run based on two alternatives (PRV active and PRV inactive). As the physical losses were modeled based on the pressure-dependent demands, the influence of the PRV can be observed by the flow amounts from the storage tanks. In addition to the quantity analyses, quality analyses were simulated for the proposed system: water age and residual chlorine.

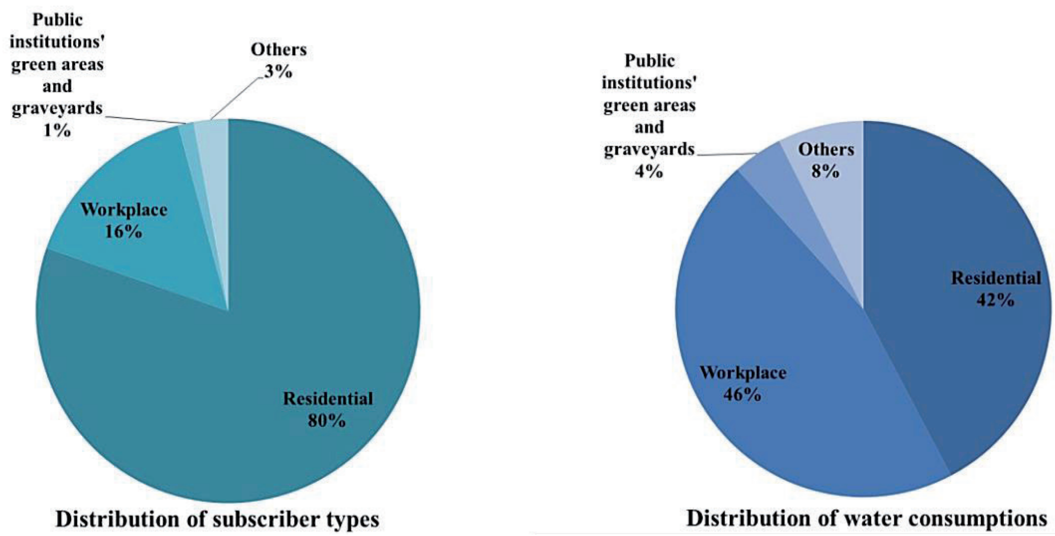
Water Consumption

Billing.

Figure 4 shows the distributions of both subscribers' type and water consumers. The total number of subscribers was 30,947 and residential consumers (80%) were the major subscribers of the existent connections, and it was followed by workplace subscribers (16%) in 2018. Nevertheless, the highest amount of water was consumed by workplaces (46%), following by residential water consumption (42%). The latest billed water volumes were analyzed to assess the water consumption trends of the main towns in the study area. Monthly billing is solely applied in Marmaris City Centre. The rest of the neighborhoods apply bi-monthly billing.

Figure 4

Distribution of Water Subscribers and Their Consumptions



Water Balance

The standard water balance table was prepared for Marmaris for the year 2018. As the production values are certain and physical loss values were estimated based on the flow meter readings from the SCADA, and unbilled authorized consumption, illegal consumption, and unauthorized consumption rates were assumed. According to the information provided by MUSKİ, there was an active unauthorized connection detection policy. This means the unauthorized consumption rate decreased from 20% of total water production to around 5% through on-site inspections and measurements. Although the water consumption of the mosques and parks were generally metered, it was assumed that 5% of total production is consumed by such users. This assumption results in a yearly unbilled authorized consumption volume larger than the billed institutional consumption. However, it should be noted that irrigation of public gardens and green areas requires an excessive amount of water due to the hot climate of Marmaris during summer. Furthermore, metering inaccuracies were assumed to have a typical value of 6% as under-reading. Figure 5 shows the results of the water balance study. The total water produced and distributed in the case area in 2018 was 14,184,650 m^3, while the billed water was 8,131,491 m^3, which resulted in a Non-Revenue Water ratio of 42.7%.

The breakdown of this NRW was the following: Unbilled authorized consumption with 5.1%, Physical Losses with 28.9%, and Administrative Losses with 8.7%.

The main assumptions in the water balance study were the amount of unbilled authorized consumption and unauthorized consumption, as well as the metering inaccuracies. The predicted values were assumed to be uniformly distributed within all neighborhoods and subscriber types according to their demands. In the modeling studies, domestic and institutional water consumptions of the city were evaluated together on a population-based approach and commercial consumptions were evaluated separately based on an aerial-based approach.

Figure 5

Standard Water Balance Table for Marmaris in 2018 (Official Gazette of the Republic of Turkey, 2014)

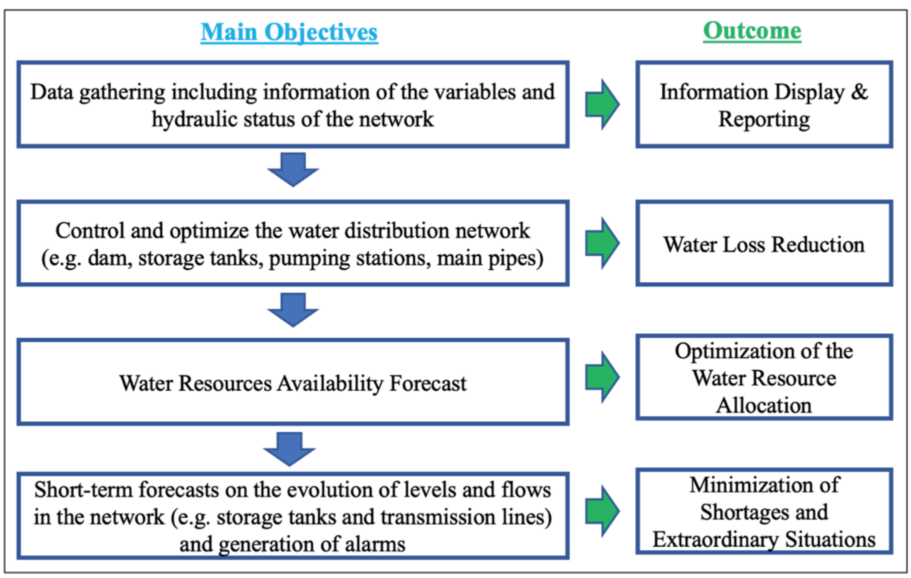
SYSTEM INPUT VOLUME 14,184,650 m^3 100%	AUTHORISED CONSUMPTION 8,853,413 m^3 62.4%	BILLED AUTHORISED CONSUMPTION 8,131,491 m^3 57.3%	BILLED METERED CONSUMPTION 8,131,491 m^3	REVENUE WATER 8,131,491 m^3 57.3%
			BILLED UNMETERED CONSUMPTION 0	
		UNBILLED AUTHORISED CONSUMPTION 721,922 m^3 5.1%	UNBILLED METERED CONSUMPTION 12.689 m^3	NON-REVENUE WATER 6,053,159 m^3 42.7%
			UNBILLED UNMETERED CONSUMPTION 709,233 m^3	
	WATER LOSSES 5,331,238 m^3 37.6%	ADMINISTRATIVE LOSSES (APPARENT LOSSES) 1,229,074 m^3 8.7%	UNAUTHORISED CONSUMPTION 709,233 m^3	
			METERING & BILLING INACCURACIES 519,841 m^3	
		PHYSICAL LOSSES (REAL LOSSES) 4,102,164 m^3 28.9%	LEAKAGE ON TRANSMISSION AND/OR DISTRIBUTION MAINS, AND SERVICE CONNECTIONS	
			LEAKAGE AND STORAGE TANKS OVERFLOWS	

SCADA Systems

The current status of SCADA Systems was analyzed within all the water facilities containing the SCADA system such as the dam, the raw water pumping stations, the water treatment plant and its pumping station, the storage tanks, and the intermediate pumping stations. The main objectives of the SCADA implementation are given in Figure 6.

Figure 6

The Main Objectives of the SCADA



The current status of the SCADA in the study area indicates remote monitoring of storage tanks and pumping stations, automatic control of the pumping stations in accordance with the level of the tanks, monitoring of the flow rates by the electromagnetic flow meters, monitoring the water pressure in the pumping stations by the pressure transmitters, monitoring the residual chlorine devices in the chlorination locations, control and monitoring systems over operator panel (HMI) for local users, alarm monitoring and verification, and tabular and graphical reporting including time-event based and statistical reporting. There is a total of 36 control panels (20 wells, 6 pumping stations, and 10 storage tanks) in the current SCADA control system.

Financial Analysis

Cost-benefit analysis.

The Cost-Benefit Analysis (CBA) is an economic tool to assess the balance between the benefits of an investment and its costs. The purpose of CBA is to facilitate a more efficient allocation of resources by analyzing the suitability for the society of an attempt rather than possible alternatives. CBA is an input for the decision-making process. The financial indicators involved in the analysis as follows: population and water demand, fixed and variable costs of the water supply and wastewater services, billed and collected water/wastewater from different subscribers, applied tariffs, and collected revenues.

The CBA concentrates on the financial analysis of the necessary investment to implement the measures proposed in the study regarding two aforementioned scenarios:

- The without-project scenario states that certain measures for higher water use efficiency were not applied in the pilot area.
- The with-project scenario states that the proposed measures were applied and its financial impact was analyzed.

Unitary price.

A financial model was developed to understand the relationship between the project variables (e.g., investment cost, population change, water demand pattern) and the emergent financial performance. For this purpose, the financial modeling study indicates four steps:

1. Definition of the base year parameters (e.g., data collection for the year 2018).
2. Definition of the future values for different parameters (e.g., capital expenditures, fixed & variable costs in line with the capacity requirements, operation & maintenance, investment costs).
3. Determination of the financial performance indicators (e.g., calculations of the Net Present Value, Interest Return Rate, Payback Period).
4. Finally, an analysis of the unitary cost of the water service concerning water use efficiency was performed.

Results and Discussion

Current Status Assessment

Water consumptions in the project area showed a considerable change from winter to summer because of seasonal population changes, where summer consumptions were 1.57 times higher than the winter consumptions. The value is generally taken as 1.30-1.50 in design works. Daily trends also show changes seasonally. The network's physical loss ratio was estimated at approximately 30% depending on the flow meter readings from the Marmaris storage tank through the current SCADA. Although it was not surprising to have such a loss rate in a relatively new ductile iron network, the level of leakage was far beyond the standard networks in Turkey, even in well-developed cities. According to the similar measurements from the outlet of the other three storage tanks, physical losses were calculated as follows: about 70% in Armutalan during the low season (24% during the peak season); about 75% in İçmeler during the low season (17% during the peak season); however, 2012 data was used to evaluate physical losses in Beldibi because of the lack of added flow meter on the outlet pipe. Therefore, data was analyzed through a CAD software, and the physical losses were estimated as 50% during the low and peak season, and it would not likely reduce during peak season because Beldibi had an inland water consumption trend, unlike İçmeler or Armutalan. The amount of leakage was expected to decrease because consumption nearly doubled and network pressures were lowered even at night during the tourism season. It can easily be indicated that water consumption in the Marmaris network was considerably more than the Armutalan network. The net consumption/total consumption ratio remarkably went up during the summer season. Furthermore, the approximative value of the maximum physical loss is assumed to be decreased during peak season. Seasonal changes in physical loss ratios showed that the physical loss ratio was profoundly based on water consumption because of the pressure reductions in the network in parallel with the consumption decreases. Water consumption in the Marmaris network (19,391 m^3/day) was more than İçmeler network (9,832 m^3/day). Results showed that there was an excessive leakage in the İçmeler network, especially in winter. Seasonal trends of leakage levels and total water consumption were similar to Armutalan. As there is a strong relationship between pressure and leakage, the network was recommended to be operated between 3 and 4 bars. Nevertheless, most of the storage tanks, which served the treated water to the network, were located in an elevation strip between 75 and 85 m. A substantial portion of the city supplied by these storage tanks was located between 0 and 25 m.

As a result, this large area was operated with pressures between 5 - 7 bars. Also, the buildings located in the region had a single or double flat. Thus, pressures were unnecessarily high in the network and should be reduced to 2-3 bars (20-30 mWC). High-pressure causes leakage, bursting, and some of the used pipe types (Asbestos Cement (AC) and Polyvinyl Chloride (PVC)) increased leaking and bursting problems under the high pressure in the network. Breakdown records supported that by showing the most frequently encountered problem was the network line bursts, especially for the small diameters (100 and 150 mm) AC pipes. High pressures could be reduced by the pressure reducing valves installed in the network. Outlet pipes and tanks could be operated with full flows, and inappropriate pipes should be replaced with more durable pipes. Nevertheless, network models should be calibrated and more manageable district metered areas (DMAs) could be established to reduce physical losses during the planning phase of the project following the results of this feasibility study. Another suggestion would be the extension of the repair team works to control physical losses for quicker response and less tight schedule.

Efficiency indexes and ratios.

The efficiency indexes, ratios, and technical performance category of the municipal water system in the study area were determined as follows:

- The water production ratio was 99.5 %, which was obtained from the flow rates measures in the inlet and the outlet of the water treatment plant, and this ratio shows the good performance of the facility.
- Non-Revenue Water (NRW) ratio was 42.7% and the determined NRW technical performance category was C *(poor NRW record; tolerable only if the water is plentiful and cheap; even then, analyze level and causes of NRW and intensify NRW reduction efforts)*.
- Physical Losses ratio was 28.9% and the performance category was C (similar to NRW).
- The administrative losses ratio was 8.7% and it was higher than the desirable rate for both unauthorized unbilled (illegal) consumption (5%) and metering & billing errors (6%). ILI value was estimated as 5.16 by dividing CARL (11,238,805 lt/day) with UARL (2,178,020 lt/day). UARL calculated by the use of the following information: Lm: 250 km; Nc: 30,286; Lp: 302.9 km; and P: 60 mWC. The calculated ILI corresponded with the Category C.

NRW, physical loss, administrative loss, and ILI ratios showed that actions need to be taken for increasing water efficiency in the network.

Model Results

A hydraulic model was used to understand the current status of the water distribution network and any potential effects of the applied practices and measures (e.g., adding new valves, changing pipes, flow rate, and pressure control, establishing DMAs and PMAs). This model includes several elements such as pump stations, storage tanks, water demands, the layout of the area, and other present hydraulic devices.

Water quantity modeling.

In Marmaris, one of the most important matters is high physical losses in the network. The major reason for the physical losses in the system was because of high pressure in the network, especially in winter times. Thus, the high-pressure problem should be eradicated. Water loss status projections considering both "without" and "with" scenarios are shown in Figure 7. The water loss projection results indicate that the expected reduction in water loss needs actions for water efficiency improvements. As a result of applying measures, the total water losses with a value in 2018 of 37.6% would decrease to 24.6% in 2023 (19.9% Physical Losses and 4.8% Administrative Losses) and would reach a value in 2038 of 20.3% (18.0% Physical Losses and 2.3% Administrative Losses).

Water demands and the ability of the water supply network to meet the rising demands were calculated for with-project and without-project scenarios. In order to observe the responses of the system to changing demands during a certain period of time, a dynamic analysis needs to be performed. In WaterCAD, it is named Extended Period Simulation (EPS). Total water demand depicted the same trend in 2018 with 14,184,650 m^3, and it would be 22,204,429 m^3 in the without-project scenario in 2038, while it would be 19,852,469 m^3 in the with-project scenario (Figure 8).

The present water supply system would not be able to provide sufficient demands in 2038 in certain locations after establishing the DMAs and PMAs. Main and primary pipelines in the Marmaris were oversized; the replacement of the pipes and changing the pipe dimensions were not necessarily required. The topography of the study area is flat, and there are mostly low elevations in this area. Hence, it has positive impacts on the future performance of the system. On the other side, it was not possible to create DMAs and PMAs without pipe replacement within the current pipelines and the topography. To illustrate, a ring line was required to supply water to isolated areas with higher elevations in Armutalan. After improvements in this study, water would significantly reach more locations.

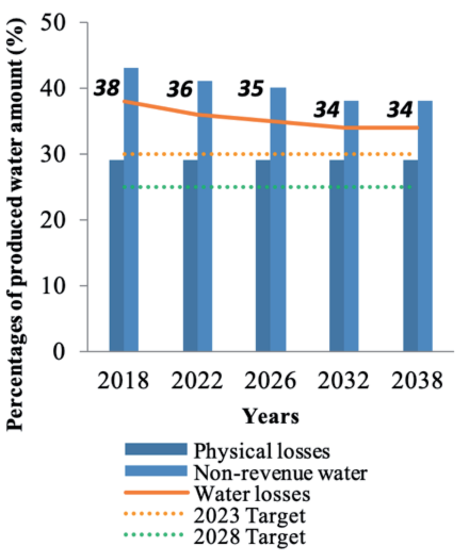
According to the information provided by the regional personnel of MUSKİ, small diameter (100 and 150 mm) AC pipes are problematic and they can frequently burst. These pipes substantially exist in the Marmaris network, and this existence is reflected in the burst records. Therefore, small diameter AC network pipes have been proposed to be replaced in the scope of the rehabilitation works. Replacement of 9,807 m of AC lines with Ductile Iron pipes, new lines that will be laid for DMA establishment, and 1,100 consumer connections are anticipated to improve the efficiency in the water supply network.

District metered areas (DMAs).

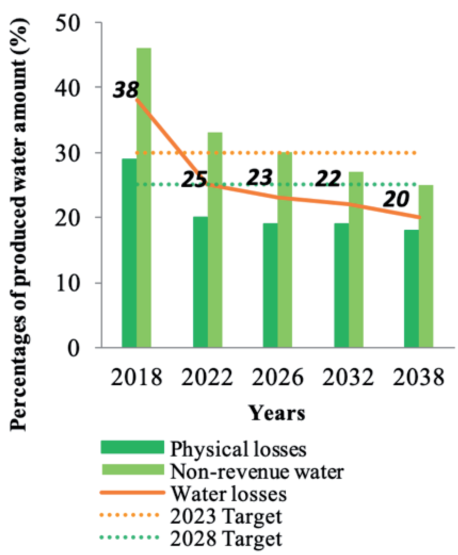
21 DMAs were established in the study area (8 in Marmaris, 7 in Armutalan, 4 in İçmeler, and 2 in Beldibi). The DMAs were established by closing the existing valves on the DMA boundaries and adding new valves on the boundary pipes which do not have isolation valves. The DMAs can also be established by placing dead ends to the boundary pipes rather than ensuring isolation by valves. This brings the advantage of providing isolation of the area to ease the management of the water leakages. Figure 9 shows the proposed DMAs and PMAs in the project area.

Figure 7

Water Loss Status Projections



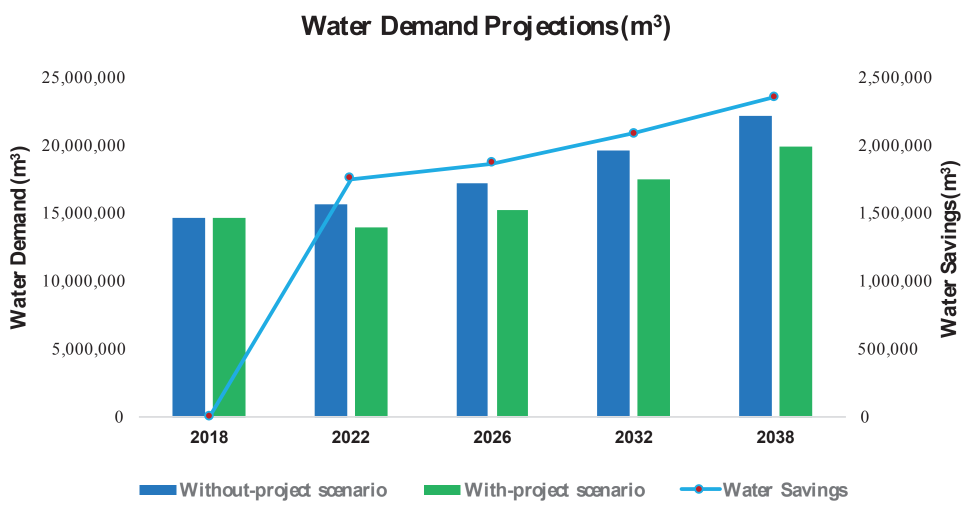
(a) "Without Project" scenario



(b) "With Project` scenario

Figure 8

Water Demand Projections



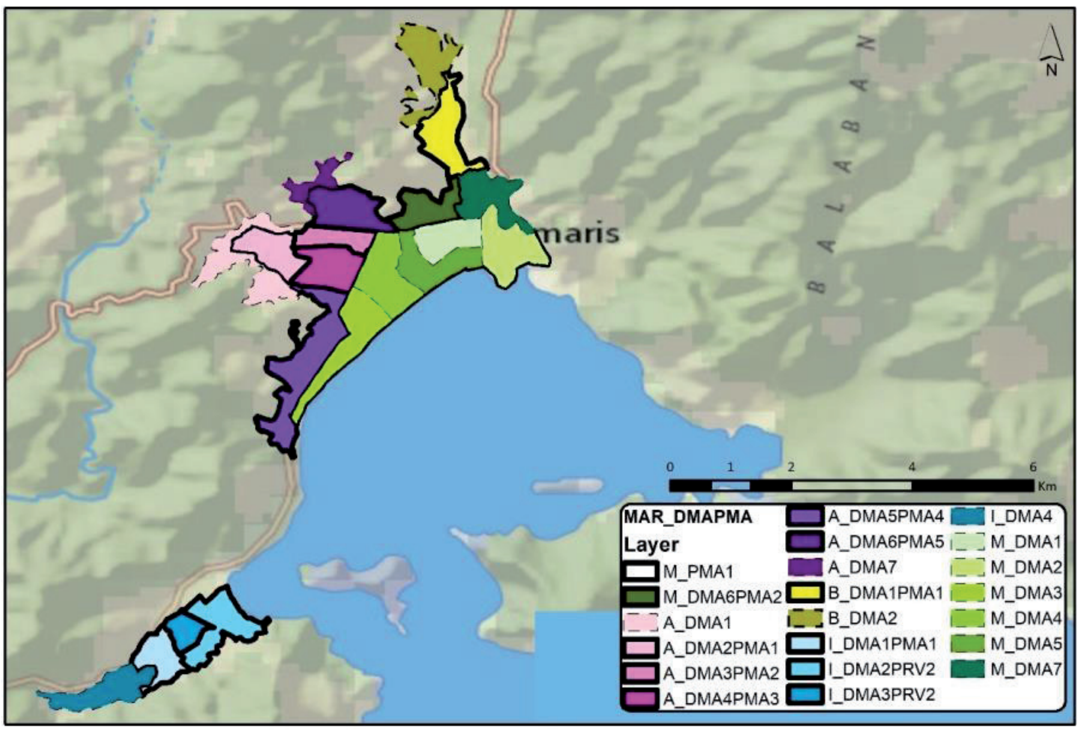
Pressure management areas (PMAs).

11 PMAs were created for pressure reduction in the study area. The established PMAs can be found in Figure 9 (boundaries shown by thick full continuous lines). PMA-M1 is the main PMA of the network that was created by adding 2 pressure-reducing valves (PRV) on the main pipelines. There are various DMAs within the boundary of this PMA. The second one was established by installing a pressure reducing valve (PRV-M3) on the main pipe at the north of the Marmaris-Datça highway. There are five PMAs established for the network in Armutalan in addition to the Marmaris network. All of the PMAs in there is also a DMA. The PMAs in Armutalan have similarities with the ones in İçmeler, where the physical loss ratio during winter is as high as 70%. PRVs were implemented to reduce the upstream pressure to a set value, regardless of its magnitude. Besides, the installed PRVs should be controlled remotely by the SCADA. PRVs can be taken into operating status during the nights while there may be no need for pressure reductions during day time because of the high consumption. Operational flexibility would ensure both the highest level of service and efficiency in water use at the same time. The comparison of storage tank outflows with and without pressure management can be seen in the appendix based on 2018 winter scenario (Figure A1).

As a result, the number of proposed flow meter chambers and PRV chambers in the network of the study area as follows: 8 flow meter chambers, 3 PRV chambers in Marmaris; 7 flow meter chambers, 5 PRV chambers in Armutalan; 2 flow meter chambers, 1 PRV chamber in Beldibi; 4 flow meter chambers, 3 PRV chambers in İçmeler.

Figure 9

Proposed DMAs and PMAs in Marmaris



Water quality modeling.

Water quality analyses were conducted in the model after the establishment of DMAs and PMAs, which affect the route of water due to isolation. Two major quality parameters were analyzed with the demand of the 2018 winter: water age, residual chlorine.

Water age in the network at the beginning was set as 0, and the Extended Period Simulation (EPS) model was run for a long period (168 hours). Beldibi pressure zone always receives freshwater as the area is the inlet point after the

DWTP. In addition to this, the water age was relatively older in the Marmaris and Armutalan networks. In İçmeler, water consumption was low; therefore, the water stays in the pipeline longer. Figure 10-a illustrates the age of water in pipes at the 168^{th} hour of the hydraulic model. Figure 10-a shows that there were water age problems in the DMAs. It is advised to implement periodic isolation valve opening and closing exercises on boundary valves or flushing activities via fire hydrants following the completion of the investments.

Residual chlorine concentrations in the network were also simulated to estimate chlorine concentrations in the system. Chlorine-water (bulk reaction) and chlorine-pipe (wall reaction) interactions are assumed to be covered by a single, linear reaction function, r = kCn; where r is the rate of reaction (mass/volume/time), k is the reaction constant (concentration raised to the power of [1-n] divided by time), C is the reactant concentration (mass/volume), and n is the reaction order. As the linear approach assumes n equals 1, the reaction equation could be simplified to r = kC. Chemical parameters of chlorine have been taken as 1.44e-9 m^2/s for diffusivity and -1.00 mg/l (1-n/day) for bulk reaction, where wall reaction is assumed to be also included. As a linear model is adopted for bulk reaction (i.e., n=1), the bulk reaction rate used in the model has become -1.00 day^{-1}. The chlorine analysis results have shown that the residual chlorine amount in Marmaris and Armutalan regions was in the desirable range (0.2-0.5 mg/L). However, in İçmeler, Adaköy, and Gökbel regions, there were low water consumption and so lower water velocity in pipelines; therefore, estimated residual chlorine amounts reduced below the minimum value in regulations (<0.2 mg/L). The amount of chlorine dosage was set as 0.8 mg/l in the DWTP to put up with spreading in the storage tank in Beldibi and transmission line. Hence, the residual chlorine amounts in Beldibi did not slightly meet the upper limit concentration in the by-law of the Ministry of Health Regulation concerning Water Intended for Human Consumption (0.5 mg/l) (Official Gazette of the Republic of Turkey, 2013). Figure 10-b shows the residual chlorine analysis results. As the hydraulic model was not calibrated for chlorine analysis, the proposal of certain remedies is not reasonable at this stage of the study. It is recommended to monitor the amount of chlorine in critical locations. Additionally, an extra chlorination system might be added to the İçmeler storage tank according to the observations.

Following the completion of the investments, MUSKI is recommended to calibrate the hydraulic model by means of the comprehensive SCADA instrumentation. Besides, the numbers of site tests at each of the DMAs are recommended to be done. It is known that models are calibrated more accurately under high flow conditions such as hydrant openings. Therefore, while calibrating a DMA, more than one field test should be performed at several hydrants. In addition, the selection of hydrants apart from the flow meter chamber increases the accuracy of the calibration.

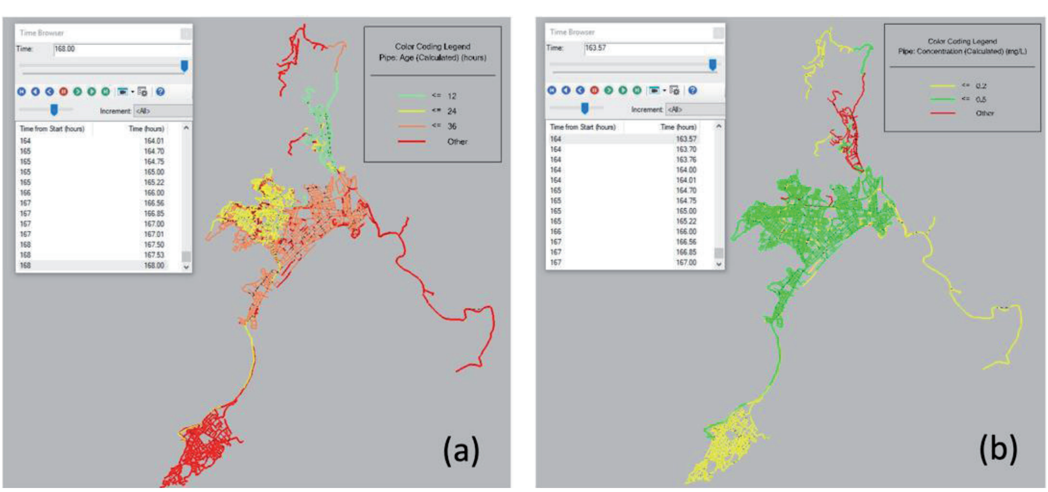
SCADA Assessment

The SCADA system should include new control stations within the DMAs and PMAs to increase water use efficiency, prevent water supply failures, and decrease water losses. The recommended new control stations should cover the monitoring of the residual chlorine, flow rates, network pressure.

The current status of the SCADA system was projected to be improved by having several upgrades, for instance, a more decent communication network through Very Small Aperture Terminal (VSAT) satellite terminals, increased electrical autonomy of the control stations by the use of larger Uninterruptible Power Supply (UPS) to avoid dataflow issues during electrical deficiencies, and more apparatus in the current control stations such as flow meters, pressure transmitters, level meters, and the position detection for valves. For this reason, recently available technologies for the extension of the current SCADA system were taken into account to have more reliable, resilient, scalable, and functional systems without jeopardizing the present performance of the system. The main functions to be performed, proposed measures and necessary extensions for the SCADA system can be seen in Figure 11.

Figure 10

Water Age Analysis Results (A) and Residual Chlorine Analysis Results (B)



These given functions should be accessed remotely from the control center; additionally, operators in the field should be able to control the system through the Human Machine Interface (HMI) interface on the control panels. They should be controlled not only manually but also automatically by Remote Terminal Unit (RTU) and/or by the central SCADA system. These operation modes (local, remote, and automatic) should be applicable at various control stations and control centers.

The new proposed extension of the current SCADA system for smoothly running, problem-free controlling, and monitoring the network should depend on standard software and hardware. Besides, it should be able to integrate with the current SCADA system. The configured system should also be able to extend further according to future necessities.

To achieve better water management within the urban distribution network, new control stations should be built and included in the SCADA system. These new control stations are mainly required for the DMAs and PMAs. Different types of control stations should be implemented for pressure and flow metering in the DMAs and PMAs. Therefore, new control panels with RTUs, GSM/GPRS communication modems, the correspondent instrumentation, and control valves should be installed inside the underground chambers built for these purposes. The proposed new control stations are as follows: 21 flow and 21 pressure metering stations, 12 pressure control stations, 4 chlorine monitoring stations.

Cost-Benefit/Unitary Price Analyses

Cash flows were calculated by subtracting the total revenues from the total costs for with- and without-project scenarios from the beginning year of the project (2018) till the final year (2038) of the planning cycles. The with-project scenario includes the investments of the measures taken under the scenario.

First, the current prices for 2018 were calculated, then constant prices have been estimated by applying a discount rate of 10% (Winpenny, 2005). Figure 12 illustrates the Cost-Benefit Analysis (CBA) for the selected scenarios in the study.

Figure 11

The Main Functions to be Performed by the Enhanced SCADA System (a) and Proposed Extensions for the Current System (b)

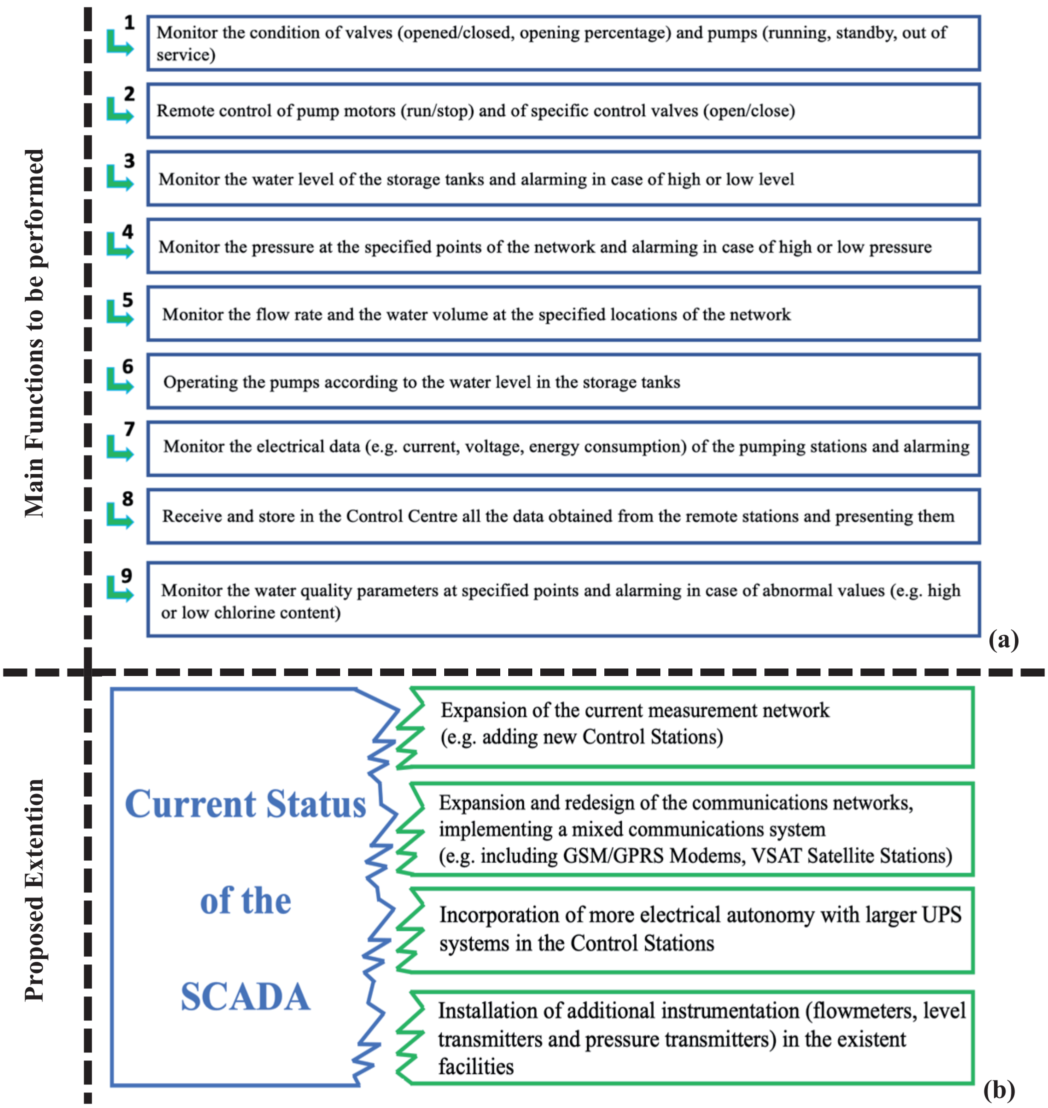


Figure 12

Cost/Benefit Balance for Without-Project and With-Project (Constant Prices)

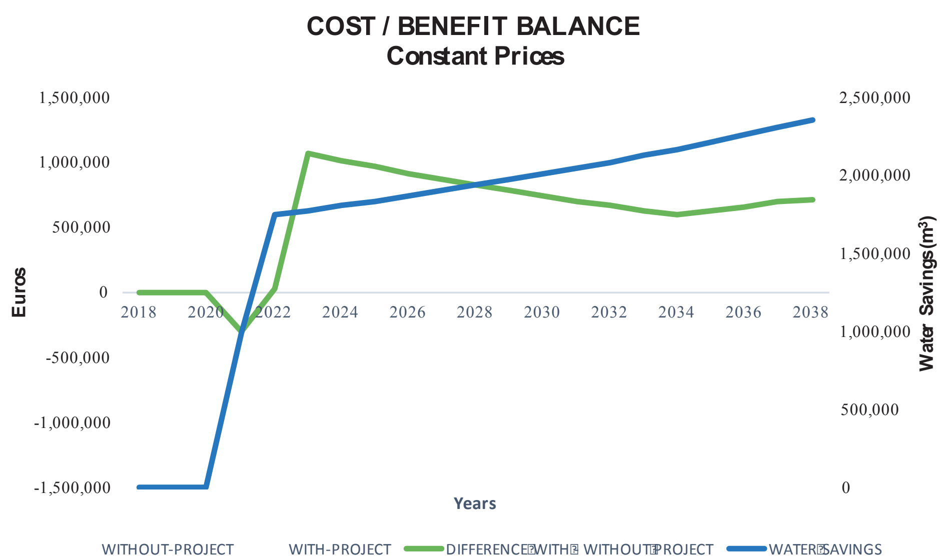
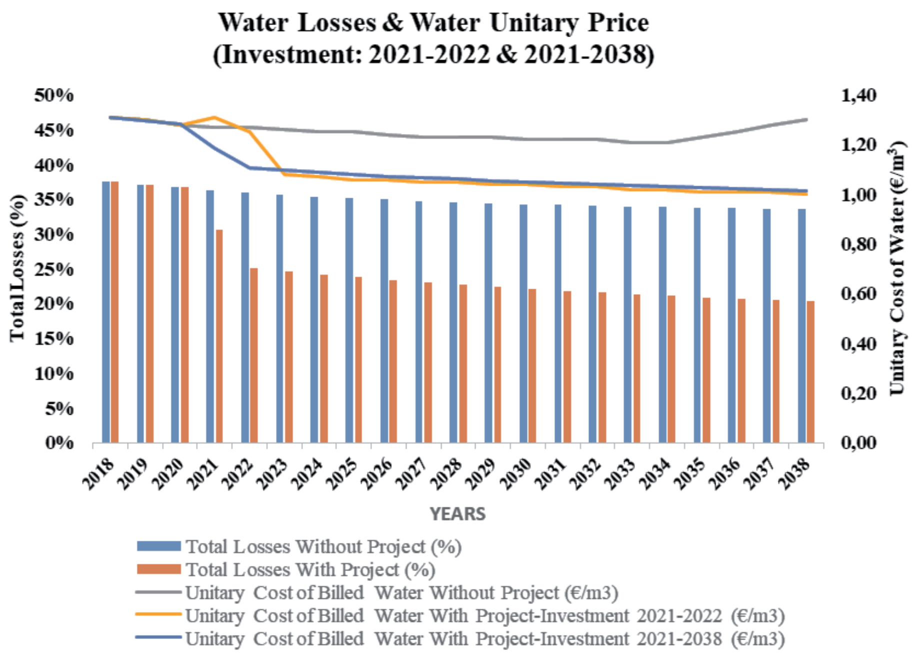


Figure 12 shows that the cash flows during the first 3 years (2018, 2019, and 2020) are the same, and the with-project scenario shows a decreasing trend between 2021 and 2022. Investments are expected to be carried out to increase water use efficiency between 2021 and 2022; therefore, cash flow changes are not expected before. The negative income of the investment costs would be during the investment period. For the with-project scenario, an increase in the cash flows is higher than the without-project scenario. After 2023, cash flows are positive in the with-project scenario; on the other hand, they are projected to be positive after 2029 in the without-project scenario. The difference in the gap between the two scenarios starts to be the largest just after the investment, then closing down steadily, and starting to be increased slightly from 2034 to 2038. Consequently, it is inevitable that the cash flows of the investments with-project scenario are financially positive and beneficial for the study area. The CBA depicted negative values regarding the Net Present Value (NPV) with the without-project scenario while the NPV was positive with the project. Internal Rate of Return (IRR) was estimated as 1% without the project and 14% with the project. The investment's payback period was estimated as 5.5 years (2027) and the payback period with a 10% discount applied was 6.8 years (2028). Finally, the abovementioned results clearly show that this project can be implemented.

The implementation of the proposed measures has a crucial impact on the water loss decrease, and the water demand in the system would reduce. Hence, the costs of water transmission and treatment would decrease, while the unitary price as well. The unitary cost of the water supply can be calculated by consisting of the cost of the water and wastewater utilization. In this study, two approaches were used to calculate the unitary cost. The first approach was the consideration of the investment to be conducted as planned in 2021 and 2022. The second approach was the consideration of the total investment shared among the total life cycle of the project from 2021 to 2038. It was found that the unitary prices vary between **1.31 €/m^3** and **1.21 €/m^3** for the without- project scenario and between **1.31 €/m^3** and **1.00 €/m^3** for the with-project scenario in the first approach. The second approach showed that the unitary price values for the with-project scenario decrease moderately from **1.31 €/m^3** to **1.02 €/m^3** while the without-project scenario remained the same because there are not any proposed measures. The reduction of water losses after rehabilitation was projected to be nearly 13% compared to the without-project scenario in 2038. Figure 13 compares the total water losses and unitary price of the water system along the project cycle from 2018 to 2038.

Figure 13

Water Losses & Water Unitary Price for Without-Project – With-Project Scenarios for 2021-2022 and 2021-2038



Other Complementary Measures

In the previous chapters, the described actions were mainly in accordance with the physical loss decreases. This section describes other complementary measures to improve management practices of the water system as follows: 1) Administrative Losses Reduction Plan, 2) Personnel Capacity Building Plan, 3) Public water saving awareness campaigns, 4) Tariff related measures.

Regarding the Administrative Losses Reduction Plan, administrative losses (apparent losses) are one of the necessary elements for water loss control. The administrative losses have two major components: meter reading failures/billing errors and unauthorized illegal consumption. Two major activities could be applied to deal with those problems: integrated customer water management and regularizations of the illegal connections.

Personnel Capacity Building Plan is a well-known conception and strategy to improve the sustainability of the water services at various levels (i.e., sectoral, institutional, and individual). It is an ongoing measure within all the activities taken place in the water sector. It also requires the implementation of several certain methods to improve sectoral productivity and so better practices in sectoral abilities. All these skills can be developed by the application of Capacity Building Plans (CBPs) including the major topics regarding the efficient use of water and better management practices. This measure should be carried out at the provincial level (not only at the district level) because of the organizational structure of the water and sewerage administration, which has to be homogenous throughout the water system staff within the consideration of the full institution.

Public water saving awareness campaigns contribute to the development of awareness at the full degree of individuals regarding the significance of the water-saving to deal with water shortages and provide sustainability in the future. It aims to increase individuals' behaviors for increasing water use efficiency. They can be implemented by giving education and awareness campaigns within the consideration of the environmental and socio-economic advantages of water-saving. This measure should be implemented not only at the district level but also at the provincial level being MUSKI managerial organization.

Tariff related measures are one of the complementary measures proposed in this study. Progressive pricing is a tool that can be used to administer water demand and support the reduction of extreme water consumption through an economic disincentive. It can be implemented by increasing water price rates in parallel with increased water consumption volumes. Hence, individuals who consume the largest amount of water would pay more beyond a specific threshold, which is generally determined by the average water demands of certain subscribers. Besides, the waterworks department may use some of the pricing analyses (e.g., affordability of the households, willingness to pay) in addition to the territorial water consumption trends when identifying the pricing blocks. Effective progressive pricing can also be monitored by establishing water conversation objectives and revenue goals. Pricing planning should also include public engagement via advertisements and meetings to inform individuals. It may cover key points about the water conversation and prevention of water consumption along with the advantages of progressive pricing. Since the tariff setting has been implemented at the level of metropolitan municipality, certain measures are not possible to apply at the district level.

Conclusion and Recommendations

This study concentrates on the efficiency aspects of the Marmaris water supply system. WaterCAD model was used as an analytical tool to simulate proposed measures in this study. Initially, for instance, pressure reduction valves are proposed to be installed to control high pressures in the network. Besides, DMAs to control leakages and PMAs to monitor high pressures should be established in the network. Infrastructures could be rehabilitated as well to control high pressures in the system. After the model runs, 21 DMAs and 11 PMAs were recommended in this study. The rehabilitation of the infrastructure could also cover the rebuilding and/or extension of the network with other elements (e.g., valves, meters, etc.). The modeling study was performed for this feasibility study; therefore, it is highly recommended to conduct more calibration tests when the investment is decided to be done. In addition to this, on-site tests are advised to carry out in each DMA; for example, hydrant openings can be used for the calibration due to the high flow status, which ensures more accurate calibration. Hence, several field tests should be implemented at different hydrants when a DMA is calibrated. Hydrant beyond the flow meters can also be selected to increase the quality of the calibration. When the investments are finalized, the calibration of the hydraulic model is highly advised by using the SCADA media. The system should also be enhanced by dealing with illegal consumption, metering inaccuracies/reading, and billing failures. Nevertheless, the current SCADA system could be improved since it only provides limited control of the system without remote control of the particular equipment. Last but not least, some complementary measures were identified to increase efficiency in the municipal water sector. After the implementation of the investments, gross water consumption per capita is expected to be 411 lcd in 2035. On the other hand, it is estimated to be 470 lcd for the without-project scenario. Water subscribers in the network would have less water compared to their demand without the project in

2035; therefore, results show that investments ensure adequate water supply in the future.

The Cost-Benefit analysis depicted negative values regarding the Net Present Value (NPV) with the without-project scenario while the NPV was positive with the project. Internal Rate of Return (IRR) was estimated as 1% without the project and 14% with the project. The investment's payback period was estimated at 5.5 years (2027) and the payback period with a 10% discount was 6.8 years (2028). The total cost of the investment was calculated as **€ 2,956,739.26** to be implemented during the years 2021 and 2022. The analysis of the unitary prices showed that they vary between **1.31 €/m^3** and **1.21 €/m^3** for the without- project scenario and between **1.31 €/m^3** and **1.00 €/m^3** for the scenario with-project.

In both cases, the decrease in the unitary price of water for the with-project scenario is more beneficial than the without-project scenario; therefore, implementation of the proposed investments is recommendable. We point out some recommendations to increase the efficiency in the municipal sector for future studies:

- The preparation of the water balance table should be done with higher precision to control the system more efficiently in a broader picture.
- Hydraulic models could be used as an analytical tool to understand complex water system conditions such as water distribution networks, and taking actions for improvements on the system.
- SCADA should be implemented to monitor and control a system and to calibrate the model remotely.
- Water authorities should perform active leak detection studies, and several teams should be formed for continuous leak detection.
- Implementation of the abovementioned complementary measures should be considered.
- An integrated assessment would be fruitful to conduct a more detailed system analysis holistically. A life cycle assessment can be applied together with hydraulic modeling, financial, and social analyses; thus, sustainability aspects would bring resilience to future circumstances.

Acknowledgment

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Appendix

Table A1

International NRW Assessment Matrix (Liemberger, 2010)

International NRW Assessment Matrix

	Technical Performance Category	NRW (Liters/connection/day) When the system is pressurized at an average pressure of:				
		10 m	20 m	30 m	40 m	≥ 50 m
Standard	A1		< 50	< 65	< 75	< 85
	A2		50-100	65-125	75-150	85-175
	B		100-200	125-250	150-300	175-350
	C		200-350	250-450	300-550	350-650
	D		> 350	> 450	> 550	> 650
Low and Middle Income Countries	A1	<55	<80	<105	<130	< 155
	A2	55-110	80-160	105-210	130-260	155-310
	B	110-220	160-320	210-420	260-520	310-620
	C	220-400	320-600	420-800	520-1000	620-1200
	D	> 400	> 600	> 800	> 1000	> 1200

Table A2

International Physical Loss Assessment Matrix (Liemberger & McKenzie, 2005; Liemberger, 2010)

Physical Loss Assessment Matrix							
Technical Performance Category		ILI	Physical Loss (Liters/connection/day) When the system is pressurized at an average pressure of:				
			10 m	20 m	30 m	40 m	≥ 50 m
Standard	A1	< 1.5		< 25	< 40	< 50	< 60
	A2	1.5 - 2		25-50	40-75	50-100	60-125
	B	2 - 4		50-100	75-150	100-200	125-250
	C	4 - 8		100-200	150-300	200-400	250-500
	D	> 8		> 200	> 300	> 400	> 500
Low and Middle Income Countries	A1	< 2	< 25	< 50	< 75	< 100	< 125
	A2	2-4	25-50	50-100	75-150	100-200	125-250
	B	4 - 8	50-100	100-200	150-300	200-400	250-500
	C	8 - 16	100-200	200-400	300-600	400-800	500-1000
	D	> 16	> 200	> 400	> 600	> 800	> 1000

"The definitions of the different Technical Performance Categories according to IWA are as follows:

Category A1: *World class NRW management performance; the potential for further NRW reductions is small unless there is still potential for pressure reductions or the accuracy improvement of large customer meters.*

Category A2: *Further NRW reduction may be uneconomic unless there are water shortages or very high water tariffs; a detailed water audit is required to identify cost-effective improvements.*

Category B: *Potential for marked improvements; establish a water balance to quantify the components of NRW; consider pressure management, better active leakage control practices, and better network maintenance; improve customer meter management, review meter reading, data handling and billing processed and identify improvement potentials.*

Category C: *Poor NRW record; tolerable only if water is plentiful and cheap; even then, analyse level and causes of NRW and intensify NRW reduction efforts.*

Category D: *Highly inefficient; a comprehensive NRW reduction program is imperative and high-priority."*

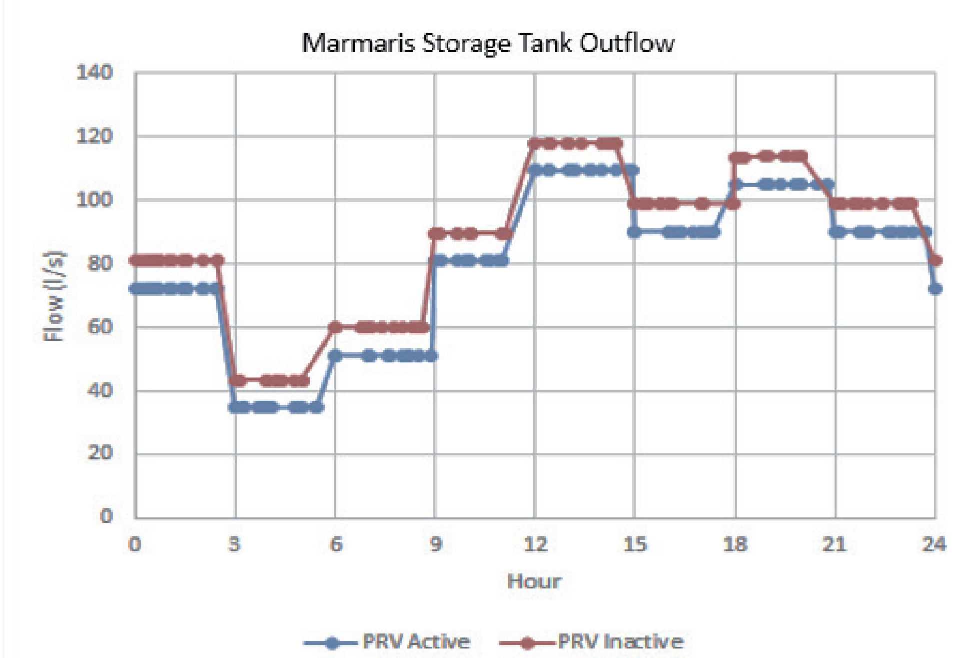
Table A3

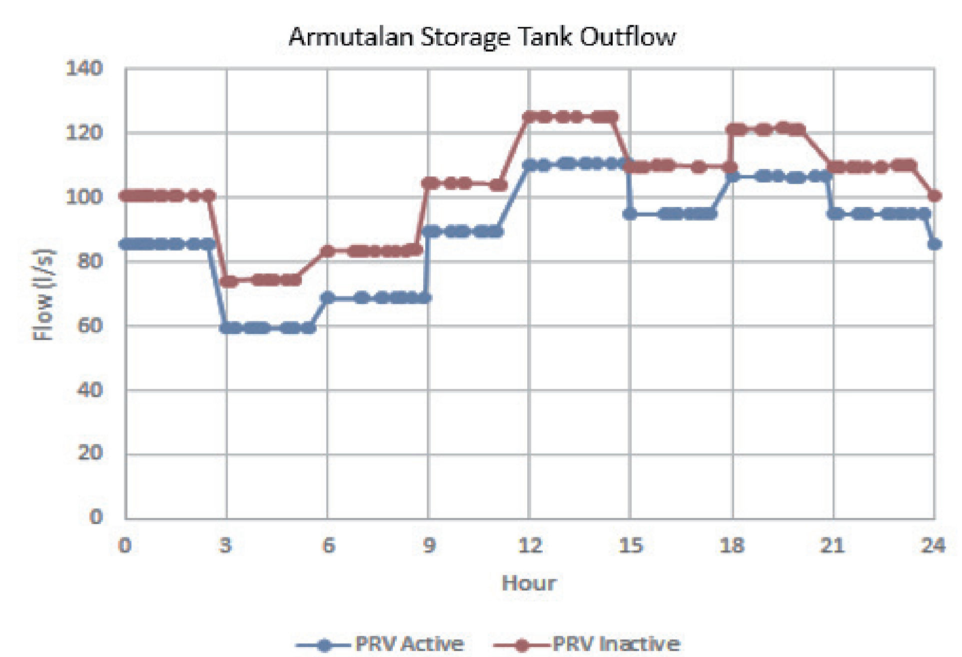
Population Projection Results for the Project Area

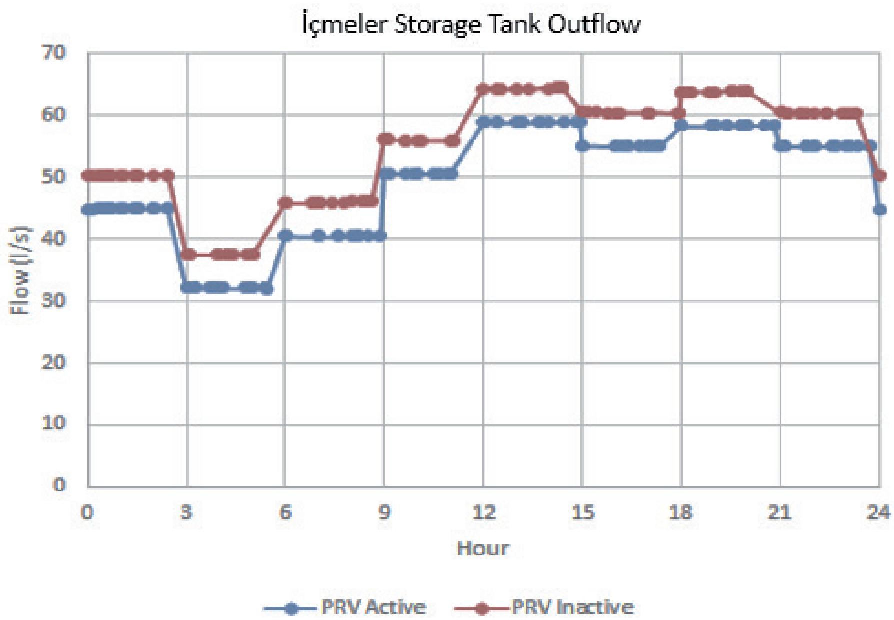
Year	Marmaris	Armutalan	Beldibi	İçmeler	Adaköy	Yeşilbelde	Total Population
2016	35,081	20,749	10,376	5,863	3,958	232	76,259
2017	36,049	21,439	10,680	6,016	4,052	234	78,470
2018	37,044	22,135	10,986	6,169	4,149	237	80,720
2019	38,066	22,837	11,293	6,322	4,248	239	83,005
2020	39,117	23,545	11,601	6,475	4,349	241	85,328
2021	40,196	24,257	11,909	6,628	4,452	244	87,686
2022	41,306	24,972	12,218	6,781	4,558	246	90,081
2023	42,445	25,690	12,526	6,934	4,667	249	92,511
2024	43,617	26,409	12,833	7,087	4,778	251	94,975
2025	44,821	27,128	13,139	7,240	4,892	254	97,474
2026	46,057	27,847	13,444	7,393	5,009	256	100,006
2027	47,328	28,564	13,746	7,546	5,128	259	102,571
2028	48,635	29,278	14,046	7,699	5,250	261	105,169
2029	49,977	29,988	14,343	7,852	5,375	264	107,799
2030	51,356	30,693	14,636	8,005	5,503	267	110,460
2031	52,773	31,391	14,925	8,158	5,634	269	113,150
2032	54,230	32,081	15,210	8,311	5,768	272	115,872
2033	55,726	32,763	15,490	8,464	5,906	275	118,624
2034	57,264	33,435	15,765	8,617	6,046	278	121,405
2035	58,844	34,095	16,034	8,770	6,190	280	124,213
2036	60,468	34,743	16,296	8,923	6,338	283	127,051
2037	62,137	35,377	16,552	9,076	6,489	286	129,917
2038	63,852	35,996	16,800	9,229	6,643	289	132,809

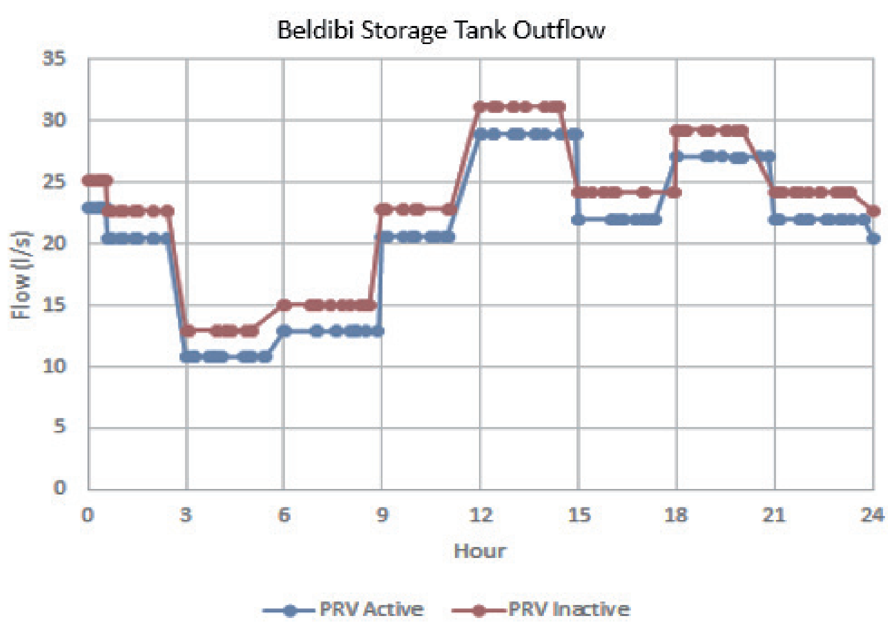
Figure A1

Comparison of Storage Tank Outflows with and without Pressure Management






İçmeler Storage Tank Outflow
Flow (l/s)
70
60
50
40
30
20
10
0
0
3
6
9
12
15
18
21
24
Hour
PRV Active
PRV Inactive


Beldibi Storage Tank Outflow
Flow (l/s)
35
30
25
20
15
10
5
0
0
3
6
9
12
15
18
21
24
Hour
PRV Active
PRV Inactive

Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Kentsel Su Temininin Verimliliğinin Artırılmasına İlişkin Fizibilite Çalışması

Bu çalışma için 2018 yılına ait adrese dayalı nüfus kayıt sistemine göre toplam nüfusu 79.296 kişi olan Marmaris ilçesi örnek alan olarak seçilmiştir. 2018 verilerine göre, içme suyu arıtma tesisinden sağlanan yıllık su miktarı 14.184.650 m^3'tür ve sadece 8.853.413 m^3'ü izinli tüketim olarak kabul edilmektedir (%62,4). İçme suyu arıtma tesisinden sağlanan yıllık su miktarının 8.131.491 m^3'ü faturalandırıldığından Gelir Getirmeyen Su (GGS) oranı %42,7'dir. GGS'nin ana bileşenini, %28,9 ile fiziki kayıplar, %8,7 ile idari kayıplar ve %5,1 ile faturalandırılmamış izinsiz tüketimler oluşturmaktadır. Tamamıyla fiziki ve idari kayıpların toplamından ibaret olan su kaybının oranı ise %37,6'dır. GGS ve teknik performans kategorilerinin Uluslararası Su Birliği (International Water Association) sınıflandırmasına göre, sistem C kategorisinde performans göstermektedir. Bu, sistemin zayıf bir GGS'ye sahip olduğu ve sadece suyun bol ve ucuz olduğu durumlarda tolere edilebileceği anlamına gelmektedir. Ayrıca, fiziki kayıp kategorisi yoğun sızıntı azaltma çabalarının gerekli olduğunu göstermektedir. Çalışma kapsamında projeli ve projesiz olmak üzere iki senaryo üzerinden projenin baz yılı olan 2018'den projenin hedef yılı olan 2038'e kadar değerlendirme yapılmıştır. Projeli senaryo ile, planlanan proje kapsamında yapılacak yatırımların yanı sıra hem su temin sistemini hem de hedef yıla kadar artacak olan su ihtiyacını karşılamaya yetecek düzeyde tutmak için gerekli yatırımlar dikkate alınmakta iken projesiz senaryo ise, su temin sisteminin kapasitesini artırmaya yönelik hiçbir yatırımın yapılmadığı temel durum senaryosudur. Başka bir deyişle, şebekede ve isale hattında herhangi bir genişleme yapılmayacak, herhangi bir su deposu inşa edilmeyecek ve İçme Suyu Arıtma Tesisi (İAT) bünyesinde üretim kapasitesini artırmaya yönelik ilave birim inşa edilmeyecektir. Diğer yandan, su sisteminin mevcut hizmet seviyesini korumak için ekonomik ömrünü tamamlamış pompaların yenileriyle değiştirilmesi gibi gerekli yatırımlar dikkate alınmıştır. Projesiz senaryo ile, 2034 yılından itibaren talebin karşılanamayacağı öngörülmekte olup gelecekteki taleplerin karşılanması adına tavsiye edilen tedbirlerin gerçekleştirilmesi önerilmektedir.

Bu çalışma, Marmaris su temini sisteminde bazı tedbirlerin alınması gerektiğine işaret etmektedir. Büyükşehir belediyelerindeki toplam su kayıplarının (fiziki kayıp ve idari kayıp) hedeflenen yıllarda belirlenen değerlere ulaşmasını hüküm altına alan "İçme Suyu Temin ve Dağıtım Sistemlerindeki Su Kayıplarının Kontrolü Yönetmelik" ine uymak için hem fiziki hem de idari kayıpların azaltılması gerekmektedir.

Bunun için ilk olarak, yüksek basınçlar, şebekeye basınç düşürücü vanaların takılması gibi iyi mühendislik uygulamaları ile kontrol edilmelidir. Buna ek olarak, İzole Alt Bölge (İAB) ile sınırları içerisinde olası sızıntıların tespit edilmesi ve izlenmesi, Basınç Yönetim Alanları (BYA) ile de şebekedeki basıncın izlenmesi kolaylaştırılmaktadır. Yüksek basınç kontrol sistemleri aynı zamanda altyapı rehabilitasyon önlemlerini de gerektirir. Asbest ve PVC borularının yüksek sızıntı ve patlama problemlerine neden olmalarından dolayı, şebekenin yüksek basınca maruz kalan bölümleri düktil, çelik gibi daha dayanıklı borularla değiştirilebilir. Altyapı rehabilitasyonu: Su verimliliği için şebeke cihazları, vanalar, basınç göstergeleri ve debi ölçerler gibi cihazlar su sisteminin yeniden inşasını ve/veya farklı unsurların eklenerek iyileştirilmesini içermelidir. Ayrıca, yönetim sisteminin iyileştirilerek izinsiz tüketim ve ölçüm yanlışlıklarının giderilmesi ve sayaç/faturalama hatalarının en aza indirgenmesi gerekmektedir. Marmaris'teki su sisteminin yönetimi ile ilgili diğer bir konu ise, şebekenin sınırlı bir şekilde izlendiği mevcut SCADA sisteminin iyileştirilmesinin gerekliliğidir.

Projeli senaryo için toplam öngörülen yatırım maliyeti 2.956.739,26 € olup, 2021 ve 2022 yıllarında yatırımın uygulanması öngörülmektedir. Yatırımların tamamlanmasının ardından Muğla Su ve Kanalizasyon İdaresi'nin kapsamlı SCADA uygulaması ile hidrolik modeli kalibre etmesi tavsiye edilmektedir. Modellerin hidrant açıklıkları gibi yüksek akış koşullarında daha doğru kalibre edildiği

bilinmektedir. Bu nedenle, bir İAB kalibre edilirken, birkaç hidrantta birden fazla saha testi yapılmalıdır. Ek olarak, akış ölçer bölmesinden ayrı hidrant seçimi, kalibrasyonun doğruluğunu arttırmaktadır.

Fayda-maliyet analizi, projeli senaryo için pozitif olmakla birlikte, projesiz senaryoda net bugünkü değer için negatif sonuçlar görülmektedir. Ayrıca, su verimliliğini artırmaya yönelik çalışmaların 2021 ve 2022 yıllarında yapılacak olması nedeniyle yatırım maliyetinin olumsuz etkileri de bu dönemde olacaktır. İç karlılık oranı ile ilgili olarak, 2038 yılına ilişkin sonuçlar projesiz senaryo için %1 ve projeli senaryo için ise %14'tür. Yatırımın geri ödeme süresi 5,5 yıldır (2027) ve %10 iskontolu geri ödeme süresi ise 6,8 yıldır (2028). Finansal analize ilişkin üç gösterge (iç karlılık oranı, net bugünkü değer, geri ödeme süresi), proje de önerilen yatırımların uygulanmasının yararını açıkça göstermektedir.

Sistemin verimliliğindeki iyileşmenin suyun birim fiyatı üzerindeki etkisine ilişkin olarak iki farklı değerlendirme gerçekleştirilmiştir: bunlardan biri 2021 ve 2022 arasında yatırımın dağıtıldığı, diğeri ise toplam yatırımın proje süresi boyunca dağıtıldığı senaryolardır. Sonuç olarak, suyun birim maliyetinin mevcut durumda 1,31 €/m^3'ten aşağıda verilen değerlere dönüşeceği hesaplanmıştır:

- Projesiz senaryo için; 2033'te **1,21 € / m^3** (minimum fiyat) ve 2038'de **1,30 € / m^3**,
- Projeli senaryo için (yatırımın 2021-2022 yıllarında dağıtılması durumunda), 2021 ve 2022 yıllarında sırasıyla **1,31 €/m^3** ve **1,25 €/m^3,** 2038 yılında ise **1,00 €/m^3**,
- Projeli senaryo için (yatırımın 2021-2038 olan proje ömrüne dağıtılması durumunda), 2038 yılında **1,00 €/m^3**.

Her iki senaryoya baktığımızda projeli senaryoda suyun birim fiyatındaki düşüşün, projesiz senaryodakinden açık bir şekilde daha fazla olduğunu görürüz. Bu nedenle, fizibilite çalışması kapsamında önerilen yatırımların uygulanması tavsiye edilmektedir.

Ayrıca, hidrolik modelleme, SCADA ve finansal analiz çalışmalarına ek olarak, içme-kullanma suyu sektöründe verimliliği artırmak için bazı tamamlayıcı tedbirler belirlenmiştir. Bunlar; idari kayıpları azaltma planı, personel kapasite geliştirme planı, su tasarrufu bilinci kazandırma kampanyaları ve tarife ile ilgili tedbirlerdir.

Son olarak, kentsel su temini sektörüne ilişkin verimliliğin arttırılmasıyla ilgili olarak gelecekte yapılacak çalışmalar için bazı öneriler aşağıda yer almaktadır:

- ✓ Daha geniş bir ölçekte sistemi daha verimli bir şekilde kontrol etmek için Su Dengesi Tablosunun daha yüksek hassasiyetle hazırlanması gerekmektedir.
- ✓ Hidrolik modeller, su temin sistemleri gibi karmaşık su sistem koşullarını anlamak ve sistemdeki iyileştirmelere ilişkin harekete geçmek için analitik bir araç olarak kullanılmalıdır.
- ✓ SCADA, sistemi uzaktan izlemek, kontrol etmek ve model kalibrasyonunda kullanmak için önerilmektedir.
- ✓ Su idareleri aktif olarak kaçak tespit çalışmalarını yürütmeli ve devamlı kaçak tespiti için ekipler oluşturmalıdır.
- ✓ Çalışma kapsamında belirtilen tedbirlere ek olarak, kapasite geliştirme ve farkındalık artırma kampanyaları gibi diğer tamamlayıcı tedbirler de alınmalıdır.
- ✓ Bütüncül değerlendirme yöntemi ile daha ayrıntılı sistem analizi yapmak faydalı olacaktır. Hidrolik modelleme, finansal ve sosyal analizlerle beraber yaşam döngüsü analizinden de yararlanılarak, gelecekteki çevresel ve iklimsel değişikliklere yönelik sektörel adaptasyon stratejileri de değerlendirilmelidir.

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Research Article

Pressure of Urbanisation on the Fish Community Structure in Küçük Menderes River Basin (Turkey)

Kentleşmenin Küçük Menderes Nehir Havzası (Türkiye) Balık Toplulukları Üzerindeki Baskısı

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Abstract

Urbanization is linked to changes in aquatic flora and fauna, including fishes, and it often leads to a decline in fish diversity, richness, and density. This study aims to determine the fish fauna and their abundance in Küçük Menderes River Basin, which is under the threat of urbanization. The field surveys were carried out in 50 different locations in lotic and lentic biotopes, and fish sampling was performed by using electro-shocker, seine-net, and gillnets in November 2017 and May 2018. A total of 21 taxa belonging to 14 families (Anguillidae, Acheilognathidae, Atherinidae, Blenniidae, Cobitidae, Cyprinidae, Gobiidae, Leuciscidae, Mugilidae, Nemacheilidae, Percidae, Poecilidae, Siluridae and Syngnathidae) was identified. Cyprinidae has the highest species richness with four taxa and the most commonly found fish species were *Squalius kosswigi* and *Cyprinus carpio*. In terms of abundance of species, *Gambusia holbrooki* was the most dominant fish species in Hırsız (the catch per unit effort = 23.28 n/min/m^2) and Kuskudan (the catch per unit effort = 24.00 n/min/m^2) streams. While *Alburnus demiri*, *Barbus pergamonensis, Cobitis fahireae, Oxynoemacheilus germencicus, Petroleuciscus smyrnaeus* and *S. kosswigi* are Anatolian endemics, *Atherina boyeri, Carassius auratus, C. gibelio* and *Gambusia holbrooki* are the invasive fish species in the basin.
Keywords: *Water pollution, invasive fish, drought, endemic, irrigation*

Öz

Kentleşme, balıkları da kapsayan sucul fauna ve floradaki değişimlerle bağlantılı olup sıklıkla balık çeşitliliği, zenginliği ve yoğunluğunda azalmaya yol açmaktadır. Bu çalışmanın amacı, şehirleşme tehdidi altındaki Küçük Menderes Nehir Havzası'nın balık faunası ile bunların bolluklarını belirlemektir. Saha çalışmaları, durgun ve akışlı biyotoplardaki 50 farklı istasyonda sürdürülmüş ve balık örneklemesi elektroşoker, ığrıp ve galsama ağları kullanılarak Kasım 2017 ve Mayıs 2018

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tarihlerinde gerçekleştirilmiştir. 14 familyaya (Anguillidae, Acheilognathidae, Atherinidae, Blenniidae, Cobitidae, Cyprinidae, Gobiidae, Leuciscidae, Mugilidae, Nemacheilidae, Percidae, Poecilidae, Siluridae ve Syngnathidae) ait toplam 21 takson tanımlanmıştır. Cyprinidae dört takson ile en yüksek tür çeşitliliğine sahiptir ve *Squalius kosswigi* ve *Cyprinus carpio* en yaygın balık türleri olarak tespit edilmiştir. Türler bollukları açısından değerlendirildiğinde, *Gambusia holbrooki* Hırsız (birim çaba başına düşen av miktarı = 23.28 adet/dk/m^2) ve Kuskudan (birim çaba başına düşen av miktarı = 24.00 adet/dk/m^2) derelerindeki en baskın balık türüdür. *Alburnus demiri*, *Barbus pergamonensis, Cobitis fahireae, Oxynoemacheilus germencicus, Petroleuciscus smyrnaeus* ve *S. kosswigi* havzadaki Anadolu endemikleri iken *Atherina boyeri, Carassius auratus, C. gibelio* ve *Gambusia holbrooki* istilacı balık türleridir.

Anahtar kelimeler: *Su kirliliği, istilacı balıklar, kuraklık, endemik, sulama*

Introduction

River basins have an essential role in the biosphere as a conduit for water and are used by humans for transportation, fisheries, hydropower, and domestic, industrial, and agricultural water supplies (Pompeu & Alves, 2005). Urbanization is a process of the increasing number of people in an area and it leads to a horizontal or vertical growth of urban areas (Hassan Rashid et al., 2018). Both increased human population and growth in urban areas increase the pressure, such as pollution and rising water requirement for domestic use, on water resources. Therefore, urbanization is one of the major threats affecting the river basins (Shukla et al., 2013), and it is linked to changes in aquatic fauna, including fishes and it often leads to declines in fish diversity, richness, and density.

Küçük Menderes River, located in the centre of the west coastline of the Anatolia, flows through the province of İzmir. Today, İzmir is one of the biggest metropolitans of Turkey and it has been an important settlement area of the Western Anatolia since the ancient ages. According to “the level of urbanisation” that means the proportion of the population living in urban areas to the country's total population, İzmir is the third largest city of Turkey. The urbanization level of the city has increased rapidly by immigration with the urbanization models originating from trade, industry, tourism and agriculture. The boundaries of the urban areas have been expanded, especially with the administration of "metropolitan" status in 1984 and the urban population of Izmir, which was 818,251 in 1980, reached 1,489,772 in 1985 and 4,367,251 today (Işık, 2005; Turkey Statistical Institute [TURKSTAT], 2020). Due to the rapidly increasing population and urbanization, many aquatic and terrestrial ecosystems in the region are under threat (Kurucu & Chiristina, 2008; Sökmen Yılmaz & Yılmaz, 2019)

Küçük Menderes River receives its waters from the small streams in Kiraz lowland and it flows into the Aegean Sea in the west of Selçuk. There are three natural lakes (Belevi, Çatal and Gebekirse) and also some dam lakes built to supply drinking and irrigation water in the river basin. Küçük Menderes River has formed saline wetlands before reaching into the Aegean Sea and these wetlands were entitled as Selçuk Bird Paradise. In 1991 it was announced as 1st and 2nd Degree natural protected area by the Ministry of Culture and Tourism and in 1994 as wildlife protection area by the Ministry of Agriculture and Forestry (Sütgibi, 2009).

Nowadays, Küçük Menderes River is under the pressure of urbanization due to its fertile agricultural lands and high industrial and tourism potential. However, the lack of infrastructure (sewage, treatment plants, etc.) and rapid population growth in the basin cause water pollution/lose and damage water balance (Yıldız et al., 2009). Many of the streams have been turned to reservoirs to provide water for domestic, agriculture and industrial purposes for the metropolitan İzmir.

A limited number of studies were conducted about the distributions of the fishes in the streams and lakes of the river basin in the past (Karaman, 1972; Balık, 1979; Balık et al., 1995; Sarsu, 1981; İlhan et al., 2009). Karaman (1972) has described *Squalius kosswigii* as a new species from the Gümüldür Stream, which was located in the Tahtalı Dam sub-basin before the construction of the dam. In the study on taxonomy and ecological characteristics of freshwater fishes in Western Anatolia, Balık (1979) has reported that eight fish species, *Salaria fluviatilis* (Asso y del Rio, 1801), *Oxynoemacheilus germencicus* (Erk'akan, Nalbant & Özeren, 2007), *Alburnus demiri* Özuluğ & Freyhof, 2008, *Chondrostoma holmwoodii* (Boulenger, 1896), *Rhodeus amarus* (Bloch, 1782), *Alburnoides bipunctatus* (Bloch, 1782) and *S. kosswigii* have been living in Gümüldür, Şaşal and Bulgurca streams. According to Sarsu (1981), freshwater fish species living in Gümüldür Stream and its associated sources have been reported as *Anguilla anguilla* (Linnaeus, 1758), *Barbus pergamonensis* Karaman, 1971, *Cyprinus carpio* Linnaeus, 1758, *Cobitis fahireae* Erk'akan, Atalay-Ekmekçi & Nalbant, 1998, *Mugil cephalus* Linnaeus, 1758, *Chelon aurata* (Risso, 1810), *A. demiri*, *C. holmwoodii*, *R. amarus*, *A. bipunctatus*, *S. kosswigi*, *O. germencicus* and *S. fluviatilis*. As a faunistic study, Balık et al. (1995) have contributed to the fish fauna of the Tahtalı Dam basin with three new species, *Petroleuciscus smyrnaeus* (Boulenger, 1896), *Gambusia holbrooki* Girard, 1859 and *Chelon ramada* (Risso, 1827). After the construction of the Tahtalı Dam, İlhan et al. (2009) have studied some biological characteristics of *Perca fluviatilis* Linnaeus, 1758, which was introduced for stocking purposes to the dam. In the study about the length-weight relationships for freshwater fish species living in Küçük Menderes River Basin, Korkmaz et al. (2015) have reported the presence of *Carassius gibelio* (Bloch, 1782) and *Carassius carassius* (Linnaeus, 1758).

These studies listed above have shown that there was no comprehensive study for the whole basin and only the fish species lists or some biological characteristics of these fishes in some locations of the basin were given and the abundance values of these fish species were not studied. The conservation and sustainability of biological diversity could be ensured by monitoring diversity using scientific methods. Therefore, it is very important to repeat the inventory and monitoring studies of fish fauna in the inland waters with time intervals (Özuluğ & Saç, 2019). However, the presenting of abundance values of the existing fish species would be highly useful to reveal time-dependent changes for future studies. The main objective of this study is to determine the recent fish fauna living in Küçük Menderes River Basin. Additionally, by calculating the abundance values of these fish, it is likely to evaluate the pressures of urbanization.

Method

The field surveys were conducted in a total of 50 sampling sites (42 streams, 1 transitional water, 2 natural lakes and 5 dam lakes) in Küçük Menderes River Basin in November 2017 and May 2018 (Figure 1, Table 1).

Figure 1

Sampling Sites in Küçük Menderes River Basin

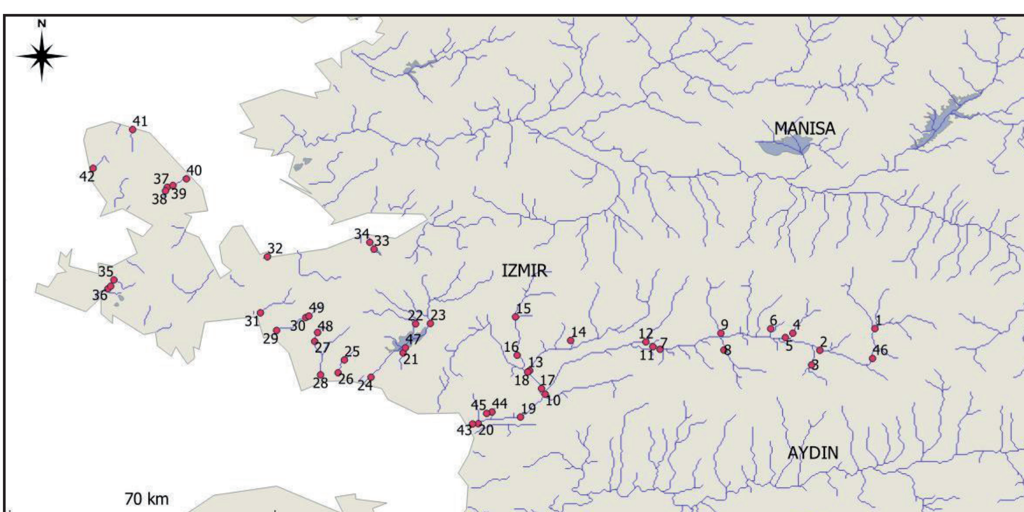

Table 1

Sampling Sites in Küçük Menderes River Basin with Coordinates

St. No	St. Name	Coordinates	Locality
1*	Keleş Creek	38.188261°N, 28.225178°E	Kiraz, İzmir
2*	Taşavra Creek	38.136694°N, 28.094658°E	Beydağ, İzmir
3*	Pirinççi Creek	38.102115°N, 28.074048°E	Ödemiş, İzmir
4**	Gelinbözü Stream	38.177378°N, 28.030595°E	Ödemiş, İzmir
5**	Küçük Menderes River-1	38.165631°N, 28.013342°E	Ödemiş, İzmir
6**	Zeytinlik Creek	38.187889°N, 27.978032°E	Ödemiş, İzmir
7***	Rahmanlar Stream	38.140291°N, 27.715971°E	Tire, İzmir
8	Eğridere Stream	38.137058°N, 27.866841°E	Tire, İzmir
9*	Aktaş Creek	38.177333°N, 27.859872°E	Ödemiş, İzmir
10*	Küçük Menderes River-2	38.032566°N, 27.443286°E	Torbalı, İzmir
11***	Küçük Menderes River-3	38.145197°N, 27.698732°E	Tire, İzmir
12**	Falaka Creek	38.156692°N, 27.682031°E	Bayındır, İzmir
13**	Ilıca Stream	38.088649°N, 27.406979°E	Torbalı, İzmir
14**	Uladı Creek	38.160030°N, 27.503622°E	Bayındır, İzmir
15*	Fetrek Creek-1	38.215895°N, 27.373613°E	Torbalı, İzmir
16***	Fetrek Creek-2	38.124985°N, 27.378049°E	Torbalı, İzmir
17***	Çevlik Creek-1	38.045394°N, 27.435825°E	Torbalı, İzmir
18***	Çevlik Creek-2	38.085461°N, 27.402874°E	Torbalı, İzmir
19***	Küçük Menderes River-4	37.978428°N, 27.384794°E	Selçuk, İzmir
20***	Küçük Menderes River-5	37.963007°N, 27.283960°E	Selçuk, İzmir
21*	Değirmendere Stream	38.130352°N, 27.106610°E	Menderes, İzmir
22	Şaşal Stream	38.199433°N, 27.136033°E	Menderes, İzmir
23	Tahtalı Creek	38.200436°N, 27.171187°E	Menderes, İzmir
24**	Koca Creek	38.072829°N, 27.030365°E	Menderes, İzmir
25*	Ürkmez Stream-1	38.114544°N, 26.966368°E	Seferihisar, İzmir
26**	Ürkmez Stream-2	38.083291°N, 26.952555°E	Seferihisar, İzmir
27**	Karakoç Stream-1	38.157961°N, 26.898151°E	Seferihisar, İzmir
28	Karakoç Stream-2	38.083766°N, 26.909176°E	Seferihisar, İzmir
29**	Yassıdere Stream-1	38.184390°N, 26.806520°E	Seferihisar, İzmir
30**	Yassıdere Stream-2	38.214620°N, 26.875686°E	Seferihisar, İzmir
31	Azmak Stream	38.225769°N, 26.767904°E	Seferihisar, İzmir
32**	Akpınar Stream	38.357671°N, 26.784006°E	Urla, İzmir
33*	Kona Stream-1	38.384826°N, 27.033001°E	Balçova, İzmir
34**	Kona Stream- 2	38.392633°N, 27.028781°E	Balçova, İzmir
35**	İncirli Stream	38.303509°N, 26.420841°E	Çeşme, İzmir
36	Hırsız Stream	38.282206°N, 26.404382°E	Çeşme, İzmir
37**	Kısık Stream	38.523252°N, 26.547126°E	Karaburun, İzmir
38**	Kışla Stream	38.514904°N, 26.542971°E	Karaburun, İzmir
39*	Kuskudan Stream-1	38.528542°N, 26.561015°E	Karaburun, İzmir
40**	Kuskudan Stream-2	38.543320°N, 26.592170°E	Karaburun, İzmir
41**	Uzun Stream	38.660341°N, 26.465133°E	Karaburun, İzmir
42**	Sudeğirmeni Stream	38.568424°N, 26.371368°E	Karaburun, İzmir
43	Transitional water	37.959942°N, 27.264050°E	Selçuk, İzmir
44	Çatal Lake	37.990383°N, 27.317102°E	Selçuk, İzmir
45	Gebekirse Lake	37.986933°N, 27.304530°E	Selçuk, İzmir
46	Beydağ Dam Lake	38.117427°N, 28.219555°E	Beydağ, İzmir
47	Tahtalı Dam Lake	38.142752°N, 27.111891°E	Menderes, İzmir
48	Kavakdere Dam Lake	38.178899°N, 26.903701°E	Seferihisar, İzmir
49	Seferihisar Dam Lake	38.217997°N, 26.882979°E	Seferihisar, İzmir
50	Alaçatı Dam Lake	38.288922°N, 26.413136°E	Çeşme, İzmir

** means the riverbed was dry in autumn 2017; ** means the riverbed was dry in both seasons; *** means fish was not captured due to water pollution.*

In streams, fish samples were collected by electro-shocker (SAMUS 725-G portable electro-shockers; frequency 50-55 Hz; 20-60 cm fishing depth) from the stations and sampling was conducted opposite direction of the water flow (European Committee for Standardization [CEN], 2003). In transitional waters, seine nets (5 mm mesh size, 30 m in length and 2 m in width) were used (CEN, 2006).

In lakes, fish samples were captured using benthic and pelagic multi-mesh gillnets. Benthic gillnets (30 m in length and 1.5 m in width) have 12 different mesh sizes from 5 mm to 55 mm. Pelagic gillnets (27.5 m in length and 6.0 m in width) have 11 different mesh sizes from 6.25 mm to 55 mm (CEN, 2015). Additionally, in shorelines of lakes, a scoop-net (2 mm mesh sized) was used to capture small fishes.

Collected specimens were sacrificed with a lethal solution of anaesthesia (clove oil) and then transferred to a 5% formaldehyde solution. In the laboratory, for each individual, standard length (SL) was measured to the nearest 0.1 cm, and total body weight (W) was weighed on a digital balance with a 0.01 g accuracy.

To determine the fish abundance, the catch per unit effort (CPUE) was calculated using the following equation; CPUE = (n/t/a) × 100 (n: specimen numbers, t: time (minute (min) for streams and hour (h) for lakes, a: sampling area) (Jordan & Willis, 2001; Mehner et al., 2005). In streams, the sampling area means the area sampled by electro-shocker and the fish samples were captured from a maximum 200 m length of sampling sections in a maximum of 20 minutes. In lakes, the sampling area means the gillnet area used for the fish catch and the maximum length of time the nets stayed in the lake was limited to 12-16 hours. For the fish species caught with seine-net and scoop-net, CPUE was not estimated.

Results

Fish were captured in 38% (19 stations) of the 50 stations, however, there were no fish in other stations due to pollution (7 stations) and drought (24 stations). A total of 21 fish species belonging to 14 families were determined in the river basin (Table 2). Cyprinidae has the highest species richness with four taxa and the most commonly found fish species were *Squalius kosswigi* (8 stations) and *Cyprinus carpio* (7 stations).

In terms of abundance of fish species, CPUE (n/t/m^2) values ranged from 0.01 to 24.00 in stream stations and *G. holbrooki* was the most dominant fish species in the Hırsız (CPUE = 23.28 n/min/m^2) and Kuskudan (CPUE = 24.00 n/min/m^2) streams. In lakes, CPUE (n/h/m^2) values ranged from 0.01 to 62.43 and *P. fluviatilis* was the most dominant fish species in Beydağ Dam Lake (CPUE = 62.43 n/h/m^2). Fish species with a CPUE (n/min/m^2 and n/h/m^2) value of 1 and above are determined as *R. amarus*, *C. carpio*, *A. demiri*, *P. smyrnaeus, S. kosswigi*, *Chelon* sp., *O. germencicus, P. fluviatilis* and *G. holbrooki.* While *A. demiri*, *B. pergamonensis, C. fahireae, O. germencicus, P. smyrnaeus* and *S. kosswigi* are Anatolian endemics, *A. boyeri* (Kavakdere Dam Lake), *C. auratus, C. gibelio* and *G. holbrooki* are the invasive fish species in the basin (Table 3).

Table 2

Fish Species Captured from Küçük Menderes River Basin and the Distribution of These Fishes by Sites

Fish species	Stations
Familia: Acheilognathidae	
Rhodeus amarus (Bloch, 1782)	22
Familia: Anguillidae	
Anguilla anguilla (Linnaeus, 1758)	44
Familia: Atherinidae	
Atherina boyeri Risso 1810	45, 48
Familia: Blenniidae	
Salaria fluviatilis (Asso, 1801)	21
Familia: Cobitidae	
Cobitis fahireae Erk'akan, Atalay-Ekmekçi & Nalbant 1998	23, 44
Familia: Cyprinidae	
Barbus pergamonensis Karaman 1971	15, 22
Carassius auratus (Linnaeus, 1758)	50
Carassius gibelio (Bloch, 1782)	15, 23, 44, 46, 47, 50
Cyprinus carpio Linnaeus, 1758	44, 45, 46, 47, 48, 49, 50
Familia: Gobiidae	
Knipowitschia caucasica (Berg, 1916)	45, 48
Familia: Leuciscidae	
Alburnus demiri Özuluğ & Freyhof, 2008	22, 23, 45
Petroleuciscus smyrnaeus (Boulenger, 1896)	8, 21, 23, 44, 45, 46
Squalius kosswigi (Karaman, 1972)	15, 22, 23, 25, 28, 31, 33, 48
Familia: Mugilidae	
Chelon aurata (Risso, 1810)	45
Chelon ramada (Risso, 1827)	45, 43
Chelon sp.	28, 31
Familia: Nemacheilidae	
Oxynoemacheilus germencicus (Erk'akan, Nalbant & Özeren, 2007)	15, 22, 23
Familia: Percidae	
Perca fluviatilis Linnaeus, 1758	46, 47, 49
Familia: Poecilidae	
Gambusia holbrooki Girard, 1859	36, 39, 44, 45, 48, 50
Familia: Siluridae	
Silurus glanis Linnaeus, 1758	47
Familia: Syngnathidae	
Syngnathus abaster Risso, 1827	45

Table 3

The Individual Numbers, Body Size and Weight Distributions and Sampling Sites of Fish Species Captured in Küçük Menderes River Basin

Fish species	St. No	n	TL (cm) min – max	W (g) min – max	CPUE (n/min/m^2; n/h/m^2)
Rhodeus amarus	22$^{S, 1}$	29	2.6 – 5.3	0.17 – 2.49	1.66
Anguilla anguilla	44^{A}	2	43.9 – 50.5	148.24 – 191.03	*
Atherina boyeri	45$^{A, 2}$	1	6.4	1.60	0.03
	48$^{A, 2}$	1	7.8	3.08	0.02
Salaria fluviatilis	21$^{S, 1}$	20	3.4 – 6.7	0.40 – 3.50	0.76
Cobitis fahireae	23$^{A, 1}$	1	5.3	0.92	0.03
	23$^{S, 1}$	7	5.1 – 6.8	0.94 – 2.47	0.06
	44^{A}	1	5.3	0.84	*
Barbus pergamonensis	15$^{S, 1}$	1	6.3	3.62	0.05
	22$^{S, 1}$	3	6.9 – 9.5	4.36 – 12.26	0.17
Carassius auratus	50$^{A, 2}$	4	8.9 – 14.5	12.07 – 45.56	0.17
Carassius gibelio	15$^{S, 1}$	6	3.1 – 4.8	0.57 – 2.14	0.30
	23$^{S, 1}$	1	31.7	743.49	0.01
	44$^{A, 2}$	19	13.0 – 20.3	39.41 – 144.52	0.32
	44$^{S, 2}$	22	16.7 – 23.7	65.46 – 242.11	0.64
	46$^{A, 2}$	12	15.5 – 19.8	70.72 – 153.05	0.31
	46$^{S, 2}$	6	17.8 – 32.0	86.34 – 561.33	0.10
	47$^{A, 2}$	21	12.2 – 30.4	27.18 – 631.71	0.44
	47$^{S, 2}$	15	20.0 – 33.3	174.4 – 796.43	0.20
	50$^{A, 2}$	4	8.9 – 15.9	9.27 – 47.79	0.17
Cyprinus carpio	44$^{S, 2}$	1	24.5	200.65	0.03
	45$^{A, 2}$	1	33.0	532.15	0.47
	46$^{A, 2}$	8	13.8 – 18.2	39.74 – 87.84	0.21
	47$^{A, 2}$	1	22.6	160.08	0.02
	48$^{A, 2}$	3	23.1 – 24.3	234.29 – 255.38	0.05
	48$^{S, 2}$	1	27.7	386.22	0.02
	49$^{S, 2}$	10	22.5 – 34.1	156.36 – 734.19	0.14
	50$^{A, 2}$	209	7.0 – 21.8	5.17 – 136.83	8.93
	50$^{S, 2}$	22	9.7 – 22.6	13.51 – 169.44	0.72
Knipowitschia caucasica	45^{A}	1	2.3	0.1	*
	45^{S}	14	1.6 – 3.0	0.04 – 0.26	*
	48^{A}	1	3.2	0.35	*
	48^{S}	1	2.7	0.20	*
Alburnus demiri	22$^{A, 1}$	1	6.7	4.40	0.04
	22$^{S, 1}$	20	5.9 – 8.5	1.79 – 6.29	1.14
	23$^{A, 1}$	4	3.6 – 5.4	0.32 – 0.95	0.11
	45$^{A, 2}$	4	14.8 – 15.8	29.36 – 36.35	0.12
Petroleuciscus smyrnaeus	8$^{S, 1}$	29	1.8 – 8.5	0.06 – 8.50	0.52
	21$^{S, 1}$	69	2.9 – 8.2	0.25 – 8.18	2.63
	23$^{A, 1}$	1	6.1	3.43	0.03
	23$^{S, 1}$	1	7.4	8.13	0.01
	44$^{A, 2}$	50	9.1 – 12.0	10.14 – 23.10	0.85
	44$^{S, 2}$	9	9.0 – 10.4	9.66 – 15.40	0.26

^{A}: Autumn; ^{S}: Spring; ^{1}:Electro-shocker; ^{2}: Gillnet; ^{3}: Beach seine-net; *Scoop net; **Seine-net

Table 3

(Continued)

Fish species	St. No	n	TL (cm) min – max	W (g) min – max	CPUE (n/min/m^2; n/h/m^2)
P. smyrnaeus (continued)	45$^{A, 2}$	16	8.5 – 11.3	8.93 – 44.81	0.03
	46$^{A, 2}$	2	9.3 – 10.4	11.65 – 15.81	0.05
Squalius kosswigi	15$^{S, 1}$	4	2.4 – 3.7	0.15 – 0.59	0.20
	22$^{A, 1}$	1	6.6	2.97	0.04
	22$^{S, 1}$	37	3.2 – 11.8	0.22 – 23.05	2.11
	23$^{A, 1}$	6	3.5 – 6.3	0.47 – 2.92	0.17
	23$^{S, 1}$	25	1.8 – 13.8	0.05 – 36.06	0.22
	25$^{S, 1}$	11	2.2 – 14.1	0.07 – 36.57	0.11
	28$^{S, 1}$	4	2.4 – 2.9	0.12 – 0.27	0.04
	31$^{S, 1}$	40	4.2 – 13.8	0.73 – 35.68	5.13
	33$^{S, 1}$	60	4.3 – 15.3	0.84 – 52.52	3.00
	48$^{A, 2}$	94	10.1 – 23.9	11.69 – 183.65	1.65
	48$^{S, 2}$	17	11.6 – 17.5	16.60 – 58.12	0.33
Chelon aurata	45$^{A, 2}$	21	15.5 – 36.0	25.15 – 356.63	0.61
	45$^{S, 2}$	1	20.0	56.98	0.02
Chelon ramada	43$^{A, 3}$	4	9.8 – 12.9	8.5 – 16.12	**
	43$^{S, 3}$	2	13.2 – 24.5	13.60 – 135.11	**
	45$^{A, 2}$	1	35.0	374.22	0.03
Chelon sp.	28$^{A, 1}$	20	2.4 – 3.1	0.12 – 0.33	0.48
	28$^{S, 1}$	1	2.7	0.20	0.01
	31$^{S, 1}$	17	2.3 – 4.8	0.10 – 1.07	2.18
Oxynoemacheilus germencicus	15$^{S, 1}$	58	2.2 – 4.1	0.08 – 0.79	2.90
	22$^{S, 1}$	34	2.6 – 4.2	0.13 – 0.75	1.94
	23$^{A, 1}$	12	4.7 – 6.2	0.89 – 2.31	0.33
	23$^{S, 1}$	1	6.5	2.50	0.01
Perca fluviatilis	46$^{A, 2}$	32	6.2 – 25.0	2.78 – 275.86	0.82
	46$^{S, 2}$	3933	1.1 – 29.8	9.02 – 492.84	62.43
	47$^{A, 2}$	81	13.0 – 29.2	27.22 – 375.65	169.00
	47$^{S, 2}$	115	14.2 – 30.4	33.00 – 443.69	1.52
	49$^{A, 2}$	2	24.2 – 26.7	193.34 – 290.76	0.05
	49$^{S, 2}$	44	15.4 – 36.1	50.78 – 864.80	0.62
Gambusia holbrooki	36$^{A, 1}$	149	1.2 – 3.9	0.03 – 0.48	23.28
	36$^{S, 1}$	60	1.4 – 4.3	0.01 – 0.94	10.00
	39$^{S, 1}$	24	2.5 – 4.8	0.15 – 1.32	24.00
	44^{A}	30	1.4 – 2.8	0.03 – 0.19	*
	44^{S}	21	1.6 – 3.0	0.05 – 0.29	*
	45^{S}	20	1.7 – 4.8	0.04 – 0.63	*
	48^{A}	24	1.8 – 3.6	0.06 – 0.48	*
	50^{A}	1	1.6	0.04	*
Silurus glanis	47$^{A, 2}$	1	26.8	105.88	0.02
Syngnathus abaster	45^{S}	3	6.0 – 7.2	0.10 – 0.19	*

^{A}: Autumn; ^{S}: Spring; ^{1}:Electro-shocker; ^{2}: Gillnet; ^{3}: Beach seine-net; *Scoop net; **Seine-net

Discussion and Conclusion

As a result of the observations made in the field, remarkable four problems are determined: (1) dryness due to atmospheric conditions and/or overuse of water in domestic/industrial sector/agricultural irrigation, (2) water pollution, (3) the presence of invasive-alien or translocated fish and (4) deterioration of river continuity (horizontally and vertically) due to hydraulic structures such as dams, flood protection structures and culverts. Many of these problems affecting Küçük Menderes River basin are thought to be the consequences of the pressures of the increasing urbanization level. We observed that while drought is the main problem for some stations, two or more problems mentioned above are effective together in the others.

In river ecosystems, fish could not be caught in total 31 stations in both sampling periods, and also19 of them were dry in both seasons. Even though 5 of them were wet in one sampling period, no fish were detected. On the other hand, habitat losses as a result of pollution and/or hydraulic structures affected 7 stations negatively (St. 7, 11, 16, 17, 18, 19, and 20) (Table 1). Fish only sampled from 11 stations; six of them were sampled in both seasons (St. 8, 22, 23, 28, 31, and 36) and five stations (St. 15, 21, 25, 33, and 39) were dry in autumn 2017, but there were water and fish in spring 2018. Since the river basin is located in the Mediterranean climate zone, the drought is expected in the riverbed in the summer period with decreasing rainfall. However, the high number of dry stations in the streams throughout the year is remarkable. This situation is not only a result of the meteorological situation but also the dams built for domestic uses or irrigation purposes. It is recommended to release the water to the riverbeds from the dams to keep the ecological processes to continue healthily.

There is a water pollution problem throughout Küçük Menderes River Basin, from the headwater to the Pamucak coast where it flows into the sea. According to field observations, the problem becomes more distinct especially in the settlement areas along the main river branch. The most prominent example of water pollution was observed in two stations located on Fetrek Creek. The first station located before the settlement area (St. 15) was dry, however, the second station was wet with domestic or industrial wastewater flow along the riverbed after the settlement area (St. 16). In order to protect the whole ecosystem, it is necessary to prevent domestic and industrial wastewater discharged to the environment without suitable treatment.

As a result of the fishing done in Küçük Menderes River Basin, 21 fish species were detected (Table 2) and three of them, *G. holbrooki*, *C. gibelio* and *C.*

auratus are invasive-alien fish for the freshwater fish fauna of Turkey (İnnal & Erk'akan, 2006; Tarkan et al., 2015). *Gambusia holbrooki* was captured from six stations (Table 2), one of them is the Hırsız Stream, which is the outlet water of the Alaçatı Dam Lake, with high catch efficiency and the other is Kuskudan Stream-1 station, which is the outlet water of Mordoğan Pond (Table 3). In these two stations, the streams are very shallow and have a very weak flow, which is almost stagnant. Although *G. holbrooki* has a wide habitat tolerance, it prefers to be in stagnant or slow-flowing waters compared to fast-flowing waters (García-Berthou, 1999; Pyke, 2005). Since there is no other fish to compete, *G. holbrooki*, an opportunistic species, is considered to have high catch efficiency at these two stations. The other four stations, where this invasive fish was determined, are the shores of the lentic water bodies (Table 2). They were obtained by using a scoop-net. The catch efficiency at these stations could not be evaluated as no specimen was caught with the standard fishing nets used in the lakes. The other two invasive-alien fish, *C. gibelio* and *C. auratus*, have entered into Turkish inland waters in the early 1980s and their first records were given from the Gala Lake in Evros River Basin (Baran & Ongan, 1988). Over time, they were introduced to other water basins in Turkey by stocking purposes. *C. auratus* was detected only from Alaçatı Dam Lake and *C. gibelio* was detected from one stream station (St. 15, Fetrek Creek) and four lentic water bodies (Table 2). It is quite important to control these three invasive species in the basin and to determine their interactions with native species which many of them are endemic fish species.

Four species, *A. boyeri*, *S. glanis*, *P. fluviatilis*, and *C. carpio,* which are native members of the freshwater fish fauna of Turkey, are translocated fish for the basin. The most important factor in their voluntary/accidental translocation is fish stocking. They can easily become dominant fish with the absence of natural predators in the inland water environment. They enter or/with their biological features such as reproduction and feeding. These translocated species, which are mostly preferred for economic reasons, may threat to biodiversity (McKinney, 2001; De Silva et al., 2009). It should be preferred to give priority to native fish species while stocking fish in river basins. Also, maximum attention should be shown not to move the unwanted species to the new environment together with the species preferred in fisheries. When an alien fish species enters a new environment, it will be both very difficult and quite expensive to remove it from there.

There are some hydraulic structures such as dams, culverts, flood protection structures, weirs and bridges in Küçük Menderes River Basin that destroy the stability of the river both horizontally and vertically. Besides, the other threats such as to take the natural riverbed in a channel, the destruction of the meanders or riparian areas, the fortification of the river banks with concrete or rocks are also remarkable for the basin. All these interventions affect the biodiversity of both the river and the terrestrial area where it interacts. Excluding the five dam lakes, one or more of the hydraulic structures listed above are present in almost all stations. Evaluating the native fish species of Küçük Menderes River basin, different fish species may show different habitat preferences from upstream to downstream; some (*A. demiri, B. pergamonensis*) prefer fast-flowing regions, while others (*R. amarus, P. smyrnaeus*) prefer slow-flowing regions with abundant vegetation; some species (*C. fahireae*) prefer sandy-muddy ground while others (*O. germencicus, R. amarus*) prefer stony sediment. However, structures in the habitat of these fish are very important threat to the survival of them. *Barbus pergamonensis, O. germencicus, P. smyrnaeus* and *S. kosswigi* are the endemic fishes living in these streams and further intervention in the riverbed may threaten the existence of these fishes in the future. Especially, in the upstream direction of the Fetrek Creek, there are deep oxbow lakes formed by the closure of the meanders and these small oxbow lakes are thought to have been used as shelters for these endemic fishes as well as other aquatic organisms during arid periods. Therefore, these deep oxbow lakes should be protected, intervention to their natural structure should be avoided and its water should not be used for irrigation. To ensure the stability of the river basin, the coordinates, types and features of all hydraulic structures should be documented and the unnecessary structures should be demolished and environmentally friendly solutions such as fish passages should be developed.

As a result of urbanization, Tahtalı, Beydağ, Kavakdere, Seferihisar, and Alaçatı dams were built for both domestic use and irrigation purposes to meet the needs of the growing population. Although these dams have already pressure on the habitat use of the native fish fauna, the introduced/translocated fishes are also important threats in the dams and the streams of the sub-basins. The Tahtalı Dam, built on the Gümüldür Stream in the 1990s, is the most important drinking water body in Izmir city and the streams and their environments in the dam sub-basin are protected by the local authorities. Despite, this sub-basin is rich in endemic species (*A. demiri*, *B. pergamonensis, C. fahireae, O. germencicus, P. smyrnaeus* and *S. kosswigi*), it is also under threat of invasive (*C. gibelio*) and translocated (*C. carpio* and *P. fluviatilis*) fish species. In the Şaşal and Tahtalı creeks, the main sources of the Tahtalı Dam, all the fish species are Anatolian endemics except *C. gibelio* (in the Şaşal Creek) and the abundance of these endemics is higher than invasive one, since *C. gibelio* mostly prefers lentic systems to lotics ones (Table 3). Although it has the potential to become one of the dominant fish of the Tahtalı Dam with its reproductive success, it has to share the same biotope with the predators *P. fluviatilis* and *S. glanis*, which were introduced to the dam for stocking purposes. These predator fishes may also control the overgrowth of *C. gibelio* population.

Previous studies reported 19 fish species living in Küçük Menderes River Basin (Karaman, 1972; Balık, 1979; Balık et al., 1995; Sarsu, 1981; İlhan et al., 2009; Korkmaz et al., 2015). Four fish species *C. holmwoodii*, *A. bipunctatus, C. carassius* and *M. cephalus*, which are reported from Gümüldür Stream, were not found in the present study. During the sampling period, the lower part of Gümüldür Stream, located at the downstream of the Tahtalı Dam embankment, was dry and seawater had entered to some part of the stream. On the other hand, the fish may have become stuck in a narrow area under changing habitat conditions after the dam construction in the upstream.

Atherina boyeri, C. auratus, S. glanis, S. abaster and *K. caucasica* were reported from the basin for the first time. It is thought that *A. boyeri* (only in Kavakdere Dam Lake)*, C. auratus* and *S. glanis* entered into the basin through fish stocking as mentioned above. *Syngnathus abaster* are originally marine fish, and the only area which is expected to catch of this fish was Gebekirse Lake because of its connection to the sea. Additionally, *K. caucasica*, a small-bodied fish that is very difficult to catch with gillnets, captured from two lakes, Kavakdere Dam Lake and Gebekirse Lake, using a small scoop-net indicating the importance of using different fishing gear to reveal the fish fauna in the ecosystems.

In conclusion, the fish fauna of Küçük Menderes River Basin (İzmir) and their abundances have been studied in detail for the first time. Total 21 fish species have been obtained, however, the number of fish species is likely to be higher. The reasons of the low number of fish species could be as follows; only two sampling periods (spring and autumn), pollution and drought in several stations, the limited (1 or 2) number of the stations in the river tributaries and the gillnet/seine net selectivity in lakes, dams and transitional waters. Six fish species (*A. boyeri*, *S. abaster*, *C. aurata*, *C. ramada*, *Chelon* sp. and *S. fluviatilis*) in the basin are of marine origin with high salinity tolerance and can live in inland waters. *Silurus glanis* and *P. fluviatilis* are native members of the freshwater fish fauna of Turkey and they were introduced into Küçük Menderes River basin for stocking purposes and these two species may threaten the existence of native fishes by their predation pressures. Therefore, it is very critical to monitor and also determine the consequent effects of these invasive and introduced species on the fish fauna, especially native species, of the basin. In addition, all stakeholders should use water with an ecosystem-based approach and prefer nature-friendly methods to eliminate the threats mentioned above in detail.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Kentleşmenin Küçük Menderes Nehir Havzası (Türkiye) Balık Toplulukları Üzerindeki Baskısı

Nehir havzaları, suyolları olmaları nedeniyle biyosferde önemli bir role sahiptirler ve insanlar tarafından ulaşımda, balıkçılıkta, hidroelektrik üretimi ile evsel, endüstriyel ve tarımsal su temini amaçlarıyla kullanılmaktadırlar. Batı Anadolu'nun önemli akarsularından biri olan Küçük Menderes Nehri, Türkiye'nin metropollerinden biri olan İzmir ili boyunca devam ederek Ege Denizi'ne akmaktadır. Kentleşme, balıkları da kapsayan sucul fauna ve florada meydana gelen değişimlerle bağlantılı olup sıklıkla balık çeşitliliği, zenginliği ve yoğunluğunda azalmaya yol açmaktadır. Günümüzde Küçük Menderes Nehri, verimli tarım arazileri ve yüksek sanayi ve turizm potansiyeli nedeniyle yapılaşmanın baskısı altındadır. Bununla birlikte, havzadaki altyapı eksikliği (kanalizasyon, arıtma tesisleri, vb.) ve hızlı nüfus artışı su kirliliğine/kaybına ve su dengesinin bozulmasına neden olmaktadır. Bu çalışmanın amacı, kentleşme baskısı altındaki Küçük Menderes Nehir Havzası'nın balık faunası ile bunların bolluklarını belirlemektir.

Saha çalışmaları, Küçük Menderes Nehir Havzası'ndaki toplam 50 örnekleme istasyonunda (42 akarsu, 1 geçiş suyu, 2 doğal göl ve 5 baraj gölü) Kasım (2017) ve Mayıs (2018) aylarında gerçekleştirilmiştir. Balık örnekleri akarsularda elektroşoker kullanılarak, geçiş sularında ise kıyı sürütme ağıyla toplanmıştır. Göllerdeki balık örneklemeleri çoklu göz açıklıklarına sahip standart bentik ve pelajik galsama ağları ile yapılmıştır. Toplanan örnekler anestezik çözelti ile bayıltıldıktan sonra %5'lik formaldehit çözeltisine aktarılmıştır. Laboratuvar çalışmasında, her balık için standart boy (SL, cm) ve toplam vücut ağırlığı (W, g) ölçümleri yapılmıştır. Her istasyon için balık bolluğu, birim çaba başına düşen av miktarı (CPUE) hesaplanmıştır.

Çalışılan 50 istasyonun %38'inde (19 istasyon) balık bulunmasına rağmen diğer istasyonlarda kirlilik (7 istasyon) ve kuruma (24 istasyon) nedeniyle balık yakalanamamıştır. Çalışma sonucunda 14 familyaya ait toplam 21 balık türü elde edilmiştir: *Alburnus demiri, Anguilla anguilla, Atherina boyeri, Barbus pergamonensis, Carassius auratus, Carassius gibelio, Chelon ramada, Cobitis fahireae, Cyprinus carpio, Gambusia holbrooki, Knipowitschia caucasica, Chelon aurata, Chelon* sp.*, Oxynoemacheilus germencicus, Perca fluviatilis, Petroleuciscus smyrnaeus, Rhodeus amarus, Salaria fluviatilis, Silurus glanis, Squalius kosswigi* ve *Syngnathus abaster*. Cyprinidae, dört taksonla en yüksek tür zenginliğine sahiptir ve en yaygın olarak bulunan balık türleri *S. kosswigi* (8 istasyon) ve *C. carpio* (7 istasyon)'dur.

Yakalanan balık türleri bollukları açısından değerlendirildiğinde, akarsu istasyonlarında CPUE (adet/dk/m^2) değerleri 0,01 ile 24,00 arasında değişmiş olup *G. holbrooki* Hırsız (CPUE=23,28 adet/dk/m^2) ve Kuskudan (CPUE=24.00 adet/dk/m^2) derelerindeki en baskın balık türüdür. Göl istasyonlarındaki balıklara ait CPUE (adet/s/m^2) değerleri 0,01 ile 62,43 arasında değişmiş olup *P. fluviatilis* Beydağ Baraj Gölü'nde en baskın balık türüdür (CPUE = 62,43 adet/s/m^2). *Alburnus demiri*, *O. germencicus, P. smyrnaeus* ve *S. kosswigi* havzadaki Anadolu endemikleri iken *A. boyeri* Kavakdere Baraj Gölü için yabancı, *G. holbrooki* ise Küçük Menderes Nehir Havzası için yabancı / istilacı balık türüdür.

Bu çalışmada, sahada yapılan gözlemler sonucunda, temel dört sorun tespit edilmiştir; (1) meteorolojik koşullar ve/veya evsel/endüstriyel kullanımlar ile /tarımsal sulama gibi nedenlerden

kaynaklı kuruma, (2) su kirliliği, (3) istilacı, yabancı veya taşınmış balıkların varlığı ve (4) barajlar, taşkın koruma yapıları ve menfezler gibi hidrolik yapılardan dolayı nehir sürekliliğinin bozulması. Bazı istasyonlar için ana sorun kuruma olsa da, bazılarında iki veya daha fazla sorunun birlikte etkili olduğu gözlemlenmiştir.

Nehir ekosistemlerinde her iki örnekleme döneminde toplam 31 istasyonda balık yakalanamamıştır. Bunlardan 19'u her iki mevsimde de kuruyken, 5'inde bir örnekleme döneminde su olmasına rağmen balık tespit edilememiştir. Diğer yandan, kirlilik ve/veya hidrolik yapıların etkisi sonucu olarak yaşanan habitat kayıpları 7 istasyonu (7, 11, 16, 17, 18, 19 ve 20) olumsuz etkilemiştir. Balık sadece 11 istasyondan yakalanabilmiştir ve bunların altısında (8, 22, 23, 28, 31 ve 36) her iki mevsimde su bulunurken beşinde (15, 21, 25, 33 ve 39) sadece ilkbahar örneklemesinde su bulunmaktaydı. Akarsulardaki bu kurumanın sadece meteorolojik nedenlerden kaynaklanmadığı, aynı zamanda evsel veya sulama amaçlı inşa edilen barajların etkisiyle de oluştuğu öngörülmüştür.

Küçük Menderes Nehir Havzası boyunca, nehrin membasından denize aktığı Pamucak sahiline kadar su kirliliği sorunu bulunmaktadır. Saha gözlemlerine göre sorun, özellikle ana nehir boyunca uzanan yerleşim alanlarında daha belirgin hale gelmektedir. Su kirliliğinin en belirgin örneği Fetrek Çayı'nda bulunan iki istasyonda gözlenmiştir. Yerleşim alanı öncesinde bulunan ilk istasyon (15. istasyon) kuru iken, yerleşim alanından sonra gelen ikinci istasyondaki akış halindeki suyun tamamen (16. istasyon) evsel veya endüstriyel kökenli olduğu görülmüştür.

Küçük Menderes Nehir Havzası'nda tespit edilen üç balık türü *G. holbrooki, C. gibelio* ve *C. auratus*, Türkiye içsu balık faunası için yabancı ve istilacı özellikteki balıklardır. Bunlara ek olarak tespit edilen diğer dört tür *A. boyeri, S. glanis, P. fluviatilis* ve *C. carpio* havzaya taşınmış balıklar olarak dikkat çekmektedir. Balık stoklaması çalışmalarında istemli veya istem dışı taşınmalar en önemli faktörlerdir ve bu yabancı balıklar girdikleri iç su ortamında doğal yırtıcıların bulunmaması ya da üreme ve beslenme gibi biyolojik özellikleri ile kolayca baskın balık haline gelebilirler. Çoğunlukla ekonomik nedenlerle tercih edilen bu türler biyolojik çeşitlilik için bir tehdit oluşturabilir.

Küçük Menderes Nehir Havzasında baraj, menfez, taşkın kontrol yapıları, savaklar ve köprüler gibi nehrin hem yatay hem de dikey yöndeki devamlılığını bozan bazı hidrolik yapılar bulunmaktadır. Buna ek olarak, doğal nehir yatağını beton kanala almak, kıyı bölgelerinin tahrip edilmesi, nehir kıyılarının beton veya kayalarla güçlendirilmesi gibi diğer tehditler de havza için dikkat çekicidir. Beş baraj gölü hariç, yukarıda listelenen hidrolik yapıların biri veya daha fazlası hemen hemen tüm istasyonlarda tespit edilmiştir. *Barbus pergamonensis, O. germencicus, P. smyrnaeus* ve *S. kosswigi* bu akarsularda yaşayan endemik balıklardır ve nehir yatağına yapılacak daha fazla müdahalenin gelecekte bu balıkların varlığını tehdit edebileceği düşünülmektedir.

Sonuç olarak, Küçük Menderes Havzası'nın (İzmir) balık faunası ve bollukları bu çalışma ile ilk kez ayrıntılı olarak incelenmiştir. Toplam 21 balık türü elde edilmiştir, ancak tür sayısının daha yüksek olması mümkündür. İstilacı ve taşınmış türlerin havzadaki balık faunası ve özellikle de doğal türler üzerindeki etkilerinin izlenmesi ve belirlenmesi oldukça önemlidir. Ayrıca, tüm paydaşlar ekosistem temelli bir yaklaşımla suyu kullanmalı ve yukarıda belirtilen tehditleri ayrıntılı olarak ortadan kaldırmak için doğa dostu yöntemleri tercih etmelidirler.

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Research Article

The Trichoptera Fauna of Ulupınar Stream and Its Relationship with Water Quality

Ulupınar Çayı'nın Trichoptera Faunası ve Su Kalitesi ile İlişkisi

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Abstract

In this study it was aimed to determine the Trichoptera fauna and water quality of Ulupınar Stream which is an important tourism destination of Antalya, based on physicochemical parameters. In recent years, this stream was adversely affected by intensive agriculture, farming and domestic wastes and was exposed to various pollutants. Seasonal analyses of physicochemical parameters and sampling of organisms belonging to the order Trichoptera were carried out from six stations selected between November 2015 and June 2016. 6 families, 10 genera and 21 species belonging to order Trichoptera were identified. Similarities between the sampling points were clustered by using Unweighted Pair Group Method with Arithmetic Mean. As a result of the Unweighted Pair Group Method with Arithmetic Mean. analysis, the 4^{th} and 6^{th} sampling point (85%) were the most similar to each other. The Principal Component Analysis was used to determine the factors caused the pollution. The Principal Component Analysis was applied to only physicochemical data sets resulted in three principal components accounting for a cumulative variance of 80.9% of for Ulupınar Stream.
Keywords: *Trichoptera, Ulupınar Stream, water quality, principle component analysis*

Öz

Bu çalışmada Antalya'nın önemli bir turizm bölgesi olan Ulupınar Çayı'nın Trichoptera faunası ve su kalitesinin fizikokimyasal parametrelere göre belirlenmesi amaçlanmıştır. Son yıllarda bu çay yoğun tarım, çiftçilik faaliyetlerinden ve evsel atıklardan olumsuz etkilenmiş ve çeşitli kirletici maddelere maruz kalmıştır. Fizikokimyasal parametrelerin mevsimsel analizleri ve Trichoptera takımına ait organizmaların örneklenmesi Kasım 2015 ile Haziran 2016 tarihleri arasında seçilen altı istasyondan gerçekleştirildi. Trichoptera takımına ait 6 familya, 10 cins ve 21 tür tespit edildi. Örnekleme noktaları arasındaki benzerlikler Aritmetik Ortalamalı Ağırlıksız Çift Grup Yöntemi kullanılarak kümelenmiştir. Aritmetik Ortalamalı Ağırlıksız Çift Grup Yöntemi analizinin bir sonucu olarak, 4. ve 6. örnekleme noktaları (85%) birbirine en çok benzeyen istasyon olmuştur. Kirliliğe neden olan faktörleri belirlemek için Temel Bileşen Analizi kullanıldı. Yalnızca fizikokimyasal veri setlerine uygulanan Temel Bileşen Analizi, Ulupınar Çayı'nın 80,9%'unun kümülatif varyansını oluşturan üç ana bileşene neden olmuştur.
Anahtar kelimeler: *Trichoptera, Ulupınar Çayı, su kalitesi, temel bileşen analizi*

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Introduction

In many countries, the need for water increases while unpolluted water resources are decreasing as a result of the deterioration of usable water resources with various factors. Due to this situation, various policies were developed to ensure the correct use and protection of natural resources both in our country and in other world states. The EU Water Framework Directive (WFD) implemented by the member states of the European Union (EU) is one of these directives. According to WFD, benthic macroinvertebrates are considered as one of the most important indicators. Pauls et al. (2008) stated that among the important benthic macroinvertebrates living in streams, members of order Trichoptera are used as a biological monitoring tool in determining water quality. When sedimentation, industrial pollution, mining and agriculture, sewage waste, acid rains accumulate on the water surface, these organisms are damaged (Graf et al., 2008).

Order Trichoptera are represented approximately with 49 families, 616 genera and 14.548 species in the world (Morse, 2011). Order Trichoptera are represented by 22 families, 461 species and 39 subspecies in Turkey (Darılmaz & Salur, 2015; Küçükbasmacı & Kıyak, 2017; Sipahiler, 2018a). In Turkey, as well as various faunistic studies were conducted to uncover the Trichoptera fauna, in ecological-based studies, the members of this order have been widely investigated as biological indicators. (Çakın, 1983; Darılmaz & Salur, 2015).

Ulupınar Stream, chosen as a study area, is flowed between Olimpos and Çıralı Bays in Antalya. Since the stream is flowed into the intensive tourism areas, many places such as pensions and restaurants are encountered on the stream or its edges.

This study aims to determine species of Trichoptera fauna of Ulupınar Stream, to determine the water quality used by physicochemical parameters and to examine the relationships between physicochemical parameters and Trichoptera species.

Method

Study Area

Ulupınar Stream, which has formed the Çıralı Plain and its coast, is born from the 900 m high slopes in the northwest of Ulupınar Village. The stream, springs from the karstic creeks, flows under the name of Hayıt Creek up to Kumluca - Antalya Highway, and then combines with Kuruseki Creek, coming from the east of Antalya with the branches of Cehennem Creek from the west of Antalya, and flows by name of Ulupınar Stream. The total length of the stream flowing in a tectono-karstic groove, is about 13 km.

The outfall section, where Ulupınar Stream disombogues into the Mediterranean Sea, generally turns north and sometimes turns south. Since the dominant wind on the shore blows from the southeast direction, the outfall of the stream is mostly shifted to the north. Although plane tree is the dominant vegetation of the valley floor of Ulupınar Stream, and on the slopes of the valley, the dominant vegetation is red pine, almost all species of maquis are common. The characteristics of sampling stations were presented in Table 1.

Collection of Trichoptera Samples

Samples were collected by 20 minutes by kicking and sweeping methods with kick-net (250 µm mesh). The samples were taken from several different sections at each station in order to include all possible microhabitats. All the samples collected were immediately fixed in formaldehyde (4%) in the field. Trichoptera individuals were taken to SDU Hydrobiology Laboratory and stored in 70% alcohol. The obtained samples were examined under a stereomicroscope and evaluated qualitatively and quantitatively.

Edington & Hildrew (1995), Pitsch (1993), Pescador et al. (1995), Wallace et al. (1990), Wiggins (1998), Waringer & Graf (2011) were used in species diagnoses.

Table 1

Key Characteristics of Sampling Stations across Ulupınar Stream

Sampling Station	Coordinates (N-E) and Altitude (m)	Habitat	Stream Morphology	Riparian Vegetation
1	36º 27’ N 30º 26’ E 245 m	Macrolithal	Macrophyte present	Well-developed on both sides.
2	36º 27’ N 30º 26’ E 246 m	Microlithal	Macrophyte present	Well-developed on both sides.
3	36º 26’ N 30º 26’ E 265 m	Macrolithal	Macrophyte present	Not well- developed
4	36º 27’ N 30º 26’ E 201 m	Megalithal	No Macrophyte present	Not well- developed
5	36º 27’ N 30º 25’ E 186 m	Macrolithal	Macrophyte present	Not well- developed
6	36º 25’ N 30º 26’ E 54 m	Microlithal	Macrophyte present	Not well- developed

Physicochemical Parameters

1 L polyethylene sample containers were used for water sample collection. Water samples were taken seasonally between November 2015 and June 2016 from each of the 6 stations. I paid attention to take the samples concurrently.

Water temperature (°C), pH, electrical conductivity (EC) µS/cm and dissolved oxygen (DO) mg/L were measured in the field by using a portable multiparameter (YSI 550A) device. Ammonium nitrogen (NH_4-N) mg/L, Nitrite nitrogen (NO_2-N) mg/L, Nitrate nitrogen (NO_3-N) mg/L, Ortho-phosphate ion (PO_4-P) mg/L, Chloride Ion (Cl^-) mg/L, Biological oxygen demand (BOI_5) (mg/L) were analysed at the University of Süleyman Demirel, Geothermal Energy, Groundwater and Mineral Resources Research and Application Centre.

In this study, physicochemical water quality was determined according to Klee (1991) methods and the Turkish Regulation for Water Pollution Control (WPCR) (2008) of the Ministry of Forestry and Water Management of the Republic of Turkey.

Data Analysis

The faunal similarities based on Trichoptera fauna between the sampling stations were assessed by using the Bray-Curtis similarity index (Sommerfield, 2008; Yoshioka, 2008). UPGMA analysis based on Bray-Curtis similarity index was applied by using the PAST3 software program. All mathematical and statistical analyses on the physicochemical and biological data sets were made by using Excel 2019 (Microsoft Office^R) (Kazi et al., 2009).

Principal Component Analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert the observation set of interrelated variables into the values of linearly unrelated variables called principal components. In this study, PCA analysis was used to evaluate the statistical correlation between physicochemical variables in Ulupınar Stream.

Results

Physicochemical Variables

The physicochemical variables were recorded seasonally. The maximum, average and minimum recorded values at the stations are given in Table 2.

Table 2

Minimum, Average and Maximum Values of Physicochemical Parameters at the Six Stations in Ulupınar Stream

		DO	pH	T°C	EC	Cl^-	NH_4-N	NO_2-N	NO_3-N	PO_4-P	BOD_5
1	Min.	6.31	7.47	10.9	269.5	5.15	<0.05	<0.01	0.09	<0.05	0.10
	Avg.	8.60	7.84	16.4	355.6	9.35	<0.05	<0.01	0.22	<0.05	1.69
	Max	9.91	8.11	19.7	451.0	19.95	<0.05	<0.01	0.41	<0.05	3.52
2	Min.	6.17	8.03	11.5	272.0	5.87	<0.05	<0.01	0.28	<0.05	0.59
	Avg.	8.01	8.28	16.6	297.1	8.04	<0.05	<0.01	1.20	<0.05	1.88
	Max	9.26	8.5	21.9	333.1	10.52	0.06	<0.01	2.98	<0.05	3.24
3	Min.	6.57	7.97	12.5	237.6	5.84	<0.05	<0.01	0.24	<0.05	0.54
	Avg.	8.40	8.19	15.0	258.4	6.32	<0.05	<0.01	0.34	<0.05	2.42
	Max	9.24	8.46	16.1	286.4	6.96	0,10	<0.01	0.61	<0.05	3.75
4	Min.	6.73	7.94	12.1	291.1	6.34	<0.05	<0.01	0.13	<0.05	0.56
	Avg.	8.68	8.15	16.3	327.9	7.20	<0.05	<0.01	0.30	<0.05	2.40
	Max	9.80	8.37	19.8	385.2	8.54	<0.05	<0.01	0.48	<0.05	4.00
5	Min.	8.44	7.77	12.9	219.0	5.57	<0.05	<0.01	0.15	<0.05	2.31
	Avg.	9.18	8.15	13.9	236.4	7.53	<0.05	<0.01	0.24	<0.05	3.03
	Max	9.99	8.41	14.6	258.6	12.64	<0.05	<0.01	0.31	<0.05	4.00
6	Min.	6.01	7.95	12.2	320.1	14.89	<0.05	<0.01	0.02	<0.05	0.65
	Avg.	7.79	8.08	19.5	427.4	16.9	<0.05	<0.01	0.26	<0.05	2.04
	Max	9.52	8.27	24.3	500.0	19.58	<0.05	<0.01	0.58	<0.05	3.75

When minimum, average and maximum values of physicochemical parameters were evaluated, it was found that the Dissolved Oxygen (DO) values varied with the stations and seasons. Its average values were fluctuated between 7.79 mg/L (station 6) and 9.18 mg/L (station 5). Average pH values were close to each other for 6 stations and all seasons. The lowest average pH value was measured at 1st station with 7.84, and the highest average value was measured at 2nd station with 8.28. The average values of the BOD_5 in the station 5 had the highest value with 3.03 mg/L and in the station 1it had the the lowest value with 1.69 mg/L while the electrical conductivity (EC) values were varied between 236.4 µS/cm (station 5) - 427.4 µS/cm (station 6). The highest ammonium nitrogen (NH_4-N) in Ulupınar Stream was measured as 0.10 mg/L at the 3rd station. NH_4-N value was measured as <0.05 mg/L at all other stations. It has been determined that nitrite nitrogen (NO_2-N) (<0.01 mg/L) and ortho phosphate (PO_4-P) (<0.05 mg/L) values were below the analysis limits. The measured values of nitrate nitrogen (NO_3-N) differed by stations and seasons. Average values were determined between 0.22 mg/L (station 1) and 0.34 mg/L (station 3). The average chloride (Cl^-) ion values varied between 6.32 mg/L (station 3) - 16.9 mg/L (station 6).

The result of the correlation matrix of physicochemical components based on PCA and the biplots, which are the graphical representation of factor loadings in different components (Component 1, Component 2 and Component 3) are given in Figure 1. The PCA was applied on 10 physicochemical parameters for Ulupınar Stream with six sampling stations to determine the variations in water quality. In this study, the eigenvalues were greater than 1 at Component 1, Component 2 and Component 3. The PCA analysis led to the explanation of 80.9% variance in case of Ulupınar Stream. According to Liu et al. (2003), the factor loadings classified as “strong”, “moderate” and “weak” corresponding to precise loading values of>0.75, 0.75–0.50 and 0.50–0.30, respectively.

Figure 1

Biplots for PCA analysis of physicochemical water quality in Ulupınar Stream

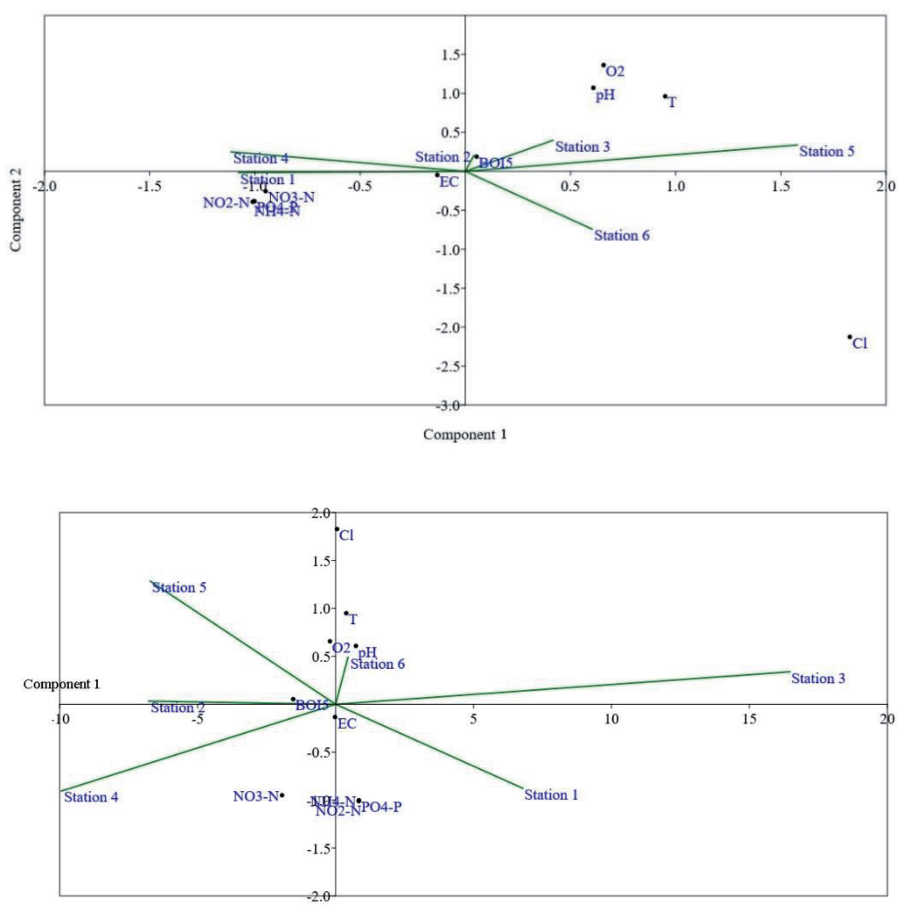
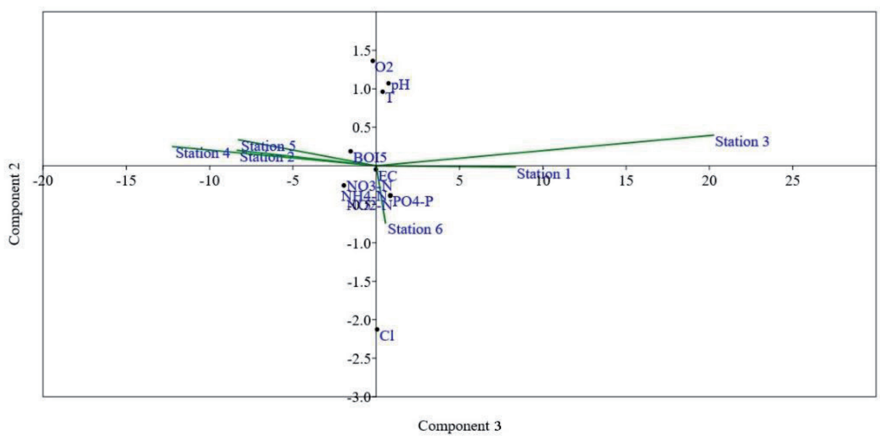


Figure 1

(Continued)



According to the data set pertaining from Ulupınar Stream, among three PCs, the Component 1 explaining 67.7% of the total variance ha strong positive loading on T°C, and Cl^-, moderate positive loading on DO, BOI_5 and pH whereas negative strong loading on NH_4-N, NO_3-N, NO_2-N and PO_4-P. The positive loading on T°C, Cl^-, DO, BOI_5 and pH have been related to pollution. According to Solanki et al. (2010), the opposite relationship between T°C and NH_4-N, NO_3-N, NO_2-N and PO_4-P are a natural process in freshwaters. According to Component 2, 30.8% of total variance has strong positive loading on DO, T°C and Ph. The strong negative loading on Cl^- in component 2. According to Component 3, 23.1% of total variance has strong positive loading on Ph, NH_4-N, NO_2-N and PO_4-P. PCA analysis is a statistical analysis that indicates which parameters are more effective in data with many variables.

Trichoptera Dataset

In this study 10 genera of 6 families belonging to the subgroup of Trichoptera, Annulipalpia, Integripalpia and Scipipalpia, and 21 taxa related to these species were determined. A total of 1.367 individuals were examined. Diagnosis of some 7 genus samples could not be made due to the lack of sufficient resources in the larval diagnostic keys used or because the samples did not complete their development. Taxa given in genus level are *Hydropsyche* sp., *Glossosoma* sp., *Agapetus* sp., *Hydroptila* sp., *Oxyethira* sp., *Rhyacophila* sp. and *Agraylea* sp. The taxa of Trichoptera fauna determined in Ulupınar Stream and their distribution by stations are given in Table 3.

Table 3

Distributions of Trichoptera Taxa in the Stations

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Phylum: Arthropoda Class: Insecta Order: Trichoptera						
Familya: Glossosomatidae						
Agapetus sp.			8		21	
Glossosoma sp.	1			1	1	4
Familya: Hydropsychidae						
Cheumatopsyche lepida	18					1
Hydropsyche fulvipes	9	3	49	140	134	135
Hydropsyche instabilis	2	2				18
Hydropsyche botosaneanui				19		2
Hydropsyche dinarica				6		3
Hydropsyche pellucidula	15	13	12			
Hydropsyche sp.	186	7	30	138	98	159
Familya: Hydroptilidae						
Agraylea multipunctata	1					
Agraylea sp.				7		
Hydroptila occulta				2		1
Hydroptila sp.	22			26	1	9
Oxyethira flavicornis				2		6
Oxyethira sp.	12			3		
Familya: Limnephilidae						
Limnephilus flavicornis			2			
Familya: Rhyacophilidae						
Rhyacophila dorsalis				2	14	2
Rhyacophila obliterata					8	
Rhyacophila pubescens					7	
Rhyacophila sp.	1					
Familya: Sericostomatidae						
Sericostoma personatum				3	1	

The highest number of individuals in Ulupınar Stream was determined at the 4th station (349). In other stations, the ranking was 6th station (340), 5th station (285), 1st station (267) and 3rd station (101), and 2nd station (25) with the lowest number of individuals.

In the 1st station, 267 individuals belonging to a total of 10 taxa were examined. The species with the highest number of individuals is *Hydropsyche* sp. (186), while this taxon *Hydroptila* sp. (22), *Cheumatopsyche lepida* (18), *Hydropsyche pellucidula* (15), *Oxyethira* sp. (12) and *Hydropsyche fulvipes* (9), *Glossosoma sp.* (1), *Rhyacophila sp*. (1) and *Agraylea multipunctata* (1) followed the species.

In the 2nd station, 25 individuals were identified and 13 of these individuals are belonging to *Hydropsyche pellucidula*, 7 individuals are belonging to *Hydropsyche sp.,* 3 individuals are belonging to *Hydropsyche fulvipes,* and lastly 2 individuals are belonging to *Hydropsyche instabilis*. At this station, a total of 4 taxa have been determined and it has the the least taxon among the other stations. Hydropsyche is the dominant breed both in terms of individual number and taxon number.

While determining 5 taxa at the 3rd station, the taxon represented by the highest number of individuals was *Hydropsyche fulvipes* (49), followed by *Hydropsyche* sp. (30), *Hydropsyche pellucidula* (12), *Agapetus* sp. (8) and *Limnephilus flavicornis* (2).

The highest number of taxa (12) and the highest number of individuals (349) in Ulupınar Stream were determined in the 4th station. In the 4th station, taxa according to the number of individuals are *Hydropsyche fulvipes* (140), *Hydropsyche* sp. (138), *Hydroptila* sp. (26), *Hydropsyche botosaneanui* (19), *Agraylea* sp. (7), *Hydropsyche dinarica* (6), *Oxyethira* sp. (3), *Sericostoma personatum* (3), *Hydroptila occulta* (2), *Oxyethira flavicornis* (2), *Rhyacophila dorsalis* (2), *Glossosoma sp.*(1).

In the 5th station, a total of 285 individuals belonging to 9 taxa have been identified and it takes third place in terms of number of individuals. *Hydropsyche fulvipes* (134) has the highest number of individuals among the determined taxa, whereas *Hydropsyche* sp. (98), *Agapetus* sp. (21), *Rhyacophila dorsalis* (14), *Rhyacophila obliterata* (8), *Rhyacophila pubescens* (7), *Hydroptila sp*. (1), *Glossosoma sp*. (1) and *Sericostoma personatum* (1) follow the taxa.

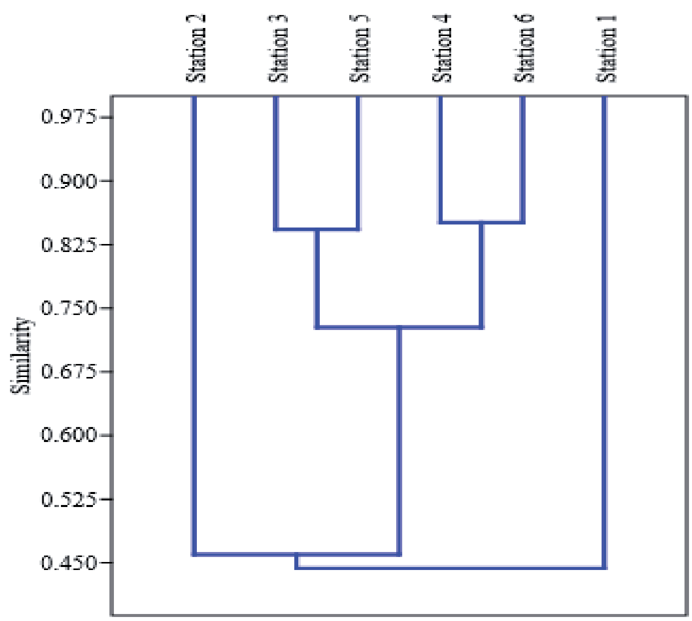
In the 6th station, 11 taxa and 340 individuals belonging to the Trichoptera order were determined and ranked second among the stations in terms of the number of species. While the taxon with the highest number of individuals in this station is *Hydropsyche* sp. (159), this taxon is *Hydropsyche fulvipes* (135), *Hydropsyche instabilis* (18), *Hydroptila* sp. (9), *Oxyethira flavicornis* (6), *Glossosoma* sp. (4), *Hydropsyche dinarica* (3), *Rhyacophila dorsalis* (2), *Hydropsyche botosaneanui* (2) followed by *Hydroptila occulta* (1) and *Cheumatopsyche lepida* (1).

The classification of the stations based on benthic macroinvertebrates composition was illustrated by using Bray-Curtis UPGMA analysis (Figure 2). As a result of the UPGMA analysis, the 4th and 6th stations (85%) were the most similar to each other. The second most similar stations to each other were determined at the 3rd and 5th stations (83%).

As a result of seasonal studies carried out in Ulupınar Stream between November 2015 and June 2016, 516 individuals were found in autumn (November), 239 individuals in winter (February), 452 individuals in spring (March) and 160 individuals in summer (June).

Figure 2

Classification of Stations Based on Similarities of in Ulupınar Stream



Discussion and Conclusion

In fact, water can dissolve certain amounts of oxygen. The ability of water for dissolving oxygen is related with its temperature. Therefore, the cold water dissolves, more oxgen and also is better for living organisms (Jens, 1980). The highest water temperature value was determined at sixth stations with 24.3^{0}C. In this period, the stream width decreased to 30 cm and depth to about 5 cm. In this study, I found out that the amount of oxygen in Ulupınar Stream changed in parallel with the temperature changes and the flow rate in the stream was determined at very low levels during all sampling periods.

While some of the members of Trichoptera live in mountain streams with high oxygen content and low temperature, some are found in rivers and in lakes (Edington & Hildrew, 1995). In this study, 11 species were identified in February, when the water temperature was the lowest. Chemical and biochemical reaction rates increase as the temperature increases. While organisms usually survive between certain temperature values, temperature changes cause increase and decrease in development and respiratory rates (Tchobanoglous & Schroeder, 1985).

When the DO value falls below 0.5-1.0 mg/L in water, life in the water stops and values below 4 mg/L of DO cause negative effects on the development of living things (Goldwald, 1965; McNelly et al., 1979). Average DO values recorded at the six stations in Ulupınar Stream vary between 7.49 mg/L and 9.18 mg/L. The highest DO value was determined as 9.99 mg/L at 5th station, the lowest dissolved oxygen value was 6.01 mg/L at 6th station. The lowest T^{o}C value and the highest DO values were determined at the 5th station. This situation shows that the DO values are inversely proportional. At the 6th station, the flow rate is very slow, the amount of water is very low and the amount of DO is determined at the lowest levels due to the absence of shading.

In aquatic systems, living organisms have a tolerance to certain pH ranges and the pH value should vary between 6.5 and 8.5 in unpolluted natural waters (Hem, 1985; Barlas, 1988; Wetzel, 1983) because bicarbonate and carbonic acid work in buffering among these values (Barlas, 1988). Many natural waters are slightly alkaline because they contain carbonate and bicarbonate (Barlas, 2002). The pH value varies between 7.4 (station 1) and 8.5 (station 2) at all stations detected in Ulupınar Stream. According to the pH values, all stations are within the limits for living them and are included in the “Class-I” water quality class according to the WPCR.

Increased pollution in streams causes an increase in the EC values (Kara & Çömlekçioğlu, 2004; Verep et al., 2005; Kalyoncu et al., 2005). The highest EC value at Ulupınar Stream during the study period was measured at the 6th station in June (500 µS/cm). The lowest EC value was measured at the 5th station (356 µS/cm) in March.

Almost all natural waters have a certain amount of CI^- and the amount of CI^- in the beds with unchanged rocks may vary between 10-30 mg/L in natural spring waters (Barlas, 1988; Hütter, 1984). The average CI^- measured at the six stations was 6.32 mg/L at the 3rd station, while its highest value was 16.9 mg/L at the 6th station. These values represent the first class water quality according to the scale of the Klee and WPCR and it is within the limits for natural spring waters.

Ammonium content in water increases due to the deterioration of organic matter, especially organic fertilizer or inorganic fertilization, domestic and industrial wastewater (Egemen & Sunlu, 1996). Ammonium nitrogen average values were measured below the analysis limits at all stations.

While NO_3-N and NO_2-N in the waters may naturally originate from some minerals, the main source is organic substances and nitrogen fertilizers. The increase in organic substances rises the concentration of NO_3-N and NO_2-N, while decreases the amount of DO. Normally, NO_2-N should not be present in drinking and using waters (Baltacı, 2000; Barlas, 2002; Egemen, 2006). The presence of NO_2-N in waters is an indicator of pollution (Barlas, 2002). In all measurements made in Ulupınar Stream, NO_2-N was found below the analysis limits. NO_3-N, which is seen as the most common form of nitrogen in rivers, is found in very small amounts in clean waters and is an important source of nitrogen for plants. As a result of the rainwater washing the agricultural land, the NO_3-N originating from the fertilizers is easily dissolved in the water and mixed with the surface waters and streams (Barlas, 2002). The average NO_3-N values in the six stations ranged from 0.22 mg/L to 1.2 mg/L.

PO_4-P content is around 0.03 mg/L in mountain streams and streams not polluted. If this amount exceeds 0.1 mg/L, contamination can be suspected (Höll, 1979). Domestic wastes, volcanic rocks and soil are among the sources of phosphorus (Baltacı, 2000; Tanyolaç, 2000; Egemen, 2006; Cirik & Cirik, 2008). The PO_4-P value remained below the analysis limits in all field studies carried out at six stations.

The amount of BOI_5 in the oligosaprob region is 1.6 mg/L and it is below in natural waters. As a result of contamination, the BOI_5 value increases and the amount of DO decreases (LAWA, 1980). While BOI_5 values in streams yield the amount of organic matter, it provides the opportunity to compare the pollution rate between streams and stations (LAWA, 1980; Kocataş, 2008). While very high values were not determined in Ulupınar Stream, the highest BOI_5 was measured as 4.00 mg/L at the 4th and 5th stations. The existence of facilities and the effect of environmental pollution are reasons for the increase in values.

As a result of the evaluation made on physicochemical variables, according to Klee (1991), all stations were determined as the average value in the first quality class (*oligosaprob-uncontaminated),* while the first five stations were determined according to the WPCR in the case of the first quality class according to all parameters. According to the average value of DO, the water quality of the stream was determined as Class II.

Our study conducted on the Trichoptera fauna and water quality in Ulupınar Stream, is the new and recent study for this region. There is any study on Trichoptera fauna and water quality for Ulupınar Stream.

As a result of the studies carried out at the stations, *Agraylea multipunctata* species were found only at the 1st station. The station has an altitude of 245 m, the average T°C values varied between 10.9°C and 19.7°C. The taxon found in the first station has a low flow rate in this study. According to Graf et al. (2008), this taxon prefers stagnant waters. According to DIN 38410 (2004), this taxon is dispersed in the betamesosaprob region and was determined in the first quality class in this study.

Cheumatopsyche lepida was found at the 1st and 6th stations. In the Ulupınar Stream, this species ranged between the lowest 54 m altitude and the highest 245 m altitude. The temperature values determined by this taxon varied between 10.9°C and 19.7°C. Graf et al. (2008) stated that this taxon is seen in areas higher than 150 m and prefers high flow areas, and average temperature values are given between 8-20°C. The results obtained from the heights matched up with the literature. According to DIN 38410 (2004), this taxon is an organism that spreads in the *betamesosaprob* region and it was found in the oligosaprob region in this study.

In the study, most individuals belong to the Hydropsychidae family. It is stated that the distribution of Hydropsychidae [*H. fulvipes* (Curtis, 1834), *H. instabilis* (Curtis, 1834), *H. botosaneanui*, *H. dinarica*, *H. pellucidula* (Curtis, 1834)] members, commonly known as a cosmopolitan family, may be different according to factors such as DO, T°C, flow rate (Wiggins & Mackay, 1978; Williams & Feltmate, 1992).

Hydroptila occulta was found at the 4th and 6th stations and it was determined the average T°C values varied between 16,3°C and 19,5°C at the stations. In terms of altitude, it has been distributed in the stations with the altitude from 54 m to 201 m. According to DIN 38410 (2004), *Hydroptila* taxa are among the organisms that spread in *betamezosaprob* region. Graf et al. (2008) stated that *H. occulta* is distributed between 150-1900 m altitudes and shows good development in stagnant waters with a temperature of 5°C-18°C. Unlike the literature information, there are elevation and temperature differences in this stream.

Limnephilus flavicornis was found only at the 3rd station in summer (June). The average temperature of the station is 15ºC and its altitude is 265 m.

Oxyethira flavicornis was found at the 4th and 6th stations and it has an altitude from 54 m to 201 m and was determined at 16,3ºC and 19,5ºC in terms of average temperatures. Graf et al. (2008) stated that this taxon is distributed in the epirhitral, metarhitral and littoral regions of stagnant and slow flow streams at an altitude more than 150 m.

Rhyacophila dorsalis species was found in the 4th, 5th and 6th stations and the altitudes were determined at stations ranging from 54 m to 201 m. The average temperature values of the stations varied between 13.9ºC and 19.5ºC. While Akyıldız & Duran (2008) express this taxon in Class IV, Keşir (2016) determines it in Class I and Class II quality classes. According to DIN 38410 (2004), these organisms are belonging to the *betamesosaprob* region. The results in this study reveal that it is in Class I quality class. Kalyoncu et al. (2008) stated that they are distributed in Class I quality class.

Rhyacophila obliterata was detected only at 5th station and only in February. The temperature of the station is between 12.5ºC and 16.1ºC. The altitude was determined as 186 m. According to DIN 38410 (2004), these organisms are belonging to the *betamesosaprob* region.

Rhyacophila pubescens was found only in 5th station and in only November. The average temperature value of the station is 13.9ºC. The altitude value is 186 m. According to DIN 38410 (2004), these organisms are belonging to the *oligosaprob* region.

Sericostoma personatum was found in the 4th and 5th stations. The temperatures of the stations varied between 12,1ºC and 19,8ºC. It altitudes were between 186 m and 201 m. Zeybek & Şahin (2016) stated that this species spread in Munzur Stream. According to DIN 38410 (2004), these organisms are belonging to the *oligo-betamesosaprob* region.

In the stream, *Agapetus* sp. was determined at the 3rd and 5th stations while *Glossosoma* sp. was determined at the 1st, 4th, 5th and 6th stations and they show the distribution in *oligosaprob* and *oligo-betamesosaprob* regions according to the saprobi index (DIN 38410, 2004).

Agraylea sp. was determined only at the fourth station, *Hydropsyche* sp. was determined at all stations, *Hydroptila* sp. was determined at the first, fourth, fifth and sixth stations, *Oxyethira* sp. was determined at the first and fourth stations, *Rhyacophila* sp. was determined only at the first station. *Rhyacophyla* taxa are distributed between *oligosaprob* and *betamesosaprob* regions, but are generally organisms of the *oligosaprob* region (DIN 38410, 2004).

Taxa belonging to Trichoptera determined in this study are the new registration for this stream. Also, all stations are free from some or any contaminants in this stream, and according to Klee (1991), all stations are determined at the *oligosaprob* level. I can say that the organisms identified in these streams are distributed in clean or slightly contaminated freshwaters.

Although the majority of the organisms identified in this study distributed in clean or slightly contaminated river sections, species tolerant to organic pollution were also encountered. This may indicate that the working area and the organisms are under pollutant effects. Almost all of the Ulupınar Stream Basin has intense tourism activities. In addition, animal husbandry is done intensely in the region and it is known that the residues formed as a result of these activities are mostly poured into the nearest water environment and streams. Domestic wastes of small villages in the basin are also left uncontrolled to the streams and their surroundings. All these adverse conditions cause an increase in the pollution load of the river basin and affect the biodiversity of the basin as negatively. In this study, it was aimed to determine the Trichoptera fauna and the water quality of Ulupınar Stream. This and similar studies will contribute to establish Turkey’s Trichoptera fauna and shed light on other systematic and ecological studies.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Ulupınar Çayı'nın Trichoptera Faunası ve Su Kalitesi ile İlişkisi

Su canlıların yaşaması için gerekli olan temel ihtiyaçlardandır. Su kaynaklarında günden güne meydana gelen çeşitli sorunlar geri dönüşü olmayacak şekilde su kıtlığına neden olmaktadır. Avrupa Birliği üyesi ülkeler, su kaynaklarının kalite ve miktar yönünden incelenmesi ve korunmasını hedeflemiştir. Aynı zamanda yeraltı ve yerüstü tüm yüzey sularının korunması ve izleme programlarının geliştirilmesi, tüm suların iyi kalite su sınıfına (iyi durum) yükseltilmesini, biyolojik, kimyasal, hidrolojik ve morfolojik açılardan su kalitesinin tanımlanması, nehir havzaları temelinde su yönetiminin oluşturulması, ekonomik enstrümanların, ekonomik analizlerin ve suyun kullanımına dair doğru ekonomik yaklaşımların geliştirilmesi ve geliştirilen nehir havzası yönetimi planlarına vatandaşların, belediyelerin, sivil toplum örgütlerinin zorunlu kamusal katılımın sağlanması gibi birçok hedefleri gerçekleştirmeyi amaçlayarak Su Çerçeve Direktifini (SÇD) hazırlamışlardır. Su ile ilgili tüm unsurları bir çatı altında toplayan SÇD sayesinde su kalitesi, su kütlelerinin ekolojik ve kimyasal özelliklerine göre tespit edilir. Biyolojik kalite unsurlarının durumu suyun biyolojik kalitesi hakkında bizlere bilgi verir.

Daha önce üzerinde çalışma yapılmamış olan Ulupınar Çayı (Antalya) inceleme alanı olarak seçilmiştir. Bu araştırmayı yapma amacımız Ulupınar Çayı'nda bulunan Triphoptera faunasını belirlemek ve belirlenen faunaya göre suyun kirliliğini saptamaktır. Aynı zamanda yapılan fizikokimyasal ölçümlere göre bölgenin kirlilik ile ilgili net sonuçlarına ulaşılmaktır. Trichoptera takımı her tip tatlı su habitatında yaşamaları ve balıklara besin kaynağı olmalarından dolayı su ekosisteminin temel canlıları arasında yer almaktadır. Trıchoptera takımı hızlı akan sularda bulunmakta, aynı zamanda bulunduğu bölgenin ekolojik yapısı hakkında araştırmacılara bilgi vermekte ve kirliliğe karşı duyarlılık göstermektedirler.

Ulupınar Çayı'nda Kasım 2015 - Haziran 2016 tarihleri arasında yapılan çalışmada Trichoptera faunasını ve su kalitesini belirleyebilmek amacıyla arazi şartlarının uygunluğuna göre 6 istasyon seçilmiştir. İstasyonlar akarsudaki karışımları ve etkileşimi yansıtacak şekilde tespit edilmiş ve sürekli akış gösteren yan kollar dikkate alınmıştır. İstasyonların koordinatları ve rakımları GPS yardımı ile ölçülmüştür. Belirlenen istasyonlarda mevsimsel olarak fizikokimyasal su analizi ve Trichoptera takımına ait organizmaların belirlenmesi için örnekler alınmış ve incelenmesi yapılmıştır. Su örnekleri için koyu renkli 1 litrelik polietilen örnek alma kaplarından yararlanılmıştır. Yapılan örneklemelerin yaklaşık olarak aynı saatlerde alınmasına dikkat edilmiştir. Su sıcaklığı (°C), pH değeri, elektrik iletkenliği (µS/cm) ve çözünmüş oksijen (mgO_2/l) ölçümleri arazide portatif multiparametre (YSI 550A) cihazı kullanılarak yapılmıştır. Amonyum azotu (NH_4^+-N), Nitrit azotu (NO_2^--N), Nitrat azotu (NO_3^--N), Orto-fosfat iyonu (PO_4-P), Klorür İyonu (Cl^-), Biyokimyasal Oksijen İhtiyacı (BOI_5) analizleri (mgO_2/l) Süleyman Demirel Üniversitesi Jeotermal Enerji, Yeraltı Suyu ve Mineral Kaynakları Araştırma ve Uygulama Merkezi'nde yaptırılmıştır. Fizikokimyasal değişkenler üzerinden yapılan değerlendirme sonucunda Klee (1991)'ye göre tüm istasyonlar ortalama değer olarak I. kalite sınıfında (oligosaprob-Kirlenmemiş), Su Kirliliği Kontrolü Yönetmeliği'ne (SKKY, 2008) göre yapılan değerlendirmede ilk 5 istasyon tüm parametrelere göre I. kalite sınıfı durumunda belirlenirken sadece 6. istasyon çözünmüş oksijen ortalama değerine göre II. kalite sınıfında belirlenmiştir.

Ölçüm yapılan fizikokimyasal verilerle türler arasındaki ilişki belirlenmeye çalışılmıştır. Sıklık, baskınlık ve benzerlik analizleri incelenerek Ulupınar Çayı'nın su kalitesi hakkında değerlendirme yapılmaya çalışılmıştır. Ulupınar Çayı'nda uygulanan benzerlik indeksi sonuçlarına göre en yüksek benzerlik IV. ve VI. istasyonlar arasında (0,78) görülmüştür.

Yapılan çalışmada Trichoptera takımına ait Annulipalpia, Integripalpia ve Scipipalpia alttakımlarına bağlı, 6 familyaya ait 10 cins ve bu cinslere bağlı 21 tür tespit edilmiştir. Toplam 1367 birey incelenmiştir. 7 cinse ait bazı örnekler teşhisi, kullanılan larva teşhis anahtarları içerisinde yeterli kaynak bulunmaması ya da örneklerin gelişimlerini tamamlamamış olması nedeniyle yapılamamıştır. Cins düzeyinde verilen taksonlar *Hydropsyche* sp*.,* *Glossosoma* sp., *Agapetus* sp., *Hydroptila* sp., *Oxyethira* sp., *Rhyacophila* sp. ve *Agraylea* sp*.'* dir.

Toplanan örneklerin mevsimsel dağılımına bakıldığında, Kasım ayında 9 takson, Şubat ayında 11 takson, Mart ayında 12 takson ve Haziran ayında 12 takson belirlenmiş, en az takson sayısı Kasım döneminde tespit edilmiştir. Bu taksonların istasyonlara göre dağılımlarında ise 1. istasyonda 10 takson, 2. istasyonda 4 takson, 3. istasyonda 5 takson, 4. istasyonda 12 takson, 5. istasyonda 9 takson, 6. istasyonda 11 taksona rastlanmıştır. En fazla takson 4. istasyonda belirlenirken en az takson 2. istasyonda bulunmuştur.

Saprobi İndeks'e (DIN 38410, 2004) göre Trichoptera faunasının kalite sınıf aralığı oligosaprob ile Beta-Alfamesosaprob arasında değişim göstermektedir. Bu sınırlar saprobi indeksin kalite sınıflandırması olarak I. kalite sınıfı ile II-III. kalite sınıfı arasında değişim göstermektedir. Saprobi değeri olarak en yüksek değere *Cyrnus trimaculatus* (2,5) sahip olurken çok az Trichoptera taksonu 2,3 saprobi değeri üzerine çıkmaktadır. *Hydropsyche* cinsinden ise sadece *Hydropsyche contubernalis* (2,4) beta-alfamesosaprob yani II-III. kalite sınıfına dahil olmakta, Trichoptera takımından hiçbir organizma III., III-IV. ve IV. kalite sınıflarında dağılım göstermemektedir (DIN38410, 2004). Trichoptera takımının üyeleri arasında tüm indekslere göre Hydropsychidae familyası ve familya üyeleri en toleranslı taksonlar durumundadır. Klee (1991)'nin metodu ile fiziksel ve kimyasal parametreler kullanılarak ortalama su kalitesi değerlendirmesi yapılmıştır. Bu değerlendirme sonucunda tüm istasyonlar I. kalite seviyesinde (Oligosaprob) olduğu belirlenmişti. Akarsu üzerinde turizm baskısı olmasına ve balık çiftliklerinin varlığına rağmen akarsu oligosabrob düzeyde belirlenmiştir.

Ulupınar Çayı'nda belirlenen Trichoptera'ya ait taksonlar bu akarsu için yeni kayıt durumundadır. Bu akarsularda belirlenen organizmalar temiz veya az kirlenmiş akarsu bölümlerinde dağılış gösteren organizmalar olduğu söylenebilir.

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Research Article

Hydrodynamic Modelling Using HİDROTÜRK Model

HİDROTÜRK Modeli Kullanılarak Hidrodinamik Modelleme

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Abstract

In this manuscript, the hydrodynamic sub-model components of HİDROTÜRK, the first national hydrological, hydrodynamic, hydrogeological, water quality, and ecological model developed for sustainable management of water resources in Turkey, have been briefly introduced with their basic theoretical and numerical backgrounds. HİDROTÜRK model includes three individually processing hydrodynamic sub-models, namely one (1-D), two (2-D), and three (3-D) dimensional written in FORTRAN programming language. Inputs and outputs of all sub-models are managed through a user-friendly interface. The 1-D hydrodynamic model solves the Saint-Venant equations, which are gradually varied unsteady flow equations written in the flow direction. It applies a dynamic wave routine. 2-D hydrodynamic model numerically solves the unsteady depth-averaged continuity and momentum equations. 2-D model is more reliable for shallow waters where the areal extent of the domain is dominant over the vertical or for completely mixed water bodies through the water depth. The 3-D hydrodynamic numerical model solves the unsteady Navier-Stokes equations in three dimensions only with the Boussinesq assumption. When the water body is deep, and variable circulations over the water depth occur, especially in the simulations of wind and density induced flows, the application of the 3-D hydrodynamic model is crucial. The software developments and preliminary tests of the models by SWMM5.0-EXTRAN and Three Dimensional Hydrodynamic, Transport and Water Quality Model -3D have been completed, and the verification studies are still ongoing. Some applications to Demirköprü Dam Lake in the Gediz River Basin are presented to show the input and output structures of hydrodynamic models.
Keywords: *HİDROTÜRK, hydrodynamic model, wave routine, continuity, momentum*

Öz

Bu makalede, Türkiye'de su kaynaklarının sürdürülebilir yönetimi için geliştirilen ilk ulusal hidrolojik, hidrodinamik, hidrojeolojik, su kalitesi ve ekolojik modeli olma özelliğine sahip HİDROTÜRK modeli, hidrodinamik alt-model bileşenleri, temel teorik ve sayısal çözümleme kapasiteleriyle kısaca tanıtılmıştır. HİDROTÜRK modeli, FORTRAN programlama dilinde yazılan, bir (1-B), iki (2-B) ve üç (3-B) boyutlu olmak üzere birbirinden bağımsız olarak çalışabilen üç ayrı hidrodinamik alt model içermektedir. Tüm alt modellerin girdileri ve çıktıları kullanıcı dostu bir

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arayüz üzerinden yönetilmektedir. 1-B hidrodinamik model, akış yönünde yazılan yavaş değişen kararsız akış denklemleri olan Saint-Venant denklemlerini çözmekte ve dinamik dalga ötelemesi uygulamaktadır. 2-B hidrodinamik model, derinlik boyunca ortalaması alınmış, kararsız süreklilik ve hareket denklemlerini sayısal olarak çözümler ve yüzey alanı büyüklüğünün su derinliğine göre çok daha baskın olduğu sığ sular için veya su derinliği boyunca tam karışımlı su kütleleri için daha güvenilir benzeşimler sunar. 3-B hidrodinamik model, kararsız Navier-Stokes denklemlerini yalnızca Bousinessq varsayımı ile üç boyutta sayısal olarak çözümlemektedir. Su kütlesinin derinlikleri fazla olduğunda ve özellikle rüzgar ve yoğunluk kaynaklı çevrintiler gibi su kolonu boyunca yön değiştirebilen akıntıların hesaplanmasında 3-B hidrodinamik modelin kullanılması gereklidir. Modellerin yazılım geliştirmeleri ve SWMM5.0-EXTRAN ve HYDROTAM-3D sayısal modelleri ile karşılaştırmalı ön testleri tamamlanmış, doğrulama çalışmaları ise halen devam etmektedir. Modellerin girdi ve çıktı formatlarını göstermek amacıyla, Gediz Nehri Havzası'ndaki Demirköprü Baraj Gölü için yapılan hidrodinamik model uygulamalarından bazılarına yer verilmiştir.

Anahtar kelimeler: *HİDROTÜRK, hidrodinamik model, dalga öteleme, süreklilik, momentum*

Introduction

Hydrodynamic modeling aims to predict velocity components, flow rates, surface-level changes, pressure gradients, and density variations due to changes in temperature, salinity, and pressure for fluids in motion. The hydrodynamic models have been subdivided into mainly three groups as one dimensional (1-D), two dimensional (2-D), and three dimensional (3-D) models concerning the dimensionality of the physical phenomenon.

Hydrologic Engineering Center-River Analysis System (HEC-RAS) is a model that simulates 1-D and 2-D unsteady flow in open channels and floodplains (Hydrologic Engineering Center [HEC], 2016). Model components include the dam break analysis, levee breaching and overtopping, and pipe flow systems. It can combine 1-D and 2-D unsteady flow modeling.

As the 1-D hydrodynamic model, the Extended Transport Model (EXTRAN) component of the Storm Water Management Model (SWMM), which has been commonly applied all over the world for surface waters, has been adapted (Rossman, 2006, 2015). EXTRAN is written in the FORTRAN language, and it is an open-source code. The code unit system is converted to the International Unit System (SI). Program inputs and outputs are all modified, and a user-friendly interface has been prepared for their management. The user interacts with HİDROTÜRK through a graphical user interface prepared for the 1-D hydrodynamic model. The interface is designed to make it easy to use the software while maintaining a high level of efficiency for the user.

Several 1-D and 2-D hydrodynamic models are developed to simulate the floodwater propagation in floodplain areas (Horritt & Bates, 2002). DHI MIKE 11 is a commonly applied model to simulate complex three-dimensional flow patterns (Thompson et al., 2004). It can handle the effects of many hydraulic structures like culverts, bridges, and dams. The Environmental Fluid Dynamics Code (EFDC) is a model system having hydrodynamic, eutrophication, sediment, and contaminant submodels. EFDC applies to enclosed water bodies, rivers, estuaries, and coastal areas (Hamrick, 1992; Ji et al., 2001).

Three Dimensional Hydrodynamic, Transport and Water Quality Model (HYDROTAM-3D) is the first national 3-D hydrodynamic, transport, and water quality model developed for coastal areas in Turkey. It has been applied to many coastal areas in Turkey to simulate wind, wave, and density induced currents and has been verified with analytical solutions and many site measurements (Balas & Özhan, 2000, 2002; Balas et al., 2012; Cebe & Balas, 2016, 2018; Genç et al., 2020). The model is based on GIS and cloud computing technology, and it includes an extensive database for coastal and estuarine water bodies in Turkey. It has electronic wind and wave climate and energy atlas, wave propagation, sediment transport, coastal morphology, and water quality modules.

Almost all circulation systems in nature have three-dimensional character. Therefore a 3-D hydrodynamic model can be expected to solve all current system behaviors in nature. However, due to the complexity of the turbulence in three-dimensions, they are generally time-consuming, and for some of the flow problems, 3-D numerical modeling would not lead to advantageous solutions and will significantly decrease the processing performance. For example, the investigation of a 500 km long river having a width of 50-200 m with a three-dimensional model is not meaningful, mainly if a local circulation event in the river cross-section is not investigated. Similar if water depths are very shallow, being typically less than 5-10 m, having a horizontal extend in the order of kilometers, use of the depth-averaged 2-D hydrodynamic model will provide reliable results. Therefore, the HİDROTÜRK model includes a 1-D hydrodynamic model to work with long and narrow water bodies, especially for rivers, a 2-D hydrodynamic model for shallow and large water bodies, and a 3-D hydrodynamic model for all other types.

Method

One-Dimensional Hydrodynamic Model

One-dimensional (1-D) hydrodynamic model is a hydraulic flood routing model developed for open channels and closed conduit systems. The open-source module named Extended Transport Model (EXTRAN.f), a 1-D hydrodynamic module, has been made operational as a one-dimensional hydrodynamic model component of the HIDROTURK model. The model numerically solves the transport equations and calculates the stream from the main drainage line to the outfall node by the dynamic displacement method. The model idealizes the channel/conduit system to links connected to nodes or junctions. Links transmit flow from node to node. The discharge, Q, is the fundamental parameter in the links. The average flow is solved in each link, assuming as constant in a time-step. Nodes are the junctions of links. The cross-sectional flow area, depth, and velocity vary in each link. Any inflows like inlet hydrographs, or outflows, like free outfalls, are defined at each related nodes. The volume, surface area, and total head are the computed variables at the nodes. At every time step of the computations, the volume change is computed that leads to the discharge and total head computations (Roesner et al., 1992). Table 1 presents the elements and their types.

Table 1

Elements and Their Types in 1-D HİDROTURK Model

Elements	Types
Links	Natural (irregular cross section) channel Rectangular Trapezoidal Power function Circular
Diversion Structures	Orifice Transverse weir Side flow weir Pump
Storage Basin	Area-stage relationship Enlarged tunnels or pipes
Outfall Structures	Transverse weir Side flow weir Outfall with gate Free outfall

When a system is to be analyzed with a 1-D model, the first step is generally to define the system and the watershed that it drains. Each of the sub-basins discharges the currents formed on its surface to a defined drainage channel. It is necessary to place a junction in the drainage routes where backwater effects, surcharge, and diversion facilities affect the flow and head computation. Junction points should be identified as each:

-Upstream terminal point(s) in the system,
-Outfall and discharge point(s),
-Bridges and culverts
-The pump station, storage point, orifice and weir diversion,
-The junction where inflow hydrographs will be input
-Points where pipe/channel size/shape changes significantly,
-Points where pipe/channel slope changes significantly.

The one-dimensional numerical hydrodynamic model solves the conservation of mass and momentum equations, known as the Saint-Venant equations, which are gradually varied, one-dimensional unsteady flow equations:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \quad (1)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial\left(\frac{Q^2}{A}\right)}{\partial x}+gA\frac{\partial H}{\partial x}+gAS_f=0 \quad (2)$$

where, Q = AV, V: average velocity, A:cross-sectional area, t:time, x:length of the channel or conduit, Q:flow rate, g: gravitational acceleration, H:hydraulic head, S_f: friction slope. The bottom slope is incorporated into gradient of H.

The model uses the momentum equation in the links and a particular lumped continuity equation for the nodes. Thus, momentum is conserved in the links and continuity in the nodes. In the dynamic wave routine, the momentum equation is combined with the continuity giving an equation for a solution along with each link at each time step.

$$\frac{\partial Q}{\partial t}-2V\frac{\partial A}{\partial t}-V^2\frac{\partial A}{\partial x}+gA\frac{\partial H}{\partial x}+gAS_f=0 \quad (3)$$

The model uses the Manning equation to express the relationship between flow rate (Q), cross-sectional area (A), hydraulic radius (R), and slope (S) in all conduits;

$$Q=\frac{1}{n}\,AR^{2/3}\,S^{1/2} \quad (4)$$

Where n is the Manning roughness coefficient and S is the friction slope.

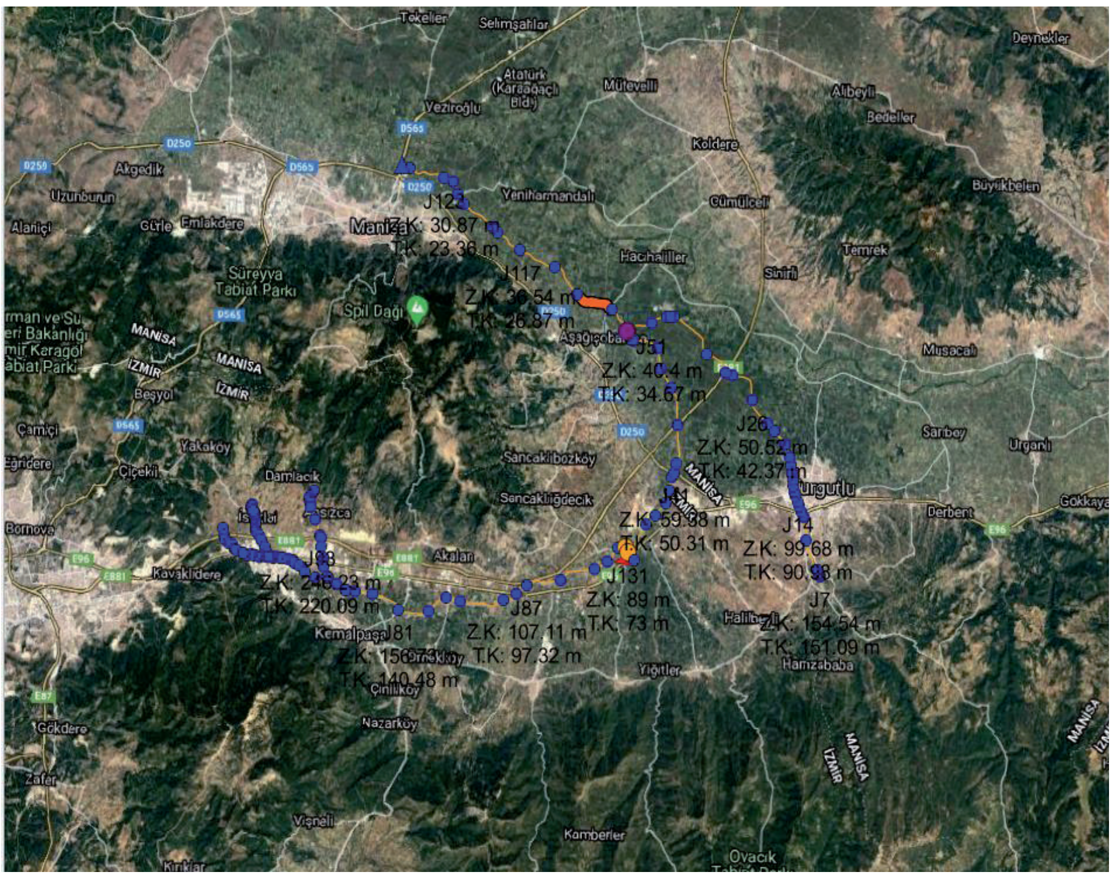
The specific function of the dynamic wave routine is to route inlet hydrographs through the network of pipes, junctions, and flow diversion structures of the main sewer system to the treatment plant interceptors and receiving water outfalls. Dynamic wave routine is used whenever it is crucial to represent surcharged or severe backwater conditions and special flow devices or structures such as weirs, orifices, pumps, storage basins, culverts, bridges, and gates. The routine can simulate pipes, manholes (pipe junctions), weirs, orifices, pumps, storage basins, and outfall structures. Typically in flow routing, when the flow into a junction exceeds the system's capacity to transport it further downstream, the excess volume overflows the system and is lost. An option exists to have the excess volume instead be stored atop the junction, in a ponded fashion, and be reintroduced into the system as capacity permits. Under steady and kinematic wave flow routing, the ponded water is stored simply as an excess volume. For dynamic wave routing, which is influenced by the water depths maintained at nodes, the excess volume is assumed to pond over the node with a constant surface area. This amount of surface area is an input parameter supplied for the junction. Alternatively, the user may wish to represent the surface overflow system explicitly. In open channel systems, this can include road overflows at bridges or culvert crossings as well as additional floodplain storage areas. 1D model calculations produce the output required for flooding analysis.

The input data of the 1-D hydrodynamic model is divided into 23 groups. 1-6 groups include control data that determines time step, start time, junction points with hydrograph input, junctions, and conduits for printing heads and flows. The identification of conduits and junctions is made in data groups 7-8. Groups 9-12 contain data for account points with storage, orifice, sluice, and pump. 13-17 groups define the discharge points and associated backwater conditions. Groups 18-19 define the initial flowrate and heads at the calculation points. Groups 20-21 provide hydrographs, and groups 22-23 define the properties of bridges and culverts.

Figure 1 shows nodes and links defining some tributaries of the Gediz River, as obtained from the HİDROTÜRK interface. Points define the nodes, and lines define the links.

Figure 1

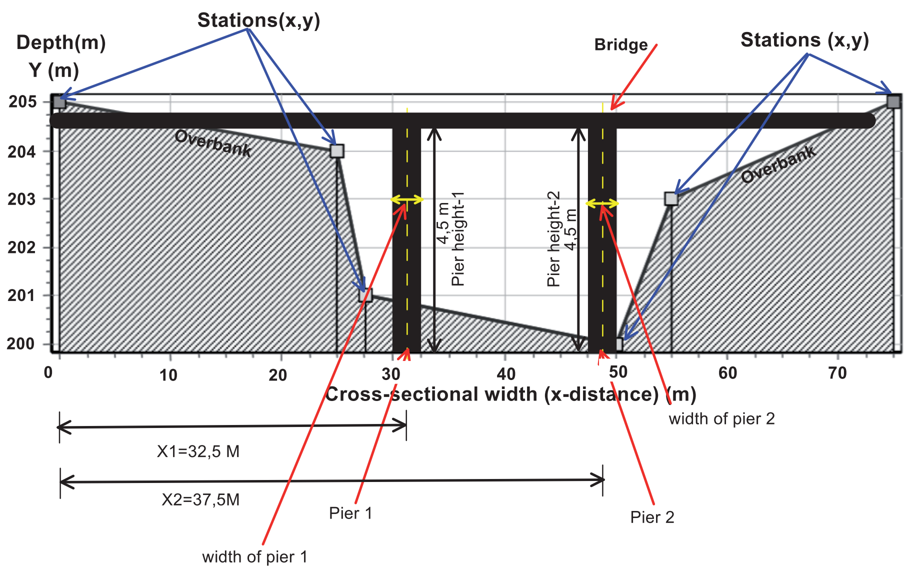
Nodes (Blue Points) and Links (Yellow Lines) that Define Some Tributaries of the Gediz River



Most open channels are represented with a trapezoidal, rectangular, or irregular cross-sections. For a user-defined irregular natural channel, the cross-sectional stations have to be defined with the variable depth (y) and the distance across the cross-section (x). A typical natural channel cross-section defined in the HİDROTÜRK model having a bridge is given in Figure 2.

Figure 2

A Typical Natural Channel Cross-Section with a Bridge



Two Dimensional Hydrodynamic Model

In relatively shallow waters, there is no significant stratification in vertical, and hydrodynamic properties do not vary over depth. Therefore water particle velocities in horizontal directions are calculated by shallow water equations. In the two dimensional hydrodynamic sub-model of HİDROTÜRK, the continuity equation is given as;

$$\frac{\partial \eta}{\partial t}+\frac{\partial Hu}{\partial x}+\frac{\partial Hv}{\partial y}=0 \tag{5}$$

The momentum equations in x and y directions are;

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-fv=-g\frac{\partial \eta}{\partial x}+\frac{\left(\tau_x^{sur}-\tau_x^{bot}\right)}{\rho_w H}+\upsilon_t^H\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \tag{6}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+fu=-g\frac{\partial \eta}{\partial x}+\frac{\left(\tau_y^{sur}-\tau_y^{bot}\right)}{\rho_w H}+\upsilon_t^H\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \tag{7}$$

In these equations; x and y: distances in horizontal plane; t: time; u and v: velocities in x and y directions, respectively; H: water depth, f: Coriolis parameter, υ_t^H:Eddy viscosity in horizontal, η: water surface level, ρ_w: density of water, τ_x^{sur} ve τ_y^{bot} :shear stress in x and y directions at the surface and at the bottom respectively. Shear stresses at the surface and bottom are calculated as in the followings:

$$\tau_x^{sur}=C_D\rho_a|U_w|U_w \; ; \; \tau_y^{sur}=C_D\rho_a|V_w|V_w \tag{8}$$

$$\tau_x^{bot}=C_B\rho_w|u|u \; ; \; \tau_y^{bot}=C_B\rho_w|v|v \tag{9}$$

In these equations, U_W and V_W:effective wind speeds in x and y directions respectively; ρ_a: air density; C_D and C_B wind factor and bottom friction coefficients respectively.

The 2-D advection-diffusion equation for the transport of salinity and temperature is given as;

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=\frac{\partial}{\partial x}\left(D_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y\frac{\partial C}{\partial y}\right)\pm S_c \tag{10}$$

where C is temperature (T) or salinity (S) concentration, D_x, D_x are turbulent diffusion coefficients and S_c is any source or sink terms in the computational domain (Tunaboylu, 2006).

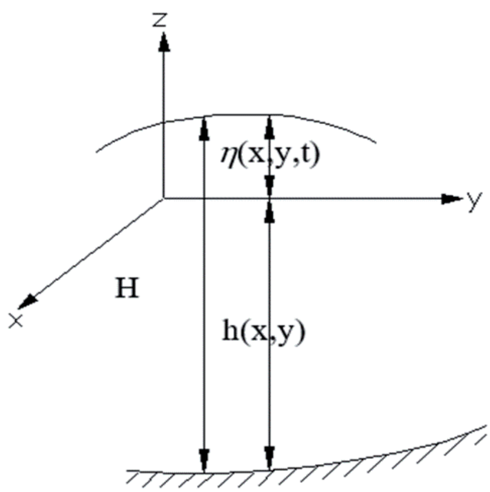
The solution algorithms are similar to the three-dimensional model that will be explained below in detail.

Three Dimensional Hydrodynamic Model

In three dimensional hydrodynamic model, 3-D Navier-Stokes Equations are solved numerically in Cartesian coordinates as depicted in Figure 3 (Balas & Özhan, 2000).

Figure 3

Cartesian Coordinate System



Model equations are given below.

Continuity equation;

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{11}$$

Momentum equations in x, y and z directions that are perpendicular to each other on a horizontal plane;

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=fv-\frac{1}{\rho_o}\frac{\partial p}{\partial x}+2\frac{\partial}{\partial x}\left(\nu_x\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\nu_y\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right)+\frac{\partial}{\partial z}\left(\nu_z\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)\right) \tag{12}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-fu-\frac{1}{\rho_o}\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left(\nu_x\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right)+2\frac{\partial}{\partial y}\left(\nu_y\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(\nu_z\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right) \tag{13}$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=gz-$$
$$\frac{1}{\rho_o}\frac{\partial p}{\partial z}+\frac{\partial}{\partial x}\left(\nu_x\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right)+\frac{\partial}{\partial y}\left(\nu_y\left(\frac{\partial w}{\partial y}+\frac{\partial v}{\partial z}\right)\right)+2\frac{\partial}{\partial z}\left(\nu_z\frac{\partial w}{\partial z}\right) \quad (14)$$

In these equations; (x, y) and z: horizontal and vertical coordinates respectively; t: time; u, v, w: velocity components in x, y and z directions on any grid point; v_x, v_y, v_z: eddy viscosities in x, y and z directions respectively; f: Corriolis coefficient, ρ(x,y,z,t): water density, g: gravitational acceleration, p: pressure.

The water's density varies with its salinity and temperature by the following equations (Gill, 1982).

$$C(h)=999.83+5.053h-0.048h^2$$
$$\beta(h)=0.808-0.0085h$$
$$\alpha(T,h)=0.0708(1+0.351h+0.068(1-0.0683h)T)$$
$$\gamma(T,h)=0.003(1-0.059h-0.012(1-0.064h)T)$$
$$\rho=C(h)+\beta(h)S-\alpha(T,h)-\gamma(T,h)(35-S)(13) \quad (15)$$

Where S is salinity (%), h is depth of water (km) and T is temperature (°C).

The temperature and salinity changes are computed from three-dimensional advection-diffusion equations (Balas & Özhan, 2000).

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+w\frac{\partial C}{\partial z}=\frac{\partial}{\partial x}\left(D_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(D_z\frac{\partial C}{\partial z}\right)\pm S_c \quad (16)$$

Where C is the temperature (T) or salinity (S) concentration, D_x, D_x, and D_z are turbulent diffusion coefficients, and S_c is any source or sink terms in the computational domain. The heat exchange boundary condition is modified to consider a heat flux from the atmosphere. In the baroclinic circulations, consideration of heat exchange might be valuable in the vertical convective term (Balas & Özhan, 2002).

The kinematic surface boundary condition depends on the water level change as defined in Equation (17).

$$\frac{\partial \eta}{\partial t}+u_s\frac{\partial \eta}{\partial x}+v_s\frac{\partial \eta}{\partial y}-w_s=0 \tag{17}$$

Here; u_s and v_s: horizontal velocity components at the surface; w_s: vertical velocity component at the surface; η: water level change. The definitions of water surface and water depth are given in Figure 3 in a 3-D Cartesian coordinate system.

The continuity equation is integrated over the water depth, and the surface kinematic boundary condition is applied to obtain the water level change equation (η) as given below:

$$\frac{\partial \eta}{\partial t}+\frac{\partial}{\partial x}\left[\int_{-h}^{\eta} u\,dz\right]+\frac{\partial}{\partial y}\left[\int_{-h}^{\eta} v\,dz\right]=0 \tag{18}$$

where; h(x, y): water depth according to still water level. H(x, y, t): Total water depth and given as H(x, y, t)=h(x, y)+η (x, y, t). The momentum equations are subject to the vertical exchange of momentum at the free surface due to the wind stress and at the bottom due to the bottom stress. Thus at the surface,

$$\tau_x^s=\tau_x^w=C_D\rho_a|W|W_x=\rho\nu_z\frac{\partial u}{\partial z} \quad \text{and} \quad \tau_y^s=\tau_y^w=C_D\rho_a|W|W_x=\rho\nu_z\frac{\partial v}{\partial z} \tag{19}$$

where ρ_a is air density, W is wind velocity and C_D is wind drag coefficient.

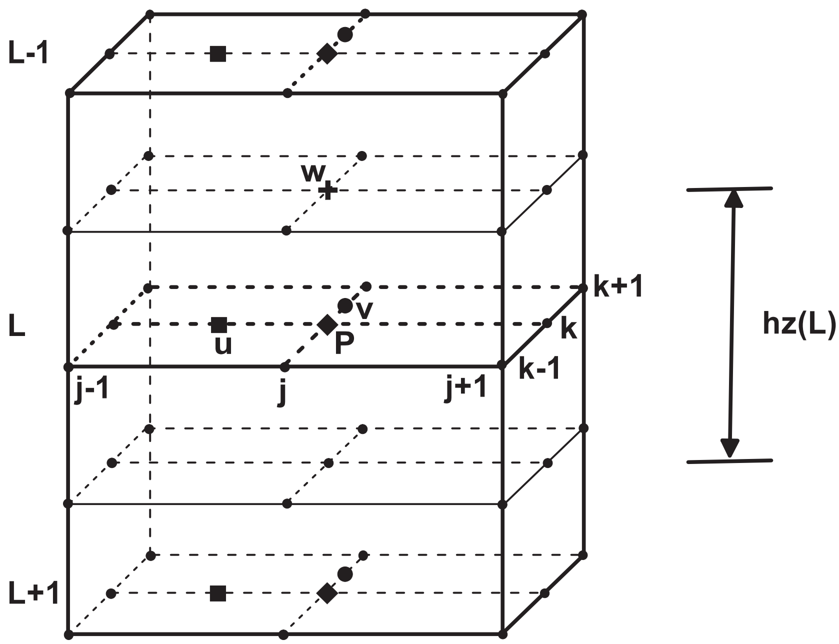
The bottom boundary condition is as follows:

$$w=-u_b\frac{\partial h}{\partial x}+v_b\frac{\partial h}{\partial y} \tag{20}$$

If any open boundary condition exists, the radiation boundary condition is applied. The land boundary conditions are usually taken as no flux. The numerical solution is based on finite differences on a staggered scheme, as shown in Figure 4.

Figure 4

Staggered Scheme Applied in Numerical Solution



The indices along x, y and z directions are j, k, and L, respectively. The grid distances along x and y directions are constant, whereas the hz (L) denotes the grid-distance along the z-direction, which is a variable. The starting point of the coordinate system is located at the free surface, and the z-axis points upward. Therefore, as the depth becomes negative, hz (L) becomes positive.

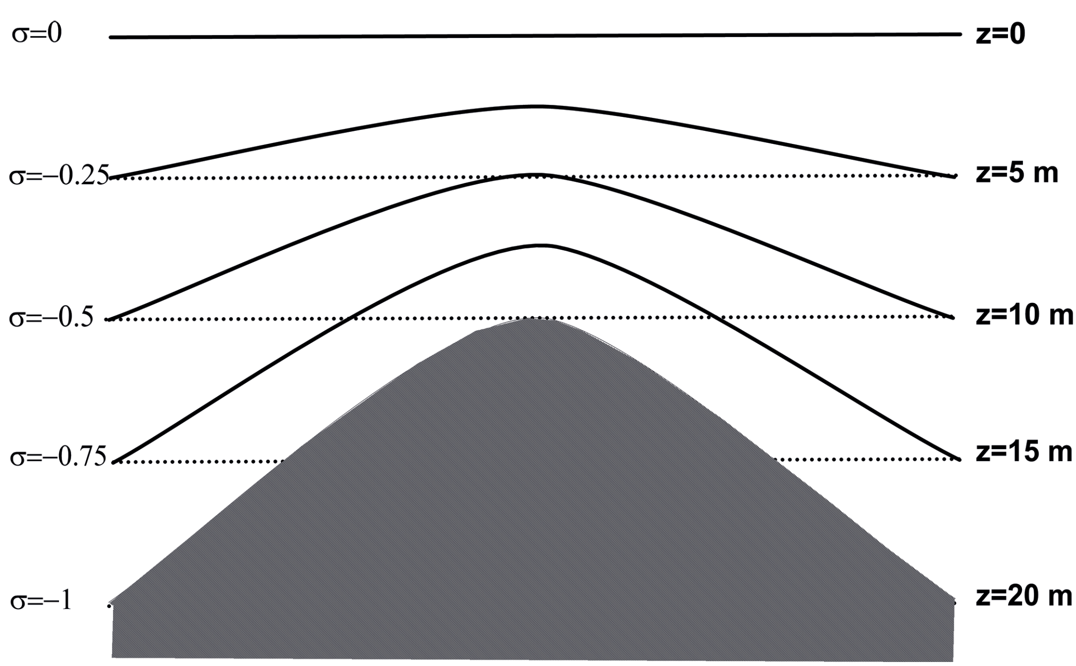
The use of constant layer thickness in the vertical processes causes inefficient processes, especially if there are abrupt variations in the topography. A dimensionless coordinate is introduced through the sigma coordinate transformation to overcome these instabilities. The vertical coordinate has been stretched; thus, the vertical grid size is expressed as a function of the computational grid depth, with the sigma coordinate transformation (Kowalik & Murty, 1993). The new coordinate defined is expressed as;

$$\sigma=\frac{z-\eta}{h+\eta} \tag{21}$$

Along with the water depth, sigma coordinate transformation has been applied to follow the bottom topography. The total depth h+η is denoted as H. The water column (from the surface where z = η to the bottom where z = -H) is transformed into a uniform depth ranging from σ=0 to σ=-1. After the application of transformation, there would be the same number of vertical layers over the whole computational domain, and created mesh follows the contours of the variable topography, as shown in Figure 5.

Figure 5

Variable Vertical Mesh with The Application of Sigma Coordinate Transformation



The sigma coordinate transformation not only changes the vertical direction, but it also affects the horizontal coordinates. All partial derivatives in equations solved are corrected according to the transformed system of coordinates. The derivative of any dependent variable f in the basic equations with respect to the vertical coordinate z is:

$$\frac{\partial f}{\partial z}=\frac{1}{H}\frac{\partial f}{\partial \sigma} \qquad (22)$$

Derivative of any dependent variable f in the basic equations with respect to the horizontal coordinate x is:

$$\frac{\partial f}{\partial x}=\left.\frac{\partial f}{\partial x}\right|_{\sigma}-\frac{1}{H}\left(\sigma\frac{\partial H}{\partial x}+\frac{\partial \eta}{\partial x}\right)\frac{\partial f}{\partial \sigma} \tag{23}$$

So all the basic equations are transformed into sigma coordinates before the application of finite difference approximations. For example, the continuity equation takes the following form:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=\frac{\partial u}{\partial x}-\frac{1}{H}\frac{\partial(H\sigma+\eta)}{\partial x}\frac{\partial u}{\partial \sigma}+\frac{\partial v}{\partial y}-\frac{1}{H}\frac{\partial(H\sigma+\eta)}{\partial y}\frac{\partial v}{\partial \sigma}+\frac{1}{H}\frac{\partial w}{\partial \sigma} \tag{24}$$

A two-time-level scheme is used in time-wise solutions of equations. The first time step, from t to t*, uses an explicit scheme to compute the variables' predictive values. At the second time step, from t* to t+1, an implicit scheme is applied to ensure dynamic stability.

The finite-difference approximations of second-order for space differencing are applied to the staggered scheme, as shown in Figure 6. The total depth is defined in all (j, k, L) points, while the above equations require all the depths in u and v points on a staggered scheme. Therefore, depths are calculated at u and v computational points and defined as HU and HV (Kowalik & Murty, 1993).

$$HU_{j,k}=0.5*(H_{j,k}+H_{j-1,k}) \text{ and } HV_{j,k}=0.5*(H_{j,k}+H_{j,k+1}) \tag{25}$$

Each term in the equations is expressed considering its position defined on the staggered scheme applied. For example, when the nonlinear advective term in the x direction of x-momentum equation, $\frac{\partial}{\partial x}(u^2H)$ is considered; first the average value of term is calculated at the depth points where surface elevation (η) is calculated which surround u point, and then difference for the derivative is applied according to scheme given in Figure 4 and Figure 6. These η points are indexed by (j, k, L) and (j −1, k, L), respectively. At the right η and at the left of grid point average values are given as;

$(UH)_r=0.5(HU_{j+1,k}*u_{j+1,k,L}+HU_{j,k}*u_{j,k,L})$ $u_r=0.5(u_{j,k,L}+u_{j+1,k,L})$

$(UH)_l=0.5(HU_{j-1,k}*u_{j-1,k,L}+HU_{j,k}*u_{j,k,L})$ $u_l=0.5(u_{j,k,L}+u_{j-1,k,L})$

So, the derivative of the term is calculated by Eq.(26).

$$\frac{\partial}{\partial x}(u^2H)=\frac{(uH)_r*u_r-(uH)_l*u_l}{hx} \quad (26)$$

As an example along the y direction derivatives in x-momentum equation, the advective term $\frac{\partial}{\partial y}(uvH)$ is expressed using all variables located up and down of the point $u_{j,k,L}$ as shown in Figure 7.

$(vH)_{up}=0.5(HV_{j,k}*v_{j,k,L}+HV_{j-1,k}*v_{j-1,k,L})$ $u_{up}=0.5(u_{j,k,L}+u_{j,k+1,L})$

$(vH)_{down}=0.5(HV_{j,k-1}*v_{j,k-1,L}+HV_{j-1,k-1}*v_{j-1,k-1,L})$ $u_{down}=0.5(u_{j,k,L}+u_{j,k-1,L})$

$$\frac{\partial}{\partial y}(uvH)=\frac{(vH)_{up}*u_{up}-(vH)_{down}*u_{down}}{hy} \quad (27)$$

Figure 6

Staggered Scheme Used in X Differencing Computations

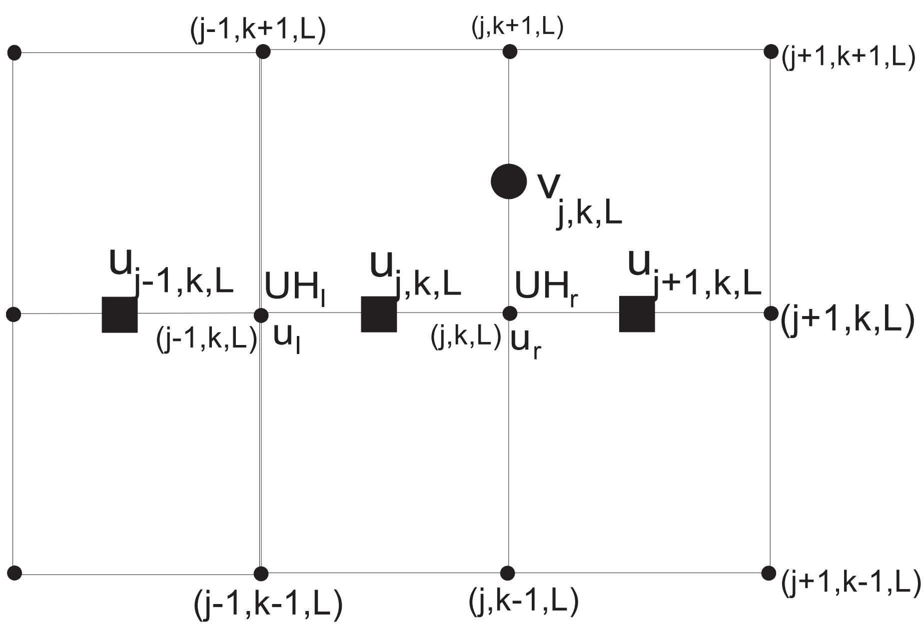
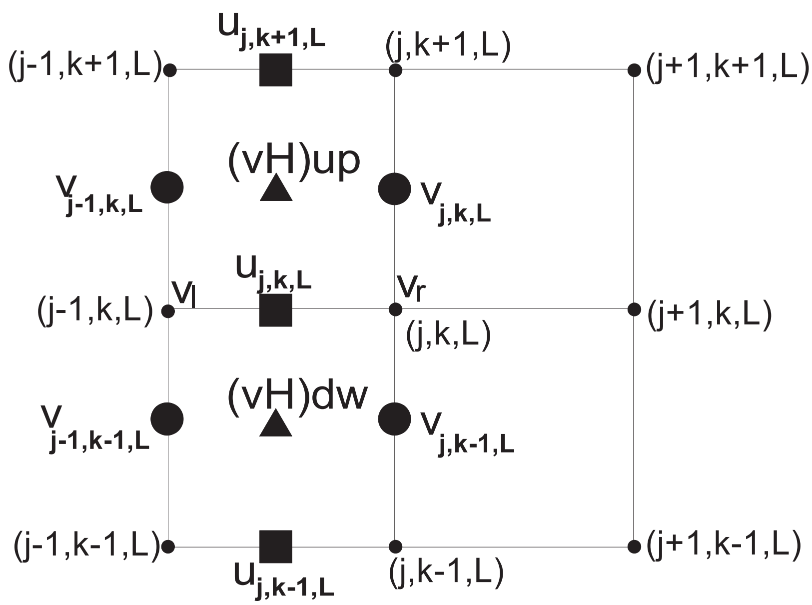


Figure 7

Staggered Scheme Used in Y Differencing Computations



For the nonlinear convective transport term in vertical $\frac{\partial}{\partial\sigma}(wu)$ in x-momentum equation, the derivative based on the values above and below the u grid point is constructed. Since vertical velocity w is not located above the u grid, but above pressure P grid point as shown in Figure 4, the averaging is performed considering the location of $u_{j,k,L}$ grid point.

$w_{above}=0.5(w_{j,k,L}+w_{j-1,k,L})$ $\qquad w_{below}=0.5(w_{j,k,L+1}+w_{j-1,k,L+1})$

$u_{above}=(u_{j,k-1,L}*hz_L+u_{j,k,L}*hz_{L-1})/(hz_L+hz_{L-1})$

$u_{below}=(u_{j,k,L}*hz_{L+1}+u_{j,k,L+1}*hz_L)/(hz_L+hz_{L+1})$

$$\frac{\partial}{\partial\sigma}(wu)=(u_{above}*w_{above}-u_{below}*w_{below})/hz_L \qquad (28)$$

Similarly, all related differencing approximations are applied considering the related computational points on staggered scheme shown in Figure 4.

Results

The developed hydrodynamic models are applied to the Gediz River basin during their testing process. In this section, the input and output structures of the models are aimed to be presented rather than the flow investigations. 1-D hydrodynamic model application to some of the tributaries of the Gediz River have been shown in Figure 8. The links (L) and nodes (J) that the changes of water surface profile, flow rate, flow velocity, and depth of water have been investigated, are selected from the map using the model interface. The time-wise water level changes over the cross-section or along the flow direction have been animated and graphically shown for the selected links or nodes. As an example, the change of water surface level is shown for the selected junction (node) J84 marked by a yellow point in Figure 8 over its natural cross-section. On the graph, the interface presents a change of water depth in time at every interested time step of output over the model's total run time. In this manner, change of water depth can be observed on the selected node cross-section in a time-wise animated manner. Likewise, the longitudinal profile of the selected links can be obtained in time-wise animation. In Figure 9, the longitudinal water depth profile of links between nodes J83 and J85, namely for L78 and L79, are presented. In both of the figures, the red line shows the maximum water level elevations that are reached during the run time.

Meanwhile, maximum water surface elevation also shows the possible flooding that might occur out of the main natural channel towards the flooding plains. It is rather easy to observe flooding plains in cross-sectional graphs. Red circles indicate the left and right overbank channel starting points on the graph (Figure 8). So the cross-sectional overbank flow information is also provided in longitudinal profiles, as shown in Figure 9, by inserting the left and right overbank points indicated by light and dark grey lines, respectively. Frequently the left and right overbank elevations on both sides of the channel are not equal to each other (Figure 8), so the lower one is used to indicate the beginning of the overbank flow. If at any time step of the computations the maximum water depth level exceeds the overbank elevations, there occurs the overbank flow.

The first step in the application of 2-D and 3-D hydrodynamic models is to input the bathymetry. The second step is to define the computational domain. The numerical grid is created for Demirköprü Dam Lake, as shown in Figure 10 by the user, stating the wet and dry cell initially. A zero water depth characterizes dry cells, whereas wet cells have a specific water depth below the surface.

Figure 8

Change of Water Depth in the Natural Channel Cross-Section at Node J84 at the End of 11 Days of Run Time

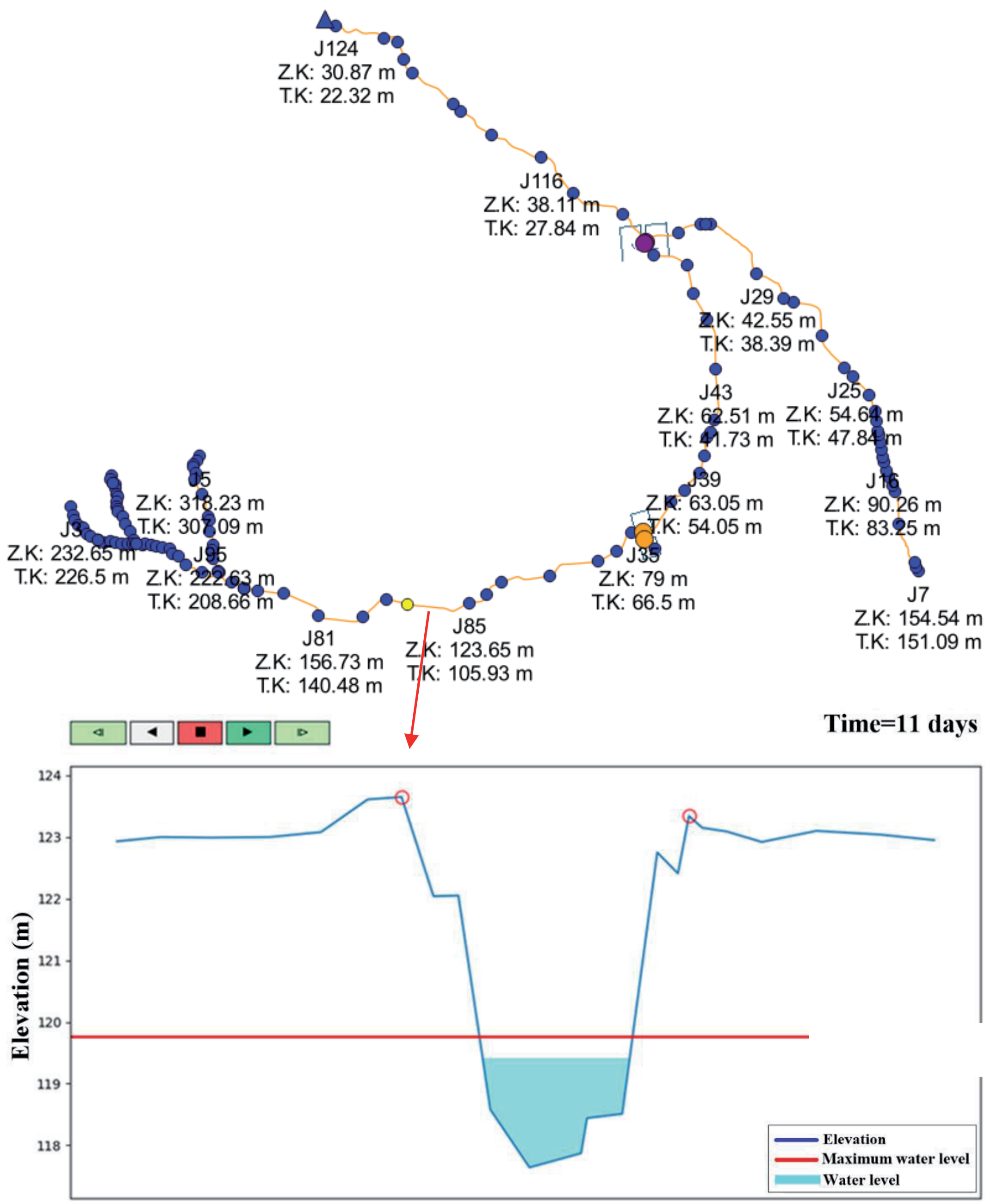


Figure 9

Longitudinal Profile of Water Depth between Nodes J83-J85 at the End of 7 Days

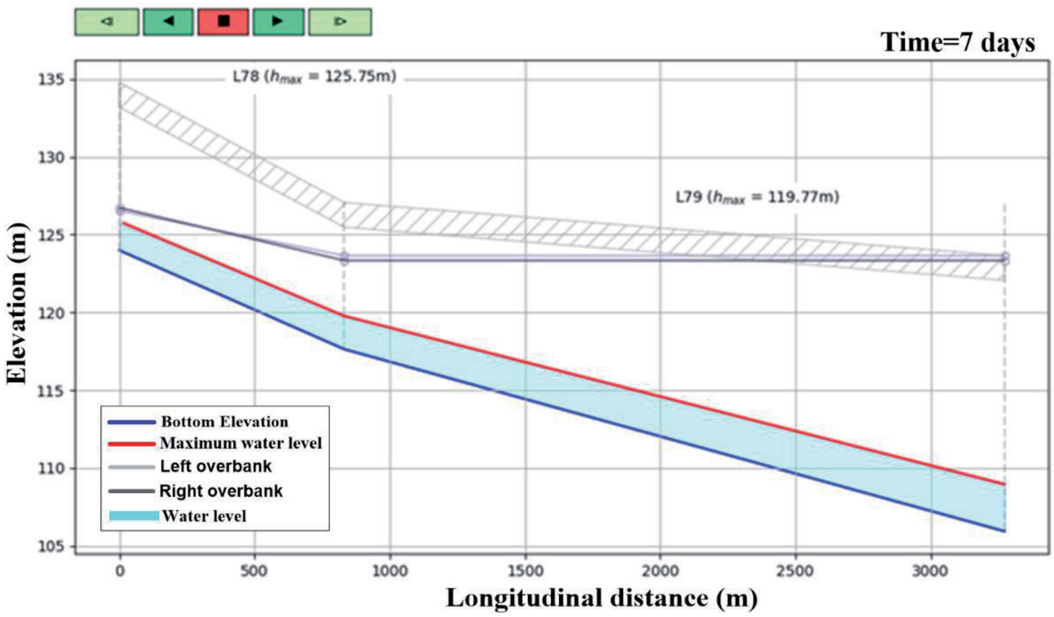
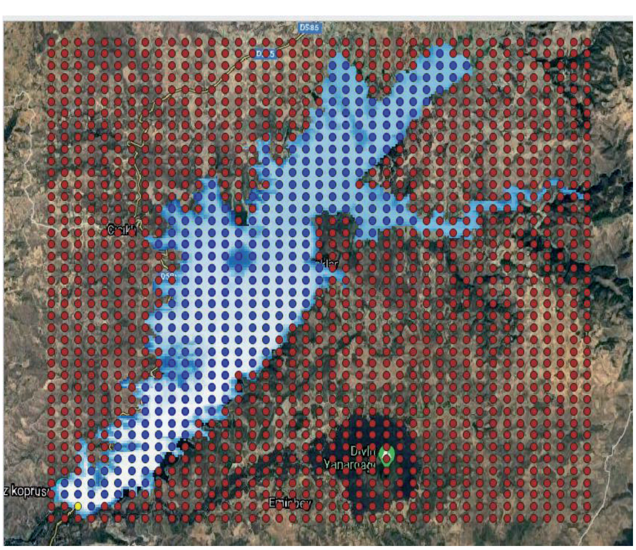


Figure 10

Computational Grid System for Demirköprü Dam Lake (Blue Dot: Wet Cell, Red Dot: Dry Cell)

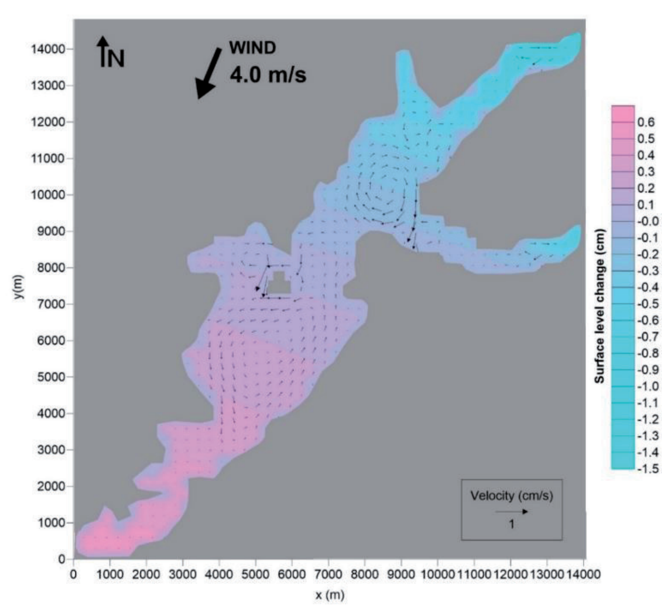


Wind force that drags the surface waters is defined with wind speed, wind direction, and wind duration in a time series over the run time. Initial values of all the variables in the fundamental equations (v, u, w, T, S, and H) are defined over the mesh system. If inflows are discharging into the system or outflows leaving the system, they are specified as hydrographs at the concerned boundary points as boundary conditions. If at certain boundaries, surface water level changes as a function of time are recorded or simulated by other means, they are specified as boundary conditions at the corresponding nearest mesh points.

2-D and 3-D hydrodynamic models of HİDROTÜRK are applied to Demirköprü Dam Lake on the Gediz River Basin. Simulations have been performed by the 2-D hydrodynamic model to obtain the average circulation pattern in the Lake. In the model, surface waters are under the influence of the wind blowing continuously from North Northeast (NNE) with a speed of 4 m/s that is the dominant wind effect for the area (HYDROTAM-3D, 2020). Hydrodynamic models successfully simulate the areal and time-wise changes of the velocity components, water level changes, temperature, and salinity distributions. The average circulation pattern and water level changes simulated at the end of one day by the 2-D hydrodynamic model are shown in Figure 11.

Figure 11

Depth Averaged Velocity Pattern at the Surface Layer and Change of Water Level (HİDROTÜRK-2D Hydrodynamic Model)



The 3-D hydrodynamic model simulates model parameters at every vertical layer. In 3-D case studies, water depth is divided into six layers following the bottom topography. The velocity pattern at the surface layer and bottom layers of Demirköprü Dam Lake at the end of the one-day simulation are presented in Figure 12 and Figure 13, respectively. Patterns are typical for wind-induced that is surface waters are dragged in the wind direction where there occurs a reverse circulation towards the bottom layers. Figure 14 presents the depth-averaged velocity pattern obtained by averaging the results over the depth and the changes in surface level. It is seen that the average velocity patterns by 2-D and 3-D simulations successfully support each other, predicting the main gyres in the Lake almost at the same locations.

Figure 12

Velocity Pattern at the Surface Layer (HİDROTÜRK-3D Hydrodynamic Model)

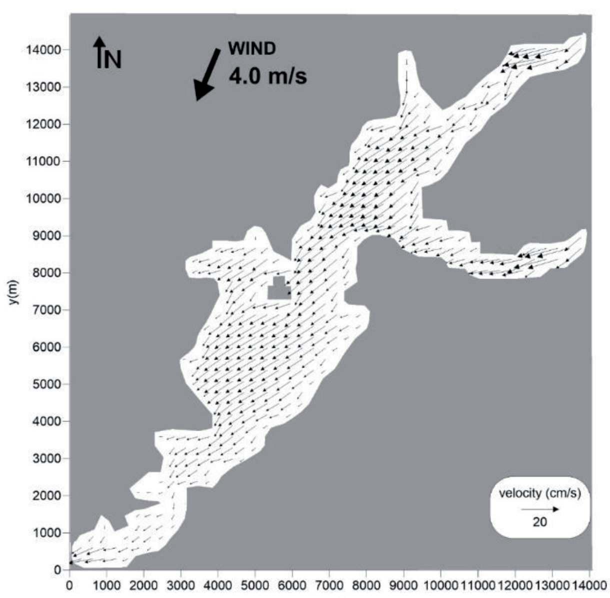


Figure 13

Velocity Pattern at the Bottom Layer (HİDROTÜRK-3D Hydrodynamic Model)

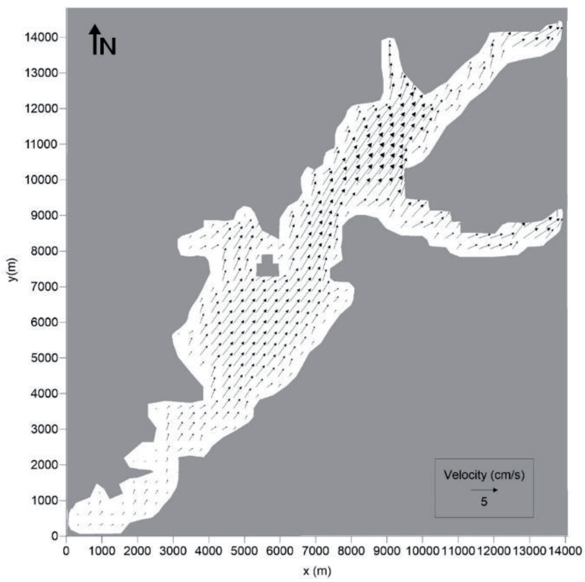
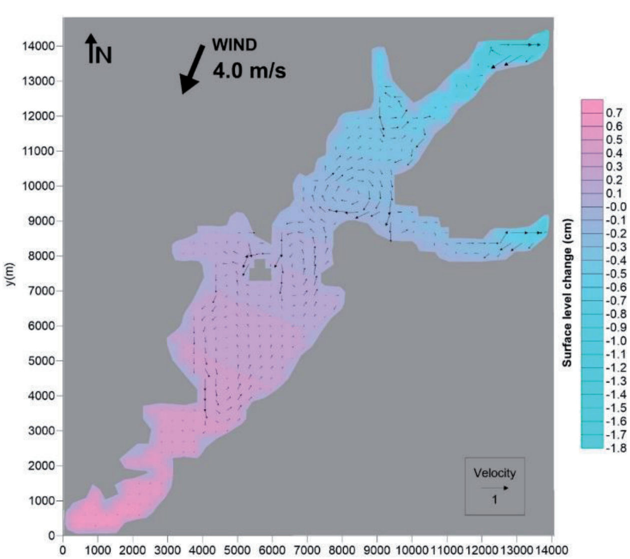


Figure 14

Depth Averaged Velocity Pattern at the Surface Layer and Change of Water Level (HİDROTÜRK-3D Hydrodynamic Model)



Conclusion

The HİDROTÜRK model is developed under the scope of the project "Development of Hydrological, Water Quality, and Ecological Modeling Tools for Sustainable Management of Water Resources in Turkey." The development of such an integrated model, including hydrological, hydrodynamic, hydrogeological, water quality, and ecological models, is significant and remarkable for the sustainable management of water resources in Turkey. The hydrodynamic model simulations are crucial for the other transport models since the turbulence and velocity patterns mainly control the advection and diffusion processes. Therefore, the degree of accuracy of the transport models is directly related to the hydrodynamic models.

HİDROTÜRK model includes 1-D, 2-D, and 3-D dimensional hydrodynamic models that can work individually or integrated. That is, the outputs of 1-D and 2-D models can be the inputs of the 3-D model. Inputs and outputs of the models are controlled and managed by a user-friendly interface to minimize possible errors that might be due to the user. The software developments and preliminary model tests by SWMM5.0-EXTRAN and HYDROTAM-3D have been successfully completed, and verification studies are still going on. At this stage, the long term and simultaneous site measurements of hydrodynamic and quality parameters at the river basins in Turkey become very important.

Acknowledgement

This work is completed under the scope of the project entitled "Development of Hydrological, Water Quality and Ecological Modeling Tools For Sustainable Management of Water Resources In Turkey," directed by İTÜNOVA Technology I.C. and supported by Republic of Turkey Ministry of Agriculture and Forestry.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

HİDROTÜRK Modeli Kullanılarak Hidrodinamik Modelleme

Bu makalede, Türkiye'de su kaynaklarının sürdürülebilir yönetimi için geliştirilen ilk ulusal hidrolojik, su kalitesi ve ekolojik modeli olma özelliğine sahip HİDROTÜRK modeli, hidrodinamik alt-model bileşenleri, temel teorik ve sayısal çözümleme kapasiteleri ile kısaca tanıtılmıştır. Hidrodinamik modellerin başarısı, türbülans benzeşimine ve taşınıma bağlı diğer tüm modellerin başarısını doğrudan etkilemektedir. Bu nedenle hidrodinamik modelleme, bütünleşik sayısal su kalitesi modellemelerinin en önemli bileşenidir. HİDROTÜRK modeli, FORTRAN programlama dilinde yazılan, bir (1-B), iki (2-B) ve üç (3-B) boyutlu olmak üzere, birbirinden bağımsız olarak çalışabilen, üç ayrı hidrodinamik alt model içermektedir. Tüm alt modellerin girdileri ve çıktıları kullanıcı dostu bir arayüz üzerinden yönetilmektedir. Geliştirilen hidrodinamik modeller istenildiği zaman bir arada da çalışabilmektedir. 1-B hidrodinamik modelin çıktısı 2-B hidrodinamik modelin girdisi, ya da 1-B ve 2-B hidrodinamik modellerin çıktıları 3-B hidrodinamik modelin girdisi olacak şekilde HİDROTÜRK modelinin kullanıcı dostu arayüzü üzerinden yönetilmekte, böylelikle kullanıcıdan kaynaklanabilecek hatalar en az düzeye indirilmektedir.

1-B hidrodinamik model, akış yönünde yazılan yavaş değişen kararsız akış denklemleri olan Saint Venant denklemlerini sayısal olarak çözmekte ve dinamik dalga ötelemesi uygulamaktadır. 1-B boyutlu modellerin kullanımı genişliği az olan uzun nehirlerdeki akışların, bu akışların su yapıları ile etkileşimlerinin ve taşkın olaylarının benzeştirilmesinde önemli araçlardır. 1-B hidrodinamik model olarak, dünyada da yüzey suyu modellemelerinde yaygın olarak kullanılmakta olan açık kaynak kodlu EXTRAN(Extended Transport Model) fortran dili yazılımı düzenlenmiş ve kullanıcı arayüzü üzerinden açık veya kapalı kanallar ve boru sistemlerindeki akışlar için kolaylıkla uygulanabilen bir yapıya getirilmiştir. Modelde, kanal yada boru akış sistemleri, düğüm noktaları ve bunları birleştiren bağlantı hatları ile temsil edilmektedir. Bağlantı hatları akışı düğüm noktalarına iletirler. Akışın debisi bağlantı hatlarındaki temel parametredir. Bağlantı hatlarında momentum denklemi, düğüm noktalarında süreklilik denklemi çözümlenir. Kesitsel akış alanı, su derinliği ve akış hızı her bağlantı hattında değişebilmektedir. 1-B model, arazi üzerinde tanımlanan hesap noktalarından hidrograf verilerini okuyabilmekte ve taşkın akımını ana drenaj hattından dinamik öteleme yöntemiyle tahliye noktalarına kadar taşıyabilmekte; dallanan ve döngüsel ağları, su düzeyi kabarmasını, serbest yüzey akışını, basınçlı akışı veya sürşarjı, ters akışı; savaklar, orifis ve pompa ile akış transferlerini ve açık veya kapalı tesislerdeki depolamanın benzetimini gerçekleştirebilmektedir. Modelde uygulanabilen kanal tipleri dairesel, dikdörtgen, üçgen, trapez veya doğal kesitli kanallar olarak değişmektedir. Kesitler üzerinde köprü ayakları ya da menfezler de tanımlanabilmekte, ve su düzeyi değişimleri için en kesit ve boy kesit profillerinin zamansal değişimleri elde edilebilmektedir. Kanallardaki su derinliği ve su yüzeyi yükseklikleri, deşarj debisi, ve akıntı hızları model çıktıları olarak düzenlenmiştir. Bir yüzeysel su akışı sistemi model ile analiz edilmek istendiğinde, çalışmanın ilk adımı akış sisteminin, havzanın ve alt-havzaların tanımlanmasıdır. Alt-havzaların her biri yüzeyinde oluşan akıntıları, tanımlanan bir drenaj kanalına tahliye eder. Drenaj güzergahlarında kabarma, sürşarj, çevirme-yönlendirme yapıları gibi akım ve su yüksekliği hesabına etki edebilecek yerlerde bir hesap noktası konulması gereklidir. Drenaj güzergahlarında hesap noktası atanması gereken yerler: memba başlangıç noktası, tahliye noktası, pompa istasyonu, depolama alanı, orifis ve savaklar, hidrograf verilerinin tanımlandığı alt-havza giriş noktaları, boru/kanal kesitinin ya da ölçülerinin belirgin şekilde değiştiği noktalar, boru/kanal

eğiminin değiştiği noktalardır. 1-B model hidrodinamik model doğrudan zaman adımlı sayısal bir modeldir.

2-B hidrodinamik model, derinlik boyunca ortalaması alınmış, kararsız süreklilik ve hareket denklemlerini sayısal olarak çözümlemekte olup, yüzey alanı büyüklüğünün su derinliğine göre çok daha baskın olduğu sığ sular için veya su derinliği boyunca tam karışımlı su kütleleri için daha güvenilir benzeşimler sunmaktadır. 2-B modelin sayısal çözümleme yöntemleri, 3-B model ile benzerdir. Modellerin girdileri, rüzgar ve gelgit özellikleri, başlangıç koşulları, yüzey akışı sınır koşulları ve su derinlikleri olup, su düzeyi değişimleri, yoğunluk değişimleri, ve hız değişimleri ise çıktılarıdır. Tüm model girdileri ve çıktıları, kullanıcı dostu arayüz üzerinden yönetilmektedir.

3-B hidrodinamik model, kararsız Navier-Stokes denklemlerini yalnızca Bousinessq varsayımı ile üç boyutta sayısal olarak çözümlemekte, zamanla değişen rüzgar ve yoğunluk gradyanı etkenli akıntıları alansal ve derinlik boyunca benzeştirebilmektedir. Su sıcaklığının, tuzluluğun, basıncın ve yoğunluğun zamansal, alansal ve derinlik boyunca değişimleri incelenebilmektedir. Su kütlesinin derinlikleri fazla olduğunda ve özellikle rüzgar ve yoğunluk kaynaklı çevrintiler gibi su kolonu boyunca yön değiştirebilen akıntıların hesaplanmasında 3-B hidrodinamik modelin kullanılması gereklidir. Geliştirilen iki ve üç boyutlu baroklinik hidrodinamik sayısal modellerde sigma koordinat dönüşümü uygulanmış ve şaşırtmacalı bir çözüm ağı üzerinde dolaylı zaman adımlı sonlu farklar yöntemi kullanılmıştır. Sigma koordinat sitemi, çözüm ağı aralıklarının yüzey ve taban tabakaları arasında sabit olması, her kesitte düşeydeki çözüm noktası sayısının eşit olması ve taban topografyasının düzenli bir biçimde takip edilebilmesi gibi sayısal çözümleme avantajları sağlamaktadır.

Modellerin yazılım geliştirmeleri, bir yüzey suyu yönetim modeli olan SWMM5.0 ve bir kıyı ve geçiş suları yönetim modeli olan üç boyutlu hidrodinamik ve taşınım modeli HYDROTAM-3D ile karşılaştırmalı ön testleri başarıyla tamamlanmıştır. Hidrodinamik modellerin ölçümsel veriler ile doğrulama çalışmaları halen devam etmektedir. Bu makalede hidrodinamik modellerin Gediz Nehri Havzası'nda yer alan Demirköprü Baraj Gölü'ne bazı uygulamaları sunulmuştur. Gelinen bu aşamada, HİDROTÜRK modelinin, bir, iki ve üç boyutlu hidrodinamik alt modellerinin doğrulama çalışmalarına devam edilmesi, bu amaçla eş zamanlı ve uzun süreli olarak hidrodinamik ve kalite parametrelerin Türkiye'nin çeşitli nehir havzalarında ve su kütlelerinde ölçümlenmesi gereklidir.

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Research Article

Impacts of Extreme Weather Events on Hydromorphology of UK Rivers

Aşırı Hava Olaylarının Birleşik Krallık Nehir Hidromorfolojisine Etkisi

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Abstract

In this study, we assessed the effects of extreme weather events on Hydro-morphological Quality Elements in rivers of the United Kingdom alongside other pressures that will provide significant challenges for the implementation of the Water Framework Directive in the UK in terms of cost-effectiveness and sustainability. While observed meteorological data and river data sets were used for assessing changes in river systems and weather patterns, for future assessments, UK Climate Projections 2018 data was used. The studies in the literature have shown that during periods of extreme events, the river hydro-morphology is affected especially in terms of river flows, sediments and riparian zones such as draughts, and intense and heavy rainfall leading to reduced or exceptionally high flow respectively. Reduced flows can lead to the loss of habitat of aquatic organisms and an increase in fish deaths. Whilst increased river flows lead to changes of the hydro-morphology of rivers including changes to sediment dynamics and channels, rivers are also under negative effects of anthropogenic hydro-morphological pressures such as building dams and water abstractions. Furthermore, changes in river hydro-morphology can cause other problems such as increasing water temperature and decreasing dissolved oxygen, and thereby degrading Biological Quality Elements and Physico-Chemical Quality Elements. To deal with and mitigate these problems, a holistic view of water policy that considers climate change projections, reduces water demand, changes agricultural and urban land use practices, improves water availability and quality is required.
Keywords: *Extreme weather events, climate change, water framework directive, ecological quality status, river hydro-morphology*

Öz

Bu çalışmada, Birleşik Krallık'taki aşırı hava olaylarının nehirlerdeki Hidro-morfolojik Kalite Elementleri üzerindeki etkileri, Su Çerçeve Direktif'i uygulamasında sorunlara yol açabilecek diğer baskılarla birlikte değerlendirilmiştir. Nehir sistemi ve hava olaylarındaki değişiklikleri değerlendirmek için gözlemlenen meteorolojik ve nehir veri setleri kullanılırken, gelecek değerlendirmeler için Birleşik Krallık İklim Projeksiyonları 2018 verileri kullanılmıştır. Literatürdeki

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çalışmalarda aşırı hava olayların olduğu dönemlerde nehir hidro-morfolojisinin özellikle nehir akışları, sedimentleri ve nehir kıyı bölgeleri açısından etkilendiği bulunmuştur. Azalan akışlar, sudaki organizmaların yaşam alanlarının kaybına ve balık ölümlerinin artmasına neden olabilir. Artan nehir akışları, sediment dinamiği ve kanallarındaki değişiklikler de dahil olmak üzere nehirlerin hidro-morfolojisinde değişikliklere yol açarken, nehirler, bina barajları ve su soyutlamaları gibi aktiviteler de dahil olmak üzere antropojenik hidro-morfolojik basınçların olumsuz etkileri altındadır. Buna ek olarak, nehir hidro-morfolojisindeki değişikler su sıcaklığını arttıran ve çözünmüş oksijen miktarını azaltan başka problemlere sebep olabilir ve böylece Biyolojik Kalite Elementleri ve Fiziko-Kimyasal Kalite Elementlerini indirgeyebilir. Birleşik Krallık'ta aşırı olayların yoğunluğunun ve sıklığının artması, Su Çerçeve Direktifi'nin maliyet etkinliği ve sürdürülebilirlik açısından uygulanmasında zorluklara neden olacağına hiç şüphe yoktur. Bu sorunlarla başa çıkmak ve bunları azaltmak için, iklim değişikliği projeksiyonlarını dikkate alan, su talebini azaltan, suyun mevcudiyetini ve kalitesini iyileştiren, tarımsal ve kentsel arazi kullanım uygulamalarını değiştiren bütüncül bir su politikası gereklidir.
Anahtar kelimeler: *Aşırı hava olayları, iklim değişikliği, su çerçeve direktifi, ekolojik kalite durumu, nehir hidro-morfolojis*

Introduction

Fossil fuel consumption has increased very substantially since the Industrial Revolution starting in the middle of 18th century England. In 1750, Great Britain produced about 5.2 million tons of coal per year, and by 1850, it was producing 62 million tonnes per year. Global fossil-fuel consumption has also increased exponentially. During the 20th century, there was more than a 1300-fold increase in the use of fossil fuels. Burning coal produces about 15 billion tonnes of carbon dioxide (CO_2) each year around the world at the present time. Coal still accounts for about a third of the world's fossil energy consumption. Fossil fuels (coal, natural gas, and oil) are the primary source of air pollution, emitting a range of pollutants to the atmosphere including CO_2, Nitric Oxide (NO_x), Sulfur Oxides (SO_x) and other greenhouse gases. Therefore, the use of fossil fuels as the world's primary energy source contributes to the many environmental problems being observed today. In particular, greenhouse gas emissions have increased the greenhouse effect and are the major cause of climate change (Intergovernmental Panel on Climate Change [IPCC], 2014).

One of the unexpected problems that climate change causes is extreme weather events (Ren et al., 2018). The frequency, intensity and duration of extreme events are also changing due to many human factors, such as the growing global population which has increased from 670 million people at the start of the industrial revolution to over 6.7 billion (a 10 fold increase); there has also been an increase in urbanisation and infrastructure across the world. Changes in extreme events can be observed in some statistical parameters such as mean and variance of events. In addition to climate change caused by anthropogenic activities, some extreme events occur due to natural variability. Therefore, it is important to take natural variability into account for a better understanding of extreme events in the future alongside changes caused by anthrophonic activity (Field et al., 2012; United Kingdom Climate Change Risk Assesment [UKCCRA], 2017).

Climate change causes some alteration on weather events such as precipitation and temperature, and this is expected to be effective on a global scale. Additionally, in some regions, some extreme events have increased, they have become more frequent and more intense in particular regions (Herrero et al., 2018; IPCC, 2013). These observations have started to be seen with increasing concern. There is some evidence that many of these increases are related to human activities. (Ren et al., 2018).

Extreme events may cause serious problems for the environment such as floods, storms, and water contamination. To illustrate, when it rains much more than expected over a short time, floods can occur and cause serious and destructive harm to river flows, regimes and sediments depending on the size of the flood. Some positive changes in river water quality can be associated with the decrease in occurrence and duration of extreme events (United Kingdom Technology for Agriculture and Genetics [UKTAG], 2008)

The world has seen an increase of 0.85 [0.65-1.06] °C in the average global (combined land and ocean surface) temperature from 1880 to 2012. This trend in global warming has also been observed in England, which is reported in the central England temperature data series, which has good correlation with temperature data sets from other global sources (UK Climate Change Risk Assessment [UKCCRA], 2017). In recent decades, the UK has had milder winters and hotter summers, and since 1990, all ten of the warmest years in the UK have occurred during this period. Surprisingly eight of them have occurred since 2002 (Kendon et al., 2015). Furthermore, the frequency of heatwaves has started to increase and have occurred many times since 2000, with the most critical recorded heatwaves occurring in 2003, 2006 and 2018. These observations show that because of the impacts of climate change, extreme events, which have serious impacts on the environment, have started to be observed more frequently and intensively in recent years (Guillod et al., 2017). The UK Climate Change Risk Assessment Report (2017) concludes that extreme events such as floods, heatwaves, and droughts will become common threats for the UK and advises regulators to take serious and permanent precautions to mitigate these forecasts.

If climate change mitigation plans are not adopted and extreme events such as floods and heatwaves become more frequent and intense in the future, such events could change the geomorphology of riverine habitat and the river ecology. It is possible to alter the river's quality and habitat quantity as extreme events such as floods change river geomorphology which consists of riparian, slope, discharge, catchment geology and sediment supply. Additionally, human activities such as engineering works for the protection of floods exacerbate the impacts of extreme floods on rivers by changing the riparian zones and river flows that minimize the river channel width over time (Death et al., 2015). During periods of extremes, a flood could not find enough channel width, and the destructive impacts of floods could be more intense (Death et al., 2015).

To deal with problems in water bodies, on October 2000, The European Parliament and The Council of The European Union published an establishment of a framework regarding water policy for their community actions (EU Water Framework Directive [WFD] 2000/60/EC, 2000). The aim of the WFD required all member states to achieve "good status" in all types of water bodies by establishing measurement programmes. For different types of water bodies, the Ecological Quality Status needs to be assessed by member states. For surface waters, the classification of ecological status is defined by Biological Quality Elements (BQEs), Physico-chemical Quality Elements (PCQEs) and Hydro-morphological Quality Elements (HMQEs) (Romero et al., 2013). Water bodies are classified into five categories used by the WFD classification scheme, and these are high status, good status, moderate status, poor status and bad status (Table 1). To achieve high status a water body must meet the conditions of each of the WFD Quality elements. A lower classification is based on the degree of deviation from reference conditions. The hydro-morphological quality element is only considered for water bodies that meet the other two quality elements. The WFD has set an objective for all water bodies in the EU to achieve at least 'good status' but almost half of the water bodies in Europe are currently below this standard.

Table 1

Definition of Ecological Status of Water Bodies under the WFD (Environment Agency, 2006)

Ecological Status	Water Framework Directive Quality Elements		
	BQE	PCQE	HMQE
High status	Meets conditions	Meets conditions	Meets conditions
Good status	Deviates slightly from reference conditions	Meets conditions	Not considered
Moderate status	Moderate deviation	Moderate deviation	Not considered
Poor status	Deviation	Major deviation	Not considered
Bad status	Deviation	Greater deviation	Not considered

A hydro-morphology assessment considers the hydrological (water flow, energy) and geomorphological (surface features) attributes of water bodies and is a "supporting element" which means that for water bodies where ecological status is less than 'high status' or is changing status from high to good ecological status, the hydro-morphological state is not taken into account as a component of overall ecological status (Environment Agency, 2006). When used in the assessment of ecological status, both natural and anthropogenic variables including river flow regimes and fluvial geomorphology are considered. High status is determined if the water body has no or very minor anthropogenic changes regarding the HMQE (The Secretary of State, 2015). Additionally, as indicated previously, the WFD requires its members to define their rivers' ecological status based on BQEs, PCQEs, as well as HMQEs which consider the hydrological regime, river continuity, and morphological conditions as detailed in Annex V of the WFD (Ilnicki et al., 2010; The Secretary of State, 2015). It is known that any changes in ecological status could be the result of changes in one or more of the elements. Although chemical elements could be measured according to their main quality, hydro-morphological elements cannot be measured in the same way (Department for Environment, Food & Rural Affairs [DEFRA], 2006).

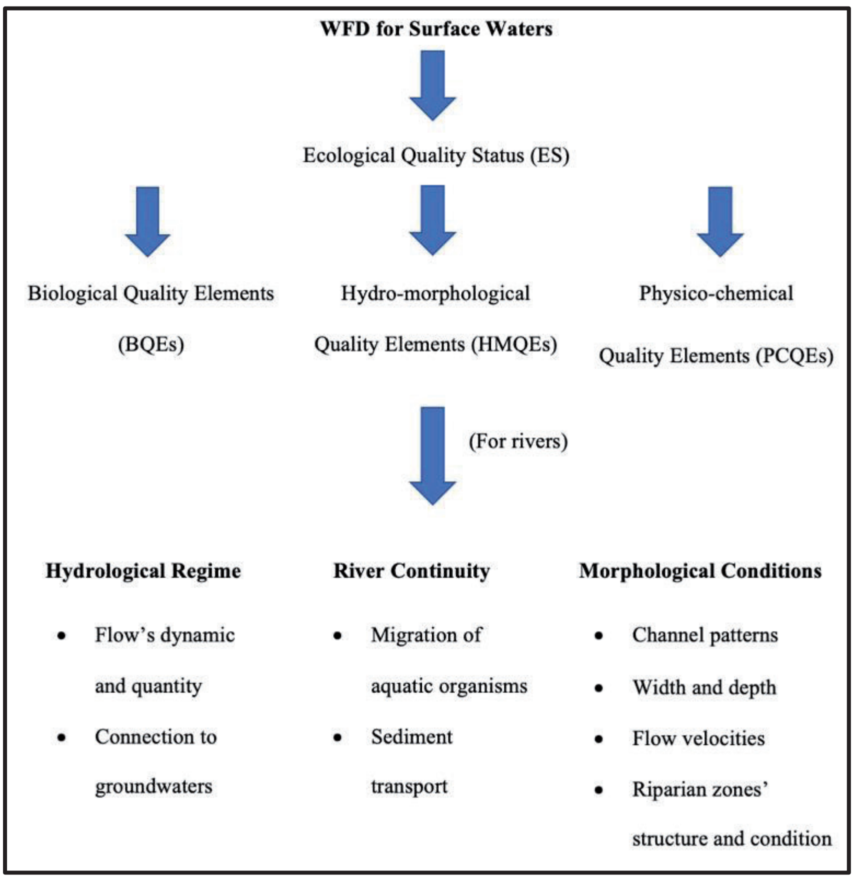
HMQEs is one of the main parts of Ecological Quality Status for surface water bodies under the water framework directive (Reynard, 2010). By helping to describe conditions of water bodies, all EU members need to consider all mandatory and recommended parameters for these elements. Surface water bodies such as rivers, and lakes have specific HMQEs including the hydrological regime, river continuity and morphological conditions as reported in Annex V of the WFD, and these are described as 'supporting the biological elements' by the WFD (The Secretary of State, 2015; United Kingdom Technical Advisory Group [UKTAG], 2003). Assessment categories of surface water bodies defined by the WFD is shown in Figure 1.

It is known that any changes in ecological status could be the result of changes in one or more of each of these elements, and HMQEs are defined to be supportive of BQEs, and the reverse case could occur (Department for Environment, Food & Rural Affairs [DEFRA], 2006; Environment Agency, 2006). It is not avoidable to have impacts on river biota whilst responding to the effects of extreme climate events and weaken ecological resilience. Any changes in river morphology, hydrology, and riparian cover could cause some problems for the cold water refugia such as salmonids. Also, any channelization for flood risk increases sediment loads and reduces habitat diversity (Whitehead et al., 2009). Furthermore, Feld et al.(2014) showed that one of the important pressures and major threats to lotic ecosystems and biodiversity in Europe is hydro-morphological alterations. Also, the study suggested that it is essential to develop and identify new indicators for detecting biodiversity loss and changes in ecosystems.

Moreover, increasing drought and flood intensity due to climate change can affect river flow regimes and morphology. Thermal impacts where reduced flow occur will be exacerbated by increased temperature. Moreover, having lower flows and higher water residence times in rivers can cause serious problems such as eutrophication, ecosystem functions, algal growth and decreasing oxygen level. It is also known that changes in water temperature can have impacts on aquatic systems and some species could be more sensitive to changes, even for small changes. Increasing rainfall comes with biophysical impacts such as diffuse pollution and soil erosion (Whitehead *et al.*, 2009; UK Climate Change Risk Assessment [UKCCRA], 2012a; Orr *et al.*, 2015; O'Briain, 2019).

Figure 1

Assessment of Ecological Status of Rivers (Adapted from DEFRA, 2009; European Environment Agency [EEA], 2018)



Any changes in air temperature and rainfall, projected by climate models could have impacts on river flows and alter dilution for pollutants. There is no doubt that chemical reaction kinetics, quality, and ecological status of water bodies will be affected by warmer water. Increased flows will cause some changes in stream power, sediment transfer and loads, which have the potential to change the morphology of rivers. Having lower flows in rivers could cause reduced dilution, and this could result in higher concentrations of pollutants, which makes the purpose of improving water quality standards hard within the WFD. Additionally, it will cause increased biochemical oxygen demand (BOD), lower dissolved oxygen (DO) concentrations, and have impacts on organic pollutant concentrations in rivers. While ammonia levels fall due to higher rates of nitrification, BOD and phosphorus levels increase under the reduced flows in the summer periods (Whitehead et al., 2009)

All monitoring programmes for assessment of river basins and flood risk should consider all ecological quality elements including hydro-morphological quality elements. Also, any effects of hydro-morphology on biological elements should be considered in the future within the timeframe of monitoring programmes. There are lots of differences among member state countries for giving priorities to hydro-morphological elements, and sediment transport is considered more in the River Basin Management Plans compared to Flood Risk Management Plans (Nones et al., 2017). To evaluate the rivers' hydrological and morphological conditions, direct and indirect pressures and nature of anthropogenic changes must be considered by the appropriate agency (The Secretary of State, 2015).

It was expected that all EU members would reach good status in all water bodies by 2015, called the first planning cycle; however, many member states faced problems to develop programmes and had limited change in their ecological status. Nearly half of the surface water bodies within the EU remained the same and did not reach the aims of the WFD. Additionally, in the first cycle (from 2009 to 2015), only 10% of water bodies that were classified at a moderate status or below reached good status. Therefore, the timeline to achieve good status was postponed to 2027 (Giakoumis and Voulvoulis, 2019; Van Rijswick and Backes, 2015).

Any changes in the future climate or socio-economy may affect the ability of member states to reach desired environmental conditions to achieve the required WFD ecological status. To exemplify, it is known that the objectives of the WFD could be more difficult by the worsening hydro-morphological issues and nutrient enrichment in the 2050s across Europe, which also applies for England and Wales. It is expected that hydro-morphology will be degraded in the future, and there should be more measures for dealing with these challenges with sustainable and cost-effective approaches and adaptations for common issues in different scenarios (Henriques et al., 2015)

An assessment of the ecological status of the UK in 2009 reported that almost half of the surface water did not meet good status. It was determined that there were many significant pressures from the point and nonpoint sources, hydro-morphological alterations and other pressures which impacted on water bodies in failing river basin districts. Additionally, UK forecasts mention the increase of precipitations and temperatures and extreme events, which will continue to increase and be more frequent in the future, however; there is not enough knowledge regarding re-occurrence time. Serious and permanent precautions for the protection of bodies is required to mitigate these threats (UK Climate Change Risk Assessment [UKCCRA], 2012). Modelling studies of UK climate predicts hotter summers which are expected to cause lower river flows and reduce water levels. Extreme events such as heatwaves also place pressures on the demands of water supply.

This study reports on the pressures and negative impacts of extreme weather events on hydro-morphological quality elements of water bodies in the United Kingdom. The paper considers the UK's weather changes and trends over the last century and identifies and considers the possible obstacles and barriers resulting from climate change and extreme events in the implication of the WFD in the UK in the future.

Method

Design and Search Strategy

The Web of Science and Scopus databases were used to address the objectives of the research. Searches were limited to English articles, published between January 1980 to present in peer-reviewed journals. UK Met Office meteorological data sets were searched for parameters such as temperature, rainfall and extreme event occurrence in the UK. Climate and other factors that could impact on HMQEs related to river hydro-morphology were determined using data sets available online. Additional parameters that have the potential to impact or change hydro-morphological quality elements were identified to assess potential problems for the implementation of the WFD in the UK. The following parameters were considered:

Temperature: To visualize the changes over the world from 1850 to 2018 and in the UK from 1884 to 2018, data sets were obtained from the UK Met Office. Additionally, maps showing temperature changes over the world and the UK was obtained from IPCC. Data for extreme events including drought periods were obtained from the UK Met Office. For future assessment, United Kingdom Climate Projections 18 data was used (UK Climate Projections 18 [UKCP18], 2018)

Rainfall: To assess observed rainfall trends in the UK, data containing annual, seasonal, and monthly participations values (mm) from 1910 to 2018 collected from the UK Met Office was used. For future assessment of precipitation changes, data was obtained from UKCP18 for the UK under five different scenarios, and from IPCC for world rainfall records.

River changes: To show any changes in rivers, data such as river flows was obtained from the UK National River Flow Archive, the UK Monthly Hydrological Summaries, Environment Agency River Hydrology, Annual State of the UK Climate, and Centre for Ecology & Hydrology.

Data Analyses

To analyse data sets to learn any impacts of extreme events on rivers, firstly data sets were reproduced using Microsoft Excel. Periodical and overall min, max, and mean values were compared and shown in the graphs to see how rainfall and temperature trends changed over the years. Also, regional values were compared to see how the UK was affected by extremes regionally. Weather maps from the UK Met Office were used and compared to assess how extreme weather events were effective over the UK. The differences and connections between hydro-morphological variables such as river flows, channel width, and riparian zones and extreme weather conditions such as heatwaves, floods, and droughts were identified by comparing the periodical weather results. For future assessment, different scenarios were shown in the same graphs, which allowed comparing the projections related to weather patterns.

Results and Discussion

Climate Change and Extreme Events Analyses

Many physical responses such as changes in air temperature, in rainfall, the melting of glaciers and ice sheets, and increasing sea levels are indicators of climate change (IPCC, 2013). According to IPCC, even if global warming was limited at 1.5 degrees above pre-industrial levels, the effects of climate change would still be effective on earth. Such scenarios demand planning and preparedness for adverse weather effects including storms, sea-level rise, heatwaves, weather-related diseases, and other effects that have adverse impacts on society and the environment (Emma, 2018).

Although regional climate change outcomes are uncertain, many latest assessments include the projection of changes in the occurrence of weather and climate events, which mainly focuses on frequency, intensity and duration. These changes, with increasing vulnerability, could increase stress on society and environment, and increase the tendency for adverse effects of climate change around the world (Field et al., 2012).

Since the 1950s, extreme events and climate events, such as a decrease in cold temperature extremes and the increase in warm temperature extremes and heavy rainfall events have started to change, some of these changes have been linked to anthropogenic influences. Other changes in extremes, that could occur include an increase in the number of warm days and nights, and a decrease in the number of cold days and nights globally. Also, in most of Europe, Asia and Australia, there has been an increase in the frequency of heatwaves and the intensity and occurrence of the temperature extremes. ((Intergovernmental Panel on Climte Change [IPCC], 2014).

UK temperature analysis.

The dominant cause of global and UK temperature changes can be attributed to increasing greenhouse gases (GHGs) in the atmosphere. Furthermore, there is a substantial body of evidence that suggests that these emissions are due to human activities rather than natural causes and the observed temperature changes are not a result of natural climate variations (Adger and Brown, 1993). These findings are based on national inventories of greenhouse gas emissions, which form a part of the UK's ratification the United Nations Framework Convention on Climate Change (UNFCCC) which came into force in March 1994. Under its obligation to the convention, the UK is required to regularly update national emission inventories of GHGs. A report lasts submitted in 2019 (Brown et al., 2019) contains national greenhouse gas emission estimates for the period 1990-2017 and includes descriptions of the methods used to produce the estimates.

Evidence of global warming is highly convincing, global temperature measurements from worldwide records show that average temperatures have risen by nearly 0.8 ºC since the late 19th century, which is a rise of 0.2 ºC/decade. This is also the case of temperature records in the UK, which like other parts of the world also show significant trends towards higher temperatures; i.e. in England, temperatures have risen by 1 ºC since the 1970s. Temperatures have also increased in other parts of the UK, in Scotland and Northern Ireland they have arisen by 0.8 ºC since 1980 (Jenkins et al., 2008). Recent decades have seen the largest increase in temperature, for example, the last decade in England was the second hottest in the past 100 years and eight new high-temperature records have been set during the last two decades. When compared to the annual average UK land temperature during the period of 1961-1990, the period of 2005-2014 was 0.9°C higher, and 2014 was the warmest year. While ten of the warmest years has observed since 1990, and eight of them has occurred since 2002 (Karoly and Stott, 2006; Kendon et al., 2016).

Hawkins (2019) visualised these temperature trends using an animated spiral graphic and later he used warning strip charts, that contain chronologically ordered coloured stripes to describe the temperatures in the UK for the period 1850 – 2018. The warning charts show that most warming years were observed in the last two decades and the latter part of the last century. Alongside higher mean temperatures over lands and seas, the UK has also experienced more extreme events and experienced milder winters and hotter summer in recent years (UK Climate Change Risk Assessment [UKCCRA], 2017).

Global climate models (GCMs) have been used to predict how temperatures will change around the world. To analyse specific regions, regional climate models (RCMs) have been useful tools in providing fine-scale and regional results. One of the RCMs is the United Kingdom Climate Projections (UKCP), first published in 2009, and supported by the UK Met Office and DEFRA (UKCP18), were used with finer scale and more detailed information by covering both land and surrounding seas around the UK. These models show that UK annual average temperatures will change by 2100 under five different scenarios at the 95th percentiles. Scenarios are for the low (RCP2.6), medium (RCP4.5 and RCP6.0), high emissions (RCP8.5), and the UKCP09 medium emissions scenario (SRES A1B), relative to baseline of 1981-2000. Even if the low scenario (RCP2.6) remained effective, the UK would still be warmer and there would be around 0.75 °C increase in annual average temperature, while the scenario would progressively get worse and for the high emissions (RCP8.5) the temperatures will increase around 8.6 °C (Lowe et al., 2019).

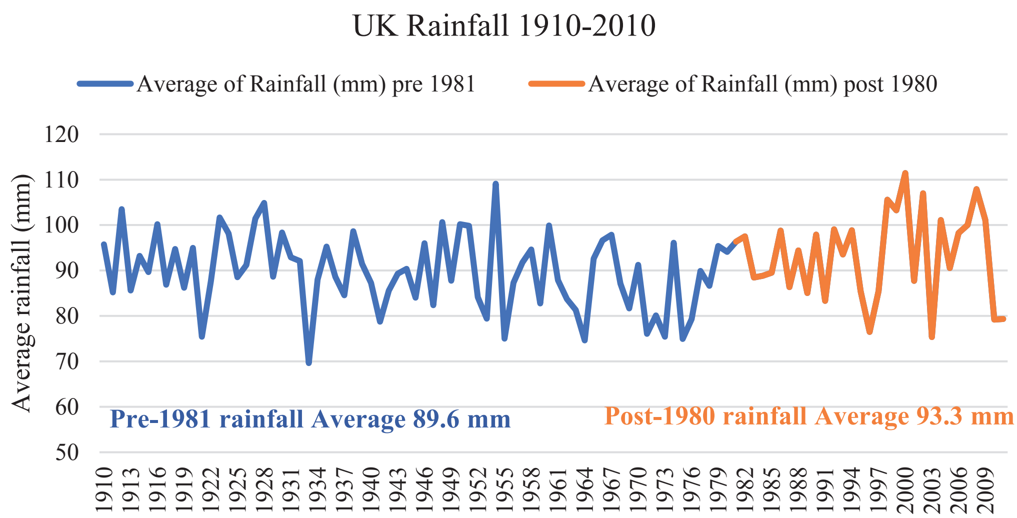
UK rainfall analyses.

Over the past 100 years, while the global precipitations have changed, the UK climate has also changed with an increase in the winter rainfall and a decrease in the summer rainfall. While more heavy rainfall events are observed winter rainfalls, the summer rainfall decreases (Emma, 2018).

In Figure 2, it is shown how the precipitations changed in the UK from the 1910s to 2018 with the value of min, max and average of 1981-2010, 1910-2018, and 1910-1980 period. While the wettest period was observed in 2000 and 2012 with 118% of average, the driest period was observed in 1993 with 74% of average. Since 1998, seven of the ten wettest years has observed. These are 2000, 2012, 2014, 2008, 2002, 2015, and 1998, respectively.

Figure 2

The UK Rainfall Time Series from 1910-2010 (Data from UK Meteorological Office, 2019)



Under the five different scenarios, UKCP18 has projected the changes in the precipitation over areas of the UK. Although annual average rainfall may not change over the 21st century, it is expected to increase in more extreme events (Emma, 2018). In the UKCP18, it is found that while a smaller increase is observed over Scotland, a larger increase is observed in the South of England. In projections of changes in 30-year mean annual, winter and summer mean precipitation by the 2050s under the medium emissions scenario, the UK is expected to see increases in winter rainfall by approximately 5% to 30%, and to see 20%-40% decrease or 1%-7% increase in summer rainfall (UK Climate Change Risk Assessment [UKCCRA], 2012). Projections show that while warmer and wetter climate will occur in winters, hotter and drier climate will occur in the summer. As a result of natural variability in the climate system, natural structure of the winter and summertime periods, cold and drier winters, or wetter summer will still occur with less frequency.

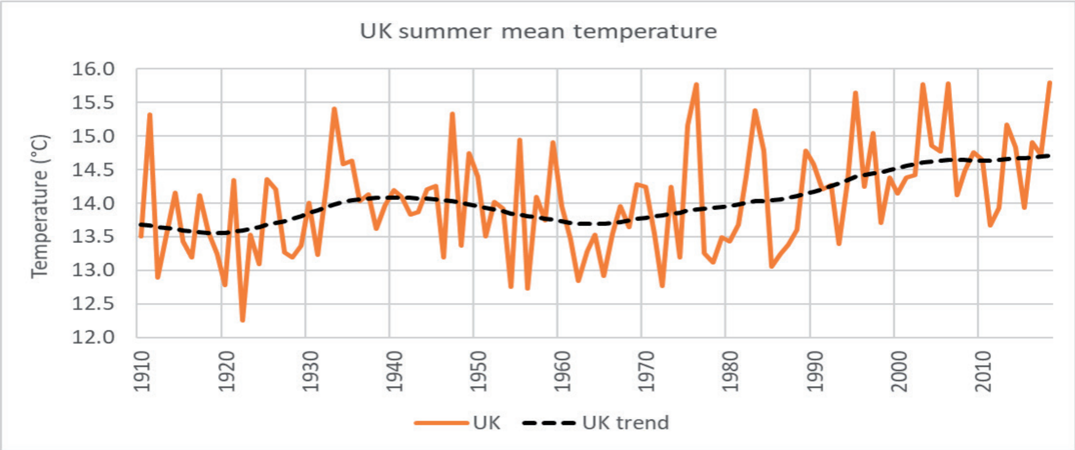
UK Extreme Events

Heatwaves.

The UK has undergone many heatwaves since the beginning of the 20th century. Figure 3 shows the summer mean temperature from 1910 to 2018 in the UK. The warmest summer of 1911 was equal with 1976, 2003, 2006 and 2018.

Figure 3

Summer Mean Temperature in the UK from 1910 (Data from UK Meteorological Office, 2018a)



Since the 1980s, heatwaves have started to become more frequent and the trend from 1910 to 2018 is upward, which has seen average summer temperatures increase by about 1.0°C from an average daily temperature of 13.6°C to 14.6°C. Furthermore, the average maximum temperature is also increasing. Table 2 shows that during the period 1981-2010 compared to the period 1961-1990, the maximum average temperature has increased in every month between the two time periods (annual average increase between the two periods is 0.6 °C)

Floods and heavy rainfalls.

Many extreme events including floods and heavy rainfalls have been intensively and frequently observed in the UK since the late 20th century. There has been a 17% increase in the total amount of extreme rains from 2008 to 2017, when compared to the 1961-1990 period. Figure 4 shows how the UK's rainfall changes annually, showing an incremental trend upwards over the last 30 years period. Additionally, while the largest changes are observed in Scotland, most of the southern and eastern areas are not affected as much. Although the extreme events vary inter-annually, the general trend is consistent with the increase in the rainfall over the UK.

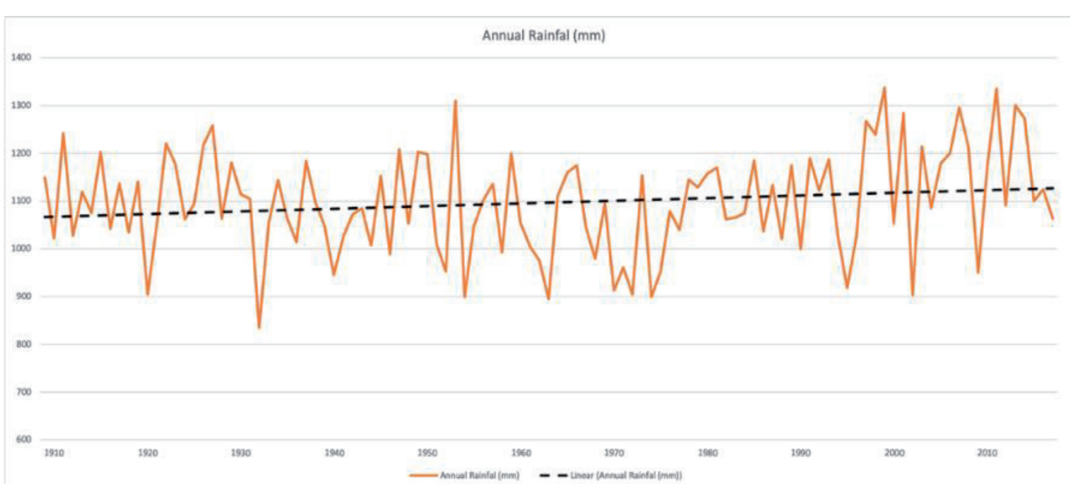
Table 2

UK Average Temperatures (Maximum and Minimum Average Temperatures in the Periods 1981-2010 and 1961-1990, and the Difference in Maximum Average Temperature)

Month	Climate Period 1981 – 2010		Climate Period 1961 – 1990		Difference in Maximum Temperature (°C)
	Maximum Temperature (°C)	Minimum Temperature (°C)	Maximum Temperature (°C)	Minimum Temperature (°C)	
January	6.4	0.9	5.7	0.4	0.7
February	6.6	0.7	5.8	0.2	0.8
March	8.9	2.1	8	1.4	0.9
April	11.4	3.4	10.6	2.8	0.8
May	14.7	6	14.1	5.5	0.6
June	17.3	8.8	17	8.4	0.3
July	19.4	10.9	18.6	10.2	0.8
August	19.1	10.8	18.4	10.2	0.7
September	16.5	8.8	16	8.4	0.5
October	12.8	6.2	12.7	6.2	0.1
November	9.1	3.3	8.4	2.7	0.7
December	6.7	1.1	6.5	1.2	0.2
Annual	12.4	5.3	11.8	4.8	0.6

Figure 4

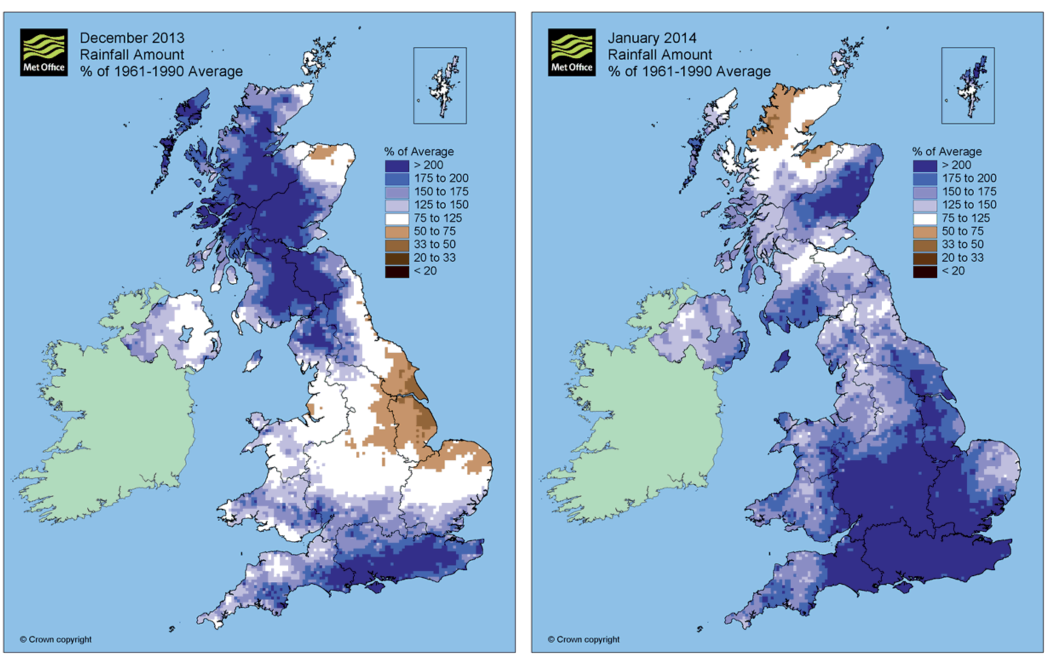
Annual Rainfall Changes in the UK from 1910 to 2018 (Data from UK Meteorological Office, 2019)



The period 2008 to 2017 has set several new rainfall records. The months of May, June and July in 2007 were exceptionally wet months with twice the 1961-1990 average. And 2012 was one of the wettest years in the UK with several destructive floods. During the year, most parts of England, Wales and eastern Scotland received twice or three times the average rainfall. Also, some local areas received over four time average (UK Meteorological Office, 2012). In December 2013 and January 2014, the UK experienced some of the most widespread and destructive floods on record which occurred in many parts of the UK. In Scotland, the rail network had periods of shut down, and many houses were left without power for weeks. While in December, heavy rainfall was effective over Scotland, the south part of the UK was affected severely in January (Figure 5) (UK Meteorological Office, 2014).

Figure 5

December 2013 and January 2014 Rainfall with 1961-1990 Average UK Meteorological Office, 2018b)



The IPCC 5th Assessment Report for policymakers' forecasts that the UK will see a rise in rainfall of about 10% in annual average rainfall by 2100 compared to the period 1985-2005. The forecast also predicts that the UK is very likely to see more heavy rainfall events in the next 50-100 years. Heavy and prolonged rainfall events, resulting in lots of rain falling in a short time will lead to a higher incidence of flooding over time. The economic growth of the United Kingdom, particularly certain parts of the UK such as the South East of England have seen a significant increase in property developments on floodplains over the past 10 years and one in five of those properties is at risk of flooding. In the UK, between 2001 and 2011, 200,000 homes were built in floodplains. Therefore, the increase in heavy rainfalls places these developments at high risk.

Impacts of Climate change and Extreme Events on Hydro-morphological Quality Elements

The UK's surface, transitional and coastal waters are highly affected by anthropogenic activity. Like many other countries, the UK has over the centuries changed the course and character of its water bodies to make water available for agriculture, to develop urban areas, to produce hydroelectric power or to protect its communities from flooding. Physical changes to water bodies that result from activity such as water abstraction, water flow engineering (dams, weirs, and locks), morphological alterations (changes to the channel, riparian and flood plain) are called hydro-morphological pressures as they alter the water flow dynamics and morphology (or physical structure) of the water body. Hydro-morphological changes can induce habitat alterations i.e. change in flow frequency, flow duration, change in sediment transport, loss of floodplains or intertidal area, change in river profile and estuaries and change in connection with groundwater (Kristensen et al., 2012). Therefore, Hydro-morphological pressures can have a significant impact on the aquatic environment.

In addition to direct impacts of anthropogenic alterations, the hydro-morphology of a river can also be affected by climate change. One of the significant results of climate change may be the increase, duration and intensity of extreme events such as floods or heatwaves, which affect the hydrological conditions of rivers, including flow and water levels (Bauwens et al., 2013; Hannaford, 2015; Lehner et al., 2006; Nováky and Bálint, 2013). These events are also known as hydrological hazards which are associated with water's movement, distribution and occurrence. Because of the complexity of systems and the interaction between hydrology and climate, for any given system, the changes it experiences in hydrological and morphological conditions is generally not widely understood or extensively studied (Arnell, 2003; Guan et al., 2016; Visser-Quinn et al., 2019; Yousefi et al., 2018).

River flow regimes are key indicators of anthropogenic climate-driven changes in river flows (Hannaford, 2015). River flow regimes help understand how spatial and temporal changes occur and to identify any future changes. Additionally, it is possible to identify and learn the river or catchments sensitivity to climate change (Bower et al., 2004; Howden et al., 2009). This type of studies to understand the relationship between climate change and extreme events and river flow is helped by the excellent gauging station network, consisting of 1400 stations. The data from these stations is kept by the National River Flow Archive. However, most of the gauging stations were installed in the 1960s and 1970s and therefore there is a lack of data from the 19th or early 20th century. Furthermore, there is considerable missing data from stations particularly during extreme flow periods of very high or low flow episodes (Dixon et al., 2006).

River flow changes in the UK during heatwaves.

Although low river flows as a consequence of dry weather which occur during heatwaves receive less attention than high flows caused by high rainfall, low flows are nevertheless a significant issue. Reduced flows reduce the protective dilution effect of rivers on aquatic life, leading to changes and the loss of habitat for aquatic animals and plants. For example, fish deaths increase during droughts and low river flow. Also, during low flow events, water abstraction for agriculture and water supply needs to be constrained, affecting households, agriculture and industry.

Evidence of low river flows during drought periods in the UK is available during two record-breaking heatwaves during this century. Figure 6 shows river flows in the July heatwave of 2006. The river flow changes were collected from monthly hydrological and described as; exceptionally high flow (black), notably high flow (dark blue), above normal (blue), normal range (green), below normal (yellow), notably low flow(orange), exceptionally low flow (red).

River flow changes in the UK during the 2018 heat wave provide further evidence of climatic effects, shown in Figure 7. The figure illustrates that river flows were highly affected during heat waves, showing that flows in May were normal, occasionally below average, but almost 80% of river flows were under normal range and some exceptionally low in July (the peak of the heatwave). In August 2018, the status was getting better and turned into normal in September.

Figure 6

River Flow Changes in the UK During the July 2006 Heatwave (Adopted from The Natural Environment Research Council's (NERC) Centre for Ecology & Hydrology (CEH) [NERC CEH], 2018)

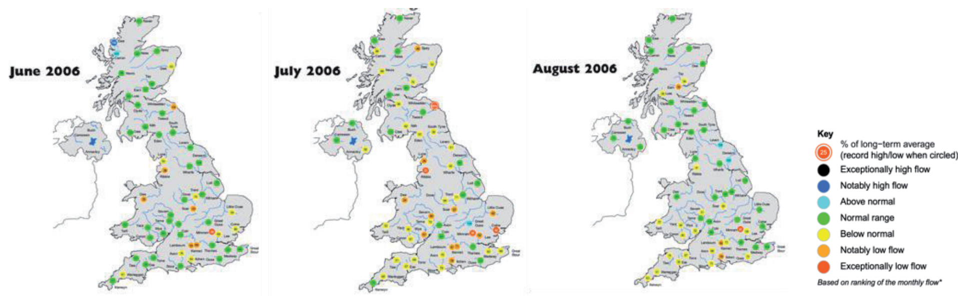
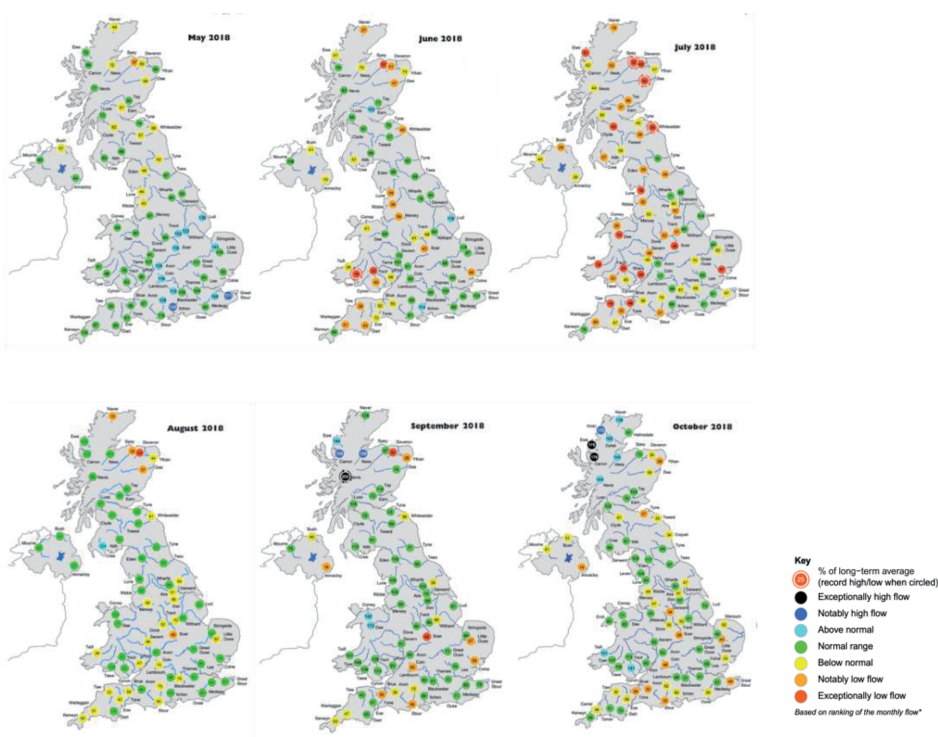


Figure 7

River Flow Changes in the UK During the 2018 Summer Heatwave (Adopted from The Natural Environment Research Council's (NERC) Centre for Ecology & Hydrology (CEH) [NERC CEH], 2018)

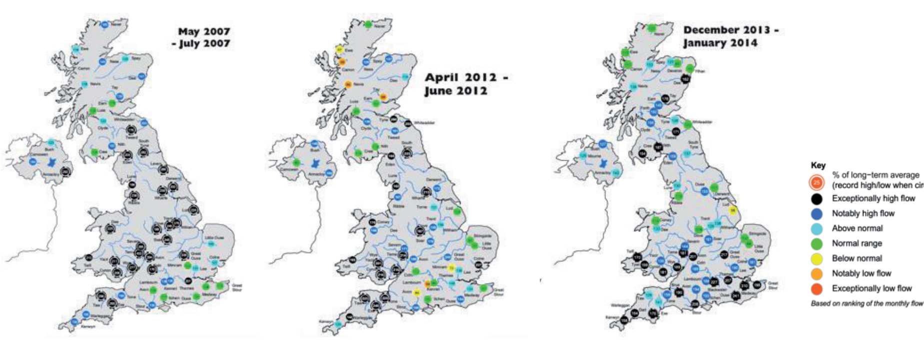


River flow changes in the UK during heavy rainfalls.

In addition to impacts of heatwaves on river flows, heavy rainfalls also have significant impacts on river flows including flooding. The UK experienced heavy and prolonged rainfall and flooding during 2007, 2012, and 2013-2014, the flooding had very destructive effects on a large number of communities in the UK. During these periods, many parts of England, Northern Ireland, and Scotland were under heavy rainfall which caused these areas to be extremely wet. When analysing the river flow changes during this period, it is found that rivers were above average flow, some had exceptionally or notably high flow as shown in Figure 8. The UK, especially central England were most affected by these extreme events in 2007.

Figure 8

River Flow Changes over the UK in 2007, 2012, and 2013-2014 (Periods of Heavy Rainfall) (Adopted from The Natural Environment Research Council's (NERC) Centre for Ecology & Hydrology (CEH) [NERC CEH], 2018)



Therefore, it is possible to say that the river flows are affected by extreme events. These effects could be either more flows above average that can cause floods and heavy rainfalls, or fewer flows below average for heatwaves.

Although many studies have focused on the relationship between hydrology and geomorphology, only a few studies have been conducted for analysing the effects of extreme events on channel hydrology and morphology (Yousefi et al., 2018). According to Phillips (2002), it is found that flash flooding has impacts on geomorphology and has caused channel changes.

The study for seasonal analyses in the UK was conducted by Hannaford and Buys (2012). It is observed that while north and west part of the UK's winter high flows were at a high level, central and southwest England and eastern Scotland's autumn high flows were at a high level. Also is found that there was an increase in the high flows of some lowland catchments and that although summer and spring flows were more complex and mixed, in some regions there were increase trends in both seasons. Other studies also showed that results are generally on the same side for the UK and that there is a tendency to increase high flows. (Hannaford, 2015).

Moreover, according to Dixon et al. (2006), flow regimes at 56 gauging stations from 1962 to 2001 in Wales And English Midlands were analysed. It is found that while significant high flow trends were observed in winter in the west of studies, flows were at a high level in east of study areas in autumn. Additionally, from 1977 to 2016 period, the increase in the annual and autumn extreme flows was observed in the Severn uplands (Biggs and Atkinson, 2011).

On the contrary, according to Hannaford (2015), there is no sufficient evidence for any long term trend (decrease or low flows) in river flows. However, past events showed that there has been remarkable hydrological volatility and that the UK rivers have been vulnerable to extremes such as major floods and storms in winters.

As indicated above, the frequency of extreme events is increasing. More heavy rainfalls accelerate the soil erosion and cause the contamination of watercourses and loss of valuable soils. Floods are the main cause of erosion, waterlogging and compaction. (Environment Agency, 2018; Reynard, 2010)

Additionally, changes in the width of River Dane, Bollin, and Severn in various years are shown in Table 3. In the study conducted in these rivers showed that there was a seasonal difference in the high flow events, and the complexity in the morphology and flows was observed. Other factors such as extended growing season and vegetation may have significant impacts on them (Hooke, 2006).

Table 3

Changes in Width of Channels

River Dane	1984	1996	2001
Width (m)	18.6	15.7	17.2
Last peak Q ($m^3 s^{-1}$)	79.4	20	130.7
River Bollin	1970	1984	2001
Width (m)	10.3	8.0	9.85
Last peak Q ($m^3 s^{-1}$)	39.56	38.91	48.65
River Severn	1973	1984	1992
Width (m)	21	25.5	26.5
Last peak Q ($m^3 s^{-1}$)	131.18	207.11	230.97

Apart from the studies in the UK, a study conducted in Iran confirmed the impacts of extremes on rivers and found that flood discharge on 14 April 2016 was at the highest level in records for the last 60 years in Karoon River. Also, it is found that the channel width was significantly affected by extreme floods by analysing the OLI Landsat images taking before and after the flood. An increase from 192m to 256m in the average channel width was observed. Moreover, extensive bank erosion (almost 1290ha) because of increased flow power caused the channel width (Yousefi et al., 2018). Additionally, the result of this study goes hand in hand with the study conducted in Austria. In this study, it is found that extreme flood had impacts on rivers and widened the channel (Hauer and Habersack, 2009).

Moreover, it is known that one of the results from a series of floods is the sediment exhaustion and that more effective floods may have more impacts on sediment changes from earlier floods. Therefore, it is more complex to understand the series of floods' effects on sediment dynamics and channels than single floods (Carling, 2013). During most high flow events, sediments tend to move, and movement can be vary depending on sediment size and hydrological regime of river (Hooke, 2006). In the UK, it is expected that extreme events will occur more frequently and with greater intensively as described above. According to Boardman (2015) and Burt et al. (2015), the increasing trend in average rainfall could cause an increase in soil erosion in southern England.

Additionally, the impacts of extremes on the river channel has been reported by Guan et al. (2016), and it is found that extreme floods have an essential impact on adjusting the river channel. The channel changes due to extreme events have impacts on flood hazards and will be increased with more extreme flooding. Therefore, it can be described as a chain or cycle that affects each other. While extremes affect the channel conditions, any changes in the channel conditions can cause greater impacts of extremes, as it is more vulnerable to any changes and external factors.

While, in higher flood events, more erosion is observed, more deposition is observed in lower events. Therefore, it is possible to say that sequential high flow year may cause an increase in the channel width and that lower and single peak flows may result in more deposition (Hooke, 2006). On the contrary, to improve morphology, increase sediment porosity, and enhance the instream and riparian fauna and flora, some low and artificial floods have been used, which removed the lateral sediments and restricted the riverbeds (Mürle et al., 2003).

Many studies have shown that having riparian vegetation has been an effective and cheap way to protect and minimize the effects of floods on banks, and that most riparian vegetation areas are less eroded. It is also responsible for the many natural systems related to water quality. However, as riparian vegetation seems to be an interface between water and territory, in extreme events such as flash floods, it is not possible to deal with floods' destructive impacts (Fernandes et al., 2016; Keesstra et al., 2012; Yousefi et al., 2018).

A study conducted by Fernandes et al. (2016) showed that the most important factor that caused changes in riparian is hydrological changes under the extreme water scarcity. It is found that an expected decrease in the annual mean flows in rivers will cause riparian shrinkage in the 21st century. These results were also corroborated by the other studies conducted by Poff and Zimmerman (2010) and Rivaes et al. (2014). The low natural streamflow caused by extreme events also leads to a reduction in both patch size and riparian zone areas. Without any adaptation, it will be more vulnerable to climate change, and will alter the overall ecosystem functions as it is an important part of them (Capon et al., 2013).

It is also reported by Garssen et al. (2014) and later by Carolina (2015) that intense and long term drought more than 30 days has impacts on narrowing the riparian wetland zone, with accelerating the riparian wetland species losses. On the other hand, modelling studies showing how the flow regime changes due to climate change confirmed that riparian areas are expected to decrease in the areas most affected by climate change (Rivaes et al., 2013).

In addition to direct impacts of extremes on riparian zones, wildfire danger should be taken into account, as high temperatures and strong winds enhance the occurrence of fire.

To simplify and summarize, Table 4 shows the effects of extreme events on river hydro-morphology on changes and risks on HMEQs.

Table 4

Important Risks and Changes from Extreme Weather Events on River Hydro-morphology

Extreme Events	Risks and Changes on HMQEs
Heatwave	Low River Flows
	Low Water Levels
	Riparian Shrinkage
Flood	High River Flows
	Riparian Changes due to Soil Erosion
	Mitigation of Aquatic Organisms
	Sediment Exhaustion
	Channel Changes due to More Deposition
	Increased Channel Width

Impacts of Human Induced Modifications on River Hydro-morphology

Water retention, abstraction, hydropower, metering, tourism, recreation, and any other activities related to anthropogenic progress have impacts and pressures on water ecosystems, especially rivers. The rivers' physiochemistry, hydro-morphology and hydrology can be modified by intense human activities to deal with the effects of climate change. The most common pressures (Table 5) for hydro-morphological alterations are non-natural flows, damming, straightened planforms, reinforced banks and in-channel structures in the rivers, has caused many rivers in Europe and the UK to be below good ecological status. (Bauwens et al., 2013; Colas et al., 2017; Nováky and Bálint, 2013; Rinaldi et al., 2013; Shuker et al., 2015; Villeneuve et al., 2018)

In urban areas, the term Urban River Syndrome described by Walsh et al. (2005) explains the ecological degradation of streams draining to urban land due to alteration of low regimes. Symptoms of urban stream syndrome include changes in channel morphology, increase of pollutants and nutrient, reduced biotic diversity and increase in tolerant species (Elbrecht et al., 2016; Shuker et al., 2015). Flows and riverine ecosystems are affected by regional developments and land use for water withdrawals. Increased point and nonpoint source pollution from urban and rural areas is a problem for the alteration of hydro-morphology. It is also possible to say that dry or wet deposition of pollutants has impacts on alterations (Johnston et al., 2017).

It is identified that almost 75% of the UK rivers have regimes that cannot be considered as natural due to hydrological alterations (Black et al., 2005). The UK Environment Agency published in 2011 a report on the state of river habitats in England and Wales in which they report that river channels have been extensively modified across England, Wales and the Isle of Man. The report states that over many centuries, rivers have been straightened, widened, deepened and dammed, mainly to improve farming or to reduce the risk of flooding. As a result, river habitats have become impoverished and the biodiversity of wildlife they support has declined. These impacts on ecological health are worsening in some areas as the demand for water increases, directly affecting river systems by excessive withdrawing of water (Environment Agency, 2018). These effects are particularly problematic during drought conditions when there are reduced flows. In the UK many rivers are affected and influenced water abstractions and discharges (Wade et al., 2015). These effects pose problems for meeting WFD good ecological status in rivers.

Table 5

Potential Drivers for Causing Pressures on Surface Water Morphology

Potential Driver	Examples of Specific Pressure
Agriculture	Water abstraction, river straightening, grazing
Urban development	Building weirs, dams, building flood banks
Water supply and wastewater management	Water abstraction/discharge
Power generation	Changes to flows
Mining, quarrying and mineral extraction	Water abstraction/contamination
Hydraulic fracturing	Water abstraction/contamination
Flood defence	Building flood walls, embankments
Coastal defence	Building walls, redirecting flow
Navigation	Straightening, widening deepening of channel, dredging
Recreation	Building structure e.g. piers, jetties, boat slipways

Pressures of Hydro-morphological Changes on BQEs and PCQEs

Changes in hydro-morphology of water bodies due to pressures from human activities or the effects of climate change, especially extremes described above places pressures ecological systems (Friberg, 2014). While extreme events directly impact on quality elements and on the ability of water bodies to reach good ecological status, any changes in the hydro-morphological quality elements may affect the others quality elements (BQE and PCQE) in negative ways. Not only do hydro-morphological alterations have direct impacts on fish, macroinvertebrates, and macrophyte, they can cause changes in water temperature and reduce the chemical status of water bodies (Reynard, 2010; Villeneuve et al., 2018).

Hydro-morphological degradation has different pressures on different organisms. While macroinvertebrates, fishes, and macrophytes responded remarkably to degradation, diatoms did not respond to the changes in the hydro-morphology (Hering et al., 2006). Villeneuve et al. (2018) also found that nutrient and organic matter flows have been affected by changes to hydro-morphology. When rivers experience lower flows especially during a heatwave or low rainfall periods, they are highly sensitive to nutrient and pollution as the dilution of chemicals is lowered. In addition to low dilution capacity, higher chemical arrivals from the riparian zones and agricultural areal would also probably increase the challenges to maintain good ecological and chemical status (Herrero et al., 2018; Outram et al., 2014). Also, low river flows reduce the oxygen level in freshwaters and increase the concentration of pollutants. Combined with higher temperatures and more sunlight, it is likely to cause increase eutrophication and algal blooms, which can disrupt the ecosystem balance (Environment Agency, 2018; Herrero et al., 2018; Reynard, 2010). In the future, it is expected that anthropogenic influences will increase the challenges of eutrophication risk because of lower flows and increased water abstraction. Particularly due to the impacts of global warming and less rainfall for the UK (Howden et al., 2009). Even at present, there are many species and habitats under pressures because of low river flows. Lower flows can cause a decrease in the richness of taxonomy because of losing habitat types. Additionally, sediments and reduction of flow velocity have directly or indirectly had negative impacts on the habitat quality of many communities such as invertebrates. When sediments and flow velocity are taken into account together, the impacts of them would be stronger than individual impacts (Elbrecht et al., 2016).

It is found that river temperature is affected by river flow, river regulation, riparian zone, river channel morphology and anthropogenic modifications (Environment Agency, 2007; O’Briain et al., 2017; Orr, Johnson, Wilby et al., 2015;

Piccolroaz et al., 2018). Also, any changes in air or ground temperatures and hydrological changes have direct impacts on water temperatures affected by the size of riparian vegetation that provides the shade for cooling the areas including river and riparian ecosystems. It is known that density, viscosity, solubility, and chemical reaction rates, called physical characteristics, are highly vulnerable to water temperature changes. In lowland river areas, it is expected that the decrease in dissolved oxygen concertation will be observed because of warmer temperatures and droughts. Therefore, it is possible to say that overall, water temperature is highly linked to water quality. Studies show that increase in air temperature caused warmer water bodies has resulted in the decrease of dissolved oxygen concertation, and increase on biochemical oxygen demand and suspended solids (Acreman et al., 2009; Bauwens et al., 2013; Cox and Whitehead, 2009; Kalny et al., 2017; The Secretary of State, 2015). On the other hand, similar to impacts of water temperature on PCQEs, invertebrates, and most communities and species in freshwater ecosystems may be affected. Freshwater species' growth rate, distribution, and reproduction are also changed by temperature variations. Recently, the water temperature has reached the lateral levels for some species in the northern part of England (Environment Agency, 2018; O'Briain et al., 2017).

Future Implications of the WFD

There is no doubt that the changes in the climate system will affect the planned improvement of the quality and management of water bodies. All member states have a responsibility under the WFD to have good status or higher in their water bodies in order to protect and improve aquatic systems across Europe by 2027. In order to achieve all objectives of the WFD, it is essential to integrate with other key policies such as urban planning, flooding, climate and energy policies. For member states, including the UK. To attain a good status in all water bodies, the most important factor is to have effective environmental management. As extensions have been applied to members in the 1st six-year plan, it would be good to consider any extensions where natural conditions such as unexpected extremes do not allow water systems to improve in time (Carvalho, Mackay, Cristina, et al., 2019). Poor links between stressors and impacts on the ecosystem have been one of the weaknesses of the WFD. In the assessment scheme, there are lots of identification of the impacts of BQEs compared to other quality elements. For the hydro-morphological pressures, in contrast, there is not enough identification, with few exceptions. Also, as discussed in previous sections, there is a possibility that across Europe, in the future we may need to live under conditions of more intense and extreme weather events, and at best weather conditions that be equal to today's extreme conditions. The changes in weather patterns are of growing concern and may cause a delay in the implication of WFD in the UK. One of the main reasons for failing to achieve objectives of the WFD is the hydro-morphological degradation of water bodies which is a key part towards the understanding of the impacts, changes and actions for the improvement of quality elements (England and Gurnell, 2016; González del Tánago et al., 2016). Hydro-morphological degradation and other pressures such as nutrient enrichment have the potential to get worse in the 2050s and this poses a major challenge for the objectives of the WFD. Planning on mitigation measures under the sustainable and cost-effective management of the WFD have become key elements of member state policy (Henriques et al., 2015).

Most WFD assessment methods have generally focussed on single stressors instead of multiple factorial stressors. However, almost half of the surface waters are under the stress of multiple factors. Inadequate consideration of all factors including climatic and extreme event considerations would cause any implementation measures to be insufficient and underestimate some serious problems in water bodies. While the management plans including single stressors are the best way to show progress in short time periods with quick improvements, more complex situations including multiple stressors need to be considered carefully within the long term planning for better management plan (Carvalho et al., 2019a)

In terms of cost benefit implication, in the 1st six-year RBMP, it was indicated that if all (or 70%) of European Water Bodies (WBs) were in Good Ecological Status by 2015, the average benefit would have been around 20 billion € or 10.9 billion € per year, respectively (Mattheiß et al., 2012). However, natural conditions and the problems in the implementation of measures have made it difficult for most member states to achieve the aims of the WFD. It is expected that the climate change will modify future precipitation, temperature and extreme events, which will put extra pressures on WFD implications, and it will cost more than before to mitigate effects not only for the UK but also for the rest of Europe (Watts et al., 2015).

Extreme weather events and climate change as a whole are expected to present significant challenges to WFD implementation in Europe and the UK. Member states need to adapt to changes in the climate and to protect ecosystems if GHG emissions cannot be reduced to acceptable levels. Various sources (Carvalho, Mackay, Cardoso et al., 2019) have provided recommendations in terms of three main topics:

(1) **monitoring and assessment**: Requires effective communications towards effective communication as well as the incorporation of innovative and monitoring and assessment tools
(2) **management:** target measures to reduce major stressors
(3) **policy integration:** Integrate policy with other sectors, including agriculture and urban development

Conclusion

It is evident that with climate change, extreme events have started to be more intense and frequent since the late 20th century. These events are forecast to have negative impacts on the environment. One of the effects is the expected changes to surface waters, including hydro-morphological changes which this study aimed to assess, that has been conducted in very few studies before. With the assessment of the observation and projection data, it is found that extreme events such as floods and heatwaves have affected river systems throughout the United Kingdom. Moreover, human activities such as building dams or providing protection from floods, and water abstraction practices, especially during heatwaves and droughts have negative impacts on river hydro-morphology.

These and other stressors can have significant and serious effects on river systems, but also other indirect stressors may exacerbate these impacts. Changes in the hydro-morphology of a water body can cause changes such as the increase in water temperature, reducing fish, macroinvertebrates and macrophyte and therefore negatively impact the BQEs and PCQEs. As the WFD requires all members to have good ecological status in all surface waters, the effects of extreme events on the hydro-morphological changes, which also cause changes in the other quality elements, affect the implementation of the WFD.

In order to solve these problems, some actions should be taken immediately to mitigate these events. Regulations and directives such as the WFD related to the improvement of water bodies must be accompanied by climate changes projections and policies. Additionally, instead of focussing on single stressors, multiple stressors should be studied to understand and to propose solutions for more complex changes in river systems. Human activities such as engineering works and restorations in rivers should be considered under the aim of the WFD and other policies related to water quality. Finally, all members should pay more attention to and be transparent on sharing and accessing data, and cooperation.

Acknowledgement

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Aşırı Hava Olaylarının Birleşik Krallık Nehir Hidromorfolojisine Etkisi

18yy ortalarında endüstri devriminin başlangıcından itibaren İngiltere'de fosil yakıt kullanımı önemli ölçüde artmıştır. Fosil yakıtlar; CO_2, NO_x, SO_x ve diğer sera gazları gibi kirleticiler salan birincil hava kirliliği kaynağıdır. Dünyanın birincil enerji kaynağı olarak fosil yakıtların kullanımı birçok çevresel probleme neden olmaktadır. Özellikle iklim değişikliğinin ana sebeplerinden birisi olan sera gazı etkisi de bu durum ile daha da artmıştır. İklim değişikliği ile birçok hava olayları değişime uğramış ve küresel ölçekte etkili olmaya başlamıştır. Bu değişimlerin başında aşırı hava olaylarının yoğunluğunun ve sıklığının artması gelmektedir. İklim değişikliği ve buna bağlı olarak artan ve sıklaşan aşırı hava olaylarının çevreye ve özellikle su kütleleri üzerine olumsuz etkileri bulunmaktadır.

Su kütleleri üzerine olan etkiler ile başa çıkabilmek için Ekim 2000 tarihinde Avrupa Birliği tarafından Su Çerçeve Direktifi (EU WFD 2000/60/EC) yayımlanmıştır. Direktifin esas amacı üye ülkelerdeki mevcut su kütlelerinin hepsinin iyi duruma getirilmesidir. Su Çerçeve Direktifi (SÇD) AB'deki tüm su kütlelerinin en azından iyi statüye ulaşması için bir hedef belirlemiştir, ancak Avrupa'daki su kütlelerinin neredeyse yarısı şu anda bu standardın altındadır. Yüzey sularında Ekolojik Kalite Durumu Biyolojik Kalite Elementleri, Fiziko-Kimyasal Kalite Elementleri ve Hidromorfolojik Kalite Elementleri ile belirlenir. Hidromorfoloji, nehir ekosistemi için önemli su kalitesi unsurlarından biridir ve Su Çerçeve Direktifine göre, hidromorfolojik kalite elementleri, biyolojik kalite unsurlarını destekleyen kalite unsurlarıdır, bu nedenle ekolojik su kalitesinin kapsamlı bir değerlendirmesi her zaman hidromorfolojik bir değerlendirmeyi içermelidir.

Bu çalışmada, Birleşik Krallık'taki aşırı hava olaylarının nehirlerdeki Hidromorfolojik Kalite Elementleri üzerindeki etkileri, Su Çerçeve Direktif (SÇD)'i uygulamasında sorunlara yol açabilecek diğer baskılarla birlikte değerlendirilmiştir. 20yy başlarından itibaren Birleşik Krallık birçok sıcak hava dalgasının etkisi altında kalmış ve özellikle 1970'lerden sonra sıklaşmaya ve artmaya başlamıştır. 1910'dan 2018'e artan bir trend gösteren sıcak hava dalgası olayları ile ortalama 1C'lik bir artış meydana geldiği görülmüştür. Birleşik Krallık'ta sıcak hava dalgası sıklığı 2000 yılından bu yana artmaya başlamış; kaydedilen en kritik sıcak hava dalgaları 2003, 2006 ve 2018'de meydana gelmiştir. 20yy sonlarında ise sel ve aşırı yağmur olaylarının arttığı görülmüştür. 2008-2017 yılları arasında meydana gelen olaylar 1961-1990 dönemi ile kıyaslandığında %17'lik bir artış meydana geldiği görülmüştür.

2006 ve 2018 yıllarında Birleşik Krallık'ta yaşanan sıcak hava dalgasında nehir akışlarının önemli bir ölçüde etkilendiği görülmüştür. 2018 Mayıs ayında nehir akışlarının normal olduğu, nadir durumlarda bazı nehirlerin normal altı akışa sahip olduğu, ancak sıcak hava dalgasının pik etkisinin başladığı Temmuz ayında nehir akışlarının %80'inin normal değerlerinin altına düştüğü tespit edilmiştir. Ağustos ve Eylül aylarında ise sıcak hava dalgasının etkisi azalmış ve nehir akışları normal seviyeye dönmüştür. Ayrıca aşırı yağışların sel ve nehir akışları üzerinde önemli etkileri olduğu görülmüş ve özellikle 2007, 2012 ve 2013-2014 yıllarında meydana gelen aşırı yağışların birçok yıkıcı etkisi olmuştur. İngiltere'nin merkezi ise aşırı yağışlardan dolayı artan nehir akışları için en çok etkilenen bölge olmuştur. Ayrıca aşırı yağışlar sonucunda yaşanan sellerin erozyon, değerli toprak kaybı ve su kaynaklarının kirlenmesi gibi birçok etkisi olmuştur.

Ayrıca Hidromorfolojik Kalite Elementlerinde meydana gelen bir değişikliğin Biyolojik Kalite Elementleri ile Fiziko-Kimyasal Kalite Elementleri üzerinde etkisi olduğu gözlemlenmiştir. Organik madde akışı ve besin maddelerinin nehirlerde meydana gelen aşırı yoğun akış veya düşük akış olaylarından etkilendiği görülmüştür. Azalan akış ile düşük seyrelme kapasitesi nehir kıyı ekosistemine gelen kimyasalların artmasına ve böylelikle mevcut ekolojik ve kimyasal durumun korumasına engel olmaktadır. Ek olarak nehir suyu sıcaklığının da nehir akışı, kıyı ekosistemi gibi hidromorfolojik etkenlerden etkilendiği görülmüştür. Nehir kıyı ekosisteminde bulunan bitki örtüsü nehir suyuna gölge sağlayarak su sıcaklığını düşürmektedir. Ancak, sicak hava dalgasi ile birlikte su sıcaklığında meydana gelen artış çözünmüş oksijen konsantrasyonunun düşmesine ve biyokimyasal oksijen ihtiyacının ise artmasına neden olmaktadır.

Su Çerçeve Direktifi'nin uygulanmasında aşırı hava olaylarının ve iklim değişikliğinin önemli ölçüde etkili olması beklenmektedir. Eğer sera gazlarının ve iklim değişikliğinin olumsuz etkileri azaltılmaz veya durdurulamazsa üye ülkelerin bu değişiklere adapte olması gerekmektedir. İzleme, değerlendirme, yönetim ve politika entegrasyonu Su Çerçeve Direktifi'nin değişiklikler ile mücadele için sunulan önerilerdir.

Sonuç olarak, aşırı hava olayların olduğu dönemlerde nehir hidromorfolojisinin özellikle nehir akışları, sedimentleri ve nehir kıyı bölgeleri açısından etkilendiği bulunmuştur. Nehir sistemleri, sırasıyla azalan ya da olağanüstü yüksek akıma sebep olan kuraklık ve yoğun ve şiddetli yağış gibi aşırı hava olaylarından önemli ölçüde etkilenmektedir. Azalan akışlar, sudaki organizmaların yaşam alanlarının kaybına ve balık ölümlerinin artmasına neden olabilir. Artan nehir akışları, sediment dinamiği ve kanallarındaki değişiklikler de dahil olmak üzere nehirlerin hidromorfolojisinde değişikliklere yol açarken, nehirler, baraj inşa etme ve su soyutlamaları gibi aktiviteler de dahil olmak üzere antropojenik hidromorfolojik basınçların olumsuz etkileri altındadır. Buna ek olarak, nehir hidromorfolojisindeki değişikler su sıcaklığını ve çözünmüş oksijen miktarını arttıran ve böylece Biyolojik Kalite Elementleri ve Fiziko-Kimyasal Kalite Elementlerini indirgeyen başka problemlere neden olabilir. Birleşik Krallık'ta aşırı hava olaylarının yoğunluğunun ve sıklığının artması, Su Çerçeve Direktifi'nin maliyet etkinliği ve sürdürülebilirlik açısından uygulanmasında zorluklara neden olacağına hiç şüphe yoktur. Bu sorunlarla başa çıkmak ve bunları azaltmak için, iklim değişikliği projeksiyonlarını dikkate alan, su talebini azaltan, suyun mevcudiyetini ve kalitesini iyileştiren, tarımsal ve kentsel arazi kullanım uygulamalarını değiştiren bütüncül bir su politikası gereklidir.

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