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# Contents

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*Research Article*

# Distribution of Benthic Diatom (Phytobenthos) Composition in Küçük Menderes River Basin

# Küçük Menderes Nehir Havzası'nda Bentik Diyatome (Fitobentoz) Kompozisyonunun Dağılımı

Cüneyt Nadir SOLAK[1], Tolga ÇETİN[2], Aydın KALELİ[1]

[1]*Dumlupınar University, Faculty of Arts and Sciences, Department of Biology, Kütahya*
cnsolak@gmail.com, aydinkaleli84@gmail.com
[2]*T.R. Ministry of Forestry and Water Affairs, Directorate General for Water Management, Ankara*
tcetin@ormansu.gov.tr
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**Abstract**

Although there are many studies on the diatoms, the most important represantatives of phytobenthos, the distribution of diatom composition is still a new issue in Turkey. This study aims to investigate the distribution of benthic diatom composition in Küçük Menderes River Basin. Samples were collected from epilithon and epipelon substrates of 7 river water bodies and 3 dams (Tahtalı, Beydağı and Alaçatı) on a seasonal basis in 2014. Hydrogen peroxide and hydrochloric acid were used to remove the organic matter from frustules and permanent slides were mounted with Naphrax solution. In total, 94 benthic diatom taxa were identified. *Nitzschia palea* (Kützing) W.Smith, *N. inconspicua* Grunow, *N. umbonata* (Ehrenberg) Lange-Bertalot, *Craticula accomoda* (Hustedt) DG Mann, *C. subminuscula* (Manguin) C.E.Wetzel & L.Ector and *Navicula veneta* Kützing were the most common taxa as an indicator of polluted waters. *Achnanthidium eutrophilum* (Lange-Bertalot) Lange-Bertalot, *A. minutissimum* var. *jackii* (Rabenhorst) Lange-Bertalot, *Navicula simulata* Manguin, *N. vandamii* Schoeman & Archibald, *Nitzschia archibaldii* Lange-Bertalot, *N. desertorum* Hustedt and *Sellaphora saprotolerans* Lange-Bertalot, Hofmann & Cantonati were the new records for Turkish diatom flora.
***Keywords:*** *Diatom, Küçük Menderes, new records, phytobenthos*

**Öz**

Fitobentozun en önemli temsilcisi olan diyatomeler ile ilgili pek çok çalışma olmasına rağmen diyatome kompozisyonun dağılımı Türkiye'de halen yeni bir konudur. Bu çalışma ile Küçük Menderes Nehir Havzası'nda bentik diyatome kompozisyonunun dağılımının araştırılması amaçlanmıştır. Örnekler 2014 yılında mevsimsel olarak 7 nehir suyu kütlesinden ve 3 baraj gölünden (Tahtalı, Beydağı ve Alaçatı) epiliton ve epipelon substratlardan alınmıştır. Organik maddenin früstüllerden uzaklaştırılması maksadıyla hidrojen peroksit ve hidroklorik asit kullanılmış ve daimi preparatlar Naphrax solüsyonu ile hazırlanmıştır. Toplamda 94 bentik diyatome taksonu teşhis edilmiştir. Kirli suların indikatörü olan *Nitzschia palea* (Kützing) W.Smith, *N. inconspicua* Grunow, *N. umbonata* (Ehrenberg) Lange-Bertalot, *Craticula accomoda* (Hustedt) DG Mann, *C. subminuscula* (Manguin) C.E.Wetzel & L.Ector ve

*Navicula veneta* Kützing en yaygın taksonlar olmuştur. *Achnanthidium eutrophilum* (Lange-Bertalot) Lange-Bertalot*, A. minutissimum* var. *jackii* (Rabenhorst) Lange-Bertalot*, Navicula simulata* Manguin*, N. vandamii* Schoeman & Archibald*, Nitzschia archibaldii* Lange-Bertalot*, N. desertorum* Hustedt ve *Sellaphora saprotolerans* Lange-Bertalot, Hofmann & Cantonati ise Türkiye diyatome florası için yeni kayıtlar olmuştur.

***Anahtar sözcükler:*** *Diyatome, Küçük Menderes, yeni kayıtlar, fitobentoz*

## Introduction

After the implementation of European Union Water Framework Directive (WFD) (2000/60/EC) (Anonymous, 2000) in 2000, ecological assessment came to the forefront in water quality monitoring studies conducted in Europe. European Member States have started to monitor a number of biological quality elements in their water bodies such as phytobenthos, phytoplankton, macrophyte, fish, macroinvertebrate, macroalgae and angiosperms. The harmonization process of the WFD in Turkey has been accelerated since 2011 with the establishment of the Ministry of Forestry and Water Affairs, General Directorate of Water Management (Anonymous, 2011). Biological monitoring studies were carried out in many river basins in Turkey (Anonymous, 2013; Anonymous 2014a; Demir et al. 2017) and are being carried out (Anonymous, 2017) on an ecological basis within the scope of By-law on Monitoring Surface and Ground Waters (Anonymous, 2014b).

The phytobenthos is an obligatory biological quality element to be monitored in rivers and lakes according to the WFD. Phytobenthos contains all phototrophic organisms from microscopic unicellular organisms to macrophytes longer than 2 meters (Anonymous, 2010). Due to the lack of practical methods, EU Member States mostly monitor diatoms in river and lake water bodies as a part of their biological monitoring studies to assess phytobenthos quality element within the scope of the WFD.

Biological monitoring of river basins significantly contributed to the study of flora and fauna in Turkey. Biological data has been obtained from many water bodies that were not studied until today and environmental needs of the taxa were determined (Anonymous, 2016; Toudjani, 2017) with the chemical samples taken at the same time with biological samples. There are number of studies carried out for algal flora in Turkey (Gönülol et al. 1996; Aysel, 2005; Solak et al. 2016) and more than 800 diatom taxa were reported.

Regarding the algal flora studies of Küçük Menderes River Basin, the algal flora of Oğlananası Lake (Gaziemir, İzmir) was identified by Aysel et al. 1998. 40 diatom taxa were identified and 10 of them were new records for Turkey. With another study, 86 diatom taxa were identified as a result of sampling on a seasonal basis in 1994 in Barutçu Lake (Selçuk, İzmir). 12 diatom taxa were new records for Turkish flora (Aysel et al. 2002). In addition, the algal flora of Laka River was identified by Aysel et al. 2001. It was found that the river can be used for drinking purposes based on the distribution of the taxa according to algal divisions. This study aims to investigate the distribution of benthic diatom composition and to prepare the taxa catalogue according to the diatom taxa obtained from the water quality monitoring study in the Küçük Menderes River Basin, and to benefit from the results for future monitoring studies carried out in the other river basins of Turkey.

## Method

### Study Site

Küçük Menderes River Basin is placed in the west of Turkey between Büyük Menderes and Gediz River Basins and its waters flow into the Aegean Sea. River basin is located between 38° 41' 05" and 37° 24' 08" northern latitudes with 28° 24' 36" and 26° 11' 48" eastern longitudes. Surface area of this basin is 702.931 ha and it corresponds to 0.9% of the surface area of Turkey (Anonymous, 2014c).

### Sampling

Samples were collected from 7 river water bodies and 3 dams (Table 1) in Küçük Menderes River Basin (Figure 1) in May, July and September in 2014. Epilithic samples were taken by brushing the submerged stones, and epipelic samples were taken by using a pipette aspirator from the sediment.

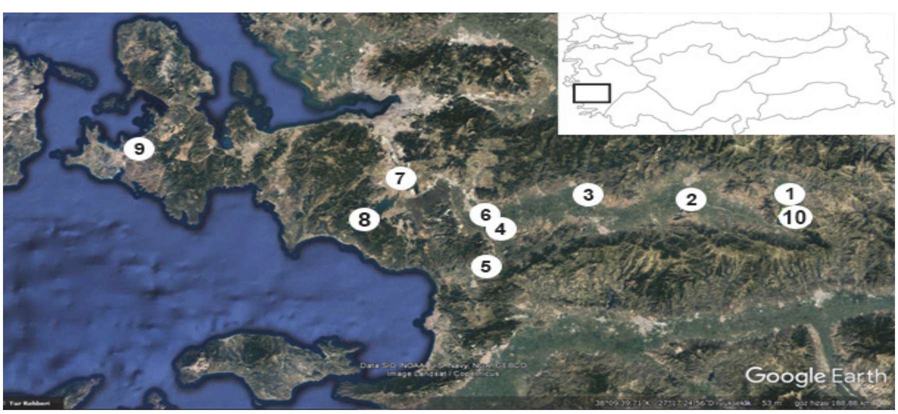



*Figure 1.* Distribution of sampling points in Küçük Menderes River Basin

Table 1

*The Coordinates of The Sampling Points of The Water Bodies in Küçük Menderes River Basin*

| Stations | Water Bodies | Coordinates | |
|---|---|---|---|
| K1 | Keleş Creek | 38°09'55.27" N | 28°13'10.55" E |
| K2 | Küçük Menderes River | 38°09'56.39" N | 27°57'51.15" E |
| K3 | Ilıca Creek | 38°09'11.05" N | 27°40'56.53" E |
| K4 | Fetrek Creek | 38°04'23.92" N | 27°24'52.89" E |
| K5 | Küçük Menderes River | 37°58'41.05" N | 27°22'44.02" E |
| K6 | Küçük Menderes River | 38°05'46.76" N | 27°23'45.49" E |
| K7 | Sangı Creek | 38°11'47.24" N | 27°09'59.25" E |
| K8 | Tahtalı Dam | 38°05'26.38" N | 27°02'58.32" E |
| K9 | Alaçatı Dam | 38°17'03.24" N | 26°24'28.46" E |
| K10 | Beydağ Dam | 38°06'32.42" N | 28°13'11.18" E |

## Sample Processing, Observation and Identification

Samples were boiled with $H_2O_2$ and HCl to remove the organic matter from frustules. After washing three times of diatoms with distilled water, the material was air-dried on cover glasses and mounted with Naphrax solution. Diatoms were observed with a Nikon Ci Light Microscope (LM) in Dumlupınar University, Turkey.

The diatoms were identified according to Hofmann et al. (2011); Krammer and Lange-Bertalot (1998, 1991); Lange-Bertalot (2001); Levkov et al. (2013); Wojtal (2009) and Wojtal and Kwandrans (2006). Reported dimensions (length, width, number of striae/10 μm) of each taxa were based on the measurements performed in this study.

## Diatom Distribution

Description of the distribution of Turkish diatom flora was made according to Gönülol (2017). The taxa reported from Turkey by Gönülol (2017) which cover 10% of the literature are categorized as "*common*" diatoms, the ones cover less than 10% are noted as "*rare*" diatoms. For each station, about 400 valves were counted and then relative abundances were calculated. If the taxon exists in 1 or 2 sampling station(s), it was named as "rare" and if it exists in more than 2 stations, it was named as "common" in this study.

## Results

A total of 94 taxa were identified and 7 of those were recorded as new taxa for Turkish diatom flora. The taxa identified in Küçük Menderes River Basin and indicated by Gönülol (2017) for Turkey as a whole are listed in Table 2 and brief notes, dimensions and distribution of each diatom are provided.

Table 2

*The Distribution of The Diatom Taxa in Turkey (Gönülol, 2017) and in This Study*

| | Status in Turkey (Gönülol, 2017) | In This Study Status | Station(s) |
|---|---|---|---|
| *Achnanthidium eutrophilum* **(Lange-Bertalot) Lange-Bertalot** | NR | R | K10 |
| *Achnanthidium exiguum* **(Grunow) Czarnecki** | R | R | K5 |
| *Achnanthidium minutissimum* **(Kützing) Czarnecki** | C | C | K7, K8, K9 |
| *Achnanthidium inutissimum* var. *jackii* **(Rabenhorst) Lange-Bertalot** | NR | R | K8 |
| *Adlafia minuscula* **(Grunow) Lange-Bertalot** | C | R | K1 |
| *Amphora pediculus* **(Kützing) Grunow ex A.Schmidt** | C | R | K1, K7 |
| *Aulacoseira ambigua* **(Grunow) Simonsen** | R | R | K10 |
| *Cocconeis pediculus* **Ehrenberg** | C | C | K1, K7, K9 |
| *Craticula accomoda* **(Hustedt) DG Mann** | C | C | K1, K3, K4, K5, K8, K10 |
| *Craticula cuspidate* **(Kützing) DG Mann** | C | R | K7 |
| *Craticula melostiformis* **(Hustedt) Mayama** | R | C | K2, K3, K9 |
| *Craticula subminuscula* **(Manguin) C.E.Wetzel & L.Ector** | C | C | K1, K2, K3, K5, K9, K10 |
| *Cyclostephanos dubius* **(Hustedt) Round** | R | C | K6, K9, K10 |
| *Cyclostephanos invisitatus* **(Hohn & Hellermann) Theriot, Stoermer & Håkasson** | R | R | K10 |
| *Cyclotella atomus* **Hustedt** | R | R | K2 |

Table 2 (continue)

*The Distribution of The Diatom Taxa in Turkey (Gönülol, 2017) and in This Study*

| | Status in Turkey (Gönülol, 2017) | In This Study Status | Station(s) |
|---|---|---|---|
| *Cyclotella meneghiniana* **Kützing** | C | C | K3, K5, K7 |
| *Cymbella cymbiformis* **C. Agardh** | C | R | K8 |
| *Cymbella excise* **Kützing** | R | R | K8, K9 |
| *Cymbella lange-bertalotii* **Krammer** | R | R | K8 |
| *Cymbella parva* **(W. Smith) Cleve** | C | R | K7 |
| *Cymbopleura amphicephala* **Näegeli** | C | R | K7 |
| *Diatoma moniliformis* **(Kützing) D.M.Williams** | C | R | K4, K5 |
| *Encyonema caespitosum* **Kützing** | C | R | K8 |
| *Encyonema ventricosum* **(C.Agardh) Grunow** | C | C | K1, K6, K7 |
| *Encyonopsis microcephala* **(Grunow) Krammer** | C | R | K6, K7 |
| *Encyonopsis minuta* **Krammer & Reichardt** | R | C | K6, K7, K8 |
| *Encyonopsis subminuta* **Krammer & Reichardt** | R | C | K6, K7, K8, K10 |
| *Fallacia pygmeae* **(Kützing) Stikle et Mann** | C | R | K10 |
| *Fragilaria capucina* var. *vaucheria* **(Kützing) Lange-Bertalot** | C | R | K8, K10 |
| *Fragilaria mesolepta* **Rabenhorst** | C | R | K8 |
| *Fragilaria perminuta* **(Grunow) Lange-Bertalot** | R | R | K8, K9 |
| *Geissleria decussis* **(Østrup) Lange-Bertalot & Metzeltin** | C | R | K1 |
| *Gomphonema olivaceum* **(Hornemann) Brébisson** | C | R | K7, K8 |
| *Gomphonema parvulum* **(Kützing) Kützing** | C | C | K1, K4, K5 |
| *Gomphonema pumilum* **(Grunow) E.Reichardt & Lange-Bertalot** | R | C | K1, K6, K7 |

Table 2 (continue)

*The Distribution of The Diatom Taxa in Turkey (Gönülol, 2017) and in This Study*

| | Status in Turkey (Gönülol, 2017) | In This Study Status | Station(s) |
|---|---|---|---|
| *Halamphora montana* **(Krasske) Levkov** | R | C | K3, K5, K10 |
| *Halamphora veneta* **(Kützing) Levkov** | C | C | K1, K2, K5, K9 |
| *Hantzschia amphioxys* **(Ehrenberg) Grunow** | C | R | K1 |
| *Hippodonta capitate* **(Ehrenberg) Lange-Bertalot, Metzeltin et Witkowski** | C | R | K10 |
| *Luticola goeppertiana* **(Bleisch) D.G.Mann** | R | R | K5 |
| *Luticola ventricosa* **(Kützing) D.G.Mann** | R | R | K5 |
| *Mayameae permitis* **(Hustedt) K.Bruder & L.K. Medlin** | R | C | K2, K3, K4, K10 |
| *Melosira varians* **Agardh** | C | R | K10 |
| *Navicula antonii* **Lange-Bertalot** | R | R | K1, K7 |
| *Navicula capitatoradiata* **Germain** | C | C | K4, K7, K8, K9 |
| *Navicula cryptocephala* **Kützing** | C | C | K4, K7, K8, K9 |
| *Navicula cryptotenella* **Lange-Bertalot** | C | R | K9 |
| *Navicula cryptotenelloides* **Lange-Bertalot** | R | R | K8 |
| *Navicula erifuga* **Lange-Bertalot** | R | R | K10 |
| *Navicula gregaria* **Donkin** | C | C | K1, K2, K3, K10 |
| *Navicula notha* **Wallace** | R | R | K10 |
| *Navicula radiosa* **Kützing** | C | R | K8 |
| *Navicula reichardtiana* **Lange-Bertalot** | R | R | K1 |
| *Navicula simulate* **Manguin** | NR | R | K2, K9 |
| *Navicula trivialis* **Lange-Bertalot** | C | R | K9 |

Table 2 (continue)

*The Distribution of The Diatom Taxa in Turkey (Gönülol, 2017) and in This Study*

| | Status in Turkey (Gönülol, 2017) | In This Study Status | Station(s) |
|---|---|---|---|
| *Navicula vandamii* **Schoeman & Archibald** | NR | R | K2, K9 |
| *Navicula veneta* **Kützing** | C | C | K1, K2, K4, K5, K6, K10 |
| *Navicula viridula* var. *germainii* **(Wallace) Lange-Bertalot** | R | R | K2, K10 |
| *Navicula viridula* var. *rostellata* **(Kützing) Cleve** | C | R | K10 |
| *Nitzschia amphibia* **Grunow** | C | R | K4, K5 |
| *Nitzschia archibaldii* **Lange-Bertalot** | NR | C | K2, K3, K10 |
| *Nitzschia capitellata* **Hustedt in A. Schmidt** | C | C | K2, K3, K4, K10 |
| *Nitzschia desertorum* **Hustedt** | NR | R | K2 |
| *Nitzschia dissipata* **(Kützing) Grunow** | C | R | K9 |
| *Nitzschia dissipata* var. *media* **(Hantzsch) Grunow** | C | R | K9 |
| *Nitzschia filiformis* **(W.Smith) Van Heurck** | C | R | K9 |
| *Nitzschia fonticola* **(Grunow) Grunow in Van Heurck** | C | R | K1, K3 |
| *Nitzschia frustulum* **(Kützing) Grunow** | C | R | K9, K10 |
| *Nitzschia inconspicua* **Grunow** | C | C | K1, K4, K8, K9, K10 |
| *Nitzschia linearis* **(C.Agardh) W. Smith** | C | R | K1 |
| *Nitzschia palea* **(Kützing) W.Smith** | C | C | K1, K2, K3, K4, K5, K6, K7, K10 |
| *Nitzschia sociabilis* **Hustedt** | R | R | K9 |
| *Nitzschia umbonata* **(Ehrenberg) Lange-Bertalot** | C | C | K1, K2, K4, K5, K6 |
| *Pantocsekiella ocellata* **(Pantocsek) K.T.Kiss & Ács** | C | R | K8 |
| *Planothidium lanceolatum* **(Brébisson ex Kützing) Lange-Bertalot** | C | R | K1, K8 |

Table 2 (continue)

*The Distribution of The Diatom Taxa in Turkey (Gönülol, 2017) and in This Study*

| | Status in Turkey (Gönülol, 2017) | In This Study Status | Station(s) |
|---|---|---|---|
| *Pseudofallacia monoculata* **(Hustedt) D.G.Mann** | R | R | K3, K10 |
| *Pseudostaurosira brevistriata* **(Grunow) D.M.Williams & Round** | C | R | K8 |
| *Reimeria sinuate* **(Gregory) Kociolek et Stoermer** | C | C | K1, K2, K7 |
| *Sellaphora pupula* **(Kützing) Mereschkovsky** | C | C | K1, K2, K3, K10 |
| *Sellaphora radiosa* **(Hustedt) H.Kobayasi** | R | R | K5 |
| *Sellaphora saprotolerans* **Lange-Bertalot, Hofmann & Cantonati** | NR | C | K1, K2, K10 |
| *Sellaphora saugerresii* **(Desmazières) C.E.Wetzel & D.G.Mann** | C | C | K1, K2, K3, K4 |
| *Sellaphora seminulum* **(Grunow) D.G.Mann** | R | R | K4, K5 |
| *Stephanodiscus hantzschii* **Grunow** | C | R | K10 |
| *Surirella brebissonii* **Krammer et Lange-Bertalot** | C | C | K1, K2, K5 |
| *Surirella minuta* **Brébisson** | C | R | K2 |
| *Surirella robusta* **Ehrenberg** | C | C | K1, K2, K10 |
| *Tryblionella apiculate* **Gregory** | C | R | K2 |
| *Tryblionella calida* **(Grunow) D.G.Mann** | R | R | K2 |
| *Ulnaria acus* **(Nitzsch) P.Compère** | C | R | K8 |
| *Ulnaria biceps* **(Kützing) P.Compère** | C | C | K5, K7, K8 |
| *Ulnaria capitate* **(Ehrenberg) Compère** | C | R | K8 |
| *Ulnaria delicatissima* **(W.Smith) M.Aboal & P.C.Silva** | C | R | K6, K8 |
| *Ulnaria ulna* **(Nitzsch) P.Compère** | C | R | K1 |

*Note. NR: New Record, C: Common, R: Rare*

***Achnanthidium eutrophilum* (Lange-Bertalot) Lange-Bertalot** (Figure 2)
Basionym: *Achnanthes eutrophila* Lange-Bertalot
Ref: Hofmann et al. 2011 p.80-pl.23: 30-35
Dimensions: Valve 9.4-10.2 µm length, 3.2-3.7 µm width and 25-26 striae in 10 µm
Distribution in Küçük Menderes River Basin: K10

***Achnanthidium exiguum* (Grunow) Czarnecki** (Figure 3)
Basionym: *Achnanthes exigua* Grunow
Ref: Hofmann et al. 2011 p.70-pl.22: 14-20
Dimensions: Valve 11.8-12.9 µm length, 4.2-4.8 µm width and 25-26 striae in 10 µm
Distribution in Küçük Menderes River Basin: K5

***Achnanthidium minutissimum* (Kützing) Czarnecki** (Figure 4)
Basionym: *Achnanthes minutissima* Kützing
Ref: Hofmann et al. 2011 p.83-pl.23: 15-21
Dimensions: Valve 9.5-11.2 µm length and 2.5-3.1 µm width
Distribution in Küçük Menderes River Basin: K7, K8, K9

***Achnanthidium minutissimum* var. *jackii* (Rabenhorst) Lange-Bertalot** (Figure 5)
Basionym: *Achnanthidium jackii* Rabenhorst
Ref: Hofmann et al. 2011 p.84-pl.23: 22-29
Dimensions: Valve 9.5-11.2 µm length and 2.5-3.1 µm width
Distribution in Küçük Menderes River Basin: K8

***Adlafia minuscula* (Grunow) Lange-Bertalot** (Figure 6)
Basionym: *Navicula minuscula* Grunow
Ref: Hofmann et al. 2011 p.91-pl.42: 76-80
Dimensions: Valve 10.2-11.4 µm length and 3.1-3.7 µm width
Distribution in Küçük Menderes River Basin: K1

***Amphora pediculus* (Kützing) Grunow ex A.Schmidt** (Figure 7)
Basionym: *Cymbella pediculus* Kützing
Ref: Hofmann et al. 2011 p.98-pl.91: 29-33
Dimensions: Valve 8.3-12.4 µm length and 2.6-3.1 µm width
Distribution in Küçük Menderes River Basin: K1, K7

***Aulacoseira ambigua* (Grunow) Simonsen** (Figure 8)
Basionym: *Melosira crenulata* var. *ambigua* Grunow
Ref: Krammer & Lange-Bertalot 1991 p. 25-pl.21: 1-16
Dimensions: Valve 4.7-5.5 µm length, 8.5-14.3 µm width, 15-18 interstriae in 10 µm
Distribution in Küçük Menderes River Basin: K10

***Cocconeis pediculus* Ehrenberg** (Figure 9)
Ref: Hofmann et al. 2011 p.132-pl.19: 17-19
Dimensions: Valve 23.4-31.4 µm length, 21.8-24.2 µm width, 18-21 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K7, K9

***Craticula accomoda* (Hustedt) DG Mann** (Figure 10)
Basionym: *Navicula accomoda* Hustedt
Ref: Lange-Bertalot 2001 p.108-pl.93: 1-6
Dimensions: Valve 18.3-23.2 µm length, 5.8-7.1 µm width and 23-25 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K3, K4, K5, K8, K10

***Craticula cuspidata* (Kützing) DG Mann** (Figure 11)
Basionym: *Frustulia cuspidata* Kützing
Ref: Lange-Bertalot 2001 p.111-pl.82: 1-3; 82: 1, 2
Dimensions: Valve 73.8-85.3 µm length, 5.8-7.1 µm width and 23-25 striae in 10 µm
Distribution in Küçük Menderes River Basin: K7

***Craticula molestiformis* (Hustedt) Mayama** (Figure 12)
Basionym: *Navicula minusculoides* Hustedt
Ref: Lange-Bertalot 2001 p.115-pl.93: 7-15
Dimensions: Valve 14.5-16.7 µm length and 3.1-3.7 µm width
Distribution in Küçük Menderes River Basin: K2, K3, K9

***Craticula subminuscula* (Manguin) C.E.Wetzel & L.Ector** (Figure 13)
Basionym: *Navicula subminuscula* Manguin
Ref: Lange-Bertalot 2001 p.202-pl.42: 45-50
Dimensions: Valve 7.9-11.4 µm length, 3.1-3.6 µm width and 20-22 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K2, K3, K5, K9, K10

***Cyclostephanos dubius* (Hustedt) Round** (Figure 14)
Basionym: *Stephanodiscus dubius* Hustedt
Ref: Krammer & Lange-Bertalot 1991 p. 64-pl.67:8a-9b; Wojtal & Kwandrans 2006 p.196-pl.15: 8, 16: 1-11
Dimensions: Valve diameter 9.9-11.2 µm. The valve has 8-11 interstriae in 10 µm
Distribution in Küçük Menderes River Basin: K6, K9, K10

***Cyclostephanos invisitatus* (Hohn & Hellermann) Theriot, Stoermer & Håkasson** (Figure 15)
Basionym: *Stephanodiscus invisitatus* Hohn & Hellermann
Ref: Krammer & Lange-Bertalot 1991 p.63-pl.67: 3, 4; Wojtal & Kwandrans 2006 p.198-pl.15: 9, 16: 12-14, 17
Dimensions: Valve diameter 9.8-11.3 µm. The valve has 9-13 interstriae in 10 µm
Distribution in Küçük Menderes River Basin: K10

***Cyclotella atomus* Hustedt** (Figure 16)
Ref: Krammer & Lange-Bertalot 1991 p.53-pl.51: 19-21; Wojtal & Kwandrans 2006 p.184-pl.4: 13-15, 6:1-6
Dimensions: Valve diameter 6.1-12.4 µm. There are 16-19 interstriae in 10 µm
Distribution in Küçük Menderes River Basin: K2

***Cyclotella meneghiniana* Kützing** (Figure 17)
Ref: Krammer & Lange-Bertalot 1991 p. 44-pl.44: 1-10; Wojtal & Kwandrans 2006 p.186-pl.4: 18-21, 7: 1-13, 9:1-8, 10:1-5
Dimensions: Valve diameter 11.3-15.4 µm. There are 6-8 interstriae in 10 µm
Distribution in Küçük Menderes River Basin: K3, K5, K7

***Cymbella cymbiformis* C. Agardh** (Figure 18)
Ref: Hofmann et al. 2011 p.148-pl.80: 1-11
Dimensions: Valve 47.8-75.4 µm length, 13.5-15.4 µm width and 8-9 striae in 10 µm
Distribution in Küçük Menderes River Basin: K8

***Cymbella excisa* Kützing** (Figure 19)
Ref: Hofmann et al. 2011 p.150-pl.77: 23-28
Dimensions: Valve 19.8-34.5 µm length, 7.5-9.8 µm width and 9-12 striae in 10 µm
Distribution in Küçük Menderes River Basin: K8, K9

***Cymbella lange-bertalotii* Krammer** (Figure 20)
Ref: Hofmann et al. 2011 p.154-pl.78: 1-5
Dimensions: Valve 50.7-71.6 µm length, 11.2-14.5 µm width and 9-11 striae in 10 µm
Distribution in Küçük Menderes River Basin: K8

***Cymbella parva* (W. Smith) Cleve** (Figure 21)
Basionym: *Cocconema parvum* W.Smith
Ref: Hofmann et al. 2011 p.156-pl.77: 29-34
Dimensions: Valve 35.4-39.5 µm length, 8.5-9.7 µm width and 10-11 striae in 10 µm
Distribution in Küçük Menderes River Basin: K7

***Cymbopleura amphicephala* Näegeli** (Figure 22)
Ref: Hofmann et al. 2011 p.160-pl.83: 11-15
Dimensions: Valve 24.1-31.5 µm length, 7.9-8.3 µm width and 13-15 striae in 10 µm
Distribution in Küçük Menderes River Basin: K7

***Diatoma moniliformis* (Kützing) D.M.Williams** (Figure 23)
Basionym: *Diatoma tenue* var. *moniliforme* Kützing
Ref: Hofmann et al. 2011 p.174-pl.2: 11-15
Dimension: Valve 18.4-27.8 µm length, 3.5-3.9 µm width and 6-9 transapical partitions in 10 µm
Distribution in Küçük Menderes River Basin: K4, K5

***Encyonema caespitosum* Kützing** (Figure 24)
Ref: Hofmann et al. 2011 p.186-pl.86: 5-9
Dimension: Valve 25.4-32.8 µm length, 8.3-11.5 µm width and 10-11 striae in 10 µm.
Distribution in Küçük Menderes River Basin: K8.

***Encyonema ventricosum* (C.Agardh) Grunow** (Figure 25)
Basionym: *Frustulia ventricosa* C.Agardh
Ref. Hofmann et al. 2011 p.192-pl.87: 18-22
Dimensions: Valve 15.4-21.2 µm length, 6.8-7.3 µm width and 12-15 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K6, K7

***Encyonopsis microcephala* (Grunow) Krammer** (Figure 26)
Ref: Hofmann et al. 2011 p.197-pl.89: 35-39
Dimensions: Valve 13.1-16.7 µm length, 3.0-3.7 µm width and 24-25 striae in 10 µm
Distribution in Küçük Menderes River Basin: K6, K7

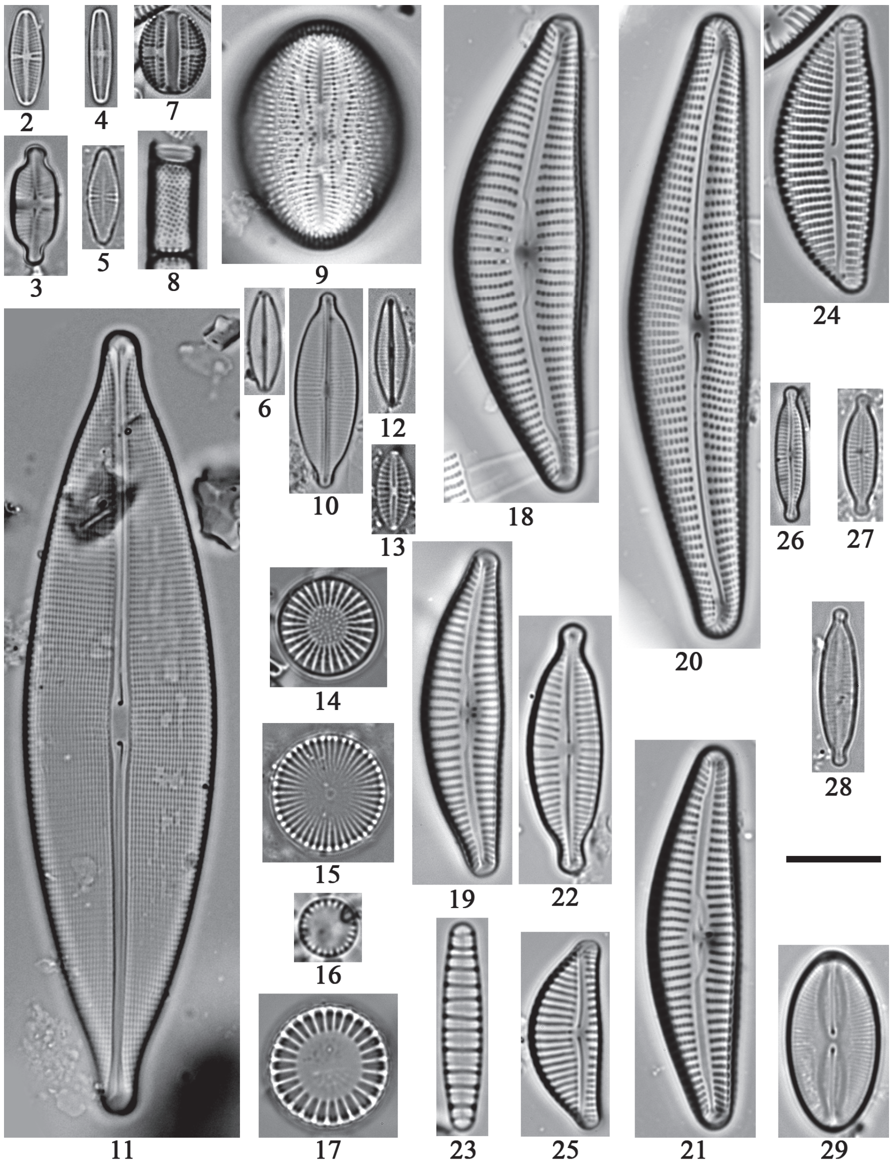
***Encyonopsis minuta* Krammer & Reichardt** (Figure 27)
Ref: Hofmann et al. 2011 p.198-pl.89: 25-34
Dimensions: Valve 9.3-15.2 µm length, 2.9-3.8 µm width and 24-25 striae in 10 µm
Distribution in Küçük Menderes River Basin: K6, K7, K8

***Encyonopsis subminuta* Krammer & Reichardt** (Figure 28)
Ref: Hofmann et al. 2011 p.198-pl.89: 17-21
Dimensions: Valve 14.3-21.4 µm length, 3.6-4.1 µm width and 24-26 striae in 10 µm
Distribution in Küçük Menderes River Basin: K6, K7, K8, K10

***Fallacia pygmaea* (Kützing) Stikle et Mann** (Figure 29)
Basionym: *Navicula pygmaea* Kützing
Ref: Hofmann et al. 2011 p.245-pl.46: 31-34
Dimensions: Valve 18.1-24.8 µm length, 9.2-14.6 µm width and 22-25 striae in 10 µm
Distribution in Küçük Menderes River Basin: K10

***Fragilaria capucina* var. *vaucheriae* (Kützing) Lange-Bertalot** (Figure 30)
Basionym: *Exilaria vaucheria* Kützing
Ref: Hofmann et al. 2011 p.277-pl.9: 1-7
Dimensions: Valve 15.1-22.3 µm length, 4.7-5.2 µm width and 9-10 striae in 10 µm
Distribution in Küçük Menderes River Basin: K8, K10

***Fragilaria mesolepta* Rabenhorst** (Figure 31)
Ref: Hofmann et al. 2011 p.267-pl.8: 22-27
Dimensions: Valve 22.3-26.7 µm length, 3.4-4.1 µm width and 16-18 striae in 10 µm
Distribution in Küçük Menderes River Basin: K8




*Figures 2-29.* 2- *Achnanthidium eutrophilum*; 3- *A. exiguum*; 4- *A. minutissimum*; 5- *A. minutissimum* var. *jackii*; 6- *Adlafia minuscula*; 7- *Amphora pediculus*; 8- *Aulacoseira ambigua*; 9- *Cocconeis pediculus*; 10- *Craticula accomoda*; 11- *C. cuspidata*; 12- *C. melostiformis*; 13- *C. subminuscula*; 14- *Cyclostephanos dubius*; 15- *C. invisitatus*; 16- *Cyclotella atomus*; 17- *C. meneghiniana*; 18- *C. cymbiformis*; 19- *C. excisa*; 20- *C. lange-bertalotii*; 21- *C. parva*; 22- *Cymbopleura amphicephala*; 23- *Diatoma moniliformis*; 24- *Encyonema caespitosum*; 25- *E. ventricosum*; 26- *Encyonopsis microcephala*; 27- *E. minuta* Krammer & Reichardt; 28- *E. subminuta* Krammer & Reichardt; 29- *Fallacia pygmaea* (Kütz.) Stikle et Mann. Scale bar: 10μm.

***Fragilaria perminuta* (Grunow) Lange-Bertalot** (Figure 32)
Ref: Hofmann et al. 2011 p.271-pl.8: 28-31
Dimensions: Valve 11.2-21.2 µm length, 2.6-3.1 µm width and 17-18 striae in 10 µm
Distribution in Küçük Menderes River Basin: K8, K9

***Geissleria decussis* (Østrup) Lange-Bertalot & Metzeltin** (Figure 33)
Basionym: *Navicula decussis* Østrup
Ref: Hofmann et al. 2011 p.284-pl.51: 40-44
Dimensions: Valve 18.1-23.4 µm length, 6.9-7.8 µm width and 15-16 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1

***Gomphonema olivaceum* (Hornemann) Brébisson** (Figure 34)
Basionym: *Ulva olivacea* Hornemann
Ref: Hofmann et al. 2011 p.310-pl.95: 1-6
Dimensions: Valve 14.0-21.3 µm length, 4.8-5.9 µm width and 9-12 striae in 10 µm
Distribution in Küçük Menderes River Basin: K7, K8

***Gomphonema parvulum* (Kützing) Kützing** (Figure 35)
Basionym: *Sphenella parvula* Kützing
Ref: Hofmann et al. 2011 p.312-pl.99: 1-5
Dimensions: Valve 10.2-15.3 µm length, 4.5-4.9 µm width and 16-18 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K4, K5

***Gomphonema pumilum* (Grunow) E.Reichardt & Lange-Bertalot** (Figure 36)
Basionym: *Gomphonema intricatum* var. *pumilum* Grunow
Ref: Hofmann et al. 2011 p.315-pl.97: 10-20
Dimensions: Valve 17.6-18.5 µm length, 4.1-4.9 µm width and 11-13 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K6, K7

***Halamphora montana* (Krasske) Levkov** (Figure 37)
Basionym: *Amphora montana* Krasske
Ref: Hofmann et al. 2011 p.328-pl.92: 12-14
Dimensions: Valve 14.1-16.1 µm length and 3.1-3.6 µm width
Distribution in Küçük Menderes River Basin: K3, K5, K10

***Halamphora veneta* (Kützing) Levkov** (Figure 38)
Basionym: *Amphora veneta* Kützing
Ref: Hofmann et al. 2011 p.330-pl.92: 20-25
Dimensions: Valve 15.2-18.3 µm length, 4.1-4.4 µm width and 17-19 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K2, K5, K9

***Hantzschia amphioxys* (Ehrenberg) Grunow** (Figure 39)
Basionym: Eunotia *amphioxys* Ehrenberg
Ref: Hofmann et al. 2011 p.333-pl.102: 1-5
Dimensions: Valve 16.1-38.4 µm length, 5.1-6.2 µm width and 19-22 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1

***Hippodonta capitata* (Ehrenberg) Lange-Bertalot, Metzeltin et Witkowski** (Figure 40)
Basionym: *Navicula capitata* Ehrenberg
Ref: Hofmann et al. 2011 p.335-pl.51: 1-6
Dimensions: Valve 21.3-24.2 µm length, 5.5-6.9 µm width and 8-9 striae in 10 µm.
Distribution in Küçük Menderes River Basin: K10

***Luticola goeppertiana* (Bleisch) D.G.Mann** (Figure 41)
Basionym: *Stauroneis geoppertiana* Bleisch
Ref: Hofmann et al. 2011 p.346-pl.45: 22-26
Dimensions: Valve 17.2-21.3 µm length, 6.8-7.3 µm width and 17-20 striae in 10 µm
Distribution in Küçük Menderes River Basin: K5

***Luticola ventricosa* (Kützing) D.G.Mann** (Figure 42)
Basionym: *Stauroneis ventricosa Kützing*
Ref: Levkov et al. 2013 p.250-pl.190: 1-57
Dimensions: Valve 12.4-17.5 µm length, 6.2-7.1 µm width and 18-20 striae in 10 µm
Distribution in Küçük Menderes River Basin: K5

***Mayamaea permitis* (Hustedt) K.Bruder & L.K. Medlin** (Figure 43)
Basionym: *Navicula permitis* Hustedt
Ref: Lange-Bertalot 2001 p.136-pl.104: 7-13
Dimensions: Valve 6.5-7.3 µm length and 3.1-3.4 µm width
Distribution in Küçük Menderes River Basin: K2, K3, K4, K10

***Melosira varians* Agardh** (Figure 44)
Ref: Krammer & Lange-Bertalot 1991 p.7-pl.4:1-8, Wojtal 2009 p.238-pl.1: 1-4
Dimensions: Valve diameter 8.5-10.9 µm
Distribution in Küçük Menderes River Basin: K10

***Navicula antonii* Lange-Bertalot** (Figure 45)
Ref: Lange-Bertalot 2001 p.15-pl.13: 1-15
Dimensions: Valve 15.5-23.2 µm length, 5.9-6.8 µm width and 12-14 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K7

***Navicula capitatoradiata* Germain** (Figure 46)
Ref: Lange-Bertalot 2001 p.22-pl.29: 15-20
Dimensions: Valve 30.3-35.7 µm length, 6.9-7.6 µm width and 12-14 striae in 10 µm
Distribution in Küçük Menderes River Basin: K4, K7, K8, K9

***Navicula cryptocephala* Kützing** (Figure 47)
Ref: Lange-Bertalot 2001 p.27-pl.17: 1-10
Dimensions: Valve 25.4-35.2 µm length, 5.9-6.4 µm width and 15-17striae in 10 µm
Distribution in Küçük Menderes River Basin: K4, K7, K8, K9

***Navicula cryptotenella* Lange-Bertalot** (Figure 48)
Ref: Lange-Bertalot 2001 p.28-pl.26: 17-32
Dimensions: Valve 18.3-27.5 µm length, 5.3-6.2 µm width and 15-17 striae in 10 µm
Distribution in Küçük Menderes River Basin: K9

***Navicula cryptotenelloides* Lange-Bertalot** (Figure 49)
Ref: Lange-Bertalot 2001 p.29-pl.18: 1-8
Dimensions: Valve 12.7-21.2 µm length, 3.9-4.1 µm width and 17-18 striae in 10 µm
Distribution in Küçük Menderes River Basin: K8

***Navicula erifuga* Lange-Bertalot** (Figure 50)
Ref: Hofmann et al. 2011 p.382-pl.38: 12-16
Dimensions: Valve 21.4-32.5 µm length, 5.2-6.9 µm width and 12-14 striae in 10 µm
Distribution in Küçük Menderes River Basin: K10

***Navicula gregaria* Donkin** (Figure 51)
Ref: Hofmann et al. 2011 p.384-pl.39: 5-11
Dimensions: Valve 17.8-27.4 µm length, 6.1-7.2 µm width and 16-19 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K2, K3, K10

***Navicula notha* Wallace** (Figure 52)
Ref: Hofmann et al. 2011 p.390-pl.31: 19-23
Dimensions: Valve 24.2-28.4 µm length, 4.7-5.4 µm width and 16-17 striae in 10 µm
Distribution in Küçük Menderes River Basin: K10

***Navicula radiosa* Kützing** (Figure 53)
Ref: Lange-Bertalot 2001 p.59-pl.8: 1-7
Dimensions: Valve 54.2-67.4 µm length, 9.1-11.4 µm width and 10-12 striae in 10 µm
Distribution in Küçük Menderes River Basin: K8

***Navicula reichardtiana* Lange-Bertalot** (Figure 54)
Ref: Lange-Bertalot 2001 p.63-pl.13: 13-25
Dimensions: Valve 13.0-17.4µm length, 5.1-6.2 µm width and 15-18 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1

***Navicula simulata* Manguin** (Figure 55)
Ref: Hofmann et al. 2011 p.400-pl.38: 6-11
Dimensions: Valve 30.2-35.4 µm length, 6.2-7.0 µm width and 14-16 striae in 10 µm
Distribution in Küçük Menderes River Basin: K2, K9

***Navicula trivialis* Lange-Bertalot** (Figure 56)
Ref: Lange-Bertalot 2001 p.73-pl.29: 1-6
Dimensions: Valve 32.8-42.4 µm length, 9.3-11.4 µm width and 11-12 striae in 10 µm
Distribution in Küçük Menderes River Basin: K9

***Navicula vandamii* Schoeman & Archibald** (Figure 57)
Ref: Hofmann et al. 2011 p.406-pl.29: 15-19
Dimensions: Valve 19.4-25.9 µm length, 4.7-5.1 µm width and 15-16 striae in 10 µm
Distribution in Küçük Menderes River Basin: K2, K9

***Navicula veneta* Kützing** (Figure 58)
Ref: Lange-Bertalot 2001 p.78-pl.14: 23-30
Dimensions: Valve 15.4-21.9 µm length, 4.9-5.7 µm width and 14-15 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K2, K4, K5, K6, K10

***Navicula viridula* var. *germainii* (Wallace) Lange-Bertalot** (Figure 59)
Basionym: *Navicula germainii* Wallace
Ref: Hofmann et al. 2011 p.383-pl.37: 5-9
Dimensions: Valve 28.7-34.3 µm length, 6.9-7.8 µm width and 13-14 striae in 10 µm
Distribution in Küçük Menderes River Basin: K2, K10

***Navicula viridula* var. *rostellata* (Kützing) Cleve** (Figure 60)
Basionym: *Navicula rostellata* Kützing
Ref: Hofmann et al. 2011 p.397-pl.37: 10-14
Dimensions: Valve 37.9-42.5 µm length, 8.7-9.9 µm width and 11-12 striae in 10 µm
Distribution in Küçük Menderes River Basin: K10

***Nitzschia amphibia* Grunow** (Figure 61)
Ref: Hofmann et al. 2011 p.433-pl.117: 9-15
Dimensions: Valve 21.5-27.4 µm length, 3.9-4.7 µm width and 15-17 striae and 7-8 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K4, K5

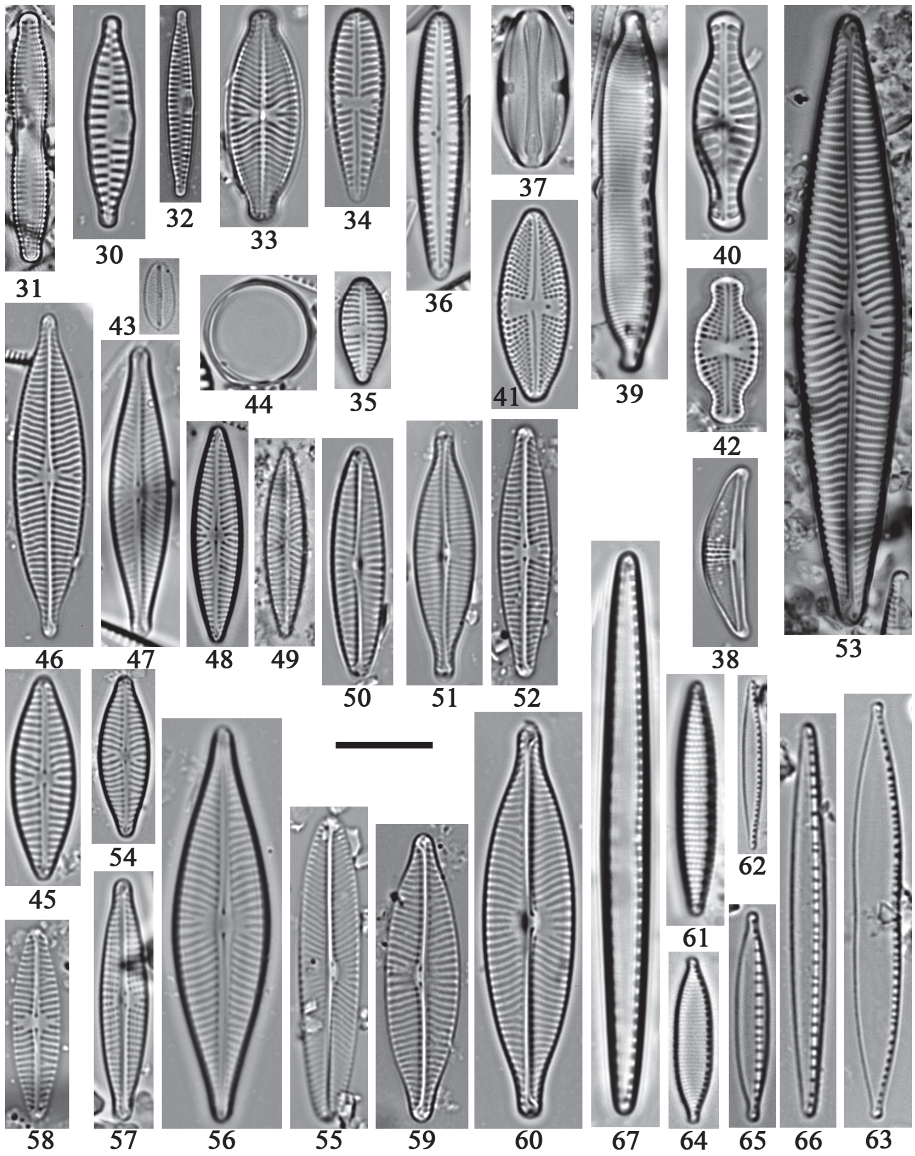
***Nitzschia archibaldii* Lange-Bertalot** (Figure 62)
Ref: Hofmann et al. 2011 p.438-pl.113: 11-16
Dimensions: Valve 14.7-25.4 µm length, 1.8-2.3 µm width and 16-19 striae and 7-8 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K2, K3, K10

***Nitzschia capitellata* Hust. in A. Schmidt** (Figure 63)
Ref: Hofmann et al. 2011 p.438-pl.113: 11-16
Dimensions: Valve 37.4-45.9 µm length, 3.9-5.1 µm width and 10-14 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K2, K3, K4, K10

***Nitzschia desertorum* Hustedt** (Figure 64)
Ref: Krammer & Lange-Bertalot 1988 p.98-pl.70: 10-13
Dimensions: Valve 16.4-17.1 4 µm length, 3.7-4.3 µm width and 25-26 striae and 14-15 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K2

***Nitzschia dissipata* (Kützing) Grunow** (Figure 65)
Ref: Hofmann et al. 2011 p.442-pl.109: 8-13
Dimension: Valve 13.4-23.2 µm length, 3.3-4.7 µm width and 8-10 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K9

***Nitzschia dissipata* var. *media* (Hantzsch) Grunow** (Figure 66)
Basionym: *Nitzschia media* Hantzsch
Ref: Hofmann et al. 2011 p.442-pl.109: 14-18
Dimensions: Valve 47.2-61.5 µm length, 4.2-5.1 µm width and 8-10 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K9



*Figures 30-67.* 30- *Fragilaria capucina vaucheriae*; 31- *F. mesolepta*; 32- *F. perminuta*; 33- *Geissleria decussis*; 34- *Gomphonema olivaceum*; 35- *G. parvulum*; 36- *G. pumilum*; 37- *Halamphora montana*; 38- *H. veneta*; 39- *Hantzschia amphioxys*; 40- *Hippodonta capitata*; 41- *Luticola geoppertiana*; 42- *L. ventricosa*; 43- *Mayamaea permitis*; 44- *Melosira varians* Agardh; 45- *Navicula antonii*; 46- *N. capitatoradiata*; 47- *N. cryptocephala*; 48- *N. cryptotenella*; 49- *N. cryptotenelloides*; 50- *N. erifuga*; 51- *N. gregaria*; 52- *N. notha*; 53- *N. radiosa*; 54- *N. reichardtiana*; 55- *N. simulata*; 56- *N. trivialis*; 57- *N. vandamii*; 58- *N. veneta*; 59- *N. viridula* var. *germainii*; 60- *N. viridula* var. *rostellata*; 61- *Nitzschia amphibia*; 62- *N. archibaldii*; 63- *N. capitellata*; 64- *N. desertorum*; 65- *N. dissipata*; 66- *N. dissipata* var. *media*; 67- *N. filiformis* Scale bar: 10µm.

***Nitzschia filiformis* (W.Smith) Van Heurck** (Figure 67)
Basionym: *Homoecladia filiformis* W.Smith
Ref: Hofmann et al. 2011 p.443-pl.116: 1-6
Dimensions: Valve 48.4-61.7µm length, 4.5-5.7 µm width and 8-10 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K9

***Nitzschia fonticola* (Grunow) Grunow in Van Heurck** (Figure 68)
Basionym: *Nitzschia palea* var. *fonticola* Grunow
Ref: Hofmann et al. 2011 p.444-pl.108: 9-15
Dimensions: Valve 27.2-35.4 µm length, 4.0-4.9 µm width and 24-28 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K3

***Nitzschia frustulum* (Kützing) Grunow** (Figure 69)
Basionym: *Synedra frustulum* Grunow
Ref: Hofmann et al. 2011 p.445-pl.112: 28-34
Dimensions: Valve 14.7-21.3 µm length, 2.9-3.5 µm width and 21-24 striae and 10-12 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K9, K10

***Nitzschia inconspicua* Grunow** (Figure 70)
Ref: Hofmann et al. 2011 p.445-pl.112: 35-40
Dimensions: Valve 6.4-10.5 µm length, 2.5-2.9 µm width and 26-28 striae and 13-14 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K4, K8, K9, K10

***Nitzschia linearis* (C.Agardh) W. Smith** (Figure 71)
Basionym: *Frustulia sociabilis* C.Agardh
Ref: Hofmann et al. 2011 p.558-pl.126: 1-5
Dimensions: Valve 45.4-62.7 µm length, 5.5-6.1 µm width and 10-12 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K1

***Nitzschia palea* (Kützing) W.Smith** (Figure 72)
Basionym: *Synedra palea* Kützing
Ref: Hofmann et al. 2011 p.454-pl.111:1-9
Dimensions: Valve 37.5-50.4 µm length, 3.6-3.9 µm width and 10-12 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K2, K3, K4, K5, K6, K7, K10

***Nitzschia sociabilis* Hustedt** (Figure 73)
Ref: Hofmann et al. 2011 p.461-pl.111: 35-40
Dimensions: Valve 27.3-35.4 µm length, 3.2-3.7 µm width and 10-11 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K9

***Nitzschia umbonata* (Ehrenberg) Lange-Bertalot** (Figure 74)
Basionym: *Navicula umbonata* Ehrenberg
Ref: Hofmann et al. 2011 p.558-pl.126: 1-5
Dimensions: Valve 45.2-65.7 µm length, 6.5-7.8 µm width and 9-10 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K2, K4, K5, K6

***Pantocsekiella ocellata* (Pantocsek) K.T.Kiss & Ács** (Figure 75)
Basionym: *Cyclotella ocellata* Pantocsek
Ref: Krammer & Lange-Bertalot 1991 p. 51-pl.50: 1-11; Wojtal & Kwandrans 2006 p.188-pl.7: 26-27
Dimensions: Valve diameter 8.2-10.4 µm. Valves have 16-18 interstriae in 10 µm
Distribution in Küçük Menderes River Basin: K8

***Planothidium lanceolatum* (Brébisson ex Kützing) Lange-Bertalot** (Figure 76)
Basionym: *Achnanthidium lanceolatum* Brébisson ex Kützing
Ref: Hofmann et al. 2011 p.510-pl.24: 41-47
Dimensions: Valve 15.1-18.4 µm length, 4.5-7.8 µm width and 12-14 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K8

***Pseudofallacia monoculata* (Hustedt) D.G.Mann** (Figure 77)
Basionym: *Navicula monoculata* Hustedt
Ref: Hofmann et al. 2011 p.244-pl.46: 13-17
Dimensions: Valve 9.2-13.5 µm length, 4.2-5.1 µm width and 21-25 striae in 10 µm
Distribution in Küçük Menderes River Basin: K3, K10

***Pseudostaurosira brevistriata* (Grunow) D.M.Williams & Round** (Figure 78)
Basionym: *Fragilaria brevistriata* Grunow
Ref: Hofmann et al. 2011 p.258-pl.9: 25-29
Dimensions: Valve 13.2-17.8 µm length, 3.9-4.8 µm width and 14-16 striae in 10 µm
Distribution in Küçük Menderes River Basin: K8

***Reimeria sinuata* (Gregory) Kociolek et Stoermer** (Figure 79)
Basionym: *Cymbella sinuata* Gregory
Ref: Hofmann et al. 2011 p.526-pl.89: 50-61
Dimensions: Valve 12.5-15.4 µm length, 3.9-4.7 µm width and 12-15 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K2, K7

***Sellaphora pupula* (Kützing) Mereschkovsky** (Figure 80)
Basionym: *Navicula pupula* Kützing
Ref: Hofmann et al. 2011 p.536-pl.41: 1, 2
Dimensions: Valve 21.4-27.5 µm length, 6.7-7.8 µm width and 20-24 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K2, K3, K10

***Sellaphora radiosa* (Hustedt) H.Kobayasi** (Figure 81)
Basionym: *Navicula seminulum* var. *radiosa* Hustedt
Ref: Hofmann et al. 2011 p.533-pl.42: 27-31
Dimensions: Valve 10.5-13.7 µm length, 3.5-3.9 µm width and 19-21 striae in 10 µm
Distribution in Küçük Menderes River Basin: K5

***Sellaphora saprotolerans* Lange-Bertalot, Hofmann & Cantonati** (Figure 82)
Ref: Hofmann et al. 2011 p.536-pl.41: 6-10
Dimensions: Valve 27.2-28.4 µm length, 8.2-8.4 µm width and 18 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K2, K10

***Sellaphora saugerresii* (Desmazières) C.E.Wetzel & D.G.Mann** (Figure 83)
Basionym: *Navicula suagerresii* Desmazières
Ref: Hofmann et al. 2011 p.201-pl.42: 37-43
Dimensions: Valve 4.5-10.8 µm length, 2.5-3.2 µm width and 26-32 striae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K2, K3, K4

***Sellaphora seminulum* (Grunow) D.G.Mann** (Figure 84)
Basionym: *Navicula seminulum* Grunow
Ref: Hofmann et al. 2011 p.537-pl.42: 22-26
Dimensions: Valve 9.2-12.5 µm length, 3.5-4.2 µm width and 19-21 striae in 10 µm
Distribution in Küçük Menderes River Basin: K4, K5

***Stephanodiscus hantzschii* Grunow** (Figure 85)
Ref: Krammer & Lange-Bertalot 1991 p.73-pl.74:12-16, 75:4-11; Wojtal & Kwandrans 2006 p.199-pl.18: 3-8, 19: 1-9
Dimensions: Valve diameter 7.4-12.3 µm. There are 9-11 interstriae in 10 µm
Distribution in Küçük Menderes River Basin: K10

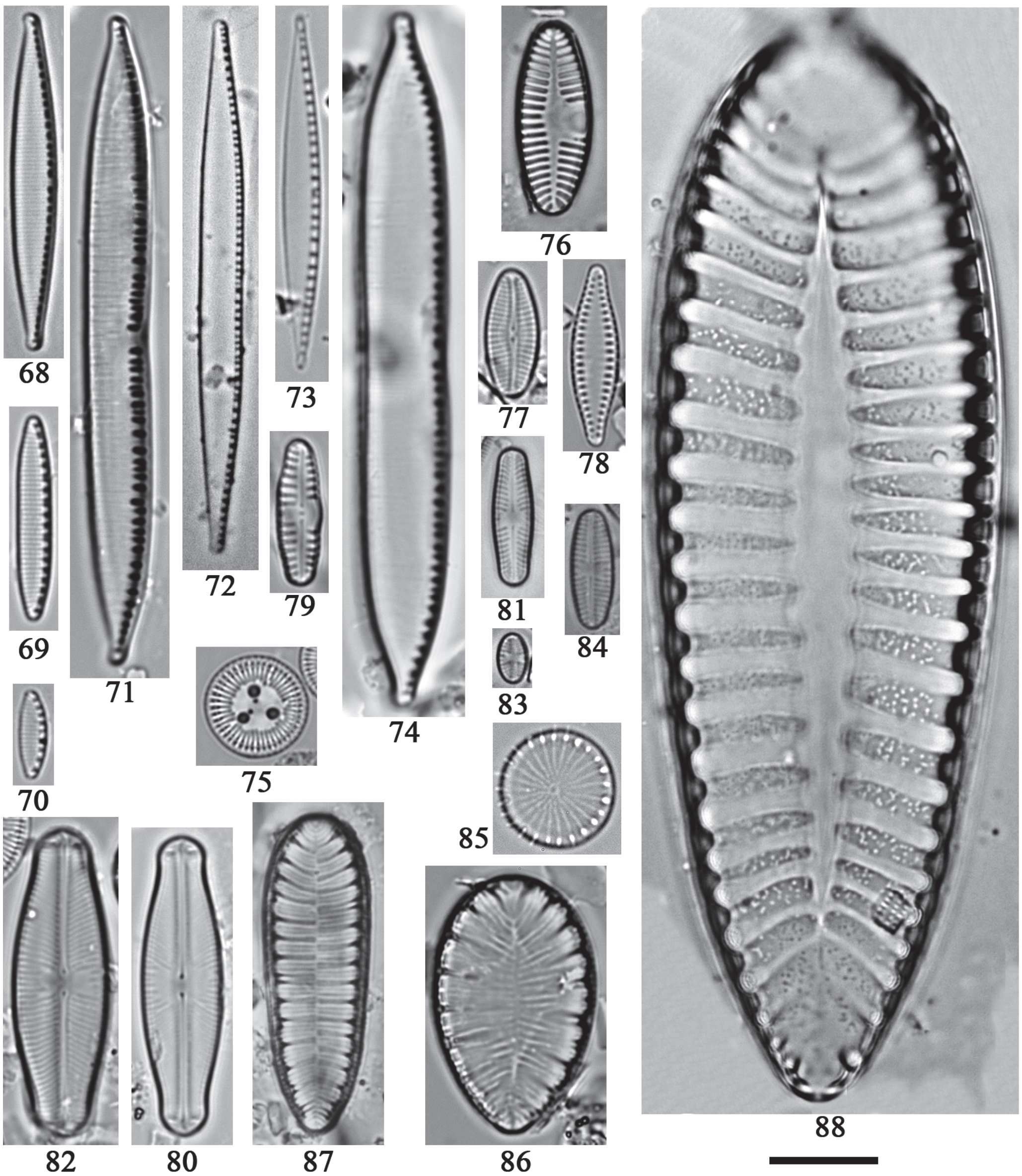
***Surirella brebissonii* Krammer et Lange-Bertalot** (Figure 86)
Ref: Hofmann et al. 2011 p.556-pl.130: 11-16
Dimensions: Valve 19.2-25.4 µm length, 13.2-15.4 µm width and 4-5 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K2, K5

***Surirella minuta*** **Brébisson** (Figure 87)
Ref: Hofmann et al. 2011 p.558-pl.131: 6-12
Dimensions: Valve 25.4-29.3 µm length, 9.2-10.8 µm width and 6-7 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K2

***Surirella robusta*** **Ehrenberg** (Figure 88)
Ref: Hofmann et al. 2011 p.559-pl.127: 1, 2
Dimensions: Valve 98.8 µm length, 31.3 µm width and 3 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K1, K2, K10

***Tryblionella apiculata*** **Gregory** (Figure 89)
Ref: Hofmann et al. 2011 p.439-pl.104: 18-22
Dimensions: Valve 32.4-41.3 µm length, 4.9-6.1 µm width and 15-18 striae in 10 µm.
Distribution in Küçük Menderes River Basin: K2

***Tryblionella calida*** **(Grunow) D.G.Mann** (Figure 90)
Basionym: *Nitzschia calida* Grunow
Ref: Hofmann et al. 2011 p.437-pl.103: 5-8
Dimensions: Valve 34.3-37.5 µm length, 6.2-7.4 µm width and 12 fibulae in 10 µm
Distribution in Küçük Menderes River Basin: K2



*Figures 68-88***.** 68- *Nitzschia fonticola*; 69- *N. frustulum*; 70- *N. inconspicua*; 71- *N. linearis*; 72- *Nitzschia palea*; 73- *N. sociabilis*; 74- *N. umbonata*; 75- *Pantocsekiella ocellata*; 76- *Planothidium lanceolatum*; 77- *Pseudofallacia monoculata*; 78- *Pseudostaurosira brevistriata*; 79- *Reimeria sinuata*; 80- *Sellaphora pupula*; 81- *S. radiosa*; 82- *S. saprotolerans*; 83- *S. saugerresii*; 84- *S. seminulum*; 85- *Stephanodiscus hantzschii*; 86- *Surirella brebissonii*; 87- *S. minuta*; 88- *S. robusta*. Scale bar: 10µm.

***Ulnaria acus* (Nitzsch) P.Compère** (Figure 91)
Basionym: *Bacillaria ulna* Nitzsch
Ref: Hofmann et al. 2011 p.256-pl.5: 1-5
Dimensions: Valve 80.5-92.3 µm length, 3.9-4.2 µm width and 13-15 striae in 10 µm
Distribution in Küçük Menderes River Basin: K8

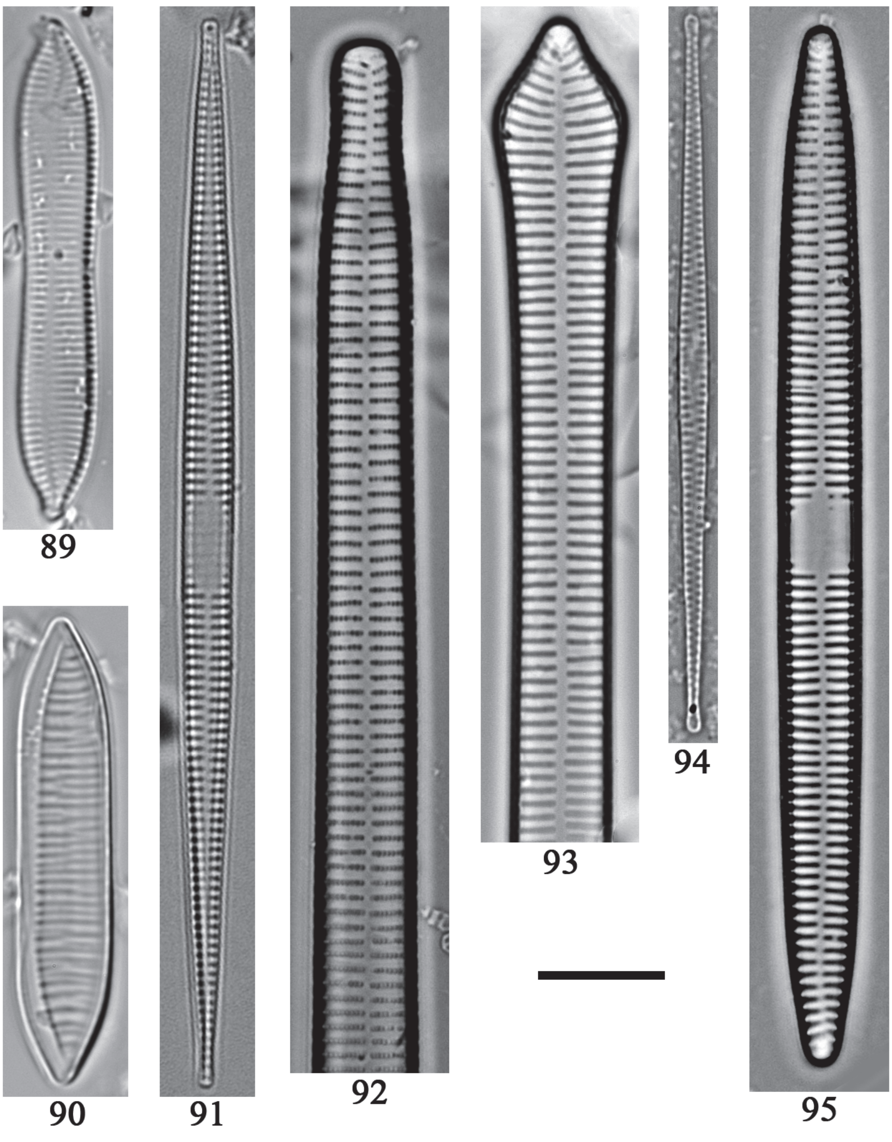
***Ulnaria biceps* (Kützing) P.Compère** (Figure 92)
Basionym: *Synedra biceps* Kützing
Ref: Krammer & Lange-Bertalot 1991 p.146-pl.121: 1-5
Dimensions: Valve 7.3-7.9 µm width and 8-9 striae in 10 µm
Distribution in Küçük Menderes River Basin: K5, K7, K8

***Ulnaria capitata* (Ehrenberg) Compère** (Figure 93)
Basionym: *Synedra capitata* Ehrenberg
Ref: Hofmann et al. 2011 p.277-pl.6: 1-3
Dimensions: Valve 7.2-7.6 µm width and 8-10 striae in 10 µm
Distribution in Küçük Menderes River Basin: K8

***Ulnaria delicatissima* (W.Smith) M.Aboal & P.C.Silva** (Figure 94)
Basionym: *Synedra delicatissima* W.Smith
Ref: Hofmann et al. 2011 p.262-pl.7: 1-6
Dimensions: Valve 47.2-58.4 µm length, 2.3-3.1 µm width and 14-15 striae in 10 µm
Distribution in Küçük Menderes River Basin: K6, K8

***Ulnaria ulna* (Nitzsch) P.Compère** (Figure 95)
Basionym: Bacillaria ulna Nitzsch
Ref: Hofmann et al. 2011 p.276-pl.5: 6-11
Dimensions: Valve 64.3-82.4 µm length, 5.7-6.5 µm width and 10-12 in 10 µm
Distribution in Küçük Menderes River Basin: K1

Among the taxa, *Nitzschia palea* was abundant in K1 and K3 stations; *Sellaphora pupula* was abundant is K2 station; *Navicula veneta* was abundant in K4; *Craticula accomoda* and *C. subminuscula* were abundant in K5 station; *Achnanthidium minutissimum* was abundant in K7; *Ulnaria delicatissima* was abundant in K8; *Cymbella excisa* was abundant in K9, *Melosira varians* and *Nitzschia frustulum* were abundant in K10.




*Figures 89-95.* 89- *Tryblionella apiculata*; 90- *T. calida*; 91- *Ulnaria acus*; 92- *U. biceps*; 93- *U. capitata*; 94- *U. delicatissima*; 95- *U. ulna*. Scale bar: 10µm.

Regarding to the ecological status of the water bodies investigated in this study, abundant taxa like *Craticula accomoda, Navicula veneta* or *Nitzschia palea* were found as good indicators for polluted waters (Lange-Bertalot et al. 2017) and the presence of these taxa indicated that the most of the sampling stations were affected by pollution.

On the other hand, there are some differences between Turkish inland waters and water bodies in this study in terms of the distribution of the taxa. *Craticula melostiformis, Cyclostephanos dubius, Encyonopsis minuta, E. subminuta, Gomphonema pumilum, Halamphora montana* and *Mayameae permitis* were rarely found in Turkey (Gönülol, 2017) but commonly encountered in this study. Similarly, *Craticula melostiformis, Gomphonema pumilum* and *Mayamaea permitis* were newly recorded for Turkish freshwater diatom flora. The results point out that the taxa mentioned above might be common in Turkish waters but further studies might be needed to present the distribution of these taxa in Turkish freshwaters in detail and reveal the big picture.

In Turkey, common diatoms are given in the articles in the studies. However, hardly any results for rare taxa can be found in the articles. On the other hand, new records and rare species are important to observe the community structure and flora of a country and to uncover the potential indicator values of the species for monitoring studies (Potapova and Charles, 2004). In this regard, some taxa were found as new records for Turkish diatom flora namely *Achnanthidium eutrophilum, A. minutissimum* var. *jackii, Navicula simulata, N. vandamii, Nitzschia archibaldii, N. desertorum* and *Sellaphora saprotolerans*.

Biological monitoring studies that carried out in different river basins of Turkey are important in terms of ecosystem based evaluation of water quality. On the other hand, these studies make a great contribution to flora and fauna studies. Biological, physicochemical and chemical monitoring is carried out simultaneously in many water bodies which have not been monitored until today and getting information on the distribution and environmental needs of the species. Establishment of visual catalogues of the species which including information about dimensions and distrubiton for each river basin will greatly contribute to monitoring studies. In this way, identification process will be easier and ecological status of the water bodies can be assessed more quickly.

## Discussion and Conclusion

In this study, 94 taxa were identified in total. Among the taxa; *Achnanthidium minutissimum, Adlafia minuscula, Amphora pediculus, Cocconeis pediculus, Craticula accomoda, C. cuspidata, C. subminuscula, Cyclotella meneghiniana, Cymbella cymbiformis, C. parva, Cymbopleura amphicephala, Diatoma moniliformis, Encyonema caespitosum, E. ventricosum, Encyonopsis microcephala, Fallacia pygmeae, Fragilaria capucina* var. *vaucheria, F. mesolepta, Geissleria decussis, Gomphonema olivaceum, G. parvulum, Halamphora veneta, Hantzschia amphioxys, Hippodonta capitata, Melosira varians, Navicula capitatoradiata, N. cryptocephala, N. cryptotenella, N. gregaria, N. radiosa, N. trivialis, N. veneta, N. viridula var. rostellata, Nitzschia amphibia, N. capitellata, N. dissipata, N. dissipata var. media, N. filiformis, N. fonticola, N. frustulum, N. inconspicua, N. linearis, N. palea, N. umbonata, Pantocsekiella ocellata, Planothidium lanceolatum, Pseudostaurosira brevistriata, Reimeria sinuata, Sellaphora pupula, S. saugerresii, Stephanodiscus hantzschii, Surirella brebissonii, S. minuta, S. robusta, Tryblionella apiculata, Ulnaria acus, U. biceps, U. capitata, U. delicatissima* and *Ulnaria ulna* were common taxa in Turkish diatom flora (Gönülol, 2017).

## Acknowledgement

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**Extended Turkish Abstract**
**(Genişletilmiş Türkçe Özet)**

**Küçük Menderes Nehir Havzası'nda Bentik Diyatome (Fitobentoz) Kompozisyonunun Dağılımı**

Avrupa Birliği Su Çerçeve Direktifi'nin (2000/60/AT) (SÇD) Avrupa'da 2000 yılında yürürlüğe girmesiyle birlikte su kalitesinin geleneksel yöntemlerle fizikokimyasal ve kimyasal olarak izlenmesi anlayışı yerini biyolojik izlemenin ön planda yer aldığı ekosistem esaslı izlemeye bırakmıştır. Avrupa Birliği Üye Devletleri fitobentoz, fitoplankton, makrofit, balık, makroomurgasız, makroalg ve angiosperm gibi birçok biyolojik kalite bileşenini nehir, göl, kıyı ve geçiş suyu kütlelerinde ekosistem esaslı değerlendirme maksadıyla izlemeye başlamıştır. Fizikokimyasal ve kimyasal izleme çalışmaları ile su kütlesinin sadece ölçüm yapılan andaki kalitesi belirlenirken, biyolojik kalite bileşenleri ile yapılan izleme çalışmaları sonucunda su kütlesinin uzun süreli durumu hakkında bilgi edinilebilmektedir.

Türkiye'de Su Çerçeve Direktifi'nin uyumlaştırılması çalışmaları 2011 yılında Orman ve Su İşleri Bakanlığı Su Yönetimi Genel Müdürlüğü'nün kurulmasıyla birlikte hız kazanmıştır. Türkiye'de ilk defa SÇD kapsamında havza bazında izleme çalışmaları Su Yönetimi Genel Müdürlüğü tarafından yürütülmüş "Havza İzleme ve Referans Noktaların Belirlenmesi Projesi" ile Akarçay, Meriç-Ergene, Susurluk, Gediz ve Sakarya nehir havzalarında gerçekleştirilmiş ve ardından bu çalışmanın kaynağını oluşturan Küçük Menderes Nehir Havzası ve ayrıca Kızılırmak, Marmara, Antalya ve Konya nehir havzaları ile izleme çalışmalarına devam edilmiştir. "Ülkemize Özgü Su Kalitesi Ekolojik Değerlendirme Sisteminin Kurulması Projesi" ile Türkiye'nin farklı coğrafi ve iklim koşullarına sahip nehir havzalarında (Batı Akdeniz, Batı Karadeniz, Doğu Karadeniz, Kuzey Ege, Ceyhan, Sakarya, Aşağı Fırat ve Aras) yapılan izleme çalışmaları ile ülkemize özgü indeksler belirlenmiştir. "Türkiye'de Referans İzleme Ağı'nın Kurulması Projesi" ile Türkiye'nin 25 nehir havzasının tamamında yapılacak izlemeler ile referans izleme noktalarının belirlenmesi çalışmalarına devam edilmektedir.

Küçük Menderes Nehir Havzası, Türkiye'nin batısında Büyük Menderes ile Gediz nehir havzaları arasında yer almaktadır. Türkiye'nin yüzey alanının yaklaşık %1'ini oluşturan havzanın sularını Ege Denizi'ne ulaştırması sebebiyle kıyı ve geçiş suyu kütleleri bulunmaktadır. SÇD kapsamında fitobentoz kalite bileşeninin sadece nehir ve göl suyu kütlelerinde izlenmekte olup, bu çalışmada Küçük Menderes Nehir Havzası'nda bulunan 7 nehir suyu kütlesi ve 3 baraj gölünde (Tahtalı, Beydağı, Alaçatı) yapılan fitobentoz izlemesi gerçekleştirilmiştir.

Fitobentoz, mikroskobik ve tek hücreli canlılardan 2 m'den uzun makrofitlere kadar tüm fototrofik canlıları kapsamaktadır. Fitobentoza yönelik pratik değerlendirme metotlarının eksikliğinden dolayı Avrupa Birliği Üye Devletleri fitobentozun en önemli göstergesi olan diyatomeleri izlemektedir. Fitobentozun en önemli göstergesi olan diyatomeler ile ilgili pek çok çalışma olmasına rağmen diyatome kompozisyonun dağılımı Türkiye'de halen yeni bir konudur. Bu çalışmada, Küçük Menderes Nehir Havzası'nda bentik diyatome kompozisyonunun dağılımının araştırılması amaçlanmıştır. 2014 yılı içerisinde Mayıs, Temmuz ve Eylül aylarında mevsimsel olarak epilitik ve epipelik diyatome örnekleri toplanmıştır. Epilitik diyatomeler nehir yatağında yer alan taşların fırçalanmasıyla, epipelik örnekler ise pipet yardımıyla sedimentten örneklenmiştir. Diyatome früstüllerinden organik maddenin uzaklaştırılması maksadıyla $H_2O_2$ ve HCL kullanılmış ve Naphrax solüsyonu kullanılarak daimi preparatlar hazırlanmıştır. Diyatomeler mikroskop yardımıyla incelenmiş ve taksonomik literatüre göre teşhis edilmiştir. Her bir preparatta ortalama 400 birey sayılmıştır. Teşhis edilen türlerin uzunluk,

genişlik ve 10 µm'deki stria sayıları raporlanmış ve türlerin görsel katalogları oluşturulmuştur. Türlerin Küçük Menderes Nehir Havzası'nda yer alan istasyonlardaki durumu ve Türkiye florasındaki durumu karşılaştırılmıştır.

Toplamda 94 bentik diyatome türünün teşhis edildiği çalışmada kirli suların indikatörü olan *Nitzschia palea* (Kützing) W.Smith, *N. inconspicua* Grunow, *N. umbonata* (Ehrenberg) Lange-Bertalot, *Craticula accomoda* (Hustedt) DG Mann, *C. subminuscula* (Manguin) C.E.Wetzel & L.Ector ve *Navicula veneta* Kützing en yaygın türler olmuştur. Türkiye diyatome florasında yaygın olarak bulunan *Achnanthidium minutissimum, Cocconeis pediculus, Craticula accomoda, C. subminuscula, Cyclotella meneghiniana, Encyonema ventricosum, Gomphonema parvulum, Halamphora veneta, Navicula capitatoradiata, N. cryptocephala, N. gregaria, N. veneta, Nitzschia capitellata, N. inconspicua, N. palea, N. umbonata, Reimeria sinuata, Sellaphora pupula, S. saugerresii, Surirella brebissonii, S. robusta* türlerinin Küçük Menderes Havzası'nda yaygın olarak teşhis edilmesi sebebiyle Türkiye diyatome florası ile benzerlik göstermiştir.

Diğer yandan, *Craticula melostiformis, Cyclostephanos dubius, Encyonopsis minuta, E. subminuta, Gomphonema pumilum, Halamphora montana* ve *Mayameae permitis* türleri Türkiye'de nadir olarak bulunan türler olurken bu çalışmada yaygın olarak teşhis edilmiştir. *Achnanthidium eutrophilum* (Lange-Bertalot) Lange-Bertalot, *A. minutissimum* var. *jackii* (Rabenhorst) Lange-Bertalot, *Navicula simulata* Manguin, *N. vandamii* Schoeman & Archibald, *Nitzschia archibaldii* Lange-Bertalot, *N. desertorum* Hustedt ve *Sellaphora saprotolerans* Lange-Bertalot, Hofmann & Cantonati türleri ise Türkiye diyatome florası için 7 yeni kayıt olmuştur. Bu türler arasında yer alan *Achnanthidium eutrophilum* ve *Nitzschia archibaldii* türleri Merkez Avrupa'da ve Almanya'da yaygın olarak görülürken *Navicula vandamii* türüne Almanya'da bulunan durgun sularda sık rastlanmaktadır.

Türkiye'de nehir havzalarında yürütülen biyolojik izleme faaliyetleri, su kalitesinin ekosistem esaslı olarak değerlendirilmesi açısından önemli çalışmalardır. Bu çalışmalar diğer bir yandan Türkiye flora ve faunası çalışmalarına da büyük katkı sağlamaktadır. Bugüne kadar izleme yapılmamış birçok su kütlesinde biyolojik, fizikokimyasal ve kimyasal izleme eş zamanlı olarak yapılmakta ve türlerin dağılımı ile türlerin çevresel istekleri hakkında bilgi edinilmektedir. Biyolojik izleme çalışmaları neticesinde teşhis edilen türlere ait ölçüm bilgilerinin ve havza bazında görsel katalogların oluşturulması izleme çalışmalarına büyük katkı sağlayacaktır. Bu sayede havza bazında yürütülen teşhis çalışmaları biraz daha kolaylaşacak ve böylece su kalitesinin ekolojik durumu daha hızlı bir şekilde değerlendirilebilecektir.

*Case Study*

# Planning Process for Drinking Water Protection: Case Study of Kartalkaya Dam Basin

# İçme Suyu Kaynaklarının Korunmasına Yönelik Planlama Süreci: Kartalkaya Baraj Havzası Örneği

Çiğdem ÖZONAT

*Ministry of Forestry and Water Affairs, Directorate General for Water Management*
*Yenimahalle-Ankara-Turkey*
cozonat@ormansu.gov.tr
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**Abstract**

Access to safe drinking water is vital for public health. Therefore, protection of these water resources is among major responsibilities of governments in order to ensure continuous supply of safe drinking water to citizens. On the other hand, drinking water resources are under severe risks throughout the world due to pollution, unsustainable use, climate change and many other effects. In order to minimize these risks, source water protection is accepted as most effective planning approach. In this study, Kartalkaya Dam was selected as a case study to discuss the theoretical framework of source water protection planning. Kartalkaya Dam is the only surface drinking water resource for Gaziantep Province. However, its water quality is at risk of deteriorating due to pollutant activities in the basin. This situation has created a need to execute a source water protection study in the Kartalkaya Dam Basin on the purpose of identifying and prioritizing management actions to bring water contamination risks to an acceptable level. Within this study, it was started with basin characterization and water quality assessment. A coupled model was developed to simulate quality for alternative future scenarios. Simulated results showed that Kartalkaya dam will be mesotrophic in case of providing 50% reduction in TN and 25% reduction in TP. Based on specified rates, pollution reduction measures were suggested. As a result of cost-benefit analysis, it is concluded that recommended measures are feasible.
**Keywords:** *drinking water, source water protection, pollution reduction, modelling, cost-benefit analysis*

**Öz**

Güvenli içme suyuna erişim kamu sağlığı için hayati önem taşımaktadır. Bu nedenle, vatandaşlara güvenli içme suyunu devamlı sağlayabilmek için bahse konu su kaynaklarının korunması devletlerin en önemli görevleri arasında yer almaktadır. Ancak, içme suyu kaynakları kirlilik, aşırı su kullanımı, iklim değişikliği ve benzeri nedenlerle önemli riskler altındadır. Bu risklerin azami düzeye indirilmesi için kaynakta koruma çalışmaları en etkili planlama yaklaşımı olarak kabul edilmektedir. Bu çalışmada, Kartalkaya Barajı su kaynaklarının korunmasına yönelik yapılan planlama çalışmalarının teorik çerçevesini değerlendirmek üzere bir vaka çalışması olarak seçilmiştir. Kartalkaya Barajı, Gaziantep için tek yüzeysel içme suyu kaynağı olmakla birlikte havzadaki kirletici faaliyetler nedeniyle barajdaki su kalitesi bozulma riski altındadır. Bu durum, Kartalkaya Baraj Havzasında içme suyu koruma planının yürütülmesi ihtiyacını doğurmuş olup; bahse konu plan ile havzadaki kirletici risklerinin kabul edilebilir seviyelere gelmesini sağlayacak eylemlerin belirlenmesi ve önceliklendirilmesi amaçlanmıştır. Bu çalışma kapsamında, öncelikle havzanın özellikleri ve mevcut su kalitesinin durumu değerlendirilmiştir. Alternatif gelecek senaryoları için su kalitesini öngörmek maksadıyla birleşik su kalite modeli geliştirilmiştir. Model sonuçları, toplam azotun % 50 toplam fosforun ise % 25 azalması durumunda Kartalkaya Barajı'nın mezotrofik olacağını ortaya koymuştur. Belirlenen oranlara dayanarak kirliliğin azalmasını sağlayacak tedbirler geliştirilmiştir. Fayda-maliyet analizi neticesinde önerilen tedbirlerin uygulanabilir olduğu sonucuna varılmıştır.

***Anahtar sözcükler:*** *içme suyu, kaynak koruma, kirliliğin azaltılması, modelleme, fayda-maliyet analizi*

## Introduction

Safe drinking water is the primary need of every human being. However, quality of drinking water resources is threatened by a variety of potential point and nonpoint sources of pollution. Therefore, protecting these water resources from contaminants is always among the top priorities of the governments in order to supply safe drinking water to citizens. This is best achieved through implementing an effective source water protection to prevent pollution problems from developing in the first place. Source water protection can be explained as basin-based planning process which aims at protecting a drinking water source through pollution reduction policies and land use management activities (Al Ibrahim and Patrick, 2017). The issue of source water protection has been discussed and promoted by different organizations at the international, national, regional and local levels since the National Source Water Protection Conference held by USEPA in 2003, and it is accepted as the first barrier in the multi-barrier system to minimize the risk of contamination in drinking water sources. Additionally, it is defined as a site-specific process which may require different protection programs due to differing characteristics of the watersheds, land use practices, potential pollution sources, as well as the nature of the stakeholder organizations and their available resources (Sklenar et. al, 2012).

Turkey also expresses a great amount of concern relating to water pollution. In order to prevent water pollution, many of laws and regulations specific to drinking water resources and basins have been adopted in last 10 years. Besides taking legal measures, many basin-based drinking water protection studies have been conducted. One of these studies has been executed in Kartalkaya Dam Basin with the aim of identification and prioritization of management actions to mitigate water contamination risks to an acceptable level. Since Kartalkaya Dam is the only surface drinking water resource for Gaziantep Province, it is crucial to take mitigation measures for the protecting the source against water contamination risks. Additionally, the protection of this source gains more importance considering the fact that the rapidly growing population due to Syrian asylum seekers has increased the Gaziantep's demand for drinking water. On the other hand, water pollution threatens the sustainability of Kartalkaya Dam. The primary water quality problems include high nutrient concentrations and bacterial contamination. Due to high nitrogen and phosphorus concentrations, Kartalkaya Dam is at risk of eutrophication. The unconscious use of fertilizers and pesticides, inadequate wastewater treatment facilities, improper disposal of waste and animal manure are considered to be the main reasons for pollution in Kartalkaya Dam. In order to minimize these contaminants, the source water protection plan for the Kartalkaya Dam Basin was developed in 2017 by Ministry of Forestry and Water Affairs. Within planning process, many interdisciplinary analyses were conducted to formulate the optimum management strategies. These analyses involve the assessment of the basin characteristics, potential causes of water quality degradation, current and future water quality. In order to simulate future quality, a coupled model was operated for four alternative scenarios. Based on the model results, pollution reduction measures were recommended. Additionally, a preliminary economic analysis was conducted in order to assess whether proposed measures are achievable and realistic. Thusly, all essential tools of source water protection was integrated into management planning process.

The purpose of this paper is to present not only the results of Kartalkaya Dam Basin Protection Planning but also a roadmap toward establishing a comprehensive source water protection plan.

## Method

This paper undertakes a case study approach into drinking water protection planning in Kartalkaya Dam Basin. It was chosen as a case study because the study conducted in the basin can be shown as a good example for integration of all essential tools of source water protection to planning process.

In the scope of study, firstly, demographic, socio-economic, physical structures, and existing land use were determined in order to present the current situation of basin. As a second step, point and diffuse pollution sources were evaluated, and monitoring studies were conducted to identify current water quality. Thirdly, a coupled water quality model for the Kartalkaya Dam Basin was developed to support the scenario analysis. Based on the model results, a basin protection plan was recommended. Finally, a preliminary economic assessment was conducted for the measures proposed in the protection plan. The technical approach of the study is illustrated in Figure 1.

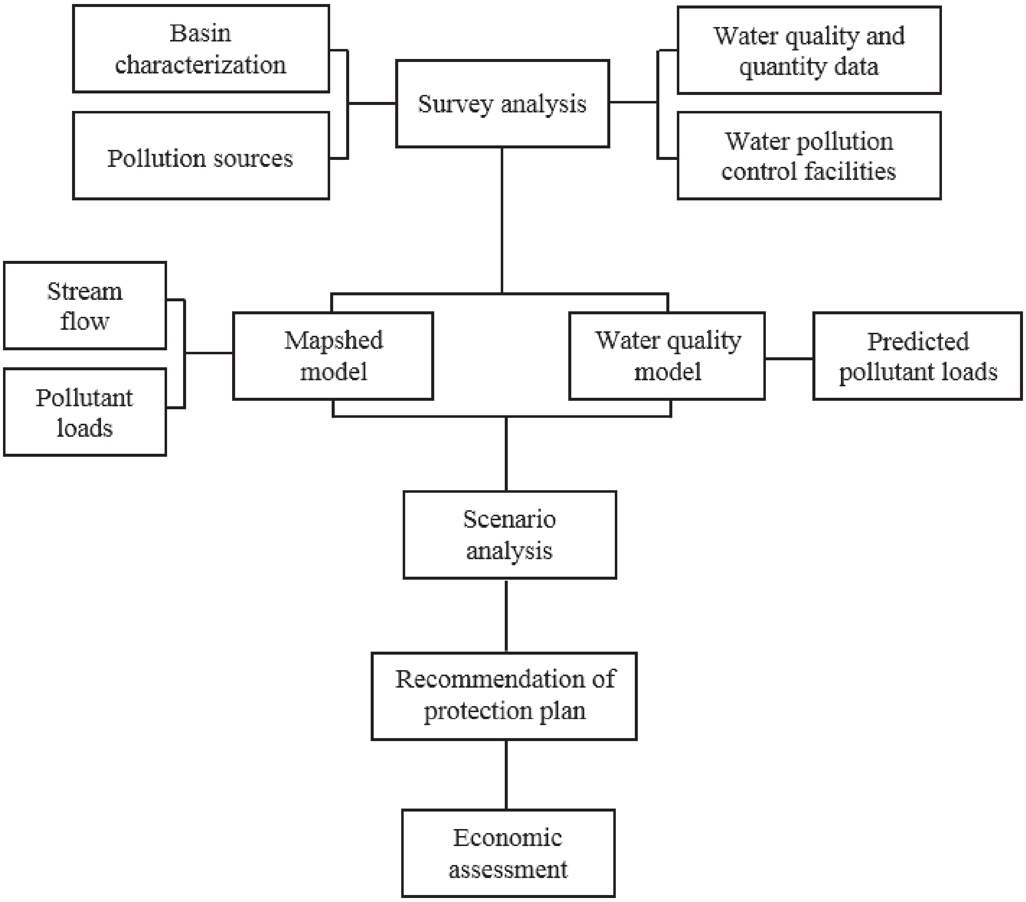


*Figure 1.* Technical approach of the study.

**Study Area**

The Kartalkaya Dam was built on the Aksu River between 1965 and 1970 in order to supply water for irrigation. Since 1986, the dam has started to be used both for irrigation and drinking water purposes. In current situation, annually 94.6 $hm^3$ of drinking water is supplied from Kartalkaya Dam to Gaziantep Province and it is the only surface drinking water resource for the city.

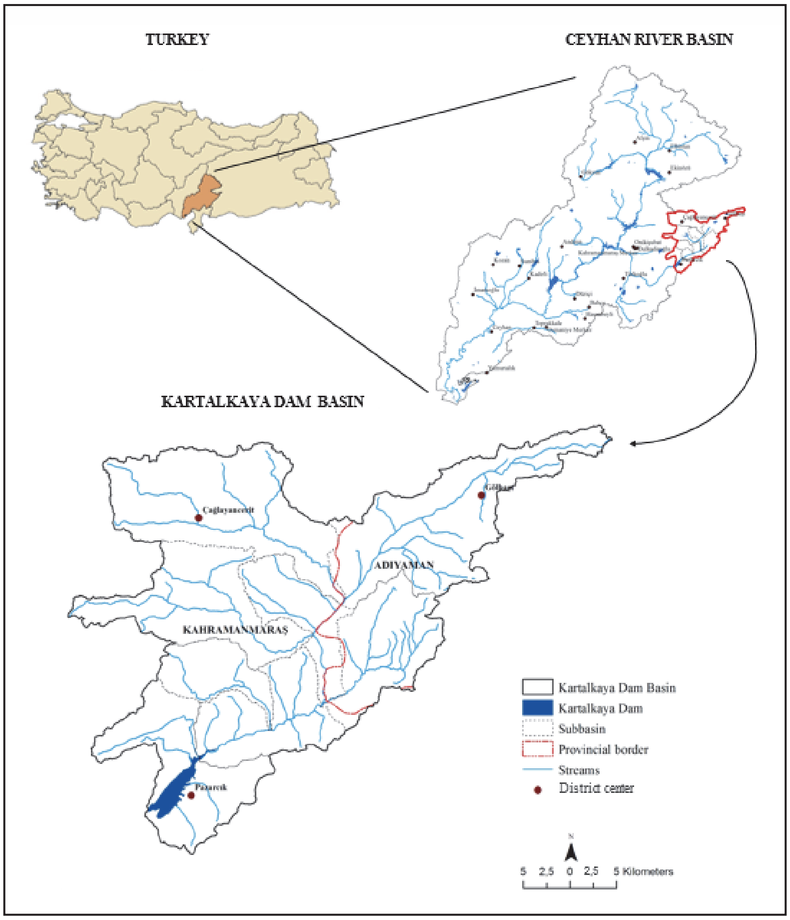


*Figure 2.* The location of Kartalkaya Dam Basin.

The Kartalkaya Dam has a reservoir area of 11 $km^2$ and a drainage area of 1088 $km^2$. The drainage area of Kartalkaya Dam covers 3 districts (Pazarcık, Çağlayancerit and Gölbaşı) and 54 villages. According to the 2016 census of Turkey, approximately 100.000 people live within the basin. The land use pattern in the Kartalkaya Dam Basin displays a typical rural region characteristic. The agricultural areas represent 59% of basin area, while pasture lands and forested areas account for 24% and 16% respectively. On the other hand, artificial areas (e.g. settlements, industrial plants) occupy a remarkably low ratio.

Since more than the half of basin area is used as cropland, agricultural runoff is the primary contaminant that currently threatens the water quality of Kartalkaya Dam.

Animal manure is an important secondary pollution source as a result of intensive livestock production. Disposal of untreated or inadequately treated domestic and industrial wastewater, and dump sites can be counted as other pollution sources that cause degradation in water quality of the dam.

**Field Survey**

Monitoring studies were conducted between April to December 2016, and measurements were performed at four distinct times in each seasons. The water samples were taken from 10 sites along the influent streams and 8 sites in the reservoir (see Figure 3). These sites were chosen based on location of pollution sources.

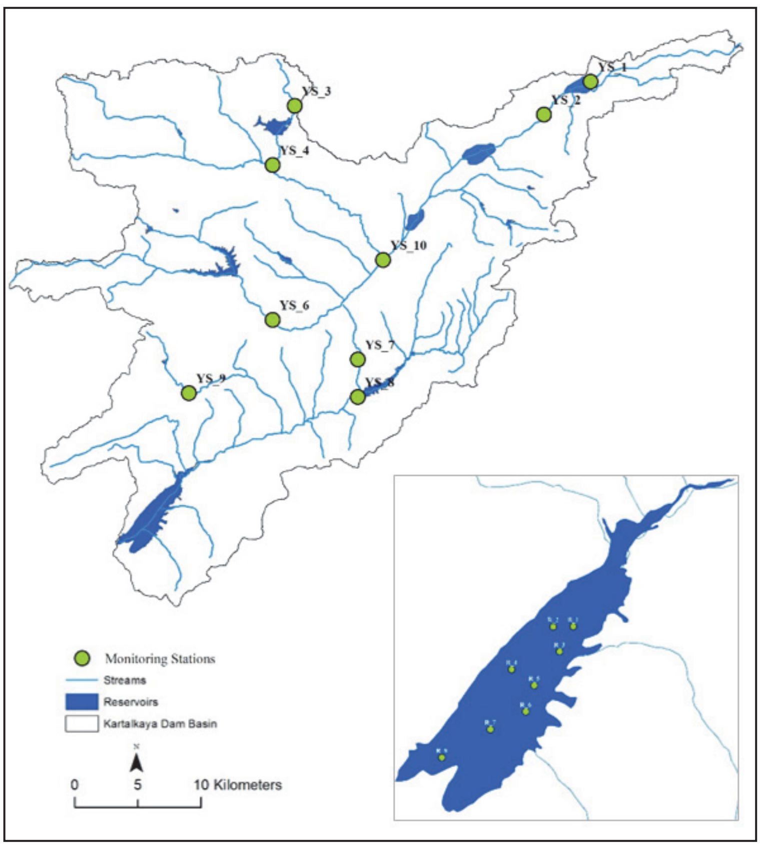


*Figure 3.* Location of sampling sites.

The water samples collected from streams were analyzed for 36 parameters listed in "By-Law on Surface Water Quality" and analysis results were evaluated according to the quality categories (Class I, Class II, Class III, Class IV) specified in the same regulation. On the other hand, the samples taken from reservoir were analyzed for 41 parameters listed in "By-Law on Quality of Surface Waters Used or Planned to Use for Drinking Water Supply" and analysis results were evaluated with accordance to the quality categories (A1, A2, A3) specified in this regulation.

Besides on-site monitoring and analysis studies, some existing hydro-chemical, hydraulic and climate datasets were collected from different public institutions. These datasets were used not only to assess status of water quality and quantity but also to calibrate the model.

**Water Quality Modelling**

Mathematical models are used as effective tools to forecast the temporal and spatial changes in the quality and quantity of water, to predict the impacts of proposed policies or practices and to select an optimal strategy for sustainable water management (Ziemińska-Stolarska and Skrzypski, 2012; Loucks and van Beek, 2017).

In this study, two different mathematical models were used to evaluate the impact of land use practices on water quality and quantity in Kartalkaya Dam Basin between the years 2017 and 2040. MapShed model, a GIS based watershed modelling tool, was applied in order to determine the stream flows in the basin and the transported pollutant loads into the reservoir. On the other hand, STELLA software, a visual programming language, was used to estimate the effects of the pollutants on the water quality of the reservoir and to stimulate how the water quality has changed through different pollution control strategies.

Mapshed model was based on different sets of data supplied from various providers. Most of the input parameters were obtained from the measured data; on the other hand, the parameters were estimated based on the literature if the data were not available. Table 1 presents all GIS level inputs and their sources.

Mapshed model was run on a daily basis between 2000 and 2012 in order to calculate the flow rate in the basin. The calibration of the model was done using data sets recorded by DSI from 12020002 numbered gauging station on Aksu River. For assessing the goodness of fit of the model, Nash-Sutcliffe Efficiency ($N_{SE}$) was used. The $N_{SE}$ value gives an aggregated measure of predictive power of the model, and values between 0 and 1 indicate that the model is acceptable (Moriasi et al. 2007). Using the calibrated Mapshed model, future stream flow values were estimated with annual periods for the years between 2017 and 2040. Additionally, input was provided into the model from the results of the Project on 'The Effects of Climate Change on the Water Resources' (SYGM, 2016). Since MPI-ESM-MR model which is based on RCP4.5 scenario provides the most suitable results for the study area, temperature and precipitation values (2017-2040) from RCP4.5 scenario of MPI-ESM-MR were used in Mapshed model. Thusly, the possible effects of climate change were also taken into account in the future flow rates.

Table 1

*Input Parameters for Mapshed Model*

| Data | Data Format | Data Source |
|---|---|---|
| Digital elevation model (DEM) | Grid (DEM layers with a scale of 1/25.000) | Ministry of Forestry and Water Affairs – General Directorate of Water Management |
| Soil map | Polygon (Vector map with a scale of 1/100.000) | Ministry of Food Agriculture and Livestock – General Directorate of Agricultural Reform |
| Landuse map (CORINE data) | Polygon (Vector map with 16 classes) | Ministry of Forestry and Water Affairs – Department of Information Technologies |
| Basin boundary | Polygon | Ministry of Forestry and Water Affairs – General Directorate of Water Management |
| Stream network | Line | Ministry of Forestry and Water Affairs – General Directorate of Water Management |
| Weather stations | Point | Ministry of Forestry and Water Affairs – General Directorate of Meteorology |
| Weather data (e.g. daily precipitation, maximum-minimum temperature) | Table (text file) | Ministry of Forestry and Water Affairs – General Directorate of Meteorology |

In addition, MapShed model was operated to estimate concentrations of nutrients (total nitrogen and total phosphorus) in the streams between 2000 and 2012. The results of the water quality monitoring conducted at downstream of Aksu River were used to calibrate the model. Mean absolute error (MAE), root mean square error (RMSE) and relative root mean square error (rRMSE) were employed as model performance coefficients. These indices measure an average magnitude of the errors in a set of predictions. As MAE, RMSE and rRMSE values approach 0, the model results become more acceptable (Moriasi et al. 2007). Using the calibrated Mapshed model, pollutant loads were predicted with annual periods for the years between 2017 and 2040.

Additionally, a water quality model was designed on a monthly basis to predict the average water quality in the Kartalkaya Dam. STELLA software program was used to create the model. Eight water quality variables including Dissolved Oxygen, Biochemical Oxygen Demand, Ammonium Nitrogen, Nitrate, Organic Nitrogen, Ortho-Phosphate, Organic Phosphorus and Alg Biomass were employed for the model. The following assumptions were made for the water quality model:

- The model operates monthly.
- The dam consists of two layers, namely epilimnion and hypolimnion layer.
- Water inlet is only from the epilimnion layer and the water outlet is only from the hypolimnion layer.
- Advective movements between layers occur only from the epilimnion layer to the hypolimnion layer.
- Material transport by interdiffusion takes place from more concentrated layers to less concentrated ones

For the calibration of the water quality model, the results of the water quality monitoring conducted in the dam were used. In order to numerically quantify the performance of the model, the coefficient of MAE, RMSE and rRMSE were used. Evaluating the model performance indicators, model parameters were adjusted to minimize the difference between the measured values and the calculated ones.

In the final stage of modelling, four possible future scenarios, which are listed in Table 2, were designed and examined by modelling analyses. Using the calibrated water quality model, the changes occurred at the trophic level of the dam were estimated for alternative future scenarios. In the model, the amount of pollutant loads predicted in MapShed model was used, and the limit values given in the "By-Law on Surface Water Quality" for trophic classification system were taken as basis.

After determining worst-case scenario, the water quality model was run to predict how the water quality will change if the pollution reduction measures are implemented. Based on model results, a pollution reduction scheme was recommended.

Table 2

*Alternative-Future Scenarios for The Kartalkaya Dam Basin*

| Scenario | An autonomous growth of population and economy | No precautions taken in terms of pollutant loads | Continuation of water abstraction for drinking purpose | No water abstraction for drinking purpose | Changes in water quality due to climate change |
|---|---|---|---|---|---|
| 1 | √ | √ | √ | | |
| 2 | | √ | | √ | |
| 3 | | | √ | | √ |
| 4 | | | | √ | √ |

**Cost and Benefit Analysis**

Evaluating the economic feasibility of proposed measures is critically important to improve the efficiency and effectiveness of pollution reduction schemes. Cost and benefit analysis is a commonly used tool for identifying, valuing and comparing costs and benefits of recommended interventions. The major objective of cost and benefit analysis is to determine whether the benefits of proposed measure outweigh its costs. Thusly, it can be a good indicator to identify whether the proposed measure is a sound investment (Buncle et al., 2013).

In this study, a preliminary economic assessment was conducted for the measures proposed in the Kartalkaya Basin Protection Plan. The objective of this assessment was to calculate monetary values of costs and benefits of proposed measures, and their monetary net effect.

Firstly, a financial and economic assessment was conducted for the cost of measures requiring investment in short-term. Methodology of this assessment comprises the following procedures:

- To identify the type of costs (e.g., fixed costs, variable costs)
- To express the value of costs in monetary values
- To convert the costs realized over time to present day values
- To mapping out the distribution of costs between stakeholders (i.e., water users and inhabitants of the basin)

The second step was to evaluate potential economic benefits generated from water quality improvements. Although the calculation of the monetary value of economic benefits is a complex task, there are some studies to measure the benefits of compliance with environmental standards. One of these studies was conducted by ECOTEC (2001) and its results were published in a report including annual benefits of full harmonization with EU environmental standards. Based on the ECOTEC report, the COWI Consultancy has calculated the annual per capita benefit of full compliance with EU environmental standards in Turkey in the context of the "Technical Assistance Project for the Preparation of 15 Wastewater Treatment Plant Projects". According to results of this study, the annual per capita benefit of full compliance with EU environmental standards ranges from € 28 to € 68 (2007 prices). Additionally, in the study, it is indicated that projects investing in only one of the water supply, wastewater collection and wastewater treatment will provide a minimum benefit value of € 28 per person per year while the projects investing in each of these areas will provide a maximum benefit value of € 68 per person per year. These estimated values were taken as basis in order to evaluate the economic benefits of measures proposed in the Kartalkaya Basin Protection Plan.

Finally, the difference between the net present values of total economic benefits and costs was calculated in order to find out whether the measures proposed in the Kartalkaya Basin Protection Plan are sound enough to support their implementation.

## Results

The monitoring results showed that water quality decreased from upstream to downstream. Total kjendhal nitrogen (TKN) concentrations in streams ranged from 0.52 to 10.5 mg/L; and total phosphorus concentrations ranged from 0.01 to 0.99 mg/L. The lowest nutrient concentrations were detected in forest areas while the highest nutrient concentrations occured in agricultural areas and urban areas, particularly near the district of Gölbaşı. Additionally, the results of analysis indicated the bacteriological contamination in all water samples collected from streams, which can be attributed to the discharge of municipal sewage and disposal of animal excreta into the water. Parallel to the analysis results of the stream samples, it was determined that nutrient and bacteriological parameters exceeded acceptable limits in the reservoir. According to these results, current water quality class of the streams ranged from Class II (slightly polluted) to Class IV (heavily polluted); while the quality of the reservoir was classified as A2 (drinkable waters with physical treatment, chemical treatment and disinfection). These analysis results also provided input for the models to perform the calibration.

Using the calibrated models, the impact of land use practices on water quality and quantity of Kartalkaya Dam was evaluated and results were shown as average annual values for the years between 2017 and 2040.

The results of MapShed model indicated that total nitrogen (TN) loads will increase from 937.431 kg/year to 1.069.621 kg/year while total phosphorus (TP) loads will increase 27.963 kg/year to 29.486 kg/year if no precaution is taken during the projection period of 2017 and 2040. Based on the results, about 10 percent of TN and 60 percent of TP were originated from point sources (see Figure 4). These results showed that both point resources and non-point sources had a role in the nutrient pollution. In other words, the pollutant loads from both point resources and non-point sources should be controlled in order to decrease nutrient concentrations in the basin.

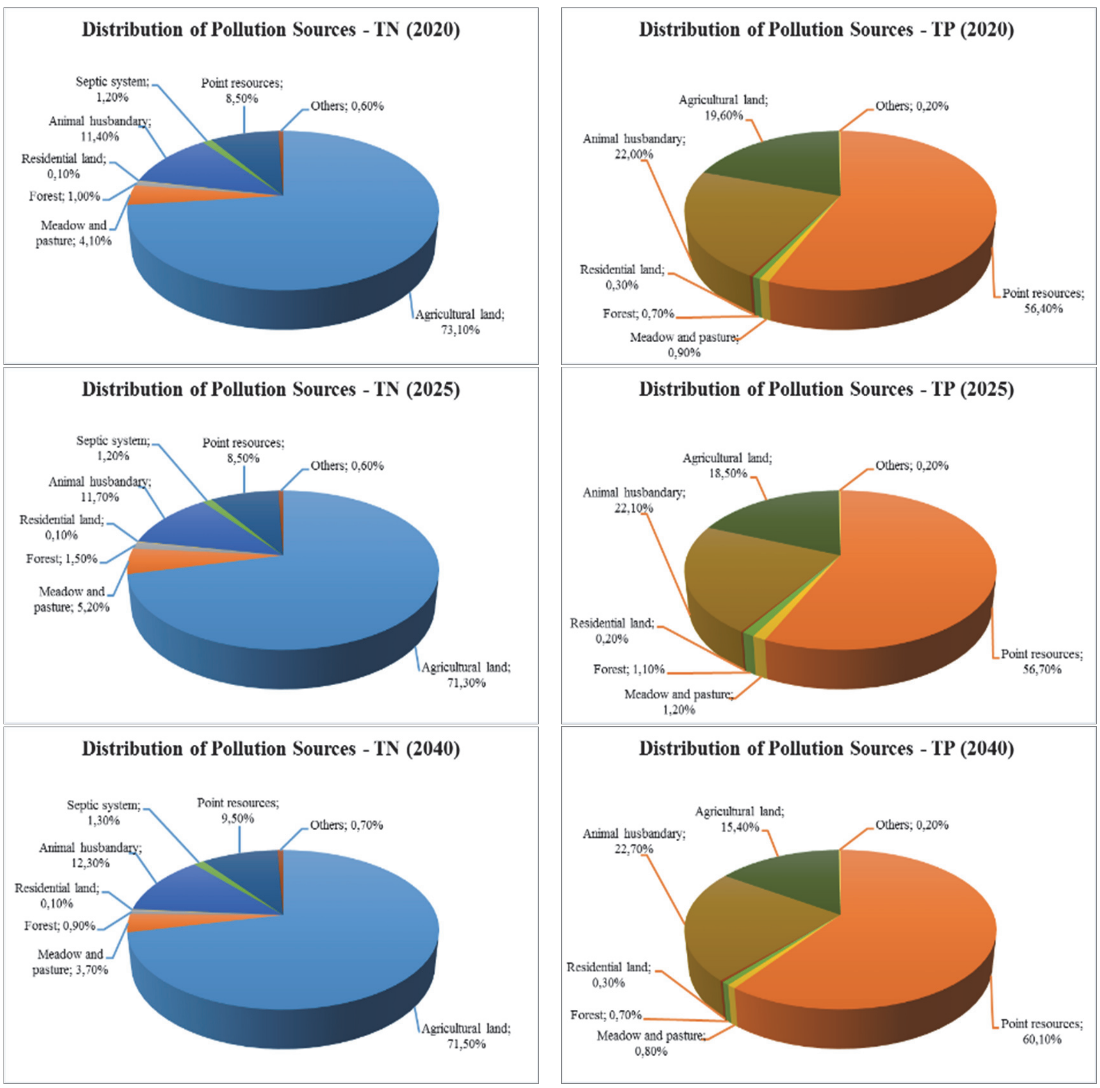


*Figure 4.* Distribution of pollution sources in the years of 2020, 2025 and 2040.

Using the predicted nutrient loads, the changes occurred at the trophic level of the dam were estimated for four possible future scenarios. According to the model results, the worst water quality condition for TN and TP was observed respectively in scenario 1 and scenario 4.

Scenario 1: Assuming an autonomous growth of population and economy with no interventions, it was observed that trophic level of the dam remains hypertrophic in terms of TN until 2040 and it will be mesotrophic in terms of TP after 2020 (see Figure 5).

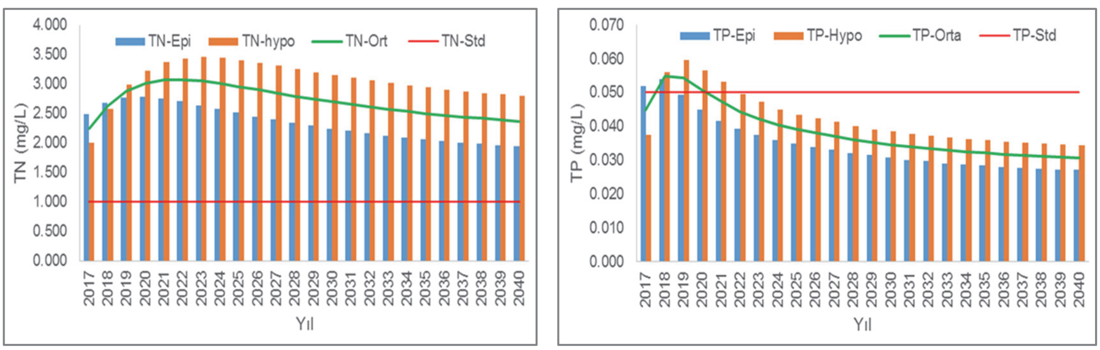


*Figure 5.* Temporal changes in TP and TN concentrations - scenario 1.

Scenario 2: Assuming continuity of current trends and no water abstraction for drinking purpose, it was observed that trophic level of the dam will be mesotrophic in terms of TN after 2027 and it remains mesotrophic in terms of TP (see Figure 6).

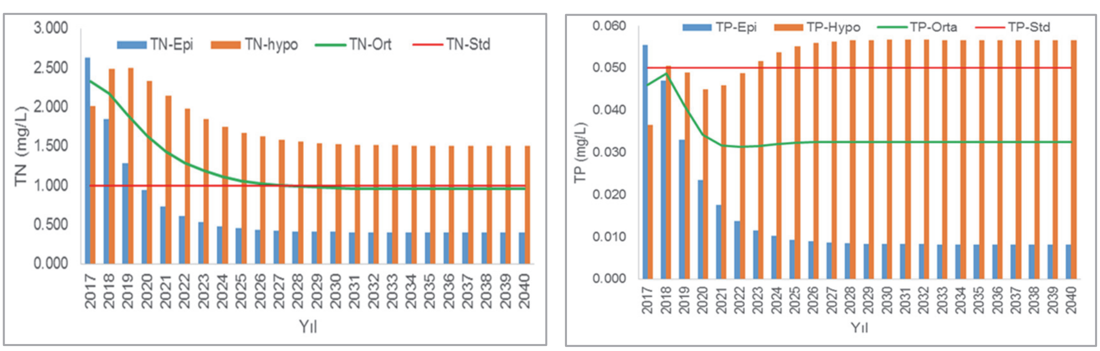


*Figure 6.* Temporal changes in TP and TN concentrations - scenario 2.

Scenario 3: Evaluating the changes in water quality due to climate change it was observed that trophic level of the dam will be mesotrophic in terms of TN after 2020 and it remains mesotrophic in terms of TP. This situation could be interpreted such that the decline in precipitation rates causes decrease in TN loads transported with surface runoff (see Figure 7).

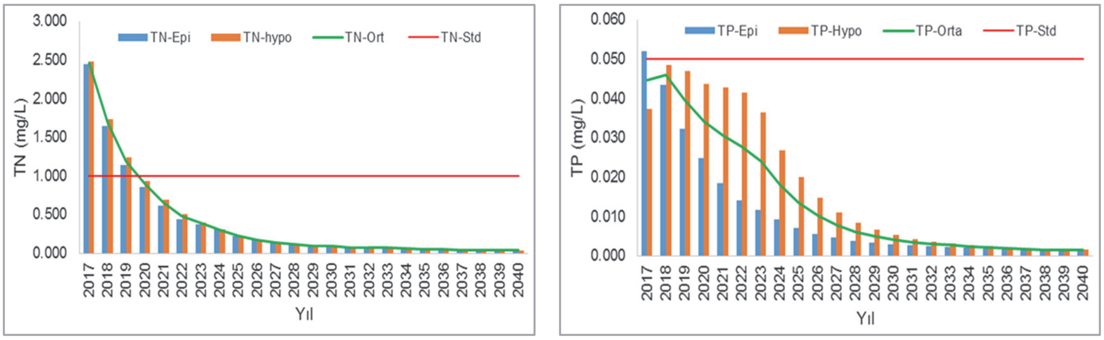


*Figure 7.* Temporal changes in TP and TN concentrations - scenario 3.

Scenario 4: Evaluating the effects of climate change and no water abstraction for drinking purpose, it was observed that trophic level of the dam will change from hypertrophic to eutrophic in terms of TN hence 2023 and it remains mesotrophic in terms of TP apart from the fact that it will be eutrophic in 2018 and 2037 (see Figure 8).

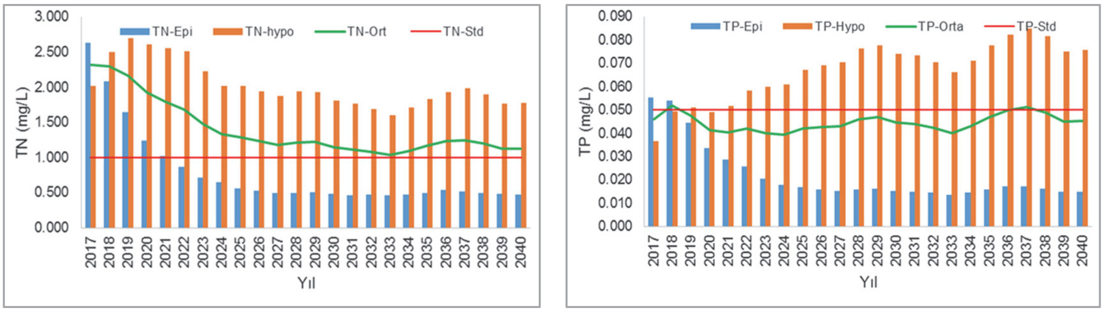


*Figure 8.* Temporal changes in TP and TN concentrations - scenario 4.

Even if the worst conditions occurred with Scenario 1 in terms of TN, it was thought that the probability of realization of this scenario is low. Therefore, scenario 4 was considered as the worst case and the measures were developed to reduce pollution loads predicted in this scenario. The model results indicated that trophic level of the Kartalkaya Dam will be mesotrophic in terms of TN and TP within 5 years in case of providing a minimum 50% reduction in TN and a minimum 25% reduction in TP for the estimated pollution loads in Scenario 4 (see Figure 9).


*Figure 9.* Temporal changes in TP and TN concentrations – implementation of pollution reduction measures.

In order to increase feasibility of measures, it was recommended to decrease pollution loads gradually by 2040 as given below.

- Until 2020: 35% for Total Nitrogen, 20% for Total Phosphorus
- Until 2025: 10% for Total Nitrogen, 5% for Total Phosphorus
- Until 2040: 5% for Total Nitrogen

Based on specified reduction rates and time schedule, a pollution reduction scheme was suggested (see Figure 10). In this scheme, it was proposed that measures will be executed in three phases, namely, the short term (2016-2020), medium term (2020-2025) and long term (2025-2040). When the measures were prioritized, both the basin's priorities and mandatory pollution control practices were considered.

Since proposed short-term measures would incur financial costs, an assessment was conducted to determine how much should be invested for the implementation and maintenance of these measures. According to the assessment, the likely cost of interventions will be around 59 million TL in total over time. The expected investments for wastewater collection, wastewater disposal and rehabilitation of landfill site will be 14, 43 and 2 million TL respectively. The details of initial investment costs and operating costs of each measure are shown in Table 3.

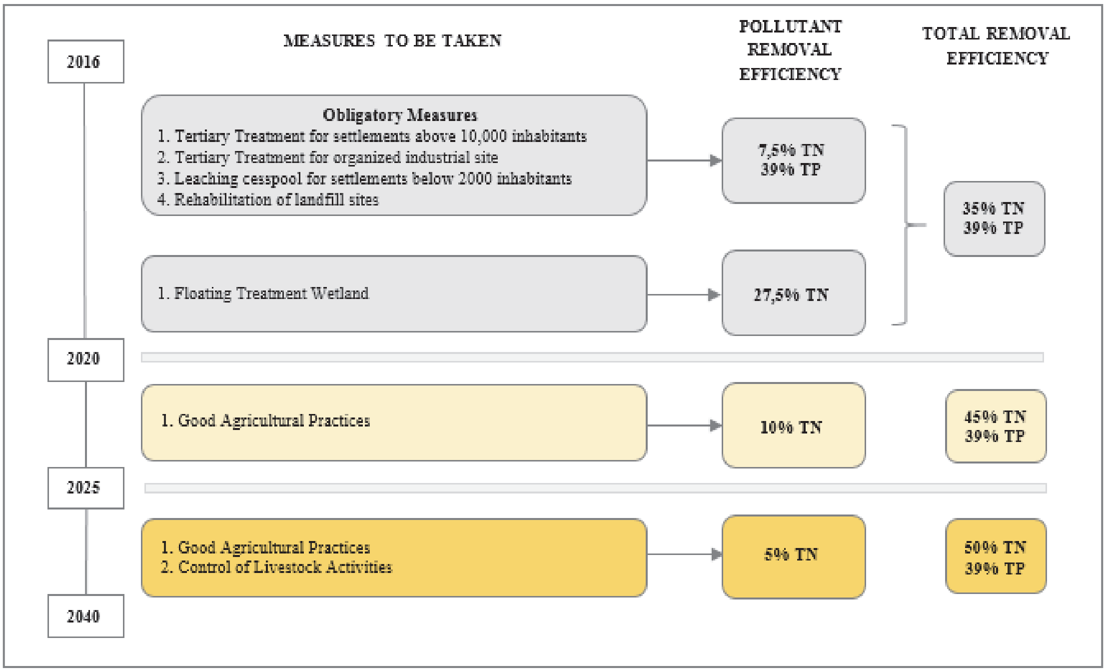


*Figure 10.* Pollution reduction scheme for the Kartalkaya Dam Basin.

Following the calculation of total costs, their distribution between stakeholders was analyzed. According to this analysis, the cost per capita will be 519 TL if inhabitants of the basin bear all the cost; on the other hand, this figure will drop to 23.3 TL if water users in Gaziantep also make payment for measures.

In order to assess the efficiency of proposed measures, the estimated costs were compared with the estimated economic benefits. If the net present value of benefits exceeds the net present value of the costs, the measures can be interpreted as sound and feasible. Therefore, it was expected that the net present value of the benefits will be more than 59 million TL. In this context, the annual per capita benefit of 47 TL (€ 11.75) is enough to make the project economically profitable when considering only the benefits to the inhabitants of the basin; on the other hand, a benefit value of 2.2 TL (€ 0.55) per person per year is sufficient when the benefits to both the inhabitants of the basin and the water users were taking account. Although these values are far below the estimated benefits provided by the ECOTEC study, it was determined that this range of benefits is even enough to make the project feasible.

Table 3

*Investment and Operating Costs of Proposed Measures*

| Measure | Initial Investment Cost (Thousand TL) | Operating Cost (Thousand TL) |
|---|---|---|
| Renewal of main collector line of Pazarcık as discrete system | 12.458 | 779 |
| Renewal of pumping stations in Pazarcık | 226 | 133 |
| Removal of wastewater from municipal social facility area located in absolute protection area | 106 | 52 |
| Conversion of Gölbaşı Wastewater Treatment Plant to advanced biological plant | 6.864 | 16.471 |
| Conversion of Planned Çağlayancerit Wastewater Treatment Plant to advanced biological plant | 4.872 | 7.527 |
| Construction of biological treatment facilities for settlements with more than 2,000 inhabitants | 2.221 | 4.624 |
| Construction of leaching cesspool for settlements with less than 1,000 inhabitants | 81 | 0 |
| Transport of wastes from dump sites to sanitary landfill | 1.862 | 0 |

## Discussion and Conclusion

Kartalkaya Dam is of capital importance for water supply to Gaziantep metropolitan area, where almost 2 million people reside. However, Kartalkaya Dam has been under the pressure of human activities such as inadequate treatment of domestic and industrial wastewater, the unconscious use of fertilizers and pesticides, and disposal of wastes. Due to these pollutant activities, the water quality is at risk of deteriorating. To reverse this situation, a drinking water protection plan for the Kartalkaya Dam Basin was developed.

Within the management planning process, a series of scientific studies were conducted to identify and prioritize the management actions for the mitigation of water contamination risks to an acceptable level. As a part of planning process, a coupled water quality model for Kartalkaya Dam Basin was operated to estimate the effects of the pollutants on the water quality of the reservoir. The model was then used for scenario analysis. Based on this analysis, it was concluded that the pollutant loads from both point resources and non-point sources should be controlled in order to improve the water quality to levels in line with the regulatory standards. In this respect, a point/nonpoint source pollution reduction scheme was recommended. Additionally, a preliminary economic assessment was conducted and it was revealed that recommended measures for improvement of water quality to mandatory standards is feasible.

Consequently, the simulation results proved that the measures proposed for reduction of water pollution can lead to fulfilment of the limits required by the legislation, and sufficient financing can be obtained for pollution reduction scheme. However, planning attempts cannot succeed in practice without enduring political will, long-term support of public, allocation of adequate funds, and well-designed control, monitoring and enforcement processes.

**Acknowledgement**

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**Extended Turkish Abstract**
**(Genişletilmiş Türkçe Özet)**

**İçme Suyu Kaynaklarının Korunmasına Yönelik Planlama Süreci:**
**Kartalkaya Baraj Havzası Örneği**

Gaziantep iline, 1986 yılından itibaren Kartalkaya Barajı'ndan içme ve kullanma suyu temin edilmekte olup ilin tek yüzeysel içme suyu kaynağı olması sebebiyle kaynağın korunması büyük bir önem taşımaktadır. Bununla birlikte, Kartalkaya Barajı, havzada yer alan evsel ve endüstriyel deşarjlardan kaynaklanan noktasal kirleticiler ile tarımsal alanlardan ve çöp depolama sahalarından kaynaklanan yayılı kirleticiler nedeniyle kirlenme tehdidi altındadır. Bu çerçevede, Kartalkaya Barajı'nın su kalitesi ve miktarının korunması ve sürdürülebilir kullanımının sağlanması maksadıyla koruma tedbirleri belirlenmiş ve bu tedbirleri içeren bir içme suyu havzası koruma planı hazırlanmıştır. Bu çalışmanın amacı, Kartalkaya Baraj Havzası'nın korunmasına yönelik yapılan planlama çalışmasının teorik çerçevesini değerlendirmek ve kapsamlı bir içme suyu koruma planı oluşturulması için gerekli araçları ortaya koymaktadır.

İçme suyu koruma planlarıyla su kalitesinin iyileştirilmesi ve sürdürülebilirliğinin sağlanması için havza özelinde en uygun arazi kullanımının ve koruma tedbirlerinin belirlenmesi amaçlanmaktadır. Koruma planlarının hazırlanması, havza karakterizasyonunun ortaya konması, kirletici kaynakların tespiti, su kalitesinin analizi, alternatif gelecek senaryoları için su kalitesinde meydana gelebilecek değişimlerin tespiti, kirliliğin azalmasını sağlayacak tedbirlerin belirlenmesi, önerilen tedbirlerin fayda-maliyet analizi aşamalarından oluşmaktadır.

Bu kapsamda, öncelikle Kartalkaya Baraj Havzası'nın teknik ve sosyo-ekonomik özellikleri havzada yürütülen çalışmalar ve mevcut verilere dayalı olarak tespit edilmiş; böylece havzanın mevcut durumu ortaya konmuştur. Ayrıca yerüstü sularının ve rezervuarın kalitesinin belirlenmesi amacıyla bir su yılını kapsayacak şekilde izleme çalışmaları yürütülmüştür. İzleme çalışmaları kapsamında, yüzeysel su kaynakları boyunca 10 istasyonda; rezervuarda ise 8 istasyonda numune alımı gerçekleştirilmiştir. İstasyonların yerleri kirletici kaynaklar göz önünde bulundurularak seçilmiştir. Yerüstü sularından alınan numunelerin analizleri, Yerüstü Su Kalitesi Yönetmeliği'nde yer alan her bir parametreye göre gerçekleştirilmiş ve analiz sonuçları yönetmelikte belirtilen kalite kategorilerine göre değerlendirilmiştir. Diğer taraftan, rezervuardan alınan numuneler, İçme Suyu Elde Edilen veya Elde Edilmesi Planlanan Yüzeysel Suların Kalitesine Dair Yönetmeliği'ndeki 41 parametre için analiz edilmiş ve analiz sonuçlarının değerlendirmesi yönetmelikteki kalite kategorilerine göre yapılmıştır. İzleme sonuçları, su kalitesinin membadan mansaba doğru düştüğünü, yerüstü sularında nütrient konsantrasyonlarının yüksek olduğunu ve bakteriyolojik açısından kirlenme oluştuğunu göstermektedir. Yerüstü sularındaki analiz sonuçlarına paralel olarak, rezervuardaki nütrient ve bakteriyolojik parametrelerin Yönetmelikteki limit değerleri aştığı tespit edilmiştir.

İlaveten, Kartalkaya Baraj Gölü havzasında mevcut arazi kullanımının su kalite ve miktarına olan etkisini değerlendirmek maksadıyla matematiksel modelleme çalışmaları yapılmıştır. Bu amaçla çalışmada MapShed ve STELLA dilinde yazılmış su kalite modeli birlikte kullanılmıştır. MapShed yazılımıyla havzada çeşitli arazi kullanım uygulamaları sonucunda baraja taşınabilecek kirletici yüklerin belirlenebilmesi, STELLA dilinde yazılmış su kalite modeliyle de bu yüklerin baraj su kalitesi üzerine etkilerinin ortaya konulması hedeflenmiştir. Kalibre edilen MapShed Modeli ile 2017-2040

yılları arasında baraja gelebilecek su miktarı ve kirletici yükler tahmin edilmiş, su kalite modeli ile de bu kirletici yükler altında baraj su kalitesinin 2017-2040 yılları arasında nasıl değiştiği incelenmiştir.

Modelleme çalışması kapsamında, Kartalkaya Barajı'nda MapShed Modeli 2000-2012 yılları arasında günlük çalıştırılarak akım değerleri tahmin edilmiştir. DSİ tarafından işletilen 12020002 no'lu akım gözlem istasyonu verileri kullanılarak akım değerleri kalibre edilmiştir. Model performans parametresi olarak Nash-Sutcliffe katsayısı kullanılmıştır. Ayrıca, MapShed ile akarsulardaki besi maddesi konsantrasyonları da 2000-2012 yılları arasında tahmin edilmiştir. Besi maddesi konsantrasyonlarının kalibrasyonu için Aksu Nehri'nin mansabında yapılan su kalite izleme çalışmasının sonuçları kullanılmıştır. Model performans katsayısı olarak MAE (ortalama mutlak hata), RMSE (kök ortalama kare hatası) ve rRMSE (nispi kök ortalama kare hatası) kullanılmıştır. Model performans katsayıları, hem debi değerleri hem de besi elementleri için modelin performansının kabul edilebilir düzeyde olduğunu göstermiştir. Kalibre edilen MapShed modeli kullanılarak 2017-2040 yılları arasında akarsu debisi ile kirletici yükleri her yıl için ayrı ayrı hesaplanmıştır. Orman Su İşleri Bakanlığı tarafından 2016 yılında tamamlanan İklim Değişikliğinin Su Kaynaklarına Etkisi Projesi'nin çıktılarından faydalanılmış olup havza alanı için en uygun sonuçların üretildiği MPI-ESM-MR modeli RCP4.5 senaryosunda 2017-2040 yılları için elde edilen sıcaklık ve yağış parametreleri kullanılmıştır. Böylelikle elde edilen debi değerlerinde iklim değişikliğinin olası etkileri dikkate alınmıştır. Sonuç olarak, Mapshed modeli TN yükünün ortalama %10'unun TP yükünün ise ortalama %61'inin noktasal kaynaklardan su kütlesine geldiğini ortaya koymuştur. Mapshed modeline ilaveten, Kartalkaya Barajı'nın aylık ortalama su kalitesi parametrelerini tahmin edebilmek üzere bir su kalite modeli tasarlanmıştır. Modelin oluşturulmasında STELLA yazılım programı kullanılmıştır. Modelin kalibrasyonu için 2016 yılında yürütülen izleme programı kapsamında alınan su numunelerine ait analiz sonuçları kullanılmıştır. Ölçülen su kalitesi değerleri ile modelin hesapladığı değerler arasındaki fark, modelde kullanılan katsayılar değiştirilerek MAE, RMSE ve rRMSE ölçütlerine göre minimize edilmiştir. Kalibre edilen su kalite modeli ile havza için geliştirilen 4 farklı senaryo neticesinde baraj gölü trofik seviyesinde meydana gelebilecek değişimler analiz edilmiştir. Bu amaçla, Yerüstü Su Kalitesi Yönetmeliği'nde verilen sınır değerler dikkate alınmıştır. Su kalite sınıfı açısından en kötü koşullar Senaryo 4 (havzada iklim değişikliğine bağlı etkilerin görülmesi ve barajdan içme suyu maksatlı su çekiminin yapılmaması) ile ortaya çıkmış ve kontrol önlemleri bu senaryo üzerinden geliştirilmiştir. Bu çerçevede, Senaryo 4'deki kirlilik yüklerinde TN için minimum %50'lik bir azalma TP yüklerinde ise minimum %25'lik bir azalma sağlanması durumunda su kalite sınıfının 5 yıl içinde TN ve TP için mezotrofik kalite sınıfında olacağı tespit edilmiştir. Belirlenen hedeflerin 2040 yılına kadar kademli olarak düşürülmesi önlemlerin uygulanabilirliğini arttıracağından 2020 yılına kadar TN için %35, TP için %20; 2025 yılına kadar TN için %10, TP için %5 ve 2040 yılına kadar TN için %5 azalma öngörülmüştür. Söz konusu azaltım oranlarının sağlanması için koruma planı kapsamında öncelikle yasal zorunluluk gereği alınması gereken önlemlerin (atıksuların ve atıkların kontrolü) yerine getirilmesi; ilaveten, baraj gölüne yüzer sulak alan yapılması önerilmiştir. Orta ve uzun vadede ise tarımsal ve hayvansal faaliyetlerden kaynaklı kirlilik yüklerinin azaltılmasını sağlayacak uygulama yöntemlerinin hayata geçirilmesi hedeflenmiştir.

Ayrıca, kısa vadede yatırım gerektiren hükümlerin maliyetleri ortaya konulmuş ve bu maliyetler için ekonomik değerlendirme yapılmış ve planlanan tedbirlerin net bugünkü değeri 58.274.336 TL olarak belirlenmiştir. Sadece havza nüfusu göz önünde bulundurulduğunda alınacak tedbirlerin kişi başına maliyetinin 519 TL olduğu; Gaziantep nüfusu da hesaba katıldığında bu rakamın 23,3 TL'ye düştüğü görülmüştür. Alınması planlanan tedbirlerin ekonomik faydalarına bakıldığında, yıllık kişi başına faydanın asgari 47 TL olması durumunda tesisin ekonomik net bugünkü değerinin pozitif olacağı; Gaziantep nüfusu dikkate alındığında ise kişi başına faydanın asgari 2,2 TL olmasının projeyi ekonomik yönden karlı kılacağı tespit edilmiştir. Su temini, atıksu toplama ve atıksu arıtma alanlarına yatırım yapan projelerin yıllık kişi başına faydasının 28 ila 68 Euro aralığında olduğu bilgisinden hareketle, koruma planında yer alan tedbirlerin ekonomik yönden yapılabilir olduğu sonucuna varılmıştır.

*Technical Note*

# Management of Water Losses in Water Supply and Distribution Networks in Turkey

# Türkiye'de İçme Suyu Temin ve Dağıtım Sistemlerindeki Su Kayıplarının Yönetimi

Ayşe MUHAMMETOĞLU[1], Habib MUHAMMETOĞLU[1],
Alev ADIGÜZEL[2], Özlem İRİTAŞ[2], Yakup KARAASLAN[2]

[1]*Akdeniz University, Environmental Engineering Department, Antalya, 07058, Kampüs, Antalya/Turkey*
aysemuh@akdeniz.edu.tr, muhammetoglu@usa.net
[2]*Ministry of Forestry and Water Affairs, General Directorate of Water Management, 06510, Yenimahalle-Ankara/Turkey*
alevkoksal@ormansu.gov.tr, oiritas@ormansu.gov.tr, ykaraaslan@ormansu.gov.tr
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**Abstract**

Water losses in water supply and distribution systems have been a serious problem in Turkey and all over the world causing economic costs and environmental drawbacks. Total water losses is the summation of real (physical) and apparent (commercial) losses. Main activities to reduce water losses include digitizing the components of network into Geographical Information Systems, dividing large water distribution networks into District Metered Areas, monitoring of flow rates and water pressures, carrying out yearly water balance, hydraulic modelling, pressure management, active leakage control, recording water consumption of the users, reducing meter errors and illegal water consumption. In 2014, the Ministry of Forestry and Water Affairs in Turkey issued a new regulation for water losses reduction, based on the methods used to determine and reduce the losses. This is followed by issuing practical description of the technical procedure to reduce the losses. The new legislation aims to reduce total water losses in all water authorities below 25% within certain time periods. All the water authorities in Turkey are required to carry out yearly water balance and report them to the ministry together with forms to follow up the efforts towards water losses reduction. In order to apply the prescribed techniques in a successful way, water losses problem should be understood well, technical and human resource capacity should be improved, and sufficient financial resources should be allocated. Also, the water utilities should have a strategic plan and a strong commitment to reduce water losses.

**Keywords:** *physical water losses, apparent water losses, Turkey, regulation, standard water balance*

**Öz**

İçme suyu temin ve dağıtım sistemlerinde gözlenen yüksek orandaki su kayıpları, Türkiye'de ve tüm dünyada ciddi bir sorun teşkil etmekte; ekonomik ve çevresel olumsuz etkilere neden olmaktadır. Toplam su kayıpları, fiziki ve idari su kayıplarından oluşur. Su kayıplarının azaltılmasında etkin olan yöntemler içinde dağıtım şebekesine ait tüm elemanların Coğrafi Bilgi Sistemleri'nde tanımlanması, büyük şebekelerin alt bölgelere ayrılması, şebekede izleme yapılması, yıllık su dengesinin oluşturulması, hidrolik modelleme, basınç yönetimi, aktif kaçak kontrolü, abonelerin su tüketimlerinin düzenli olarak kaydedilmesi, sayaç hatalarının giderilmesi ve izinsiz tüketimin azaltılması yer alır. 2014 yılında Türkiye Cumhuriyeti Orman ve Su İşleri Bakanlığı tarafından içme suyu temin ve dağıtım sistemlerindeki su kayıplarının tespiti ve kontrolü için belirtilen yöntemleri içeren yeni bir yönetmelik yayımlanmıştır. 2015 yılında da su kayıplarının tespiti ve kontrolü için teknik bilgileri içeren teknik usuller tebliği yayımlanmıştır. Yeni yönetmelik ile tüm büyükşehir ve il belediyelerindeki su idareleri toplam su kayıplarını belirtilen süreler içinde %25 seviyesine indirmekle yükümlüdür. Tüm su idareleri yıllık su dengesi formlarını hazırlamalı ve bu formlarla birlikte su kayıplarını azaltmaya yönelik çalışmalarını Bakanlığa bildirmelidir. Belirtilen tüm unsurların başarı ile uygulanabilmesi için öncelikle sorunun yeterli düzeyde anlaşılması, teknik kapasitenin geliştirilmesi, altyapının yenilenmesi için yeterli mali desteklerin bulunması ve ilgili idari kurumun su kayıplarını azaltmaya yönelik bir stratejik planının ve kararlılığının olması gereklidir.

**Anahtar sözcükler:** *fiziki su kayıpları, idari su kayıpları, Türkiye, yönetmelik, standart su dengesi tablosu*

## Introduction

In recent years, water resources are under an increasing stress due to impacts of climate change, population increase and economic development. Water scarcity is recognized as a main threat particularly in the Mediterranean area. Thus, water utilities should become highly efficient throughout the entire water supply process, to guarantee sufficient quantities of good quality water. Since water is one of the most valuable natural resources, water losses in the Water Distribution System (WDS) represent an urgent problem that needs to be managed (Kanakoudis & Muhammetoglu, 2014).

Water losses include Physical/Real losses and Apparent/Commercial losses (Figure 1). Water losses may occur at several points of a Water Supply System (WSS) including treatment works, trunk mains, service reservoirs, water meters and billing system. Water losses usually represent the biggest part of the so-called Non Revenue Water (NRW), which is the water that does not bring in revenues to the water utility. A World Bank study showed that approximately 45 billion $m^3$ of water is annually being lost through leakage corresponding to 35% of the total water supplied. If half of this water was saved, 100 million people would have access to safe water without any further investment (World Bank, 2006). NRW has negative environmental (lost water and energy) and economic (lost revenues) impacts. Water losses imply greenhouse gases (GHG) emissions since the water volume being lost has been pumped, treated and distributed, using energy. Water losses related GHG emissions are even higher when desalination is used as the main water supply process (Kanakoudis & Muhammetoglu, 2014).

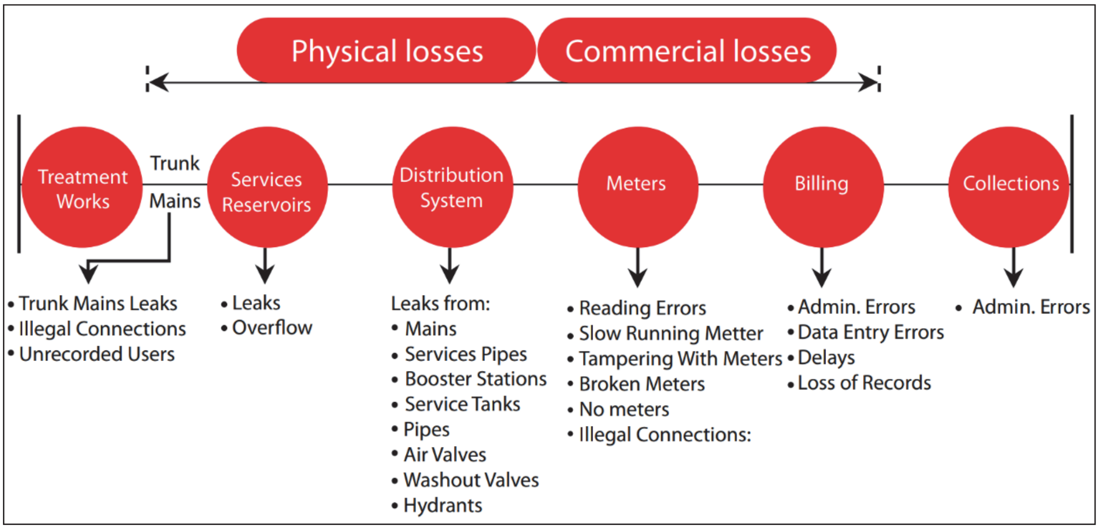


*Figure 1*. Typical losses from a water supply system (MNRW, 2008).

The share of physical and apparent water losses within total water losses shows great differences between countries. As an example, due to high levels of illegal water consumption in some African countries, the share of apparent losses within total water losses is higher than many other non-African countries. In general, approximately 60% of total water losses are comprised of physical losses and the remaining 40% are accounted for apparent losses (Muhammetoglu & Muhammetoglu, 2017). Although NRW in Turkey was determined as 43.6% for the year 2012 according to the records of Turkish Statistics Institute (TSI, 2012), many municipalities in Turkey have no equipment to measure System Input Volume (SIV) which represents the total volume of supplied water to the WDS. Consequently, NRW estimations in many WDSs in Turkey are based on questionnaires and therefore they are not accurate (Güçlü, 2014). The percentage of NRW is reported to be less than 10% for some developed countries, but it could even exceed 70% for undeveloped countries (IBNET, 2017).

The main benefits of reducing water losses are reducing pumping and water treatment costs, increase in revenue water, delay of investments for new water infrastructure, postponing the need for new water resources, protection of water quality and reducing the risks of water borne diseases, reduction in frequency of pipe bursts and water cuts, service life extension of pipes and other equipment, and improving satisfaction of water subscribers. Understanding and quantifying NRW and water losses components is the first step for management of urban water losses. Additionally, water utilities should have a long-term commitment to develop a NRW reduction strategy. This paper briefly describes the fundamental principles for reducing water losses and improving operational efficiency in Turkey.

## Method

This section presents the essential methods used to detect and reduce water losses.

### Water Balance

Water balance calculation is basic for water losses determination and management and it is usually carried out in terms of volumes for one year. It shows the followings:

i. Volumes of physical and apparent water losses

ii. Volumes of the components of physical water losses (losses from reservoirs, losses from pipes) and components of apparent water losses (meter accuracy and data handling errors, illegal water usage)

iii. Volumes of the legal water consumption components (billed metered, billed unmetered, unbilled metered, unbilled unmetered)

iv. Volumes of water which reveals revenue. This is the volume of water that is billed.

### Dividing the Network into District Metered Areas

It is difficult to manage water losses in a large Water Distribution Network (WDN) because the calculated water losses represent an average of the whole area. Therefore, it is a well-accepted procedure to divide a large WDN into smaller isolated areas, called District Metered Areas (DMAs), in order to manage water losses effectively and also to monitor water quantity and quality efficiently by noticing even the small variations of the water quantity and quality parameters. Water is supplied to each DMA at one or more locations where flow rates and water pressures are monitored and can be controlled (Figure 2). Consequently, the water balance at each DMA can be calculated and management measures can be effectively applied.

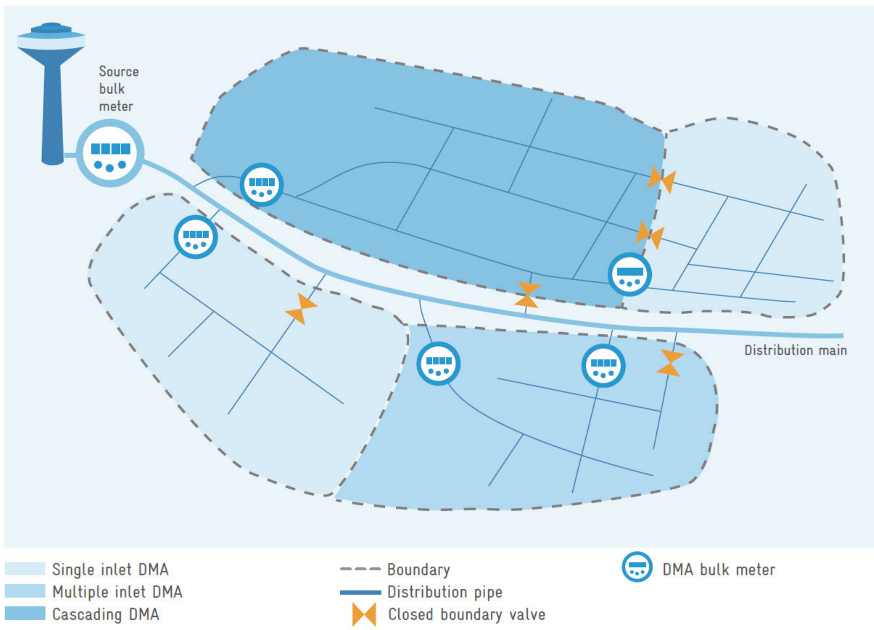


*Figure 2*. Typical DMA layouts (Farley, 2001; Fallis et al., 2011).

**Monitoring and Assessment**

Monitoring the flow rates, water pressures, levels of water in the reservoirs, and energy consumptions in WDNs is crucial to establish the water balance table, detect leakage, supply data sets to the hydraulic and water quality model and manage water losses. Many water authorities now have SCADA (Supervisory Control and Data Acquisition) system where many drinking water quality and quantity parameters are continuously monitored, analyzed and assessed by an integrated Real Time Monitoring (RTM)-SCADA system. The integrated system may also cover the pumping stations, balancing/service reservoirs, water sources and many stations located on the water mains. The system usually monitors water levels in the reservoirs, operation of pumps in the pumping stations and position of valves (open, closed, partially open) in the network in addition to energy and water consumptions (Figure 3). The display screen at the SCADA Center can show instantaneous water flow rate, stored water volume, instantaneous and previous day SIVs of water. Schematic presentation of data collection and transfer between key components of the system is presented in Figure 4. The monitored data sets are archived at the SCADA Center for evaluation and usage for hydraulic and water quality modelling applications. The system gives automatic alarms when the measured data sets are not within the predetermined limits. Also, it produces reports and charts for multipurpose analyses. It is important to monitor and assess minimum night flow (MNF) at each DMA. MNF is the lowest flow rate and it usually occurs between 02:00 and 05:00 in domestic areas. Tourism and industrial areas may show a different trend. Most of MNF in domestic areas represents leakage as the water usage during MNF is at minimum (Farley, 2001; Fallis et. al., 2011).

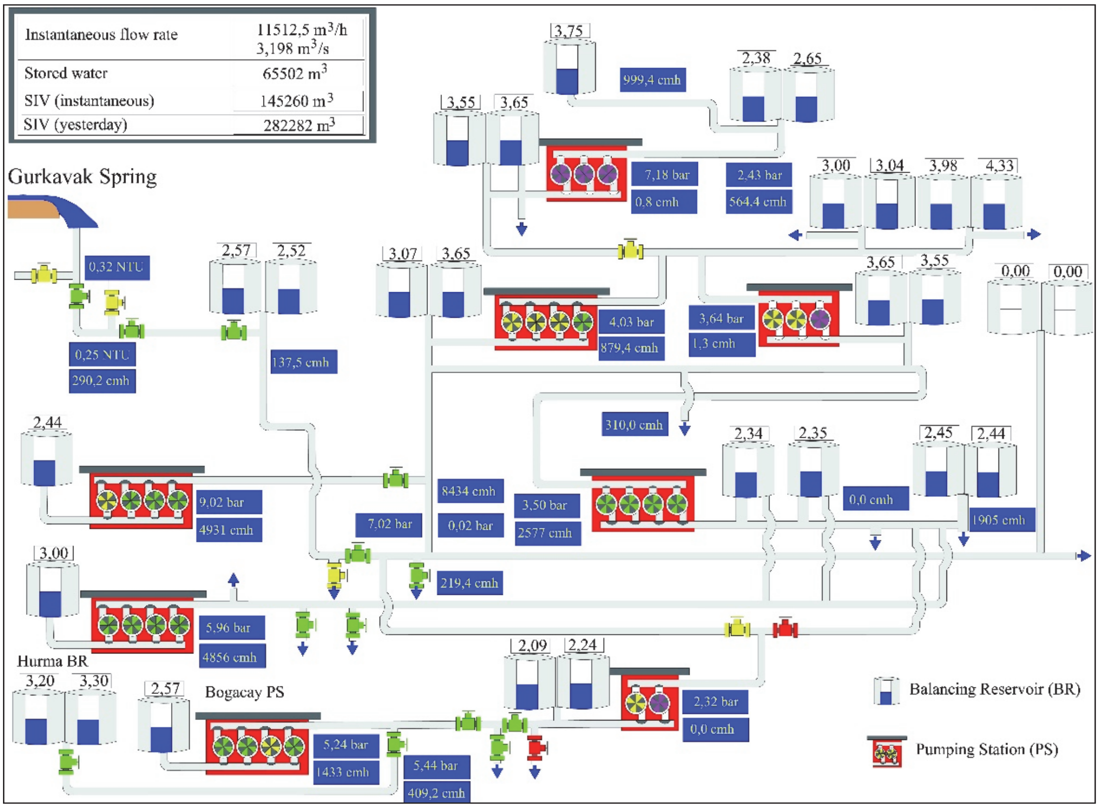


*Figure 3*. The general display screen of integrated RTM-SCADA system (Kara et al., 2016).

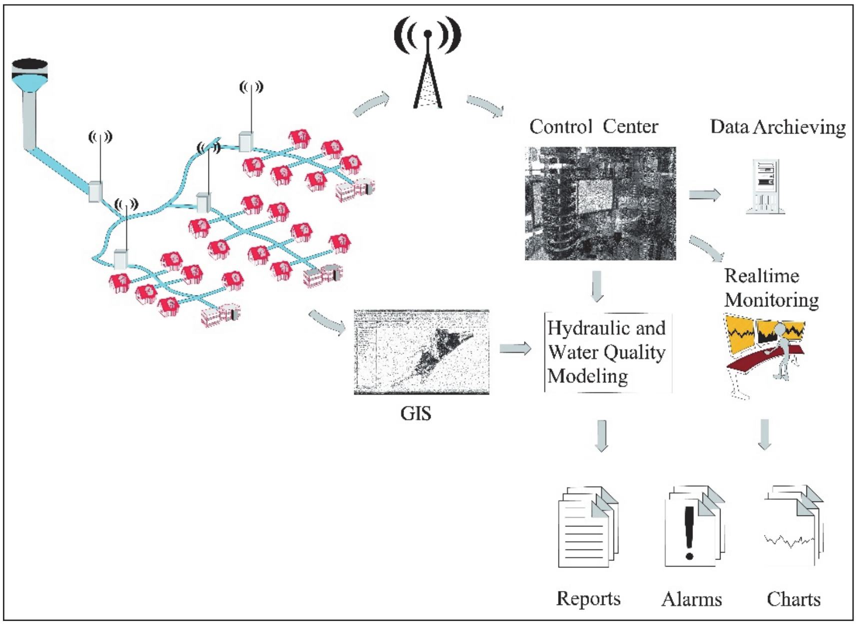


*Figure 4.* Schematic presentation of data collection, transfer and interpretation (Kara et al., 2016).

**Hydraulic Modelling**

Hydraulic modelling in WDN is used to predict the hydraulic parameters such as water velocity, flow rate and pressure. The predictions can be achieved at different locations in the network (e.g. at end points, the highest or lowest elevation, before or after the distribution reservoirs, etc.) and also at the desired seasons, dates (different days of the week) and times (different hours of the day). Thus, it is possible to predict the hydraulic parameters at space and time. Hydraulic modelling is a powerful tool to predict the impacts of different management scenarios on the hydraulics of WDN such as decreasing water losses and reducing water demands. However, hydraulic models should be well calibrated and verified by using different and numerous data sets collected through monitoring. Consequently, the models can yield reliable predictions.

**Pressure Management**

Water pressure in water distribution system is affected mainly by the elevation of the pipes, elevation of reservoirs and other elements besides pumping head (if any) and variation of water consumption. Variation of water consumption leads to variation in water velocity and hence variation in head losses (Morrison et al., 2007). As a result, water pressure usually shows considerable spatial and temporal variations. Therefore, the level of water pressure at some locations may not comply with the existing related regulations. Hydraulic models are efficient tools to predict the spatial and temporal variations of water pressures (Karadirek et al., 2012).

The WDN should be divided into a number of DMAs with suitable sizes in order to apply pressure management. Water pressure is usually measured at the entrance of the DMA and at the critical pressure points. Different types of Pressure Reducing Valves (PRVs) can be used to regulate the pressure at the critical points. Excess water pressure implies excess leakage from WDNs. Therefore, reducing water pressure alone leads to immediate reduction in leakage (Thornton & Lambert, 2005). Moreover, avoiding excess water pressure has many benefits such as reducing pipe bursts and increasing service life of pipes and other equipment. Recently, a pump as turbine (PAT) has been applied for pressure reduction and energy production (Muhammetoglu et al., 2017a, b).

**Reducing Physical Water Losses**

The four pillars of a leakage management strategy include (i) pressure management, (ii) repairs, (iii) active leakage control, and (iv) asset management (Figure 5). The large square in the middle represents the Current Annual Real/Physical Losses, which tends to increase as the distribution network ages. But the rate of increase can be constrained by an appropriate combination of the four components of a successful leakage management strategy. Unavoidable Annual Real Losses (UARL) is the lowest technically achievable volume of physical losses at the current operating pressure. Introducing or strengthening any of the four components will have an effect on the potentially recoverable losses.

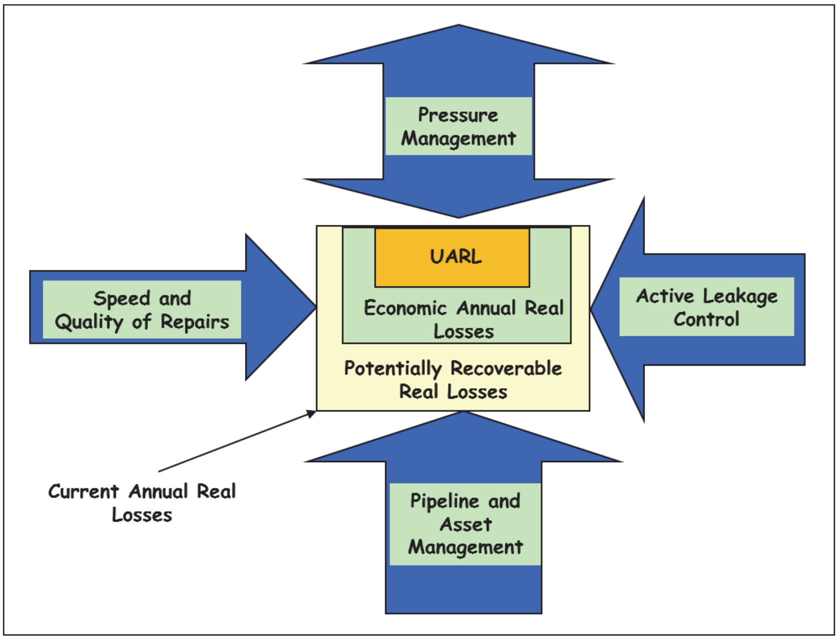


*Figure 5*. The four pillars of real water losses reduction (Lambert & McKenzie, 2002) (UARL, Unavoidable Annual Real Losses).

**Reducing Apparent Water Losses**

Apparent water losses are not visible, which lead many water utilities to neglect apparent losses and focus on physical losses. However, reducing apparent losses increases revenue. Apparent losses can be divided into four basic divisions, namely: i. customer meter accuracy, ii. illegal use (unauthorized consumption), iii. meter reading errors and iv. data handling and billing errors. In many cases, water passes through the meters but is not recorded accurately. The four pillars to reduce apparent water losses are depicted in Figure 6.

## Results and Discussion

One of the main duties of General Directorate of Water Management, within The Turkish Ministry of Forestry and Water Affairs, is to establish policies and to prepare legislation regarding the prevention and sustainable use of water resources. Therefore, a department has been recently established within the directorate to improve water efficiency. The department gives utmost importance to reduce water losses from water supply and distribution systems in Turkey. A new regulation on water losses management "*Control of Water Losses from Drinking Water Supply and Distribution*

*Systems*" was issued in May 2014 taking into consideration the methods used to detect and reduce water losses (OSİB, 2014), which were described in the previous section. In July 2015, practical and technical procedure for detecting and reducing water losses was issued (OSİB, 2015). The new regulation obligates the metropolitan and provincial municipalities to reduce water losses to 30% within 5 years starting from 2014, and to 25% within the following 4 years. Regarding the other municipalities, water losses should be reduced to 30% within 9 years and to 25% within the following 5 years.

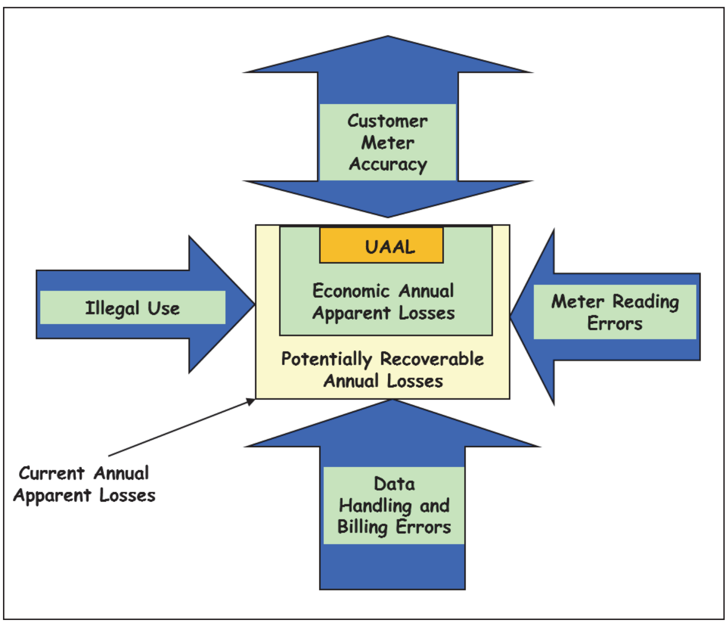


*Figure 6*. The four pillars of apparent water losses reduction (Rizzo et al., 2007; AWWA, 2009) (UAAL, Unavoidable Annual Apparent Losses).

The following actions are listed in the regulation to detect and reduce water losses:

- All water supplied to the network should be measured and recorded regularly.
- All water supplied to users should be measured by water meters. The water meters should be read and recorded regularly.
- The age of water meters should not exceed 10 years.
- Yearly water balance should be carried out and reported to the Ministry.
- The WDN should be divided into suitable number of DMAs, the new ones should be designed with DMAs.

- All flows to the DMAs and critical pressure should be measured and recorded.
- Maximum water pressure head in WDN should not exceed 60 m if possible.
- The elements and data sets of the WDN should be digitized into Geographical Information System (GIS).
- Monitoring system (such as SCADA) should be established.
- Acoustic equipment should be used to reduce physical water losses.
- Hydraulic modelling should be carried out.

The water balance required by the Turkish regulation is slightly modified from the IWA (International Water Association) and AWWA (American Water Works Association) water balance (Alegre et al., 2006; AWWA, 2009) where the "*leakage on transmission and distribution mains*", and "*leakage on service connections*" components are combined in one component as presented in Table 1. This simplifies the components of the physical water losses because it is difficult to determine the two types of leakage separately and it is much easier to determine them as one component.

Table 1

*Water Balance Showing Water Losses and NRW Components (OSİB, 2014)*

<table>
<tr><td rowspan="8">System Input Volume</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="6">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="4">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Meter Inaccuracies and Data Handling Errors</td></tr>
<tr><td rowspan="2">Physical Losses</td><td>Leakage on Transmission and Distribution Mains, and Service Connections</td></tr>
<tr><td>Leakage and Overflows from Storage Tanks</td></tr>
</table>

Recently, a handbook for managing water losses was written in Turkish and published in July 2017 (Muhammetoglu & Muhammetoglu, 2017) with the financial and technical support of Ministry of Forestry and Water Affairs. The handbook includes ten chapters and several appendices with national and international practice examples. The handbook describes the methods used to detect and reduce physical and apparent water losses in a simple but practical way targeting the managers, decision makers, engineers, and technicians in the water administrations. Additionally, many water losses training sessions for the personnel of the water administrations were organized by the Ministry of Forestry and Water Affairs.

Municipalities in Turkey should aim for apparent water losses that are less than 10% of the authorized consumption. Reducing apparent losses requires a low level of investment with a short payback period, but it needs sustained management commitment, and community support. Municipalities in Turkey should focus on apparent losses in the beginning of water losses reduction program since the activities can be undertaken with little effort and the payback is fast.

Regarding the establishment of DMAs, it is important to ensure that all pipes into and out of the DMA are either closed or a flow meter is installed to measure the flow rates. Therefore, a zero pressure test should be applied to control if the DMA is hydraulically isolated or not. The test is carried out by closing all inlet valves to the DMA, and then ensuring that the water pressure within the DMA drops to zero after waiting for some time. The pressure should drop to zero because no water should enter to the DMA after closing the valves. If the pressure does not drop to zero, then it is possible that another pipe is allowing water to enter into the DMA.

Once the DMA has been established, the water balance table required by the water losses regulation should be prepared. For example, total water losses can be calculated as the difference between Total Inflow in DMA (System Input Volume) and Authorized Consumption in DMA. Total Inflow in DMA can be measured using the flow meter(s) installed at the entrance to the DMA and also at the exit of the DMA if any. Authorized Consumption can be calculated from all the customer meter readings assuming that all users are metered (as required by the regulation). It is essential to establish a record for all water subscribers in the DMA in order to calculate the legal water consumption of the DMA accurately. Leakage and overflows from storage tanks are not usually considered because most DMAs do not contain any reservoirs

Dividing a network into a number of DMAs creates many end points and may considerably change the hydraulic and water quality characteristics of the zone. In this respect, water pressures, flow velocities in pipes and residual chlorines may considerably change. Therefore, a hydraulic and water quality model should be used and applied to predict the changes as a result of dividing the network into DMAs.

Accordingly, hydraulic and water quality modelling helps to choose the optimum design of the DMAs that yields the minimum drawbacks.

If all the authorized consumptions by the users are metered (as required by the water losses regulation) then the water balance table will be simplified and all the components of the authorized consumption will be determined based on measurements and not estimation. In practice, many water authorities face difficulties in estimating unmetered water consumption components in the water balance (billed or unbilled). This problem can be solved by installing water meters to all the users including the unbilled users such as religious facilities, parks and public toilets. However, converting all unmetered consumptions to metered consumptions may take some time and in some cases this may extend to years. The progress in this aspect should be recorded and monitored by the responsible institutions. Similarly, the SIV is not measured in many cases and rough assumptions are usually used for this purpose. Instead, SIV should be measured continuously and accurately all around the year. Some water authorities do not have enough financial resources to upgrade their infrastructure to measure the SIV but the yearly progress in this field should be recorded and reported.

The Turkish water losses regulation requires the water authorities to reduce water losses to certain levels within certain periods of time. The regulation mentions the key steps towards reducing water losses such as establishing the water balance, dividing the network into DMAs, digitizing the elements of the WDS into the GIS, monitoring, hydraulic modelling, etc. However, the infrastructure and human resources of many water authorities are very poor. Therefore, the yearly progress in the mentioned aspects should be monitored well in order to follow up the improvements in water losses reduction efforts.

The only performance indicator (PI) for water losses used in the Turkish regulation is the percentage value. It is easy to calculate and understand and therefore suitable to start with for water losses management. However, this PI is affected by the water consumption and does not take into consideration the number and length of service connections, length of the main pipes and water pressure. Also, this PI does not differentiate between physical and apparent water losses. Therefore, it is highly recommended to use additional PI such as the Infrastructure Leakage Index (ILI) which is widely used all over the world. ILI takes into consideration the existing physical water losses, number and length of service connections, length of the mains and the average operating pressure.

The water authorities should employ qualified engineers and training sessions should be organized to train the engineers on water losses issues, especially hydraulic modelling and pressure management. The developed hydraulic and water quality models need continuous updating because the WDS is dynamic and it shows continuous changes with time and space in terms of water consumptions, elements of WDS, quantity and quality of water resources, etc. The technical staff/engineers of the water authorities should be able to use and update the developed models. It is not practical to rely on the private sector for the development, updating and use of the models.

The water authorities should initially prepare the standard water balance table, calculate PI and the economic value of lost water to understand and control their water losses problem. A water authority should form a water losses control group and this group should have a clear water loss reduction strategy and targets. The strategy should include, among others, actions to reduce time for Awareness, Location and Repair (ALR) of leakages. Water authorities should follow a virtuous circle where investments are made to reduce NRW which in turn helps to increase revenues and decrease operational costs. In this way, there will be more revenues to spend for operational improvements and further NRW reduction programs. Furthermore, reduction of water losses is everyone's responsibility and raising public awareness is very important.

## Conclusion

The recent water losses regulation, technical document and the handbook on control of water losses in water supply and WDNs are efficient steps to improve the current status of water losses reduction in Turkey. However, there are still some important lacking points such as the followings:
- Water balance calculations should be applied to each DMA of the WDN.
- It is important to employ qualified engineers capable of upgrading and using the GIS, hydraulic and water quality models of WDNs besides careful evaluation of the monitored parameters.
- The infrastructure needed to determine and reduce water losses such as measuring the SIV, installing water meters to the unbilled customers, GIS, DMAs, hydraulic modelling and pressure management should be upgraded.

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**Extended Turkish Abstract**
**(Genişletilmiş Türkçe Özet)**

**Türkiye'de İçme Suyu Temin ve Dağıtım Sistemlerindeki Su Kayıplarının Yönetimi**

İçme suyu temin ve dağıtım sistemlerinde gözlenen yüksek orandaki su kayıpları, pek çok ülkede ve ülkemizde ciddi bir sorun teşkil etmektedir. Su kayıplarının azaltılması ile su kaynakları korunur (üretilen ve temin edilen su miktarı azalır), pek çok ekonomik kazanım (su alma, arıtma, terfi vb.) elde edilir ve su kaynaklı hastalık riskleri azaltılmış olur. Toplam su kayıpları, idari ve fiziki su kayıplarını içerir. Yeni içme suyu dağıtım şebekelerinde bile su kayıpları bulunmakta ise de bu oran gelişmiş ülkelerde %10 seviyesinin altındadır. Ülkemizde içme suyu temin ve dağıtım sistemlerindeki su kayıpları oranı tahmin edilenden daha fazladır ve konuya özellikle su idareleri tarafından özel önem gösterilmesi gerekmektedir. Ülkemizde yürürlükte olan su kayıplarının kontrolüne ilişkin mevzuat ile içme suyu temin ve dağıtım sistemlerindeki su kayıpları oranının %25'e indirilmesi hedeflenmektedir. Son dönemde ülkemizde içme suyu temin ve dağıtım sistemlerindeki su kayıplarının belirlenmesi, azaltılması ve yönetimi çalışmaları önem kazanmış olup 2014 yılında Orman ve Su İşleri Bakanlığı tarafından "İçme Suyu Temin ve Dağıtım Sistemlerindeki Su Kayıplarının Kontrolü Yönetmeliği" ve 2015 yılında da aynı yönetmelik için Teknik Usuller Tebliği yayınlanmıştır. Bu makalede, ülkemizde içme suyu temin ve dağıtım sistemlerindeki su kayıplarının kontrolü açısından mevcut durum değerlendirilmekte ve su kayıplarının kontrolü açısından önem arz eden faaliyetler hakkında bilgiler sunulmaktadır.

İdari su kayıplarının azaltılması için abone tüketimlerine uygun boyutta ve yüksek ölçüm hassasiyetine sahip olan sayaçların kullanımı, büyük hacimde su tüketimi olan kullanıcılar için idari kayıpların dikkatle izlemesi, tüm su kullanıcılarına faturalandırma yapılmıyor olsa bile sayaç takılması, sayaçların doğru şekilde monte edilmesi, eskimiş ve arızalı sayaçların kullanılmaması, izinsiz tüketimlerin engellenmesi, sayaç okuma, işleme ve faturalama hatalarının sürekli olarak azaltılması önemlidir. Fiziki su kayıplarının azaltılması için de şebekede basınç yönetimi ve aktif sızıntı kontrolü uygulamaları, boru hattı (varlık) yönetimi ile onarım hızı ve kalitesinin iyileştirilmesi öncelikli faaliyetlerdir. Su kayıplarının etkin bir şekilde azaltılması için büyük içme suyu dağıtım şebekelerinin hidrolik olarak bağımsız, küçük alt bölgelere (DMA) ayrılması gereklidir. DMA oluşturma aşamasında DMA boyutu, DMA girişinde debi ve basınç ölçmek için ihtiyaç duyulan cihazların sayısı, DMA içindeki basınç değişimleri, DMA sınırları ve gerekli olan kapatma vanası dikkate alınmalıdır. Her DMA için, DMA içindeki tüm su kullanıcılarını içeren ayrı bir abone veri tabanı oluşturulmalıdır. DMA alanına giren su debisi sürekli olarak izlenmeli ve her DMA için minimum gece debisi analizi yapılarak sızıntı düzeyi takip edilmeli, boru tamiratı veya yenileme yapılması için değerlendirmeler yapılmalıdır.

Kentsel su kayıplarının azaltılması için önemli olan çalışmalar arasında su idareleri tarafından her yıl Standart Su Dengesi Tablosunun oluşturulması ve Orman ve Su İşleri Bakanlığı'na ulaştırılması büyük önem arz etmektedir. Bu tablo, su kayıpları bileşenlerinin anlaşılması ve ilgili bileşenler için uygun azaltma yönteminin seçilmesinde yardımcı olmaktadır. İçme suyu şebekelerinde uygun DMA'ların oluşturulması, boru bağlantılarının değiştirilmesi, su kayıpları seviyesindeki değişimlerin incelenmesi, hidrolik parametrelerin (debi, basınç, hız) tüm şebeke için zamansal ve mekânsal olarak analiz edilebilmesi amacı ile içme suyu dağıtım şebekeleri için hidrolik modelleme çalışması yapılmaktadır. Hidrolik model için gerekli olan pek çok girdi verisi Coğrafi Bilgi Sistemi ve izleme çalışmalarından elde edilmektedir. Fiziki su kayıplarının kontrolünde basınç yönetimi için farklı basınç düşürme vanaları kullanılabilmektedir. Basınç yönetimi ile şebekedeki fazla basıncın azaltılması, boru

patlaklarının oluşma sıklığının azalması, şebeke elemanlarının kullanım sürelerinin uzaması vb. faydalar sağlanır. Veri tabanlı İzleme ve Kontrol Sistemi (SCADA) ve gerçek zamanlı izleme ile su miktarı ve kalitesi değişimleri görsel olarak izlenebilmekte, depo, pompa ve vanalar uzaktan kontrol edilebilmekte, boru patlakları tespit edilebilmektedir. Su kayıpları seviyesi belirlendikten sonra her şebeke için uygun olan idari ve fiziki su kayıpları mücadele yöntemleri önceliklendirilerek hayata geçirilmektedir. Belirtilen tüm unsurların başarı ile uygulanabilmesi için öncelikle sorunun yeterli düzeyde anlaşılması, teknik kapasitenin geliştirilmesi, altyapının yenilenmesi için yeterli mali desteklerin bulunması ve ilgili idari kurumun su kayıplarını azaltmaya yönelik bir stratejik planının ve kararlılığının olması gereklidir.

*Research Article*

# Bioassessment of Ecological Status of Three Aegean Reservoirs Based on Phytoplankton Metrics

# Üç Ege Barajının Fitoplankton Metriklerine Dayalı Ekolojik Durumunun Biyodeğerlendirilmesi

Abuzer ÇELEKLİ[1], Assane Anabi TOUDJANI[1],
Hacı Ömer LEKESİZ[1], Seda KAYHAN[1], Tolga ÇETİN[2]

[1]*Gaziantep University, Faculty of Arts and Sciences, Department of Biology, Gaziantep, Republic of Turkey*
celekli.a@gmail.com, tassaneanabi@yahoo.fr,
omerlekesiz16@gmail.com, sedakayhan@outlook.com
[2]*Ministry of Forestry and Water Affairs, General Directorate of Water Management, Ankara, Republic of Turkey*
tcetin@ormansu.gov.tr
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**Abstract**

Assessing freshwater quality is getting more important since the implementation of the European Union Water Framework Directive. In the present study, the water quality of three reservoirs of the North Aegean basin of Turkey was assessed using Mediterranean Phytoplankton Trophic Index and Phytoplankton Trophic Index. Data were collected seasonally between summer 2014 and summer 2015 from three reservoirs. The reservoirs showed alkaline waters. The highest nutrients values of TP (203.5 µg $L^{-1}$) at Bayramiç Reservoir and TN (1012.0 µg $L^{-1}$) at Sevişler Reservoir were recorded. A total of 120 species were recorded and mostly represented by Bacillariophyta. The relationship between phytoplankton species and environmental variables was examined using multivariate analyses. The phytoplankton composition and distribution were governed by environmental variables. The most important structuring factors were total phosphorus, orthophosphate, total kjeldahl nitrogen, biological oxygen demand, total organic carbon, and temperature. The first two CCA axes explained 31% of cumulative percentage variance of species data with 97.7% between species-environment correlations, the situation which was also confirmed the Monte Carlo test ($p= 0.002$, $F = 1.157$). Med-PTI indicated good quality waters for Ayvacık and Bayramiç Reservoirs, while Sevişler Reservoir had a moderate water quality. Based on the PTI, the waters of the Bayramiç and Sevişler Reservoirs were classified as or moderate ecological status, while Ayvacık Reservoir indicated a good water quality. From these results, the Med-PTI and the PTI seem to be appropriate metrics for assessing the water quality of the reservoirs in the North Aegean River Basin.

**Keywords:** *water quality, phytoplankton, Med-PTI, PTI, reservoir*

**Öz**

Avrupa Birliği Su Çerçeve Direktifi'nin uygulanmasıyla birlikte su kalitesinin değerlendirilmesi büyük önem kazanmıştır. Bu çalışmada, Türkiye'nin Kuzey Ege Havzası'nda bulunan üç barajın su kalitesi Akdeniz Fitoplankton Trofik İndeksi ve Fitoplankton Trofik İndeksi kullanılarak değerlendirilmiştir. Veriler üç barajdan 2014 ve 2015 yaz dönemi arasında mevsimsel olarak toplanmıştır. Üç baraj alkali su özelliği göstermiştir. En yüksek nutrient değerleri olarak TP (203,5 µg $L^{-1}$) Bayramiç Baraj Gölü'nde ve TN (1012,0 µg $L^{-1}$) Sevişler Barajı'nde kaydedilmiştir. Toplamda 120 tür teşhis edilmiş ve türlerin çoğunluğu Bacillariophyta ile temsil edilmiştir. Fitoplankton türleri ve çevresel değişkenler arasındaki ilişki multivaryete analizler ile incelenmiştir. Fitoplankton kompozisyonu ve dağılımını çevresel değişkenler yönetmiştir. Toplam fosfor, ortofosfat, toplam Kjeldahl azotu, biyolojik oksijen ihtiyacı, toplam organik karbon ve sıcaklık en önemli faktörler olmuştur. İlk iki CCA ekseni tür verisinin %31 kümülatif yüzde varyansının %97,7 tür-çevre korelasyonu ile açıklamış ve durum Monte Carlo testi (p= 0,002 ve *F* = 1,157) ile doğrulanmıştır. Med-PTI, Ayvacık ve Bayramiç Barajları için iyi su kalitesini gösterirken Sevişler Barajı'nı orta su kalitesinde indike etmiştir. PTI'ye göre Bayramiç ve Sevişler Barajları orta ekolojik durumda sınıflandırılmışken Ayvacık Barajı iyi su kalitesinde indike edilmiştir. Sonuçlara göre, Med-PTI ve PTI'nin Kuzey Ege Havzası'nda bulunan barajların su kalitesinin değerlendirilmesinde uygun metrikler olduğu görülmüştür.

***Anahtar sözcükler:*** *su kalitesi, fitoplankton, Med-PTI, PTI, baraj*

## Introduction

Water is one of the essential factors for civilization, and also among the most important items in the new world order. Surface watercourses provide a number of ecosystem services to all living organisms and humans, such as water supply and purification, climate and flood regulation, fishery and recreation (Wallis et al. 2012). The water quality is of great importance also for human lives as it is commonly consumed and used by households (Cieszynska et al. 2012). During the last decades, anthropogenic activities have deteriorated water quality of reservoirs worldwide (Katsiapi et al. 2011; Çelekli and Öztürk, 2014). The increasing availability of nutrients such as nitrogen and phosphorous in freshwaters, especially associated with eutrophication, is affecting the performance of aquatic ecosystems (Leira et al. 2009; Delgado and Pardo, 2014).

Due to this, the European Union Water Framework Directive (WFD) required member states to assess and classify their surface water quality bodies (Directive, 2000). In this regard, biological quality elements such as phytoplankton, phytobenthos, macrophytes, benthic macroinvertebrates and fish are recommended by WFD as biological indicators for the assessment of surface waters (Directive, 2000; EC, 2009). The use of biological communities for monitoring the biotic integrity of aquatic ecosystems has a long history (Karr, 1981; Beck and Hatch, 2009) and their use will likely increase as human-induced pressures continue to increase and as pressures are exacerbated by climate warming (Brucet et al. 2013). Effective biological assessment should be based on reliable pressure–impact relationships (Karr and Chu, 1999; Dale and Beyeler, 2001; Davies and Jackson, 2006; Hering et al. 2006). Although the use of multiple taxonomic groups is thought to better distinguish the effects of multiple stressors (Dale and Beyeler, 2001; Hering et al. 2006) few studies have compared the response of different organism groups to different types of environmental stress (Johnson et al. 2006; Johnson and Hering, 2009).

Phytoplankton can be used as a good indicator of water quality changes, given its sensitivity and dynamic responses to changes in the surrounding environment (Reynolds, 1984, 2002; Padisák et al. 2006; Cheshmedjiev et al. 2010; Katsiapi et al. 2011; Çelekli and Öztürk, 2014). A number of phytoplankton indices such as phytoplankton trophic index (PTI) based on the composition, independently of the geographic region (Phillips et al. 2013) and the Mediterranean phytoplankton trophic index (Med-PTI) using the phytoplankton biovolume (Marchetto et al. 2009) have been developed for the purpose of Water Framework Directive (WFD). From that point, aims of the present study were to i) determine phytoplankton composition, ii) to evaluate relationship between phytoplankton assemblages and environmental factors and iii) assess water quality by use of the Mediterranean Phytoplankton Trophic Index (Med-PTI) (Marchetto et al. 2009) and Phytoplankton Trophic Index (PTI) (Philips et al. 2013) of three reservoirs in the North Aegean River Basin of Turkey.

## Method

### Sampling and Analyses

Phytoplankton samples were collected seasonally between September 2014 and August 2015 from three reservoirs in the North Aegean River Basin of Turkey (Figure 1). Hydrobios plankton net (55 µm mesh size) was used to collect net-plankton. Water samples (250 ml) were directly taken from just beneath of the surface water from each reservoir for phytoplankton enumeration. Phytoplankton samples were fixed with lugol-glycerol's solution according to the standard method (Utermöhl, 1958; CEN, 2004, 2006). Water samples were stored in coolers with ice packs during the transfer to the laboratory for the analyses.

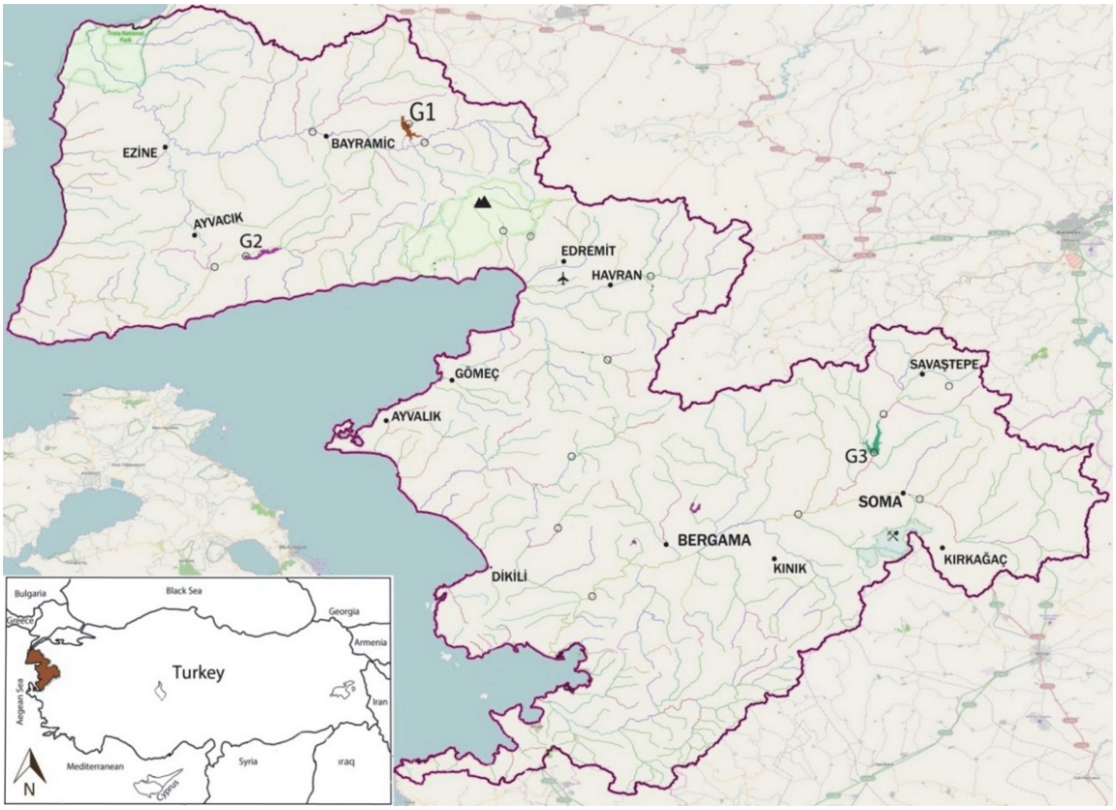


*Figure 1.* Location of three reservoirs (G1: Bayramiç Reservoir, G2: Ayvacık Reservoir, G3 Sevişler Reservoir).

Environmental variables such as pH, conductivity, salinity, dissolved oxygen and temperature measured *in situ* using an YSI professional plus oxygen–temperature meter. Water transparency was measured using a 20-cm Secchi disk (SD). Geographical data (altitude, latitude, and longitude) were recorded from a geographical positioning system. Geomorphological characteristics of the reservoirs are given in Table 1.

Analyses of chemical variables such as total nitrogen (TN), nitrate nitrogen ($NO_3$-N), nitrite nitrogen ($NO_2$-N), ammonium nitrogen ($NH_4$-N), total Kjeldahl nitrogen (TKN), total phosphorus (TP), orthophosphate ($PO_4$-P), biological oxygen demand ($BOD_5$) and dissolved oxygen (DO), and total organic carbon (TOC) were carried out in laboratory using standard methods (APHA, 2012).

Table 1

*Geographical and Morphometry Characteristics of The Reservoirs*

| Reservoir | | Typology | Longitude | Latitude | Cons. | Altit. (m) | Reser. Area (ha) | Max. depth (m) |
|---|---|---|---|---|---|---|---|---|
| Bayramiç | G1 | R1D2A2J2 | 26.66980 | 39.81087 | 1996 | 159 | 608 | 41 |
| Ayvacık | G2 | R1D2A1J2 | 26.47838 | 39.60825 | 2007 | 307 | 64.3 | 43 |
| Sevişler | G3 | R1D2A1J1 | 27.55003 | 39.26500 | 1981 | 158 | 472 | 48 |

*Note. R= altitude, D= depth, A= surface area, J= geology, Cons= construction, Altit= altitude Reser=reservoir*

Phytoplankton taxa were identified using a light microscope (Olympus BX53) equipped with DP73 model digital camera and imaging software (Olympus CellSens Vers. 1.6) (CEN, 2003, 2004). Taxonomic identifications were performed following Ettl (1983), Komárek and Fott (1983), Krammer and Lange-Bertalot (1991a, b; 1999a, b), Komárek and Anagnostidis (1998), John et al. (2002), Wehr and Sheath (2003).

The enumeration of phytoplankton was done at magnifications of 400–600× (2 transects) under an inverted microscope (Olympus CKX41) (Utermöhl, 1958; Lund et al. 1958). Total biovolume for each taxon was calculated by multiplying the cell density by the unitary cell biovolume of the taxon, which was calculated using geometric shapes of cells proposed by Hillebrand et al. (1999) and Sun and Liu (2003).

Phytoplankton Trophic Index (PTI) (Philips et al. 2013) and the Mediterranean Phytoplankton Trophic Index (Med-PTI) (Marchetto et al. 2009), used to assess the status of the reservoirs according to the Water Framework Directive were calculated using the following Eq-1 and 2 respectively and then

$$PTI = \frac{\sum_{j=1}^{n} a_j * s_j}{\sum_{j=1}^{n} a_j} \qquad \text{(Eq-1)}$$

Where $a_j$ is the proportion of $j^{th}$ taxon in the sample and $s_j$ is the optimum of $j^{th}$ taxon in the sample.

$$MedPTI = \frac{\sum_{j=1}^{n} b_{j,k} * v_k * i_k}{\sum_{j=1}^{n} b_{j,k} * i_k} \quad \text{(Eq-2)}$$

Where, $b_{j,k}$ is the biovolume, $v_k$ is trophic value, and $i_k$ the indicator value of the *n* species in the sample.

**Multivariate analysis.**

A canonical correspondence analysis (CCA) was performed using the CANOCO software, version 4.5 to describe the structuring factors governing the composition of phytoplankton assemblages. Following ter Braak and Smilauer (1998), unimodal response models were employed for the ordination of analyses along gradients. Selected environmental variables were transformed log (x+1), except pH to reduce skewness (ter Braak and Smilauer, 1998). A weighted average (WA) regression of CALIBRATE program (Juggins & ter Braak, 1992) was used to estimate diatom species optima (*uk*) and tolerance (*tk*) levels for the environmental variables. For this purpose, weighted-average metrics assess only a single pressure (e.g. nutrients) or related pressures of environmental factors on organisms. For these analyses species representing over than 1% of the total biomass were selected.

## Results

### Physical and Chemical Parameters

The mean water quality parameters of the water bodies are presented in Table 2. The reservoirs had alkaline waters and no significant differences in pH and temperature values among reservoirs. The highest conductivity (434.5 µS $cm^{-1}$) and salinity (0.21 ppt) were measured at Sevişler Reservoir. With regard to nutrients, the highest values of TN (1012.0 µg $L^{-1}$) and N-$NO_3$ (217.0 µg $L^{-1}$) were recorded at Sevişler Reservoir, following at Bayramiç Reservoir. On the other hand, relatively higher TP (203.5 µg $L^{-1}$) value was found to be at Bayramiç Reservoir. Sevişler and Bayramiç Reservoirs had higher and similar TOC value than that of Ayvacık Reservoir. Ayvacık Reservoir had a higher Secchi depth value than those of Sevişler and Bayramiç Reservoirs.

Table 2

*Mean ± SD (Standard Deviation) Values of Water Quality Parameters for All Seasons*

| Variables | Unit | G1 | G2 | G3 |
|---|---|---|---|---|
| pH | | 8.8±0.1 | 8.7±0.1 | 8.8±0.2 |
| Temperature | °C | 22.2±6.7 | 19.9±7.2 | 21.4±6.7 |
| Conductivity | µS $cm^{-1}$ | 275.8±71.8 | 343.8±96.9 | 434.5±107.5 |
| DO | mg $l^{-1}$ | 9.3±1.8 | 8.6±1.9 | 8.8±0.9 |
| TSS | mg $l^{-1}$ | 9.4±11.9 | 2.2±0.4 | 7.5±9.5 |
| BOD | mg $l^{-1}$ | 22.8±26.5 | 13.3±8.8 | 10.5±7.6 |
| COD | mg $l^{-1}$ | 72.0±74.9 | 51.8±35.4 | 46.5±28.4 |
| TOC | mg $l^{-1}$ | 20.28±30.3 | 16.1±17.2 | 20.6±32.8 |
| N-$NH_4$ | µg $l^{-1}$ | 100.0±0.0 | 93.5±26.8 | 254.8±309.5 |
| N-$NO_2$ | µg $l^{-1}$ | 4.25±2.6 | 17.00±22.2 | 60.3±60.6 |
| N-$NO_3$ | µg $l^{-1}$ | 139.0±72.2 | 101.5±23.0 | 217.0±110.7 |
| TKN | µg $l^{-1}$ | 642.0±574.8 | 578.3±362.7 | 546.0±271.4 |
| TN | µg $l^{-1}$ | 764.5±593.1 | 681.8±462.4 | 1012.0±561.4 |
| TP | µg $l^{-1}$ | 203.5±214.5 | 173.8±195.6 | 105.8±54.3 |
| P-$PO_4$ | µg $l^{-1}$ | 109.5±148.8 | 74.8±57.6 | 57.0±36.1 |
| Salinity | ppt | 0.15±0.02 | 0.18±0.03 | 0.21±0.04 |
| SD | m | 1.43±0.67 | 2.18±0.40 | 1.58±0.79 |

Box plots of TN, N-$NO_3$, TP, and P-$PO_4$ are given in Figure 2a, b, c, and d, respectively. A spatial variability was detected following the physicochemical variables of the reservoirs during the study period. The mean value of the chemical factors was mainly low at Ayvacık Reservoir comparing to the other reservoirs.

**Phytoplankton and Environmental Relationship**

During the present study, a total of 120 taxa were recorded and most of them belong to Bacillariophyta. Phytoplankton species such as *Cocconeis placentula*, *Cryptomonas ovata, Cyclotella bodanica, Cyclotella iris, Pediastrum simplex*, *Scenedesmus communis* and *Ulnaria ulna* were commonly found during the study period.

Among the total phytoplankton species, 64 phytoplankton taxa with abundance higher than 1% of the total biomass were selected for the multivariate analyses. To elucidate relationship between these phytoplankton species as response variables and six (6) environmental factors, CCA was performed. The phytoplankton composition and distribution were governed by environmental factors such as TOC, P-$PO_4$, temperature, TKN, $BOD_5$, and TP. The first two CCA axes explained 31% of cumulative percentage variance of species data with 97.7% between species-environment correlations during the study period (Table 3). The Monte Carlo test confirmed that the first two axes were highly significant (p= 0.002, $F$ = 1.157).

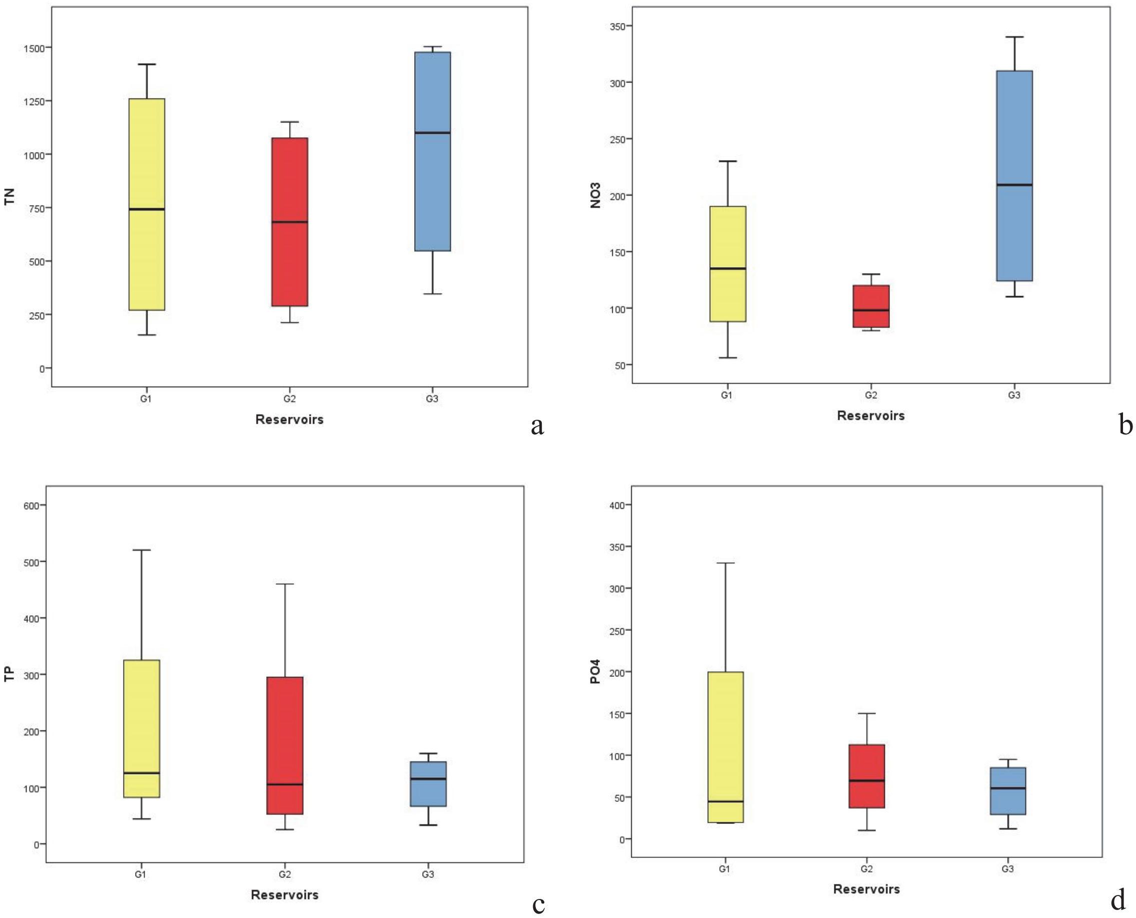


*Figure 2.* Box plot diagrams showing the variations of environmental variables among reservoirs: Codes of reservoirs are given in Table 1.

Relationship between species-environment is given on the ordination (Figure 3). Arrows of temperature, $BOD_5$ and TOC were associated with Bayramiç Reservoir while Ayvacık Reservoir had relatively lower TOC, temperature and $BOD_5$. Previously given common found species were mainly located the center of the ordination. The distribution of species such as *Ceratium furcoides*, *Merismopedia glacua*, *Coelastrum* *astroideum*, *Closterium dinae*, *Mougeotia gracilima* and *Tetraedron minimum* was governed by high temperature and TOC while phytoplankton species such as *Cocconeis placentula*, *Cyclotella meneghiniana, Cymatopleura elliptica*, *Gomphonema parvulum, Navicula capitatoriata, Pediastrum simplex* and *Ulnaria ulna* were related to TP and P-$PO_4$.

Table 3

*Summary of Canonical Correspondence Analysis Using Monte Carlo Permutation Test for Phytoplankton-Environment Relationship*

| Axes | 1 | 2 | 3 | 4 | Total inertia |
|---|---|---|---|---|---|
| Eigenvalues | 0.957 | 0.879 | 0.791 | 0.662 | 5.918 |
| Species-environment correlations | 0.997 | 0.977 | 0.966 | 0.934 | |
| Cumulative percentage variance | | | | | |
| of species data | 16.2 | 31.0 | 44.4 | 55.6 | |
| of species-environment relation | 26.2 | 50.3 | 71.9 | 90.0 | |
| Sum of all eigenvalues | | | | | 5.918 |
| Sum of all canonical eigenvalues | | | | | 3.653 |
| Test of significance of first canonical axis: eigenvalue = 0.957 | | | | | |
| | F-ratio = 1.157 | | | p-value = 0.0020 | |

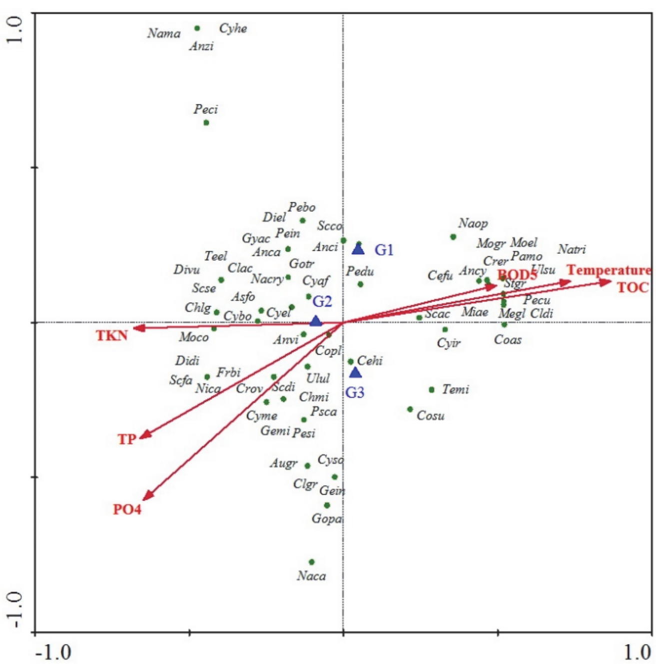


*Figure 3.* Canonical correspondence analysis plot of species-environmental relationships in the sampling reservoirs (up triangular). TOC, total organic carbon; $BOD_5$, biological oxygen demand; TP, total phosphorus, and TKN total Kjeldahl nitrogen. Codes of species are given in Table 5.

Results of WA regression are presented in Table 4. *Scenedesmus communis, Cocconeis placentula*, *Cyclotella meneghiniana*, *Ulnaria ulna*, *Gomphonella parvula*, *Pediastrum simplex*, *Scenedesmus acutus* were associated with high TP and P-$PO_4$ concentrations while *Straurastrum gracile*, *Peridiniopsis cunningtonii*, *Peridinium cinctum*, *Melosira lineata* and *Cryptomonas erosa* had relatively low TP tolerance values. *Tetrastrum elegans*, *Schoderia setigera*, *Geminella interrupta*, *Cymatopleura elliptica*, *Closterium gracile* and *Chlamydomanas globasa* were associated with high TN. With regard to temperature *Scedenasmus falcatus, Nitzschiana calida, Dinobryon divergens* were associated to the lowest optima value of temperature (12.5 °C), while *Ulothrix subconstricta*, *Straurastrum gracile*, *Pandorina morum*, *Navicula trivialis*, *Mougeotia elegantula* had the highest optima value of temperature (28.1°C).

**Phytoplankton-based Indices and the Ecological Status of the Reservoirs**

The ecological status of the reservoirs was assessed of based on phytoplankton metrics specially Med-PTI and PTI (Table 5). The highest Med-PTI and PTI values were recorded at Ayvacık Reservoir and Sevişler Reservoir respectively. With regard to ecological status, values of the Med-PTI index indicate good quality waters for Ayvacık and Bayramiç Reservoirs while Sevişler Reservoir had a Moderate water quality. Based on the PTI index, the waters of the Bayramiç and Sevişler Reservoirs were classified as or moderate ecological status while Ayvacık Reservoir indicated a good water quality.

Table 4

*Weighted Average Regression in The Reservoirs. $U_k$ and $T_k$ Indicated Optima and Tolerance, Respectively*

| | | Temperature | | $BOD_5$ | | TOC | | TKN | | TP | | $P\text{-}PO_4$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Codes | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ |
| *Anabaena catenula* | Anca | 27.8 | 3.7 | 59.4 | 9.1 | 12.4 | 16.1 | 1360.0 | 291.6 | 120.0 | 94.3 | 68.9 | 49.6 |
| *Anabanea circinalis* | Anci | 27.4 | 0.8 | 42.7 | 31.9 | 23.0 | 20.3 | 992.4 | 703.6 | 84.9 | 67.2 | 46.0 | 43.9 |
| *Anabanea cylindrica* | Ancy | 27.7 | 0.7 | 20.7 | 5.6 | 60.1 | 14.6 | 240.0 | 116.9 | 34.9 | 9.5 | 13.3 | 6.2 |
| *Anabanea viriabilis* | Anvi | 26.4 | 1.3 | 33.6 | 24.2 | 7.8 | 4.2 | 1003.6 | 338.3 | 135.2 | 20.2 | 78.9 | 13.2 |
| *Anabaena zinserlingii* | Anzi | 17.6 | 3.7 | 2.8 | 9.1 | 1.0 | 16.1 | 849.0 | 291.6 | 130.0 | 94.3 | 20.0 | 49.6 |
| *Asterionella formosa* | Asfo | 21.4 | 9.2 | 20.0 | 10.5 | 8.4 | 5.6 | 813.9 | 210.7 | 114.2 | 35.4 | 71.8 | 8.1 |
| *Aulocaseria granulata* | Augr | 19.6 | 5.4 | 7.5 | 4.9 | 4.3 | 1.3 | 577.6 | 321.8 | 244.9 | 207.3 | 150.5 | 135.3 |
| *Bacillaria vulgaris* | Bavu | 14.0 | 3.7 | 2.8 | 9.1 | 2.8 | 16.1 | 464.0 | 291.6 | 100.0 | 94.3 | 46.0 | 49.6 |
| *Ceratium furcoides* | Cefu | 27.3 | 0.9 | 17.2 | 4.2 | 55.0 | 20.2 | 313.7 | 74.2 | 28.9 | 5.7 | 9.4 | 3.6 |
| *Ceratium hirindunella* | Cehi | 23.0 | 7.3 | 12.7 | 2.1 | 21.0 | 20.4 | 722.3 | 358.4 | 88.1 | 73.1 | 53.1 | 48.2 |
| *Chlamydomanas globasa* | Chlg | 13.5 | 1.1 | 5.3 | 5.0 | 6.7 | 7.7 | 659.4 | 391.7 | 92.9 | 14.1 | 52.3 | 12.7 |
| *Choroccocus minutus* | Chmi | 17.6 | 3.7 | 6.4 | 9.1 | 5.2 | 16.1 | 550.0 | 291.6 | 130.0 | 94.3 | 75.4 | 49.6 |
| *Closterium aciculare* | Clac | 14.9 | 2.5 | 3.6 | 2.5 | 3.4 | 1.7 | 484.9 | 60.8 | 107.3 | 21.2 | 53.2 | 20.8 |
| *Closterium dinae* | Cldi | 28.0 | 3.7 | 20.2 | 9.1 | 69.7 | 16.1 | 260.0 | 291.6 | 33.0 | 94.3 | 12.0 | 49.6 |
| *Closterium gracile* | Clgr | 25.9 | 3.7 | 12.9 | 9.1 | 4.5 | 16.1 | 910.0 | 291.6 | 160.0 | 94.3 | 95.0 | 49.6 |
| *Cocconeis placentula* | Copl | 20.2 | 6.6 | 13.3 | 12.7 | 12.2 | 24.3 | 369.9 | 289.8 | 309.6 | 224.9 | 144.1 | 120.5 |
| *Coelastrum astroideum* | Coas | 28.0 | 3.7 | 20.2 | 9.1 | 69.7 | 16.1 | 260.0 | 291.6 | 33.0 | 94.3 | 12.0 | 49.6 |
| *Cosmarium subcostatum* | Cosu | 26.8 | 1.5 | 16.1 | 5.2 | 32.8 | 46.1 | 627.3 | 459.6 | 104.8 | 89.8 | 58.9 | 58.7 |
| *Cryptomonas erosa* | Crer | 27.6 | 0.8 | 20.2 | 5.6 | 59.3 | 15.2 | 249.6 | 116.1 | 34.1 | 9.4 | 12.8 | 6.1 |
| *Cryptomonas ovata* | Crov | 17.9 | 6.7 | 8.0 | 5.1 | 6.0 | 4.9 | 688.2 | 365.8 | 187.8 | 162.7 | 87.4 | 42.5 |
| *Cyclotella bodanica* | Cybo | 19.6 | 6.8 | 20.5 | 23.0 | 8.0 | 4.7 | 818.9 | 363.7 | 112.7 | 21.7 | 66.5 | 11.9 |
| *Cyclotella iris* | Cyir | 27.1 | 1.1 | 18.2 | 6.0 | 44.3 | 30.0 | 422.5 | 347.6 | 66.8 | 64.3 | 34.1 | 42.0 |
| *Cyclotella meneghiniana* | Cyme | 14.2 | 1.6 | 5.7 | 3.9 | 7.0 | 6.3 | 507.6 | 471.5 | 339.8 | 241.7 | 170.2 | 131.7 |
| *Cymatopleura elliptica* | Cyel | 15.1 | 3.7 | 3.8 | 9.1 | 3.7 | 16.1 | 210.0 | 291.6 | 460.0 | 94.3 | 150.0 | 49.6 |

| | | Temperature | | $BOD_5$ | | TOC | | TKN | | TP | | $P\text{-}PO_4$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Table 4 continue | | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ |
| *Cymatopleura solea* | Cyso | 25.9 | 3.7 | 12.9 | 9.1 | 4.5 | 16.1 | 910.0 | 291.6 | 160.0 | 94.3 | 95.0 | 49.6 |
| *Cymbella excisa* | Cyaf | 19.0 | 5.8 | 8.3 | 4.9 | 15.3 | 18.5 | 647.6 | 280.4 | 93.4 | 52.2 | 44.4 | 35.1 |
| *Cymbella helvetica* | Cyhe | 17.6 | 3.7 | 2.8 | 9.1 | 1.0 | 16.1 | 849.0 | 291.6 | 130.0 | 94.3 | 20.0 | 49.6 |
| *Dinobryon divergens* | Didi | 12.5 | 3.7 | 9.9 | 9.1 | 13.8 | 16.1 | 1018.0 | 291.6 | 80.0 | 94.3 | 64.0 | 49.6 |
| *Diploneis elliptica* | Diel | 27.8 | 3.7 | 59.4 | 9.1 | 12.4 | 16.1 | 1360.0 | 291.6 | 120.0 | 94.3 | 68.9 | 49.6 |
| *Geminella interrupta* | Gein | 25.9 | 3.7 | 12.9 | 9.1 | 4.5 | 16.1 | 910.0 | 291.6 | 160.0 | 94.3 | 95.0 | 49.6 |
| *Geminella minor* | Gemi | 17.6 | 3.7 | 6.4 | 9.1 | 5.2 | 16.1 | 550.0 | 291.6 | 130.0 | 94.3 | 75.4 | 49.6 |
| *Gomphonema parvulum* | Gopa | 22.5 | 7.6 | 9.7 | 7.2 | 3.9 | 1.3 | 693.1 | 480.8 | 274.8 | 254.6 | 170.0 | 166.2 |
| *Gomphonema truncatum* | Gotr | 25.5 | 3.7 | 24.7 | 9.1 | 5.9 | 16.1 | 720.0 | 291.6 | 130.0 | 94.3 | 75.4 | 49.6 |
| *Merismopedia glacua* | Megl | 28.0 | 3.7 | 20.2 | 9.1 | 69.7 | 16.1 | 260.0 | 291.6 | 33.0 | 94.3 | 12.0 | 49.6 |
| *Microcystis aeruginosa* | Miae | 28.0 | 0.1 | 22.9 | 4.0 | 67.5 | 3.2 | 196.9 | 92.6 | 38.3 | 7.8 | 15.5 | 5.2 |
| *Monorophidium contortum* | Moco | 13.5 | 1.1 | 5.3 | 5.0 | 6.7 | 7.7 | 658.5 | 391.7 | 93.0 | 14.1 | 52.3 | 12.7 |
| *Mougeotia elegantula* | Moel | 28.1 | 3.7 | 25.8 | 9.1 | 65.1 | 16.1 | 129.0 | 291.6 | 44.0 | 94.3 | 19.3 | 49.6 |
| *Mougeotia gracilima* | Mogr | 26.7 | 3.7 | 14.3 | 9.1 | 41.0 | 16.1 | 365.0 | 291.6 | 25.0 | 94.3 | 6.9 | 49.6 |
| *Navicula capitatoriata* | Naca | 15.2 | 3.7 | 2.8 | 9.1 | 2.6 | 16.1 | 230.0 | 291.6 | 520.0 | 94.3 | 330.1 | 49.6 |
| *Navicula cryptotenella* | Nacry | 25.5 | 3.7 | 24.7 | 9.1 | 5.9 | 16.1 | 720.0 | 291.6 | 130.0 | 94.3 | 75.4 | 49.6 |
| *Navicula margalithii* | Nama | 17.6 | 3.7 | 2.8 | 9.1 | 1.0 | 16.1 | 849.0 | 291.6 | 130.0 | 94.3 | 20.0 | 49.6 |
| *Navicula oppugnata* | Naop | 26.7 | 3.7 | 14.3 | 9.1 | 41.0 | 16.1 | 365.0 | 291.6 | 25.0 | 94.3 | 6.9 | 49.6 |
| *Navicula trivialis* | Natri | 28.1 | 3.7 | 25.8 | 9.1 | 65.1 | 16.1 | 129.0 | 291.6 | 44.0 | 94.3 | 19.3 | 49.6 |
| *Nitzschiana calida* | Nica | 12.5 | 3.7 | 9.9 | 9.1 | 13.8 | 16.1 | 1018.0 | 291.6 | 80.0 | 94.3 | 64.0 | 49.6 |
| *Pandorina morum* | Pamo | 28.1 | 3.7 | 25.8 | 9.1 | 65.1 | 16.1 | 129.0 | 291.6 | 44.0 | 94.3 | 19.3 | 49.6 |
| *Pediastrum boryanum* | Pebo | 22.2 | 7.1 | 22.5 | 27.2 | 21.9 | 32.6 | 753.6 | 493.3 | 96.1 | 44.2 | 36.9 | 26.5 |
| *Pediastrum duplex* | Pedu | 24.0 | 6.2 | 20.3 | 11.2 | 26.4 | 35.6 | 393.0 | 344.0 | 175.7 | 198.8 | 72.8 | 60.7 |
| *Pediastrum integrum* | Pein | 27.8 | 3.7 | 59.4 | 9.1 | 12.4 | 16.1 | 1360.0 | 291.6 | 120.0 | 94.3 | 68.9 | 49.6 |
| *Pediastrum simplex* | Pesi | 21.4 | 5.4 | 12.1 | 9.6 | 4.6 | 1.4 | 618.9 | 286.4 | 227.4 | 184.7 | 139.0 | 120.6 |
| *Peridiniopsis cunningtonii* | Pecu | 28.0 | 0.1 | 22.9 | 4.0 | 67.5 | 3.2 | 196.8 | 92.6 | 38.3 | 7.8 | 15.5 | 5.2 |
| *Peridinium cinctum* | Peci | 16.3 | 2.5 | 2.8 | 9.1 | 1.6 | 1.3 | 713.9 | 272.2 | 119.5 | 21.2 | 29.1 | 18.4 |
| *Pleurosigma acuminatum* | Plac | 27.8 | 3.7 | 59.4 | 9.1 | 12.4 | 16.1 | 1360.0 | 291.6 | 120.0 | 94.3 | 68.9 | 49.6 |

| Table 4 continue | | Temperature | | $BOD_5$ | | TOC | | TKN | | TP | | $P\text{-}PO_4$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ |
| *Pseudoanebena catenata* | Psca | 17.6 | 3.7 | 6.4 | 9.1 | 5.2 | 16.1 | 550.0 | 291.6 | 130.0 | 94.3 | 75.4 | 49.6 |
| *Scedenasmus falcatus* | Scfa | 12.5 | 3.7 | 9.9 | 9.1 | 13.8 | 16.1 | 1018.0 | 291.6 | 80.0 | 94.3 | 64.0 | 49.6 |
| *Scedenesmus dispar* | Scdi | 17.6 | 3.7 | 6.4 | 9.1 | 5.2 | 16.1 | 550.0 | 291.6 | 130.0 | 94.3 | 75.4 | 49.6 |
| *Scenedesmus acutus* | Scac | 22.8 | 9.1 | 13.6 | 11.6 | 43.1 | 46.6 | 239.8 | 35.4 | 205.1 | 301.9 | 67.6 | 97.6 |
| *Scenedesmus communis* | Scco | 22.0 | 6.3 | 14.0 | 10.9 | 22.3 | 27.5 | 438.8 | 275.4 | 142.0 | 158.2 | 53.3 | 53.2 |
| *Schoderia setigera* | Scse | 14.0 | 3.7 | 2.8 | 9.1 | 2.8 | 16.1 | 464.0 | 291.6 | 100.0 | 94.3 | 46.0 | 49.6 |
| *Straurastrum gracile* | Stgr | 28.1 | 0.1 | 23.6 | 4.0 | 66.9 | 3.2 | 180.7 | 92.6 | 39.7 | 7.8 | 16.4 | 5.2 |
| *Tetraedron minimum* | Temi | 27.1 | 1.5 | 17.1 | 5.2 | 42.2 | 46.1 | 533.9 | 459.6 | 86.5 | 89.8 | 47.0 | 58.7 |
| *Tetrastrum elegans* | Teel | 14.0 | 3.7 | 2.8 | 9.1 | 2.8 | 16.1 | 464.0 | 291.6 | 100.0 | 94.3 | 46.0 | 49.6 |
| *Ulnaria biceps* | Ulbi | 12.5 | 3.7 | 9.9 | 9.1 | 13.8 | 16.1 | 1018.0 | 291.6 | 80.0 | 94.3 | 64.0 | 49.6 |
| *Ulnaria ulna* | Ulul | 17.6 | 5.3 | 6.7 | 6.9 | 14.5 | 27.4 | 353.2 | 160.0 | 249.2 | 218.5 | 118.5 | 117.5 |
| *Ulothrix subconstricta* | Ulsu | 28.1 | 3.7 | 25.8 | 9.1 | 65.1 | 16.1 | 129.0 | 291.6 | 44.0 | 94.3 | 19.3 | 49.6 |
| | | RMSE | 1.22 | | 1.91 | | 4.72 | | 102.09 | | 44.32 | | 20.53 |
| | | R2 | 0.96 | | 0.98 | | 0.96 | | 0.92 | | 0.92 | | 0.87 |

Table 5

*Medpit, PTI and Ecological Status of The Reservoirs*

| Reservoir | MedPTI | Ecological status | PTI | Ecological status |
|---|---|---|---|---|
| Bayramiç Reservoir | 2.73 | Good | 2.30 | Moderate |
| Ayvacık Reservoir | 3.30 | Good | 2.14 | Good |
| Sevişler Reservoir | 2.59 | Moderate | 2.32 | Moderate |

The Figure 4 indicated the relationships between logTP and the phytoplankton based indices. It is shown in this figure that the indices had a well-fitting with logTP. However, the highest coefficient of determination ($R^2 = 0.962$) showed that PTI was more competitive and had a remarkable correlation with logTP than Med-PTI (Figure 4a).

## Discussion and Conclusion

### Physical and Chemical Parameters

Spatial and temporal changes were observed in physicochemical variables of three reservoirs during the study period. The reservoirs showed alkaline water with pH ranged from 8.7 to 8.8. These pH values were higher than the mean pH value found at Alleben Reservoir (Çelekli and Öztürk, 2014) and similar to those found at İkizcetepeler Reservoir by Sevindik et al. (2017) in Turkey. The highest conductivity (434.5 µS $cm^{-1}$) and salinity (0.21 ppt) were measured at Sevişler Reservoir. These means conductivity were higher than those found at Pampulha Resevoir in Brazil (Figueredo and Giani, 2001) and similar to those of Sau Reservoir, a deep Mediterranean reservoir located in northeast Spain (Becker et al. 2010). With regard to nutrients, the TP values which ranged from 105.8 µg $L^{-1}$ to 203.5 µg $L^{-1}$ at studied reservoirs were higher than those the mean TP reported by Marchetto et al. (2009) for deep Reservoirs in Italy such as Cedrino, Cuga, Sos Canales, Pattada and Temo Reservoirs during the year 2006 and Valparáıso Reservoir (Negro et al., 2000) Spain. The values of TN ranged from 681.8 µg $L^{-1}$ to 1012.0 µg $L^{-1}$ were too higher than the mean TN reported by Chen et al. (2009) for Zeya reservoir in China. These high nutrients coming from especially anthropogenic activities such as agriculture, sewage discharge in surrounding areas and excessive net-cage fish farming in reservoir mainly impacted the reservoirs (Wetzel 2001).

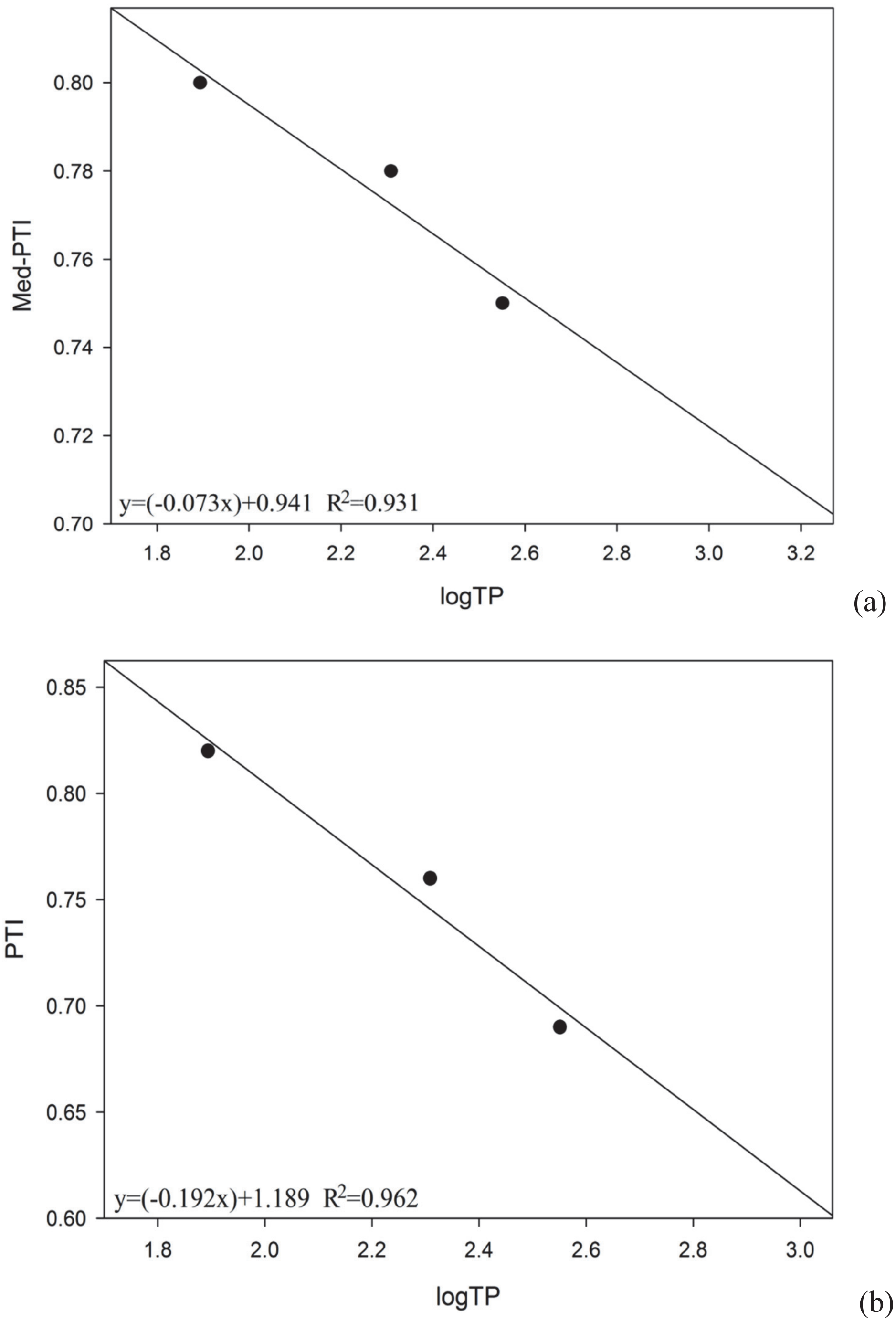


*Figure 4.* Relationship between logTP a) MedPTI and b) PTI in the reservoirs.

## Phytoplankton Composition and Their Environmental Relationships

During the present study, Bacillariophyta was the most dominant group in the phytoplankton composition. Dominancy of this group in phytoplankton community is also agreement with previous studies in Valparáiso Reservoir (Negro et al. 2000), El Gergal Reservoir (Hoyer et al. 2009) Spain, Marathonas Reservoir (Greece) (Katsiapi et al. 2011), Paraja limno-Reservoir in Spain (Molina-Navarro et al. 2014) and in Alleben Reservoir by Çelekli and Öztürk (2014) and İkizcetepeler Reservoir by Sevindik et al. (2017) in Turkey.

Multivariate analyses (CCA and WA) indicated that *S. communis, C. placentula*, *Cyclotella meneghiniana*, *U. ulna* and *P. simplex* were associated with high nutrients (TP) concentrations. *C. meneghiniana* was considered as a pollution tolerant species (Venkatachalapathy and Karthikeyan, 2013; Wang et al. 2014) and as species typical of polluted environments (Van Dam et al. 1994; Salomoni et al. 2006). *P. simplex* occurs in the freshwater plankton of various eutrophic reservoirs from neutral to alkaline water bodies (Komàrek and Jonkovskà, 2001; Pasztaleniec and Poniewozik, 2004). According to Krammer and Lange-Bertalot (1991a), *U. ulna* has been adapted to different ecological conditions. *S. communis* was indicated to have a wide distribution in freshwaters, mainly in those with moderate temperature and in the slightly eutrophicated ones (Hegewald, 1977; Bica et al. 2012).

## Ecological Status and Water Quality

Ecological status of lentic ecosystems can be assessed using phytoplankton biovolume and composition as metrics (EC, 2009; Poikane et al. 2011; Phillips et al. 2013). In the present study, the water quality of the reservoirs was evaluated by the use of phytoplankton metrics such as the Mediterranean phytoplankton index (Med-PTI) (Marchetto et al. 2009) and the phytoplankton trophic index (PTI) (Philips et al. 2013). Two ecological statuses (good and moderate) were recorded for the reservoirs during the study period.

The good ecological status recorded at Ayvacık Reservoir based on Med-PTI (3.30) and PTI (2.14). This status could be a consequence of the low land use for agriculture which generates inorganic and organic nutrients and the low free to roam through the water bodies of organic pollutants generated from human activities. Besides, Ayvacık Reservoir is a newly constructed reservoir and was not be affected by natural eutrophication. This ecosystem is especially affected by water fluctuation for irrigation purposes. Similar ecological status, using PTI and Med-PTI was previously found in Mediterranean reservoirs such as Sau Reservoir (Spain) (Becker et al. 2010) and Pareja limno-reservoir (Spain) (Molina-Navarro et al. 2014). On the other hand, the input of wastewater and the organic pollutants generated by agricultural activities, and fish farming could be the causes of the moderate states observed Sevişler Reservoir based on Med-PTI (2.59) and PTI (2.32) indices. Furthermore, this reservoir is an old reservoir in the North Aegean River Basin, it was constructed in 1987, and its water level fluctuated and decreased to 5 m in the summer due to irrigation. Its water quality could also be affected by the natural accumulation of sediments coming from the catchment area. The moderate ecological status was found to be similar with status of deep Mediterranean reservoirs (Italy) (Marchetto et al. 2009), some lakes in Europe (Philips et al. 2013) and the Alleben Reservoir in Turkey (Çelekli and Öztürk, 2014) which indicated similar physicochemical characteristics. Furthermore, the significant positive relationship between PTI and TP observed during the present study was previously found in European freshwater bodies (Philips et al. 2013). This indicated that PTI as a metric can be used to assess water quality of lentic ecosystems.

With regard to EQR, Bayramiç Reservoir had two ecological status (moderate or good) with a good water quality (2.73) based on Med-PTI and a moderate water quality (2.30) based on PTI. Both indices showed same ecological status for Ayvacık Reservoir with a good status and Sevişler Reservoir with moderate status. This change in water quality could due to the water retention time which could a key factor in seasonal changes for physicochemical variables (Çelekli and Öztürk, 2014). Previously, Straškraba (1999) demonstrated the influence of water retention on the vertical stability of reservoirs. According to Soares (2008), despite the similarities between reservoirs, which are in the same geographical region with similar climate, and are comparable in size, the distinct watershed features and water retention time could be responsible for marked differences between these reservoirs.

Multivariate approaches indicated that phytoplankton composition and distribution were mainly governed by environmental factors by TP, DO, TKN, $BOD_{5,}$ TOC and temperature. The first two CCA axes explained 31% of cumulative percentage variance of species data with 97.7% between species-environment correlations during the study period. With regard to the ecological status, values of the Med-PTI indicated good quality waters for Ayvacık and Bayramiç Reservoirs, while Sevişler Reservoir had a moderate water quality. Based on the PTI, Bayramiç and Sevişler Reservoirs were classified as or moderate ecological status, while Ayvacık Reservoir indicated a good water quality. From these results, the Med-PTI and the PTI seem to be appropriate metrics for assessing the ecological status of the reservoir.

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**Extended Turkish Abstract**
**(Genişletilmiş Türkçe Özet)**

**Su Kalitesinin Biyolojik Değerlendirmesi: Üç Ege Barajının Fitoplankton Metriklerine Dayalı Ekolojik Durumu**


Su kalitesinin insan yaşamındaki önemi büyüktür. Gün geçtikçe antropojenik etkilerin artmasıyla birlikte Avrupa'da ve dünyada bulunan birçok baraj gölündeki su kalitesi kötüye gitmektedir. Azot ve fosforun su kütlelerindeki artışıyla birlikte ötrofikasyon meydana gelmekte ve su kalitesinin yanında birçok sucul ekosistem bu durumdan etkilenmektedir. Bu yüzden Avrupa Birliği Su Çerçeve Direktifi (SÇD) ile su kütlelerinin durumunun fitoplankton, fitobentoz, makrofit, makroomurgasız ve balık gibi birçok biyolojik kalite bileşeni ile değerlendirilmesi zorunlu hale getirilmiştir.

Su Çerçeve Direktifi'nin uygulanmaya başlamasıyla birlikte su kalitesinin değerlendirilmesi büyük önem kazanmıştır. Fitoplankton SÇD'ye göre özellikle durgun sularda su kalitesi değişimlerinin gözlenmesinde kullanılan önemli bir indikatördür. SÇD'nin uygulanması maksadıyla Avrupa'da su kalitesinin değerlendirilmesi için fitoplankton indeksleri geliştirilmektedir. Akdeniz Fitoplankton Trofik İndeksi (Med-PTI) ve Fitoplankton Trofik İndeksi (PTI) geliştirilen indeksler arasında en yaygın kullanılan indekslerdir. Bu çalışmada, Türkiye'nin Kuzey Ege Nehir Havzası'nda bulunan üç baraj gölünde (Bayramiç, Sevişler ve Ayvacık) öncelikli olarak fitoplankton kompozisyonu belirlenmiş, fitoplankton kompozisyonu ve çevresel faktörler arasında ilişki kurulmuş ve nihai olarak su kalitesi Akdeniz Fitoplankton Trofik İndeksi (Med-PTI) ve Fitoplankton Trofik İndeksi (PTI) kullanılarak değerlendirilmiştir.

Fitoplankton örnekleri üç baraj gölünden 2014 ve 2015 yaz dönemi arasında mevsimsel olarak toplanmıştır. pH, iletkenlik, tuzluluk, çözünmüş oksijen ve sıcaklık parametreleri arazide ölçülmüştür. Toplam azot, nitrat azotu, nitrit azotu, amonyum azotu, toplam Kjeldahl azotu, toplam fosfor, ortofosfat, biyolojik oksijen ihtiyacı ve toplam organik karbon standard metotlar kullanılarak laboratuarda ölçülmüştür. Fitoplankton taksonları kameralı ışık mikroskobu ile ilgili teşhis kitapları kullanılarak teşhis edilmiştir. Fitoplankton sayımları invert mikroskop yardımı ile Utermöhl metoduna göre gerçekleştirilmiş ve geometrik şekillerden faydalanılarak fitoplankton biyohacimleri hesaplanmıştır. Kanonik Uyum Analizi (CCA) CANOCO 4.5 programı, Weighted Average regresyon analizi ise CALIBRATE yazılımı ile gerçekleştirilmiştir.

Üç barajın da suları alkali özellik göstermiştir. En yüksek nutrient değerleri olarak Bayramiç Barajı'nda TP 203,5 µg $L^{-1}$ olarak ölçülmüşken Sevişler Barajı'nda TN 1012,0 µg $L^{-1}$ olarak ölçülmüştür. Toplamda 120 fitoplankton türü teşhis edilmiş ve teşhis edilen türlerin çoğunluğu diyatomeler ile temsil edilmiştir. Fitoplankton türleri ve çevresel değişkenler arasındaki ilişki multivaryete analizler ile incelenmiştir. Fitoplankton kompozisyonu ve dağılımı çevresel değişkenler ile uyumlu çıkmıştır. TP, P-PO4, TKN, BOİ5, TOC ve sıcaklık en önemli faktörler olmuştur. İlk iki CCA ekseni tür verisinin kümülatif yüzde varyansının %31'ini %97,7 tür-çevre korelasyonu ile açıklamış ve durum Monte Carlo testi (p= 0,002, $F$ = 1,157) ile doğrulanmıştır. *Ceratium furcoides*, *Merismopedia glacua*, *Coelastrum astroideum*, *Closterium dinae*, *Mougeotia gracilima*, ve *Tetraedron minimum* türleri yüksek sıcaklık ve toplam organik karbon ile ilişkilendirilirken, *Cocconeis placentula*, *Cyclotella meneghiniana, Cymatopleura elliptica*, *Gomphonema parvulum, Navicula capitatoriata, Pediastrum simplex,* ve *Ulnaria ulna* türleri toplam fosfor ve ortofosfat ile ilişkilendirilmiştir.

Ağırlıklı ortalama rekrasyon analizi sonuçlarına göre; *Scenedesmus communis, Cocconeis placentula*, *Cyclotella meneghiniana*, *Ulnaria ulna*, *Gomphonella parvula*, *Pediastrum simplex*, *Scenedesmus acutus* türleri yüksek toplam fosfor ve ortofosfat toleransına sahipken, *Straurastrum gracile*, *Peridiniopsis cunningtonii*, *Peridinium cinctum*, *Melosira lineata* and *Cryptomonas erosa* ise düşük toplam fosfor tolerans değerlerine sahip çıkmıştır. *Tetrastrum elegans*, *Schoderia setigera*, *Geminella interrupta*, *Cymatopleura elliptica*, *Closterium gracile* ve *Chlamydomanas globasa* yüksek toplam azot ile ilişkilendirilmiştir. *Scedenasmus falcatus, Nitzschiana calida, Dinobryon divergens* türleri sıcaklık açısından en düşük optima değerine (12.5 °C) sahipken *Ulothrix subconstricta*, *Straurastrum gracile*, *Pandorina morum*, *Navicula trivialis*, *Mougeotia elegantula* sıcaklık açısından en yüksek optima değerine (28.1°C) sahip çıkmıştır.

Med-PTI ve PTI İndeksleri sonuçlarına gore, Med-PTI Ayvacık ve Bayramiç Baraj Gölleri için iyi su kalitesini gösterirken Sevişler Baraj Gölü'nü orta su kalitesinde indike etmiştir. PTI İndeksi'ne gore Bayramiç ve Sevişler Barajı orta ekolojik durumda sınıflandırılmışken Ayvacık Barajı iyi su kalitesinde indike edilmiştir. Sonuçlara gore, Med-PTI ve PTI'nin Kuzey Ege Havzası'nda bulunan baraj göllerinin su kalitesinin değerlendirilmesinde uygun metrikler olduğu görülmüştür.

*Review Article*

# Permanent Solution to Water Conservation: Educating Responsible Citizens from All Ages

# Suyun Korunmasında Kalıcı Çözüm: Her Yaştan Sorumlu Yurttaşların Eğitimi

Özlem Sıla OLĞUN

*Ministry of Forestry and Water Affairs, General Directorate of Water Management, Ankara, The Republic of Turkey*

osolgun@ormansu.gov.tr

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**Abstract**

This study was conducted to review current research about water and environmental education and to discuss what educators can do for teaching responsible citizens variables to conserve water and environment. Literature was reviewed for this study. In this resepect, It was reviewed within four main topics: Responsible citizenship variables in water and environmental education; studies about water related environmental science literacy; teaching methods used in water and environmental education; studies conducted about water and environmental education in Turkey. The results of the study have shown that there are many important responsible citizenship variables such as having emphathetic perspective about environmantal problems, having active role in environmental issues, having awareness about these issues, having self esteem to solve issues, understanding recycling waste management issues… The results also indicate that the characteristics of water, the hydrological cycle, the conservation of matter and the nature of the scientific processes are abstract and difficult to understand by the individuals. The other important results are that education provides the most important solution for preventing environmental problems before it emerges; many research conducted on environmental education in Turkey have concerned the attitude of students toward the environment; educators should implement student-centered teaching methods that enhance active involvement of individuals in water and environmental issues. I beside developing cognitive skills such as literacy about environmental issues, affective skills, such as emphatic perspective toward environmental issues, values and attitudes toward water and environment should be integrated into school curriculum for educating responsible citizens from all ages.

***Keywords:*** *Water conservation, environmental education, educating responsible citizens.*

**Öz**

Bu çalışmada, su ve çevre eğitimi ile ilgili güncel araştırmalar gözden geçirilerek bireylerde suyu ve çevreyi korumak için sorumlu vatandaşlık davranışları kaznadırmak maksadıyla su ve çevre eğitimi kapsamında neler yapabileceği tartışılmıştır. Çalışmanın metodu olarak literatür taraması yapılmıştır. Literatür taramasının dört ana başlığı bulunmaktadır: Su ve çevre sorunları konusunda sorumluluk sahibi vatandaşlık değişkenleri; su ve çevre bilimi okuryazarlığı ile ilgili çalışmalar; Su ve çevre eğitiminde kullanılan öğretim yöntemleri; Türkiye'de su ve çevre eğitimi üzerine yapılan çalışmalar. Çalışmada sonuç olarak, çevre sorunlarına karşı empati kurmak, çevre konularında aktif rol almak, bu konularda bilinçli olmak, çevre sorunlarını çözmede kendine güveninin olması, atık yönetiminin anlaşılması gibi birçok sorumlu yurttaşlık değişkeninin olduğunu görülrmüştür. Ayrıca, yapılan literatür çalışmasının çıktıları, bireyin su ve çevreyi korubilmesi için gerekli olan suyun özellikleri, hidrolojik döngü, maddenin korunumu ve bilimsel süreçlerin niteliği konularını anlamada güçlük çektiğini göstermiştir. Çalışmanın diğer sonuçları da; eğitimin, çevresel sorunların ortaya çıkmadan önlenmesi için en önemli çözümü sağladığı; sorumluluk sahibi yurttaş yetiştirmek için, bireyin su ve çevre konularında aktif katılımını artıran öğrenci merkezli öğretim yöntemlerinin uygulaması gerektiği; Türkiye'de çevre eğitimi ile ilgili yapılan çalışmaların çoğunun öğrencilerin çevreye karşı tutumları ile ilgili olduğu tespit edilmiştir. Sonuç olarak tüm yaştan su ve çevre korumaya sorumlu vatandaşlar yetiştirmek için su ve çevre konuları okur-yazarlığı gibi bilişsel becerilerin yanı sıra, çevre olaylarına karşı empatik perspektif geliştirmek, çevre olaylarına karşı empati geliştirmek, su ve çevreye yönelik değerler ve tutumlar gibi duyuşsal becerilerde okul müfredatına entegre edilmelidir.

***Anahtar sözcükler:*** *Suyun korunması, çevre eğitimi, sorumlu vatandaş yetiştirilmesi.*

## Introduction

Education is a systematic process through which a child or an adult acquires knowledge, experience, skill and attitude. It makes an individual civilized, refined, cultured and educated. For a civilized and socialized society, education is the only means (Parankimalil, 2012). Hungerford and Volk (2013) imply that fundamental aim of education is shaping human behavior. Human societies establish educational systems in order to develop responsible citizen who will behave in desirable ways. In education, some of the desired behaviors are sharply defined, e.g., skills useful in reading and mathematics. Other desired behaviors are more complex, e.g., concious consuerism, productive employment, responsiple citizenship behavior.

Individuals having responsible citizenship behaviour help people and the planet, have knowledge about their role in their communities, their country, and their world. Therefore, they participate in activities that make their world a better place by solving environmental problems. Hungerford and Volk (2013) defined environmentally responsible citizens as one who has (1) an awareness and sensitivity to environment and its problems and issues (2) a basic understanding of environment and its problems and issues, (3) having concern for the environment and motivation for actively participating in environmental protection, (4) skills for identifying and solving environmental problems and issues, and (5) active involvement at all levels in working toward solution of environmental problems and issues.

An early and widely accepted model for environmental education has been described as: "Increased knowledge leads to favorable atitudes… which in turn lead to action promoting better environmental quality" (Ramsey and Rickson 1976). However, recent research argue that environmental education should not only advocate a particular viewpoint or course of action, but also it should teach citizens how to weigh various sides of an issue through critical thinking and it enhances their own problem-solving and decision-making skills. Study conducted by Covitt, Gunckel and Anderson (2009) descibed the goal of environmental education is to aid citizens in becoming environmentally knowledge-able and, above all, skilled and dedicated citizens who are willing to work, individually and collectively, toward achieving and/or maintaining a dynamic equilibrium between quality of life and quality of the environment. That is, most educators firmly thought that, if we teach learners about something, behavior can be modified. In some cases, perhaps, this is true. However, in educating for generalizable responsible environmental behavior, the evidence is to the contrary. Issue awereness does not lead to behavior in the environmental dimention. Environmental issues that must be resolved through investigation, evaluation, values clarification, decision making, and finally, citizenship action.

Teaching responsible citizenship skills to conserve water and environment require different instructional practices. Therefore, it is necessary to introduce current research about water and environmental education and to discuss what educators can do for teaching responsible citizens variables. For this reason, this study has conducted to review current research about water and environmental education and discussed how to improve education that enhances individual's responsibility about water and environmental conservation.

## Method

Literature was reviewed in this study. Review has four main topics: Responsible citizenship variables in water and environmental education; studies about water related environmental science literacy; Teaching methods used in water and environmental education; studies conducted about water and environmental education in Turkey.

### Responsible Citizenship Variables in Water and Environmental Education

Studies carried out by Hines et al. (1986/1987) categorized the environmental education variables that contribute to responsible citizenship behaviors: (1) entry-level variables, (2) ownership variables and (3) empowerment variables. Entry-level variables enhance a person's decision making. One of these variables are environmental sensetivity which is defined as an empathetic perspective toward the environment. Other entry-level variable androgyny is a variable that describes individuals who are active in helping solve environmental issues. One of the other variable is knowledge of ecology that refers to an ecological conceptual basis for decision-making, e.g., concepts associated with population dynamics, nutient cycling, succession, homeostasis etc. Attitudes toward pollution technology economics are variables that have shown themselves to be significant in some of the research.

Second level variables are ownership variables. The individual having these variable owns the issues, i.e., the issues are extremely important, at a personal level. In-depth knowledge (understanding) of issues appears crucial to ownership. Before individuals can engage in responsible citizenship behavior, they must understand the nature of the issue and its ecological and human implications. When indviduals have an in-depth understanding of issues, they appear more inclined to take on citizenship responsibilty toward those issues.

Next ownership variable is personal investment. In that case, the individual is strongly related with the environmental issue because person has a special interest in it. For example, an individual who thoroughly understands the economics of recycling and who uses a substantial amount of recyclable material and who might feel a substantial personal economic invesment in recycling. However, the motivation might not necessarily have to be economic, it could be environmental in nature if the person has good ecological concepts about waste disposal, biodegradabilty and nutrient cycles and undestands the broad human involvement in these things. Recycling might become a strong personal need which could be translated as "personal investment"

Third level variables are empowerment variables that are crucial in the training of responsible citizens. These variables give human beings a sense that they can make charges and help solve important environmental issues. One empowerment variable is perceived skill which can be translated as human beings believing that they have the "power" to use citizenship to help resolve issues. Traning also results in improved students' self concepts and a belief that they have been more fully incorporated into society.

Knowledge of environment action strategies is that the skill component is dependent on the knowledge variable. In the studies that examined behavior, learners gained an in-depth knowledge of issues as well as learning about action strategies. Thus, it would appear unlikely that citizenship action skills taught without issue related knowledge would prompt responsible behaviour in individuals (Holt 1988).

Locus of control refers to an individual's belief in being reinforced for a certain behavior. A person with an internal locus of control expects that she/he will experience success or somehow be reinforced for doing something. Success, in turn, appears to strengthen his/her internal locus of control. On the other hand, a person with an external locus of control does not believe that he/she will be reinforced for doing something and therefore, probably will not do it. An individual who believes that he/she has good fishing skills is more likely to attempt fishing because there is an expectation of success or reinforcement for this behaviour. This person has an internal locus of control for fishing.

An individual who believes that he/she is powerless to make changes in society probably will not act in a citizenship dimention. There is no expectation of success or reinforcement for acting. This person has an external locus of control for trying to help resolve environmental issues. An improved locus of control may well result when students have had an oppotunity to apply these skills successfully in the community.

Intention to act seems also related to the empowerment variable. If a person intends to take some sort of action, the changes of that action occurring are increased. It is likely that this variable is closely related to both perceived skills in taking action and locus of control. Intention to act may also share a synergistic relationship with personal investment.

Other study conducted by Barr (2003) mentioned about campaing, DEFRA 2002, using a range of media to disseminate environmental information. It focused five environmental behavior: Water conservation, energy saving, sustainable transport use, waste management and noise reduction. Citizens are urged to find out the "facts" and increase their awareness by appreciating the various saving that can be made by, for example, switching off lights or using a water butt. The campaing helpfully recognizes the significance of the need for incentives and the necessity for environmental action to be seen as normative behaviour alongside awareness raising.

One other research carried out by Burgess et al (1998) argued that sustainability is predicated on the belief that individuals and institutions can be persuaded to accept responsibility for the production of environmental problems and change their everyday practices to alleviate future impacts. They also argued that behaviour is dependent on a greater range of influences than merely a linear process of information to action, which seeks to fill the "value action gap" in system that has been described as AIDA (Awareness-Information-Decision-Action). In the study, Barr (2003) summarized the three factors influence environmental actions as: Social and environmental values; situational factors and psychological variables. The research presented in this paper indicated that waste minimalization and recycling behaviours have widely differing antecedents. In terms of recycling, high level were achieved when convenience was maximized, effort minimized and subjective norms activated. From the recycling viewpoint, individuals appear to be well aware of the need to recycle and generally do so if given the means. The data show that recycling is well accepted by citizens as an actively that is worth undertaking, so long as the means exist. In contrast, waste minization behaviour is far more infrequent than recycling and apears to be dependent on various value-based and demographic criteria. The evidence presented therefore, points to three flaws in assuming that increasing awereness of environmental problems can change behaviour. In the first instance, behaviour is contingent upon at least three alternative sets of factors: Personel situation, psychological perception and personality characteristics, and finally environmental values. The second flaw relates to the first in that alternative behaviours, even within the same behavioural realm (such as waste management) have divergent antecedents. The third flaw relates to the implementation of policy in particular awareness campaigns that take little acount of the demographic trends in environmental behaviour.

**Studies about Water Related Environmental Science Literacy**

Environmental science literacy is defined as the capacity to understand and participate in evidence-based decision making about the effects of human actions in environmental systems. The need for an environmentally literate citizenry is evident given the scientific concensus that human populations are fundamentally altering the natural systems that sustain life on Earth. Today, all, citizens need to be able to understand environmetal issues and make informed decisions that will help maintain and protect Earth’s life supporting systems. For example, individuals should be able to trace water and the materials that water carries through visible and invisible parts of systems. Water can become invisible as it goes underground or evaporates, invisible parts of systems, and it can become visible as it comes up through springs or condenses into precipitation. Similarly, materials in water can take both visible (e.g., sediment, trash) and invisible (e.g. bacteria, dissolved pollutants) forms. As water and other materials cross the boundaries between visible and invisible, they do not cease to exist, and they can be traced through systems in their invisible and visible forms (Coyle, 2005).

Another supportive research was conducted by Covitt, et al. (2009) developed a framework of emprically grounded cirricular goals for water-science literacy and documented the challenges that students face in achieving these goals. Water related environmental science literacy requires an understanding of multiple issues ranging from atomic-molecular (changes of state and solutions) to large (watersheds, aquifers and human water-purification and distribution systems). Yet, the authors found that most students do not systematically trace water and other materials through systems and do not account for invisible aspects of water systems at the atomic molecular and landscape scales. The authors discuss curricular implications and the importance of helping students develop a richer understanding of water systems. They came to appreciate that describing visible movements of water is not the same as tracing water or materials that it carries through connected systems. Students who reasoned informally fail to account for water after it is no longer visible (e.g., when the ground soaks it up or when it runs off or evaporates).They also show little awareness of parts of systems that are too small (e.g., molecules in solution) or too large (watersheds) to be readily visible. On the other hand, environmentally literate citizens can systematically account for water that enters a system (e.g. watershed); every molecule that enters will stay in the system until it leaves, and individuals can trace all those molecules through the system. Likewise, they can systematically trace materials in water-such as pollutants and sediments-as they enter, travel with, and separate from water.

The study conducted by Sobel, Vo, Alred, Dauer and Fores (2017) was about students' scientifically informed decision making about socio-hydrological issues. They mentioned that students need to understand the properties of water and the nature of scientific processes and practices in order to engage effectively with contemporary water-related challenges with scientific and social dimentions. However, students have difficulty in understanding core hydrologic concepts, and more work is needed to determine how they structure their decision making about socio-hydrological issues. In their study, they investigated undergraduate students' decision making with a focus on the resources to make and support their decisions about socio-hydrological issues. They showed that students more effectively form a clear and consistent decision than support their decision with accurate scientific information statements or provide support for their opinion statements. Their findings of the study provide understanding of the development of scientific literacy and engagement with decision making about socio-hydological issues among undergraduate students. As a result of their study, existing literature was improved by offering a frame by which students can learn to engage in decision making and preliminary analysis of how introductory students consider decision making about socio-scientific issues as a foundation for more work to advance these skills.

Having a connected understanding of water in environmental systems is one important aspect of responsible environmental decision making. Although other aspects including understanding of social and economic systems and personal values and practices are also important (Dietz, 2003), a fundamental understanding of water in environmental systems is essential in helping citizens reason effectively about how human actions impact natural and environmental systems services. Consequently, water science literacy is central to preparing citizens to make informed decisions. Author's research on students' understandings shows that individuals are not developing fundamental water literacy in school. K-12 standart science curriculum does not support students in developing their literacy about water in connected natural and human-engineered systems. Although many domains need to be adressed in prearing students for citizen responsibilities, educators cannot neglect the importance of building a strong K-12 science curriculum and teaching methods that provides students with the tools necessary for making informed decisions.

**Teaching Methods Used in Water and Environmental Education**

Different kinds of teaching methods are used for water and environmental education. Study conducted by Middlestadt et al. (2001) examined the effect of recommendation water conversation at the household level and impact of using interactive teaching methods to promote conservation behaviors among students and their families. Comparisons were made among 671 students (424 experimental, 247 control) belonging to high school eco-clubs in central Jordan. Most students were girls in rural settings. The experimental group consisted of students whose teachers implemented an interactive curriculum and promoted household water-conservation behaviors. Teachers of students in the control group did not participate in curriculum implementation, but those students were exposed to lectures about biodivesity issues. The results indicated that students who were exposed to the new curriculum demonstrated a higher level of knowledge about water conservation and performed recomended behaviors more often than students in the control group.

One another teaching method implemented for improving water awareness is modeling. It is a core scientific practice for learners in conceptualizing, investigating and explaining natural phenomena and persuading others about their conclusion (Gilbert, 2004). Past research has highlighted the challenges elemantary students experience when engaging in modeling (Lehrer & Schauble, 2010). When elementary students are provided both curricular and instructional supports to engage in the practice of modeling, they can learn to use models effectively to reason about complex processes and the dynamics that underlie large-scale systems. One such systems is te hydrologic cycle, a core topic introduced in the elementary grade (NGSS Lead States, 2013). They concluded that students require opportunties to engage in the practices of modelling to learn about the hydrologic cycle. Similarly, Vo et al. (2015) carried out a study with elementary teachers. In their study they emphasized that elementary teachers play a crucial role in supporting students' model based reasoning about natural issues such as water cycle. They mentioned that little research existed about elementary teachers' learning to foster model centered, science learning environment. They conducted an study using qualitative research methods to investigate six 3rd-grade teachers' pedegogical reasoning and classroom instruction around modeling practice (construct, use, evaluate and revise) and epistemic considerations of scientific modelling (generality/abstraction, evidence, mechanism, and audience). Their study findings pointed out that all teachers emphasized a subset of modelling practices-construction and use- and the epistemic consideration of generality/abstraction. There was observable consistency between teachers' articulated conceptions of scientific modelling and their classroom practices. Another finding of the study indicated that a subset of the teachers more strongly emphasized additional epistemic considerations and, as a result, better supported students to use models as sense-making tools as wel as representations. These findings provide important evidence for developing elementary teacher support to scaffold students' engagement in scientific modelling.

One another study about teaching hydrologic cycle with modeling was conducted by Forbes, Zangoni and Schwarz (2015). In their study they mentioned that water was a crucial topic therefore, students should concern themselves articulation, negotiation, and revision of model-based explanations about hydrologic phenomena. However, past reseach has shown that students, particularly early learners, often try to understand hydrologic phenomena and that scientific modeling remains underemphasized in elementary science learning environments. For this reason, more research should be needed to understand and promote early learners' engagement in domain-specific modeling practices. To answer this need, they made use of design-based research to encourage and search 3rd-grade students' model-based explanations for the water cycle, They reported on the development of a set of emprically based learning performances that comrised K-12 grades. Second, they reported on findings from research investigating 3 rd-grade students' model-based explanations within the students generate and highlight both target concepts and modeling practices emphasized in students' model based expanation for hydrologic cycling.

Another study was conducted by Rosen, Scanlon & Smith (2007). They concerned about better ways to educate students about water because current education was failling to promote good decisions about water by citizens and political leaders. They emphazied that current education system create water savvy citizens of tomorrow who will take personal action to ensure effective stewardship of water support evidence-based water policies. Their study the Texas Aquatic Science Project and Curriculum arose after researchers learned that educational enhacements such as an instructonal video smart phone application, interactive learning game, or even many of these taken together, would have little effect on fulfilling the objective of Headwaters to Ocean Project to better educate students about water. Where there is no context for integrating use of technology-enhanced educational materials into a course of study, there will be little or no use by teachers or students. Their work indicated that building this context for education about water through Texas Aquatic Science would allow for the integration of technology-based educational products into teaching. But even more important, the new comprehensive curriculum would enable more effective teaching by teachers and better learning students about water in the classroom and through informal place-based experiental education.

**Studies Conducted about Water and Environmental Education in Turkey**

A wide range of solutions to environmental problems are proposed by many reseachers. Education provides the most important solution for preventing environmental problems before it emerges (Şimşekli 2001). Many reseachers in Turkey conducted study about students' attitudes towards the environment (Önder, 2015; Tuncer et.al., 2009; Kahyaoğlu, 2009). The attitudes affect how individual relate to the other people and to all our activities in the environment, and so have major influence on our prospects for achieving a sustainable water and environment. Having positive attitudes towards environmental protection can be seen as serious steps for problem solving. The study conducted by Önder (2015) examined the attitudes of primary school students toward environment in terms of gender, whether they live in a house with garden or not; they have pets or not, their schools have environmental clubs or not, if they are participated in the club activities or not, if they participate in the environmental or scout camps or not, whether they plant or not. Results showed that girls' environmental attitudes are more positive compared to the boys'. However, there is no signicant difference between the scores of boys and girls towards environment in terms of living in house with garden or not, having a pet or not, having clups at school or not. The findings also showed that the students who participate in club activities have more positive attitudes towards the environment compared to the students who do not participate in. In addition, the students' participation in environmental camp does not a cause a significant difference on their environmental attitudes. Also, there is no significant difference between the attitudes of the students who plant and do not plant. In their research Tuncer et. al. (2009) concluded that indivuduals are aware of the importance of environmental issues although they do not imply the awareness in their life style.

The study conducted by Kahyaoğlu (2009) argued that environmental problems cannot be solved by using techology and legislation, because solving these problems are related to attitudes and values of the people. In another study Gaye et al. (2009) investigated environmental literacy of pre-service teachers at public universities in Turkey. The results showed that environmental background of pre-service teachers is positively related to environmental literacy and students' attitudes in favor of gender. Taştepe and Aral (2014) studied with 3rd year undergrade child development students enrolled in the elective course "Child and Nature", for their evaluation of the course as wel as to reveal their perspectives on environmental awareness. The results of the study showed that while the "Cld and Nature" course sufficiently covers environmental problems, its shortage of lecture hours and lack of real life alication reduce the effectiveness of environmental problem coverage.

When looked studies searching about relationship between attitudes and students' age, it was advised that the environmental sensitivity of families ougth to be encouraged by implementing ecological activities from small aged children to elderly people (Kahyaoğlu, 2009). In his study Alim (2013) found that the third year students educated with basic concepts of the environment are more successful than the first year students who have not taken any course about the environment and showed the differences which can be accounted for the gender although it is a general concensus that these differences fade away depending on their attainment of the environmental education.

Beside to studies about students' attitudes, some studies are about the instructional methods used in environmental education in Turkey. For example, Kahyaoğlu & Kaya (2012) argued that lecturing is not enough to internalize the environmental issues. Currently, student in many schools of different countries are taught with active learning method rather than just lecturing knowledge. Eco-schools are example to these teaching method (Kahyaoğlu & Kaya, 2012) studied a water school workshop with students. The data were gathered through qualitative and quantitative instruments before and after the water school. The results showed that the water school is generally effective on the students' conception about water, attitudes toward water usage, awareness of environment and general opinions related to the water. Some other studies argue that developing students' sensitivity to the environment can be improved by cooperation with non-governmental organization (Taştepe & Aral, 2014; Kahyaoğlu & Kaya, 2012). In this context, UNESCO, UNEP, Ministry of Environment, Universities, Municipalities and some non-governmental organizations (NGOs) studied about environmental education in Turkey. Environmental issues covered in the education because curriculum is not enough for improving environmental awareness (Ünal et al., 1999, Külköylüoğlu, 2000, Kiziroğlu 2000, Şimşekli 2001). In this respect, Taştepe & Aral (2014) suggested to develop individual's environmental knowledge, skills and attitudes together with theoretical and active learning methods.

## Conclusion and Recommendations

Environmental problems grow gradually and their effects are felt in various ways. Among the various solutions offered to solve these problems, enhancing individual responsibility towards water and environmental issues has been considered as priority. Thus, education provides the most important solution for preventing environmental problems before it emerges (Şimşekli 2001). For this reason, teaching responsible citizens who have knowledge, experience, skills, values and attitude should be the primary goal to conserve water and environment.

The results of this study concerning environmental literacy show that the students who have difficulty in understanding core hydrologic concepts, water cycle, conservation of matter and water. Particularly, early learners often have difficulty in conceptialization and explaining water-related phenomena, for example groundwater and subsurface dimentions of the water cycle (Forbes, Zangori, & Schwarz, 2015). Students who reasoned informally fail to account for water after it is no longer visible (e.g., when the ground soaks it up or when it runs off or evaporates).Water can become invisible as it goes underground or evaporates, and it can become visible as it comes up through springs or condenses into precipitation. They also show little awareness of parts of systems that are too small (e.g., molecules in solution) or too large (watersheds) to be readily visible. On the other hand, environmentally literate citizens can systematically account for water that enters a system (e.g. watershed); every molecule that enters will stay in the system until it leaves, and individuals can trace all those molecules through the system. Likewise, they can systematically trace materials in water-such as pollutants and sediments-as they enter, travel with, and separate from water (Covitt et al, 2009). From these results it can be concluded that, all citizens need to be able to understand environmetal issues and make informed decisions that will help to maintain and protect Earth's life supporting systems. For this reason, they have to know complex and abstract issues for making decision and solving problems related with water and environment. In addition, current concepts such as, water footprinting, participation in decision making for environmental issues, polluter pays principle of environmental law, water treatment, the treatment stages of drinking water need to be embraced and have to be integrated into curriculum by considering students' conceptual level, for educating responsible individuals towards water and environmental conservation.

The results of the study concerning environmental objectives and variables have shown that there are many important responsible citizenship variables such as having emphathetic perspective about environmantal problems, having active role in environmental issues, having awareness about these issues, having self esteem to solve environmental issues, having perception that they can make charges and help solve important environmental issues, having improved self concepts and a belief that individuals have been more fully incorporated into society, locus of control, personel investment (Covitt, 2009), understanding waste management, waste minimalization and recycling (Burgess et. al,1998). It can be noticed that these variables are mostly related with emotions/affections and values.

These type of responsible citizen variables, can be developed by student-centered active learning methods such as video smart phone applications, interactive learning and modelling. They are suitable for water and environmental education

(Kahyaoğlu & Kaya, 2012; Taştepe & Aral, 2014,). On the other hand it should not be ignored that responsibility of individuals cannot occur without knowledge (Holt 1988). There is mutual interaction between teaching cognitive skills, such as, issue related knowledge and teaching emotional/affective skills.

The research about environmental education in Turkey mainly focused on emotional variable, the attitudes and awereness of students towards the environment and methods of teaching water and environmental issues (Çoban et. al. 2011; Kahyaoğlu & Kaya, 2012; Taştepe & Aral, 2014). They argued that The 2005 Science and Technology Course Curriculum, in which environmental education topics are given, is not designed to equip students about environmental issues (Taycı & Uysal, 2009). The results of this literature review also support this information and indicate that the instruction must go beyond an awareness or knowledge transfer thereof environmental issues should become an integral part of the instruction designed for behavioral change. In other words, objectives of instruction should encompass not only knowledge, attitudes, and skills, but also create emphatic perspective towards the environment and active participation in the society. Students must be given the opportunity to develop an environmental sense and are prompted to become responsible and active citizens.

**Recommendations for Teaching Responsible Citizenship**

Developing responsible citizenship needs to be taught fostering both cognitive and emotional/affective skills. For improving cognitive skills, educators should make deep content analysis to emerge what students know, which topics they have difficulty in and how to teach the difficult topics. Therefore, existing curriculum concerning about water and science issues should be analyzed in detail to find out what it is required in order to increase the number of water and science literate citizens. While arranging the water and environmental education, individual's cognive level should be considered from kindergarden to university, because students' from different ages have different conceptual understanding level (Ahioğlu-Lindberg, 2011). Therefore, curriculum should be designed with respect to conceptual level. Content should be organized from simple to complex, from concrete to abstract.

Educators should implement student-centered instructional methods that help citizens having a deeper understanding of water and environmental conservation and developing skills to make informed and responsible decisions such as hands-on, inquiry based, and applicable to life. For improving emotional/affective domains such as values and attitudes, students should participate actively to the learning process. For example, educators can hold a discussion on what citizenship means including the rights and responsibilities of the citizens. It should also be provided the environment where students share personal stories on solutions to water related and environmental problems. Encouraging to write a poem, story, play or song about citizenship are also good examples for teaching values and attitudes. In addition, the students can be asked to search for local citizens who contribute to the creative solutions to water and environmental problems. Motivating or honoring the students is another advisable way to teach values and attitudes. Individuals can be encouraged to read, analyze and debate on newspaper articles related to the topics concerning water and environment. Guest speakers may be invited to share their knowledge of water and environmental issues. Students should be encouraged to visit science museums and national parks. They may be motivated to participate in community service projects related to water and environmental issues.

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## Extended Turkish Abstract
## (Genişletilmiş Türkçe Özet)

### Suyun Korunmasında Kalıcı Çözüm: Her Yaştan Sorumlu Yurttaşların Eğitimi

Bu çalışmada, su ve çevre eğitimi ile ilgili güncel araştırmalar gözden geçirilerek bireylerde suyu ve çevreyi korumak için sorumlu vatandaşlık davranışları kaznadırmak maksadıyla su ve çevre eğitimi kapsamında neler yapabileceği tartışılmıştır. Çevre sorunlarına çok çeşitli çözüm yolları önerilse de sorunların kaynağında, ortaya çıkmadan önlenmesi en kayda değeridir. Bunun içinde en önemli faktörün eğitim olduğu birçok çevrelerce kabul edilmektedir. Bu nedenle çalışmada, su ve çevre eğitimi ile ilgili güncel araştırmalar gözden geçirilerek sorumlu vatandaşlar yetiştirmek maksadıyla su ve çevre bilimi eğitimi konusunda mevcut durum tespiti yapılmış eğitimcilerin neler yapılabileceği tartışılmıştır. Çalışmada yapılan literatür taramasının dört ana başlığı bulunmaktadır: Su ve çevre sorunları konusunda sorumluluk sahibi vatandaş değişkenleri; su ve çevre bilimi okuryazarlığı ile ilgili çalışmalar; su ve çevre eğitiminde kullanılan öğretim yöntemleri ve Türkiye'de su ve çevre eğitimi üzerine yapılan çalışmalar.

Çalışmada yapılan literatüre taraması sonucu, su ve çevre sorunlarına karşı sorumlu yurttaşlarda olması gereken davranışların su ve çevre olaylarına karşı empati kurmak, çevre sorunları hakkında aktif rol almak, bu konularda bilinçli olmak, çevre sorunlarını çözmede kendine güveninin olması, atık yönetiminin anlaşılması, su ve çevre sorunlarını çözebileceği ve değiştirebileceğini düşünmesi, sorumluluk alabilme algılamaları, önemli çevresel problemleri çözmeye yardımcı olma, kendine özgü konseptler geliştirme ve bu konudaki inançları geliştirme, kişisel yatırım, içsel motivasyon (Covitt, 2009), atık yönetimini, atıkların minimumlaştırılmasını ve geri dönüşümünü anlamak (Burgess ve diğerleri, 1998) gibi birçok önemli değişkenin olduğunu göstermiştir. Bu değişkenlerin birçoğu bilişsel olduğu kadar duyuşsal ve değerlerle ilgilidir.

Yapılan literatür taramasının çıktıları bireyin su ve çevreyi korubilmesi için gerekli olan suyun özellikleri, hidrolojik döngü, suyun gözle görülemeyen molekular özellikleri, suyun halleri, havza kavramı, maddenin korunumunu ve bilimsel süreçlerin niteliği konularını anlamada güçlük çektiğini göstermiştir. Örneğin, suyun yeraltına geçtiğinde ya da buharlaştığında görünmez olması ilkokul öğrencilerine anlaşılması zor gelmektedir. Bununla birlikte suyun gözle görülmeyen moleküler boyutu gibi suyla ilgili kavramların en büyük boyutu olan havza konusunu da anlamakta güçlük çekmektedirler. Fakat su ve çevre konularında okuryazar öğrenciler, her bir su molekülünün ekosisteme girmesini ve hareketini takip edebilecek yeteneğe sahip olduğu tespit edilmiştir. Ayrıca, suya kirletici olarak katılan materyalleri takip edebilmektedirler. Bu nedenle, suyun ve çevrenin korunması için bireylerin çevre konularını analiz edebilecek ve değerlendirme yapabilecek derecede bilgiye sahip olmaları gereklidir.

Sorumluluk sahibi vatandaş davranışlarını artırmak için bireyin su ve çevre konularında aktif katılımını ve karşılıklı iletişimi artıran, soyut kavramları somutlaştıran modellemeler gibi öğrenci merkezli öğretim yöntemleri uygulanmalıdır. Sonuç olarak, her yaştan sorumlu vatandaşlar yetiştirmek için su ve çevre okur-yazarlığı gibi bilişsel becerilerin yanı sıra, su ve çevreye yönelik değerler ve tutumlar gibi duygusal becerilerin okul müfredatına entegre edilmesi gereklidir. Ayrıca su ayak izi, suyun arıtımı, içme suyunun evlere ulaşana kadar geçtiği evreler, Çevre Kanunu'nda yer alan kirleten öder ve katılımcılık prensibi gibi bireylerin su ve çevrenin korunmasında aktif sorumluluk ve katılımını ön plana çıkaracak ve onları su ve çevre konularında bilinçli ve sorumlu bireyler haline getirecek konular, müfredata yerleştirilmelidir.

Çalışmanın diğer sonuçları da; eğitimin, çevresel sorunların ortaya çıkmadan önlenmesi için en önemli çözümü sağladığı; Türkiye'de çevre eğitimi ile ilgili yapılan çalışmaların çoğunun öğrencilerin çevreye karşı tutumları ile ilgili olduğu tespit edilmiştir. Sonuç olarak tüm yaştan su ve çevre korumaya sorumlu vatandaşlar yetiştirmek için su ve çevre konuları okur-yazarlığı gibi bilişsel becerilerin yanı sıra, çevre olaylarına karşı empatik perspektif geliştirmek, çevre olaylarına karşı empati geliştirmek, su ve çevreye yönelik değerler ve tutumlar gibi duyuşsal becerilerde okul müfredatına entegre edilmelidir. Sonuç olarak her yaştan su ve çevre konularına duyarlı ve sorumlu yurttaşlar yetiştirebilmek için geleceğin su ile ilgili karar mekanizmalarında yer alacak, geleceğin ebeveynleri olarak toplumu oluşturacak bireylerin, öğrencileri merkeze alan, bilişsel yetenekler kadar duyuşsal yetenekleri geliştirmeyi hedefleyen, doğaya ve insana duyarlı, değerleri ve tutumları ön plana alan bir eğitim sistemi ile eğitilmesi gereklidir.

*Research Article*

# Reservoir Operations & Water Allocation Model: New York City Delaware River Basin Reservoirs

# Rezervuar Operasyonları & Su Tahsisi Modeli: New York Şehri Delaware Nehir Havzası Rezervuarları

Burcu TEZCAN[1], Mira S. OLSON[2], Patrick GURIAN[2]

[1]*Ministry of Forestry and Water Affairs General Directorate of Water Management, 06510, Yenimahalle-Ankara-Turkey*
burcut@ormansu.gov.tr
[2]*Drexel University, Civil Architectural and Environmental Engineering, Philadelphia PA, USA*
mso28@drexel.edu, pgurian@drexel.edu
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**Abstract**

The New York City (NYC) reservoirs in the Delaware River Basin are essential sources for goods and services, such as drinking water supply, recreation, power generation, and a host of ecosystem services. The reservoirs are located at the headwaters of the Delaware River, which supply water to New York, New Jersey, Pennsylvania and Delaware. However, the river is vulnerable to water shortages under changing climate conditions and needs to be managed wisely. This study developed a hydrologic model within the Stella modeling software for the NYC reservoirs to determine how historical reservoir management policies perform at meeting water demands in the basin and out-of-basin. The model provides information to better understand the interconnected effects of demands from water use sectors under different climate conditions, and to help addressing water shortages under water-stressed conditions. The model simulates reservoir releases based on inflows to reservoirs, water demand by sectors and historical reservoir management policies. The model predictions were compared with historical data to assure that the model was operating in the designed manner. The impact of this study extends directly to decision makers for water resources management, and stakeholders who rely on water resources in the basin.

**Keywords***: water resources management, water allocation, stella modelling*

**Öz**

Delaware Nehir Havzası’nda bulunan ve New York şehrine içme ve kullanma suyu sağlayan rezervuarlar aynı zamanda enerji, ekosistem ve rekreasyon gibi sektörler için de önemli su kaynaklarıdır. Bu rezervuarlar Delaware Nehri’nin üst kısmında bulunmakta ve New York, New Jersey, Pennsylvania ve Delaware gibi önemli eyaletlere su temin etmektedir. Ancak, değişen iklim koşulları sebebi ile nehir susuzluk tehdidi altında kalmakta ve bu nedenle akıllıca yönetilmesi gerekmektedir. Bu çalışmada, Stella isimli bir yazılım programı kullanılarak New York rezervuarları için hidrolojik bir model geliştirilmiştir. Bu model sayesinde, rezervuar işletim kuralları Stella programına matematiksel denklemler kullanılarak girilmiş ve havza içi ve dışı su ihtiyacı belirlenmiştir. Ayrıca, farklı iklim koşullarında, havzadaki su kullanımının, sektörler üzerine etkileri daha iyi anlaşılmış ve olası kuraklık durumunda havzadaki su kıtlığı gibi problemler ele alınmıştır. Çalışılan modelde, rezervuarlara giren

su miktarı ve her bir sektörün su ihtiyacı ile rezervuar işletim kuralları baz alınarak, günlük deşarj edilen su miktarı belirlenmiş ve sahada ölçülen veri ile karşılaştırılmıştır. Bu çalışmanın etkisi su kaynaklarının yönetiminde karar vericiler ile havzadaki su kaynaklarına ihtiyaç duyan paydaşlara kadar uzanır.

***Anahtar sözcükler:*** *su kaynakları yönetimi, su tahsisi, stella modeli*

## Introduction

The Delaware River Basin (DRB) is located in New York, New Jersey, Pennsylvania, and Delaware, and it comprises an area of nearly 13,600 square miles (Figure 1). Most of the basin is forested and contains important ecological lands and water bodies that are vital for people and nature. The mainstream of the river begins in Hancock, NY, and flows 330 miles to the mouth of the Delaware River Bay where it enters to the Atlantic Ocean (TNC, 2011).


*Figure 1.* Delaware River Basin. Adapted from “Delaware River Basin Commission (DRBC) website” by DRBC, 1996 – 2018.

The priority of the reservoirs is water supply to NYC. The reservoirs are also essential source for goods and services to the DRB, and thus they provide water for downstream requirements, and to protect the environment and wildlife. Therefore, operation of the reservoirs includes daily decisions on how much water to deliver, release, and spill from each reservoir, as well as how much water to divert between reservoirs. These decisions are complicated sometimes due to a variety of competing demands, including municipal water supply demand, downstream ecological and human demands, flood control, and drought prevention (Mandarano et. al, 2013).

Moreover, climate change along with population growth and economic development has important effects on water resources, especially to the DRB rivers because the reservoirs in the DRB supply approximately half of the city's municipal water supply (Klipsch et. al, 2010). In addition, the flow in the Delaware affects the position of a fresh water and salt-water interface in the lower basin. Low flow in the river during summer and drought conditions can result in the migration of salt fronts to the upstream and thereby affects fresh water intakes used for water supply for Philadelphia and Mid-Hudson areas (Burns et. al., 2017). Furthermore, flow alterations are threatening the survival of freshwater animals, such as mussels, amphibians and crayfish. Therefore, under changing conditions, it is important to better understand the interconnected effects of watershed characteristics, streamflow, climate and sectoral water demand on water resources to implement an integrated and adaptive framework for more sustainable and effective water management. To do this, there is a significant requirement for system-level modeling tools to address water management challenges.

During this study, the Stella (ISEE, 2017) simulation platform was used for the stakeholder-focused Shared Vision Planning process since it allows both stakeholders and technical participants to understand how decisions in one part of the system affect other parts of the system in water resources management puzzle (Leitman et. al, 2015; Creighton, 2010). Stella is an object-oriented graphical modeling environment and provides a high level of user accessibility and simplifies maintenance for complex systems. It also offers the option to prevent a stock from becoming a negative. This option is important for water resources models that non-negativity option never be used (Palmer, 2010).

In this study, a system-oriented approach is developed to evaluate demands of the various water use sectors in the river, and their interactions. A hydraulic model is developed within the Stella modeling software to determine how historical reservoir management policies perform at meeting water demands in the basin and out-of-basin for the years of 1980-2005. The model also helps to better understand the interconnected effects of the water use sectors under different climate conditions, and addresses water shortages under water stressed conditions.

# Method

## Basin Description and Water Use Sectors

The DRB encompasses four states and 42 counties, and its population is approximately 7.3 million people (USGS, 2017). However, over 15 million people including NYC and northern New Jersey depend on the DRB resources even though they are not located in the basin. Three upstream reservoirs in the DRB, Cannonsville, Pepacton and Neversink, supply drinking water to NYC from the Catskill Mountains located in southeastern New York State. New Jersey also is a water importer from the basin through the Delaware and Raritan Canal (Mandarano et. al, 2013).

Although the Delaware River is the longest undammed river in the east of the Mississippi, total permanent storage capacity of the tributary reservoirs is over 400 billion gallons. Therefore, reservoir releases affect the flow in the main stem of the Delaware River and the largest tributaries. Reservoir storage and releases are used for water supply, flood control, hydropower generation, water quality management, recreational fishing and boating, and support of aquatic habitat (HydroLogics, 2004).

Total withdrawals in the DRB for 2010 were divided into four major sectors: drinking water sector, including public supply and self-supplied domestic use, power generation sector, including thermoelectric power withdrawals, industrial sector, including mining and commercial water use, and agricultural sector, including irrigation, livestock, and aquacultural water use (Figure 2).

Power generation sector is further categorized into thermoelectric and hydroelectric generation power sectors. Based on a United States Geological Survey report, water withdrawals for thermoelectric power generation are considered offstream withdrawals, and therefore included in the calculation of total water withdrawal (Hutson et al., 2010). However, water used for hydroelectric power is not considered a withdrawal because water flowing through a dam is considered as an instream use (Ludlow et al., 2000).

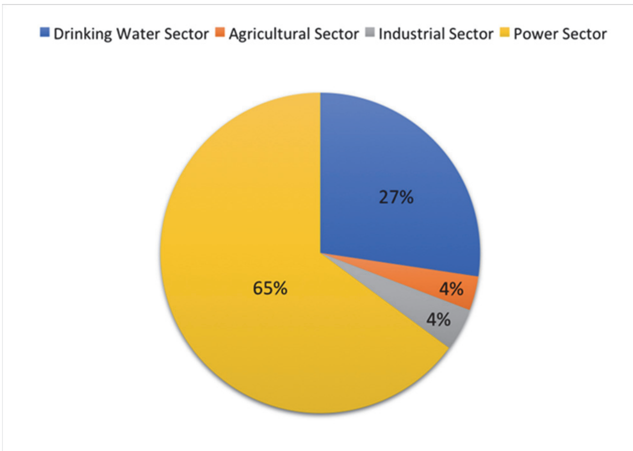


*Figure 2.* Sectoral water allocation in the Delaware River Basin for 2010.

## History of Water Management Policies in the Basin

There have been conflicts over the management of the Delaware River for hundreds of years. One of the most important treaties was signed in 1783 between New Jersey and Pennsylvania. Based on this treaty, these two states agreed that there would be no dams on the Delaware main stem. During the 1900s, the basin states decided to focus on multiple approaches to resolve securing water allocation for growing population. To allocate water resources equitably, New York, Pennsylvania and New Jersey appointed commissioners to negotiate a compact in 1924. However, they weren't able to reach an agreement. Eventually NYC received a permit to export water out of the basin for drinking water supply; The US Supreme Court decree of 1931 affirmed the diversion of 440 mgd water to NYC (Mandarano et. al., 2013), and permitted the City to build two dams, Pepacton and Neversink. The location of the dams is shown in Figure 1. However, there were no environmental interests or specified provisions for ecological flows in the 1931 decree (Ravindranath et. al, 2016).

After the 1931 decree, NYC and New York State petitioned the Court to increase its diversion from the Delaware River Basin for water supply purposes. Pennsylvania joined New Jersey to protest the case. An amended decree was issued on June 7, 1954 that increased NYC's diversion to 800 mgd upon the construction of the Cannonsville Reservoir located in the Delaware's West Branch. New Jersey was also allowed to allocate 100 mgd water through the Delaware and Raritan Canal. In addition to diverting water for drinking water requirements of states, the decree obligated NYC to make reservoir releases (as needed) to maintain a minimum flow requirement of 1,750 cfs at the USGS gauge station at Montague, NY or 3,400 cfs at Trenton, NJ. Furthermore, the decree required that NYC release into the Delaware River an excess release quantity (ERQ), which was estimated to be 83% of the volumetric difference between the City's total safe yield and its forecasting annual water consumption. Based on the amount calculated in the decree, an excess release bank (ERB) was established. The aim of the ERB is to assist lower basin drought. The releases from the bank are become effective at Montague on June 15 until the following March 15, or until the combined storage is equal to or lower than the drought warning line, or until the cumulative releases from the excess release bank becomes equal to seasonal quantity, whichever occurs first. However, in case of emergency, the Delaware River Basin Commission (DRBC) might use water from the ERB for thermal releases to support downstream fisheries or lower basin water demand without considering above conditions (DRBC, 1977; U.S., 1954; Mandarano et. al, 2013; Ravindranath et. al, 2016).

Recognizing that litigation through the Supreme Court is not an effective way to manage water resources in the basin, the basin states agreed on forming a commission, which negotiates a compact to guide water resources management. As a result, the DRBC was created in 1961 and the governance of the basin unified in one body. The DRBC consists of the governors of the four states and a federal commissioner appointed by the president (Mandarano et. al., 2013).

After a historical drought between 1961 and 1967, it was obvious that there was a need for conservation release rules to protect downstream fisheries from low flows or excessive water temperatures. The inadequacy of conservation releases resulted in New York State's Environmental Conservation Law in 1976, which includes augmented conservation releases from the Cannonsville, Pepacton and Neversink reservoirs (experimental release program). With this law, temperature targets of 75 °F as a daily maximum and 72 °F as a daily average at USGS gages at Callicoon, Harvard, Woodbourne, and Hale Eddy located downstream of the Cannonsville, Pepacton and Neversink reservoirs were also set. New York State Department of Environmental Conservation (NYSDEC) also specified a thermal stress bank of 6,000 cfs-day to meet these targets by cold-water releases from reservoirs. The thermal stress bank was created to ensure that enough water was actually in the reservoir for fishery protection (Ravindranath et. al., 2016). The following studies by NYSDEC and experiences showed the benefit of these releases on ecosystem; as a result, docket D-77-20 CP was approved by DRBC (Mandarano et. al., 2013). The combined total of the augmented releases and thermal releases could not exceed the excess release bank water quantity based on the docket D-77-20 CP. However, this rule did not take part in the first revision of the docket in 1983. After approval of the docket in 1983, instead of limiting the augmented conservation releases with the amount of water in the excess release bank, the drought operation rule curve was used to regulate the conservation releases depending on the combined storage of the reservoirs.

In 1983, the decree parties unanimously approved Interstate Water Management Recommendations of the Parties of the Supreme Court Decree of 1954 to the Delaware River Basin Commission Pursuant to Commission Regulation 78-20. This is generally known as the 1983 Good Faith Agreement (GFA). Under the GFA, the experimental release program, which was established in the original 1977 docket, became permanent and releases were limited based on drought operation curves, which are the main component of the GFA. Drought operation curves set a criterion that separates the levels of drought as drought warning and drought emergency based on the combined storage of the three NYC Delaware Basin Reservoirs (Figure 3). It is important to note that in 1999, DRBC approved Revision 4 which implemented to raise the drought warning line by 4 billion gallons (DRBC, 2017).

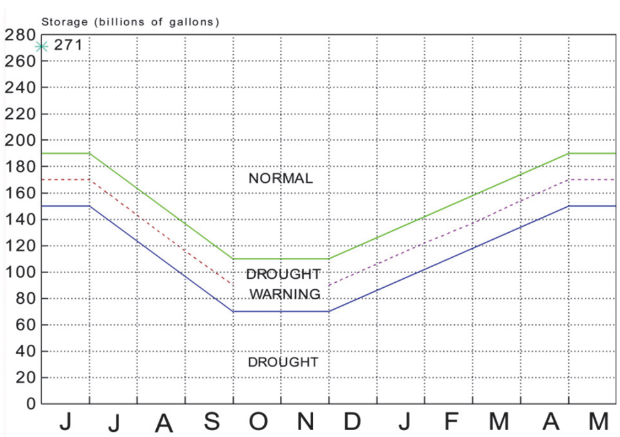


*Figure 3.* Drought Operation curve for Cannonsville, Pepacton and Neversink Reservoirs. Adapted from "Delaware River Basin Commission (DRBC) website" by DRBC, 2008.

Using these drought definitions as a framework, Table 1 shows an adaptive allocation and flow objective schedule established in the GFA. In Table 1, the drought warning line was separated into two categories which are illustrated by the red dashed line in Figure 2: the upper half, and the lower half. The upper half of the drought warning level were limited between the normal conditions line and drought warning line while the lower half was restricted between the drought warning and drought line. Based on combined storage of the NYC Reservoirs, the GFA sets target flows for out of basin allocations, as well as, Montague and Trenton. During drought conditions, the

GFA calls for a reduction of releases out of basin, and sets a specific release schedule depending on the four predetermined salt front river mile locations for Montague and Trenton (Table 2). Drought conditions' operations are mandated by the GFA when the combined reservoir levels decrease below the drought-operating curve for 5 consecutive days (U.S., 1954; DRBC, 1982a).

There were 9 revisions from the DRBC's first release policy, Docket D-77-20 CP of May 1977 until the adoption of Flexible Flow Management Plan (FFMP) in September 2007. Until 2007, the adjustments of conservation releases, thermal targets and thermal protection banks were minor, except the Revision 1 in November 1983, the Revision 7 in May of 2004, and the Revision 9 of September 2006 (Ravindranath et. al, 2016).

With implementation of the GFA to the Revision 1 of 1983, there was an important modification that resulted in reduction of conservation releases to basic releases during drought warning and drought emergency conditions, and it would only be returned to the augmented levels after the combined storage reached to 25 BG above the drought warning level and remained at there for 15 consecutive days (DRBC, 2017). It is important to note that Revision 1 was the last revision approved with any expiration date. Therefore, if the decree parties cannot reach an agreement on the subsequent revisions or extensions in the future, they could fallback on the release policy defined in Revision 1 (Ravindranath et. al, 2016).

Table 1

*Allocation and Flow Objective Schedule*

| Storage condition | NYC allocation (mgd) | NJ allocation (mgd) | Montague flow objective (cfs) | Trenton flow objective (cfs) |
|---|---|---|---|---|
| Normal | 800 | 100 | 1750 | 3000 |
| Upper half – Drought warning | 680 | 85 | 1655 | 2700 |
| Lower half – Drought warning | 560 | 70 | 1550 | 2700 |
| Drought | 520 | 65 | 1100 – 1650* | 2500 – 2900* |
| Severe Drought | To be negotiated based on conditions | | | |

*Varies with time of year and location of salt front as shown on Table 2.

In 2002, Revision 5 was amended. Based on the amended Revision 5, using the habitat bank to augment flows at Hale Eddy, Harvard, and Bridgeville below the NYC reservoirs was required. Also, during drought conditions, the allowance was made to use the habitat bank as the summer baseline release levels to augment conservation releases. In addition, the total quantity of the thermal release bank is defined explicitly (9,200 cfs-days) in the amended Revision 5. In 2003, after the approval of the Revision 6, this amount was reduced to 4567 cfs-days (DRBC, 2017).

Table 2

*Flow Objectives for Salinity Control during Drought Periods*

| Seven-day Average Location of 'Salt Front' River – mile (R.M.) | Flow objective, Cubic Feet Per Second At: | | | | | |
|---|---|---|---|---|---|---|
| | Montague, N.J. | | | Trenton, N.J. | | |
| | Dec - Apr | May - Aug | Sept - Nov | Dec - Apr | May - Aug | Sept - Nov |
| Upstream of R.M. 92.5 | 1600 | 1650 | 1650 | 2700 | 2900 | 2900 |
| Between R.M. 87.0 and R.M. 92.5 | 1350 | 1600 | 1500 | 2700 | 2700 | 2700 |
| Between R.M. 82.9 and R.M. 87.0 | 1350 | 1600 | 1500 | 2500 | 2500 | 2500 |
| Downstream of R.M. 82.9 | 1100 | 1100 | 1100 | 2500 | 2500 | 2500 |

Revision 7 of 2004, made a number of adjustments. There were now three different banks and all of them were interrelated in a complex fashion each other. These banks were an ERB, a thermal release bank (TRB), and a supplemental release bank, which constituted a habitat bank. The aim of the habitat bank is to support tailwaters of the reservoirs. It also established a new concept by setting minimum flow targets at Hale Eddy on the West Branch of the Delaware River, at Harvard on the East Branch of the Delaware River, and at Bridgeville on the Neversink. These flow targets were subject to water availability in the habitat bank (DRBC, 2004). The conservation release rules were becoming increasingly complex with Revision 7. Consequently, The Decree Parties stated their intention to develop a long-term program. The basis of the program was considered to be based on sustainable sources of water, while releasing water based upon the overall needs in the tail waters below the reservoirs, as well as in the main stem and in the bay (Ravindranath et. al, 2016).

The intention for Revision 7 was to endure until May 31, 2017. However, due to severe floods in 2005 and 2006, Revision 9 was approved in 2006 resulting from political pressure of the public and the governors of New Jersey and Pennsylvania. The revision established a spill mitigation program, which aimed to increase releases from the reservoirs to achieve an 80% of reservoir void from September 1 to February 1. NYC reservoirs in the Delaware River Basin are not designed for flood mitigation; therefore the DRBC is named the program as spill mitigation rather than flood mitigation (Ravindranath et. al, 2016).

A fundamental change to the conservation release program was made with the approval of the FFMP in 2007, which established an adaptive release schedule. The adaptive release schedule included releases for habitat protection and the new discharge mitigation program. The FFMP was designed to provide a more natural flow regime. It was also more adaptive than the previous operating schedules for controlling releases and diversions from NYC reservoirs. The aim of the FFMP was to address competing demands in the basin, as well as drought management, flood mitigation, protection of cold-water fishery, diverse array of habitat requirements in the main stem river, estuary and bay, and salinity repulsion (DRBC, 2011).

The initial implementation cycle of the FFMP was from 2007 to 2011. The 2011 FFMP is a set of principles, rules and procedures for the management of storage, water supply, conservation releases, diversions, flow targets relating to the allocation of water from the DRB (DRBC, 2011).

The latest FFMP, called Flexible Flow Management Program - Operational Support Tool (FFMP-OST), is effective until May 31, 2017. It holds the promise of further improving the ecological health of the upper Delaware River while using water more carefully (DRBC, 2017).

**Structure and Operation of the NYC-DRB Stella Model**

The NYC-DRB Stella model uses daily time step and simulates twenty-four years of historical policy decisions for the NYC Delaware River Basin Reservoir System which consists of three large reservoirs; Cannonsville, Pepacton and Neversink. The main portion of the model consists of mapped water balance, which shows the inflows and withdrawals of the system. The releases from Cannonsville and Pepacton reservoirs meet at the Delaware River above Port Jervis, NJ. Then, they join with releases from the Neversink Reservoir at Port Jervis, NJ (Figure 4).

The basic concept of a mass balance is the change in storage, which equals to sum of the inflows minus the sum of the outflows as illustrated in *Equation 1*.

$$\text{Change in storage} = [\sum inflows\,] - [\sum outflows] \quad (1)$$

Looking in detail at the mass balance for the NYC reservoirs, *Equation 2* incorporates all the components into the hydrological system of the reservoir.

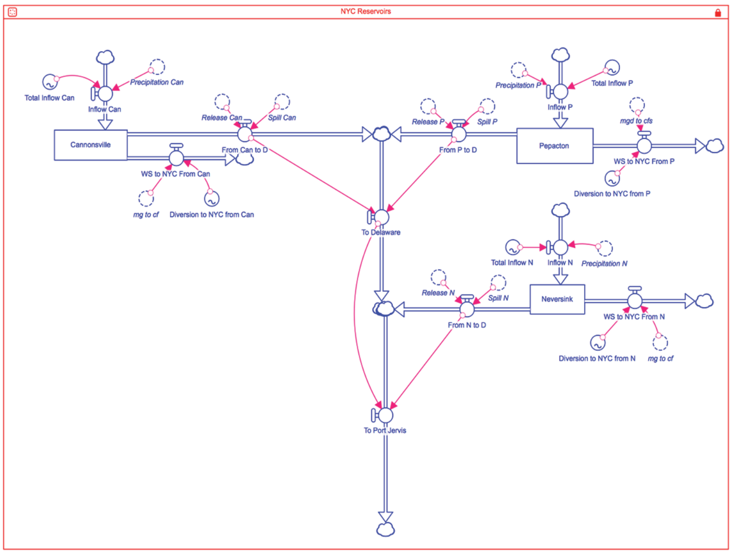


*Figure 4.* The Stella model of the NYC reservoirs in the Delaware River Basin.

Change in storage = Initial storage of the reservoir + (precipitation that falls onto the reservoir + streamflow that runs into the reservoir) – (spill + controlled release + water supply to NYC from the reservoir) (2)

The inflow to each reservoir includes historical rainfall onto the surface of the reservoir, and streamflows that flow into the reservoirs. Streamflow data comes from two different sources. The data available for gauging stations are obtained from the United States Geological Survey (USGS). The data of the ungauged inlets are estimated using the StreamStats online software program and the Delaware River Basin Streamflow Estimator Tool (DRB-SET) established by the USGS (Stuckey and Ulrich, 2016). The basin characteristics are identified for ungauged stream locations in the StreamStats Beta Version 4. Then, daily mean streamflows are computed in the DRB-SET for selected locations in the Delaware River Basin. In addition, direct precipitation onto the NYC reservoirs is considered in the model. Twenty-four years of daily precipitation data for each reservoir were taken from the CLIMOD2 online tool established by the Northeast Regional Climate Center (Center N. R. C., 2015).

The outflows of the reservoirs are the NYC water diversion, controlled releases and spill. To maintain proper operating conditions in the NYC reservoir system, water for NYC demand is transferred from the reservoirs through diversion tunnels. In the model, water diversions were set up before the reservoir outlets. The three diverted outlets, Water Supply to NYC from Cannosville, Water Supply to NYC from Pepacton and, Water Supply to NYC from Neversink, are drawn as flows in the schematic diagram in Figure 3.

The outlets, from reservoirs to the Delaware River (From Cannosville to Delaware, From Pepacton to Delaware, From Neversink to Delaware), consist of the controlled releases and spill. The spill was activated based on the reservoir operation zone. The spillway simply dumps the excess water when reservoir volume is above the operation zone. If the volume was not above the operation zone, the spill equation was set equal to zero. *Equation 3* shows the mathematical definition of the spill for the NYC-DRB Stella Model.

Spill = IF Inflow + Reservoir Storage – Demand – Water Supply to NYC From Reservoir >= Seasonal Reservoir Pool Operation Zone THEN Inflow + Reservoir Storage – Demand–Seasonal Reservoir Pool Operation Zone–Water Supply to NYC From Reservoir ELSE 0 (3)

The controlled releases from the reservoirs were based on total water demand of the basin. The daily water demand for each sector was determined in the basin. In the NYC-DRB Stella model, there are three kinds of water use sectors: Wildlife and Aesthetic (Conservation Releases), Fisheries (Thermal Releases), and Lower Basin Water Demand (Direct Releases for Montague). In addition, habitat bank releases were implemented into the demand equation starting from 2002. *Equation 4* defines the total demand for water use sectors in the basin. The first part of the equation was limited until 1983 due to the commitment defined in the Docket D-77-20 CP. Based on the commitment, the augmented conservation releases and the thermal stress releases were not to exceed the total volume of the excess release bank during any water year. Therefore, the cumulative volume of the thermal releases and the augmented conservation releases were limited to the cumulative volume of the excess release bank, and the conservation releases was defined in first part of the demand equation together with the thermal releases.

Demand = IF TIME >= 0 AND TIME <= 1126 THEN Thermal & Conservation Releases + Direct Releases for Montague ELSE IF TIME > 1126 AND TIME < 7788 THEN Conservation Releases + Thermal Releases + Direct Releases for Montague ELSE Conservation Releases + Thermal Releases + Direct Releases for Montague + Habitat Bank Release (4)

The controlled releases were made to meet water demand of the basin if the volume of the reservoir was above the total volume of the demand. In this case, the total amount of the demand was released from the reservoirs. If it was not above, the total volume of the reservoir and the inflow were released.

There are different types of banks in the NYC-DRB Stella model. The aim of these banks is to store water in the reservoirs for water demands of various sectors in the basin. Excess release bank stores water to maintain the Montague flow target. TRB is used to support fishery habitat in the downstream of the reservoirs, and habitat bank is established to support tailwaters of the reservoirs. The DRBC assigns a certain amount of water to these banks for every year, and the releases based on the basin demand are limited with these banks. In case of drought emergency conditions, the DRBC might establish additional amount of water to use for downstream purposes. No releases are made if excess release bank equals to seasonal quantity for lower basin demand, or if thermal release bank equals to the amount of water that the DRBC established for the fishery protection, or if habitat bank equals to the amount of water that the DRBC established to support tailwaters of reservoirs.

**Structure and Operation of Water Use Sectors in the NYC-DRB Stella Model**

Conservation release schedules had been established to protect wildlife and aesthetic of the environment at the downstream of the reservoirs. The schedules were revised four times for the Pepacton and the Neversink Reservoirs, and five times for the Cannonsville Reservoir between 1980 and 2005. Each revision was modeled in the model individually based on its schedule. If the combined storage of the NYC reservoirs is above the drought warning line, and maintains 15 billion gallons (BG) above this level for 15 consecutive days, the reservoirs release water depending on the augmented release schedule. If it is below the line and stays 5 consecutive days below or at the drought warning level, then reservoirs release water based on basic release schedule.

To protect trout species downstream of the NYC reservoirs, thermal stress releases are made from each reservoir. Reservoir releases were made whenever the maximum water temperature at designed downstream USGS gaging stations, Harvard (station number: 01417500), Woodbourne (station number: 01436500) or Hale Eddy (station number: 01426500), exceeded a maximum of 75 °F. The temperature data for each station was taken from USGS. However, there is no water temperature data for the Woodbourne station. Thus, the Bridgeville station was used to get daily maximum water temperature data. The Bridgeville station is located 17 miles downstream of the Neversink Reservoir, and 11 miles downstream of the Woodbourne station. The cumulative volume of these releases was restricted to 6,000 cfs-days from all reservoirs, and it was used between May 1st and November 1st. Furthermore, the thermal stress releases were released if the combined storage of the NYC reservoirs was above the drought warning line. However, there were some exceptions in the model. In case of drought emergency conditions, thermal releases made under the drought conditions for fishery production, and additional releases added to 6,000 cfs from the excess release bank.

To ensure that the lower basin gets enough water, the Montague flow target was established by DRBC in 1983 based on the drought operation curves. In the model, direct releases from the NYC-DRB reservoirs were made based on the different flow targets at Montague under normal, drought warning, and drought conditions.

Flows of the Delaware River at Montague are composed of following parts (NYCDEP, 1974):

1. Controlled releases from Lake Wallenpaupack on Wallenpaupack Creek, Pennsylvania for the production of hydroelectric power.
2. Controlled releases from Rio Reservoir on the Mongaup River, New York for the production of hydroelectric power.
3. Uncontrolled runoff above the Montague, New Jersey.
4. Controlled releases from Cannonsville, Pepacton, and Neversink Reservoirs of the City of New York.

The NYC-DRB reservoir releases are necessary to maintain the Montague flow objective. However, determination of the amount of release from each reservoir is complex because there is a time difference between the combined flows from the other sources and required flow at Montague. Therefore, water released from the reservoirs were scheduled in the model to allow for differences in travel times.

In the model, the Stella produced a message warning of a circular connection of the simulated outflow of reservoirs and water use sectors. Therefore, the observed data was used to estimate thermal and lower basin releases instead of simulated outflow data for each reservoir.

The NYC-DRB Stella model runs for 15 years of record (1980 – 1995) to simulate reservoir releases from the outlet of each reservoir. The reason why the model runs until 1995 is because of the data availability for the Rio Reservoir. The reservoir release data, which are used to calculate the uncontrolled streamflow above Montague are only available until 1995. The model outputs were compared with historical data to ensure that the model operates in the designed manner.

## Seasonal Reservoir Pool Operation Zone

Each reservoir has been modeled based on a seasonal reservoir operation zone, which is a function of time and volume of the reservoir. The reservoir operation zone was implemented into the model to regulate the spill from the reservoirs depending on the available volume of water. Long-term median storage was computed on the basis of 23 years of reservoir volume records to calculate the daily seasonal reservoir operation zones (Figure 5). Based on the operation zone, when the total volume of reservoir and inflow is higher than the volume of the pool zone at the specific time steps, excess water from the reservoir is spilled. The daily reservoir storage data was gathered from Delaware River Master Report for the period of between 1980 and 2005 (ODRM, 2016).

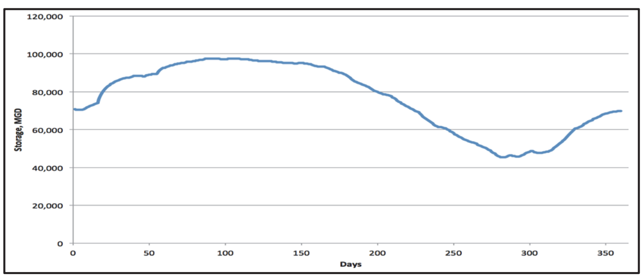


*Figure 5.* Seasonal pool operation zone for Cannonsville Reservoir.

## Results

The historical streamflow and precipitation, and reservoirs operation parameters were employed to generate results with the NYC-DRB Stella model. The generated and actual historical outflow and storage for each reservoir were compared and verified for accuracy. As an example, Figure 6 shows observed and simulated outflows for a fifteen-year simulation (1980 – 1995) for the Cannonsville reservoir.

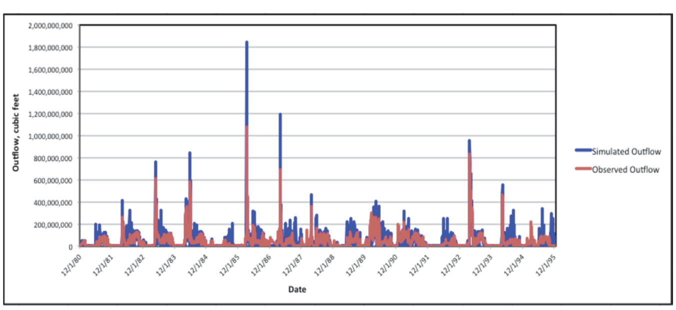


*Figure 6.* Observed versus simulated outflow for Cannonsville Reservoir.

Figure 7 indicates the years that drought emergency in the basin was declared by the DRBC. Throughout fifteen years, only four states of emergency were declared due to drought in the Delaware River Basin. As seen from Figure 6, during the drought emergency, releases from each reservoir were made for minimum conservation purposes based on the basic release schedule. The releases were returned to the augmented levels after the combined storage reached 25 BG above the drought warning level and remained at these levels for 15 consecutive days. Inflows to the reservoirs generally exceeded draft rates during the December through May, and thereby increased the reservoir's storage (Figure 8).

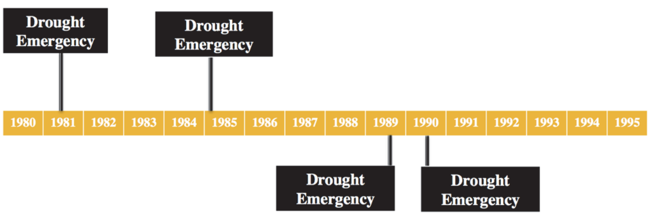


*Figure 7*. Drought emergency conditions for the Delaware River Basin between the years of 1985 and 1995.

In 1982, the precipitation in April was the greatest for the month in the record, thus all three reservoirs spilled before the month ended. In 1986, the capacity of the combined storage was increased during the winter months, and thus all three reservoirs spilled. Throughout August and September 1993, the amount of precipitation decreased significantly, therefore the storage continued to decline above normal rates (Figure 8).

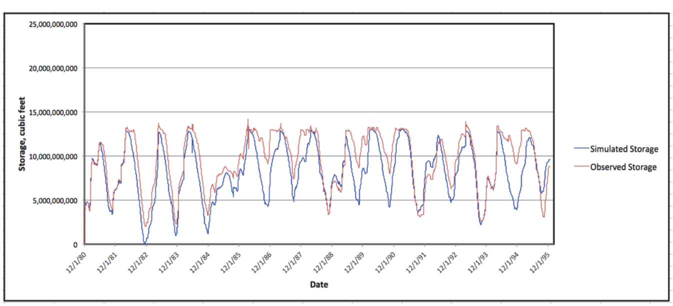


*Figure 8*. Observed versus simulated storage for Cannonsville Reservoir.

Even though the model followed a similar trend for the storage of the each reservoir, the model projects more spills compared to actual data. This might be the result of large inflows into the reservoirs. Therefore, estimated inflow through DRB-

SET and recorded data by USGS along with the precipitation was compared with actual inflow by calculating it via mass balance. To calculate the inflow, the daily actual storage data was subtracted from the outflow (reservoir releases and NYC diversion) for each reservoir. Figure 9 illustrates the comparison of estimated inflow by using DRB-SET tool and calculated inflow by using actual data for Cannonsville Reservoir. Based on the figure, the inflow data trend used in the model was very close to the actual inflow data calculated through mass balance.

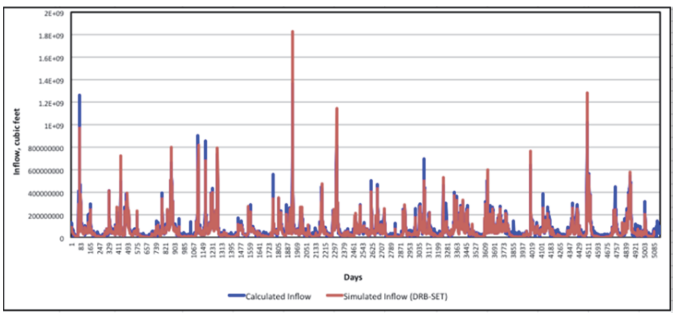


*Figure 9.* Estimated versus calculated inflow for Cannonsville Reservoir.

The seasonal reservoir operation zone, which determines the spill from the reservoirs depending on the volume of water inside the reservoir was calculated based on the long-term median storage on the basis of 23 years of reservoir storage records. To determine the reason why reservoirs spill more water than actual state, the observed daily storage records were compared with the long-term median storage for each reservoir. As an example, Figure 10 shows the comparison of actual daily storage and long-term median storage data for Cannonsville Reservoir. According to the figure, on some days reservoirs do not spill although actual reservoir storage is above the long-term median storage. However, the model spills if the storage is higher than the long-term median.

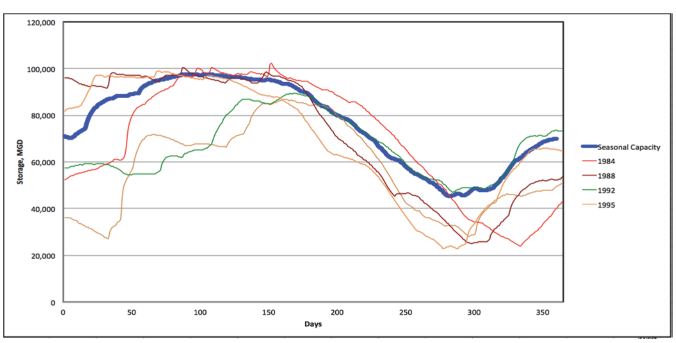


*Figure 10.* Actual daily storage versus long-term median storage for Cannonsville Reservoir.

To determine statistically significant differences between each year and the long-term median seasonal capacity, a non-parametric statistical analysis was performed with 95% confidence limits. Table 3 summarizes the results for three reservoirs. The difference between actual storage data and the long-term median of seasonal capacity for each reservoir was not statistically significant. Therefore, the seasonal operation zone approach was used in the model to represent an amount of seasonal storage in the reservoirs. This approach provides a guidance to determine the amount of storage available for both downstream purposes and recreational use of the reservoirs.

Table 3

*Comparison of Actual Storage Data For Each Year and The Long-Term Median Seasonal Capacity For Three Reservoirs*

| Years | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Significance | | | | | | | |
| Cannosville | 0.15 | 0.17 | 0.22 | 0.16 | 0.27 | 0.17 | 0.21 | 0.18 | 0.14 | 0.19 | 0.18 | 0.26 | 0.14 | 0.43 | 0.17 |
| Pepacton | 0.17 | 0.17 | 0.20 | 0.17 | 0.18 | 0.18 | 0.18 | 0.15 | 0.26 | 0.20 | 0.17 | 0.21 | 0.16 | 0.20 | 0.18 |
| Neversink | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 |

Furthermore, the actual and simulated outflow data was compared for each reservoir by using mean squared error to test the model accuracy. Table 4 shows the results for each reservoir. According to the table, the results indicate that the deviation of the actual data and simulated data is not large.

Table 4

*Comparison of Actual and Simulated Outflow by Using Mean Squared Error for Each Reservoir*

| Reservoirs | Mean Squared Error (%) |
|---|---|
| Cannosville | 2 |
| Pepacton | 7 |
| Neversink | 6 |

## Discussion and Conclusion

The Delaware River Basin has been home to contentious debates over water allocation and management in the Eastern United States. The four states in the basin, New York, Pennsylvania, New Jersey and Delaware, have been negotiating on water allocation agreements since the early years of the republic. Extensive hydrological modeling approaches have proceeded from the negotiations. The model described in this study included the development of the NYC reservoirs model, which predicts reservoir releases based on inflows to reservoirs, water demand by sector and historical reservoir management policies. The impact of this study extends directly to decision makers and stakeholders who rely on water resources in the Delaware River Basin.

The Stella model is developed for NYC reservoirs operation to better understand cumulative effects of water withdrawals on water resources and reservoir operations under different climatic conditions. Moreover, running the simulation over the period of fifteen years and analyzing the main droughts in the basin shows how different operations manage drought over the historical record. These simulations enable to compare the various operations for future scenarios.

Through the use of non-parametric statistical technique, the difference between actual daily storage data for each reservoir and the long-term median were compared. The analysis showed that there are no significant differences between datasets. Therefore, the seasonal operation zone approach was accepted to use in the model. With this approach, the available storage was determined in each reservoir for downstream purposes and recreational use of the reservoirs. In addition, the mean squared error was estimated to compare simulated and actual outflow data for each reservoir. The results show that the error between the actual and simulated data was not large. In other words, the model predicts the outflow of each reservoir close to the actual outflow data.

However, some limitations still exist in this developed model. For instance, the Stella model produces a message warning of a circular connection of the simulated outflow and water use sectors such as fish and lower basin demand sectors. Therefore, an observed data is used to calculate water demand for fish and lower basin. Furthermore, the future climate scenarios have not been covered in the model. To determine their effects on river characteristics, the current reservoir operation techniques will be implemented into the model, and then it will be run under climate projections.

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**Extended Turkish Abstract**
**(Genişletilmiş Türkçe Özet)**

**Rezervuar Operasyonları & Su Tahsisi Modeli: New York Şehri Delaware Nehir Havzası Rezervuarları**

Nüfus artışı ve sanayileşme ile birlikte su kaynaklarına olan talebin artması, iklim değişikliği sebebi ile yağış ve sıcaklık rejimlerinin değişmesi sonucu su kaynaklarının kullanıcılar arasında adil ve dengeli bir şekilde paylaştırılması her geçen gün daha da önem kazanmaktadır. Bu sebeple, su kaynaklarının daha verimli ve uzun vadede kullanılabilmesi için havza bazında bir su yönetimi planı yapılması gerekmektedir. Böylelikle, hem suyun sürdürülebilir yönetimi hem de koruma – kullanma dengesi sağlanmış olur.

Amerika Birleşik Devletleri'nde havza bazında su kaynaklarının eşit dağılımını sağlamak ve oluşacak problemleri en aza indirgeyebilmek amacıyla havzadaki su kaynaklarının tek bir kurum üzerinden yönetilmesi için havza komisyonları oluşturulmuştur. Bu komisyonlar sayesinde her bir havzadaki suların yönetiminden sorumlu kişiler tek bir çatı altında toplanmış, geçmişteki koordinasyonlardan kaynaklı problemler en aza indirilmiştir.

New York, Pennsylvania, New Jersey ve Delaware eyaletleri sınırları içerisinde yer alan Delaware Nehir Havzası'ndan sorumlu Delaware Nehir Havzası Komisyonu havzanın problemlerine bütüncül bir yaklaşım ile çözümler üretmektedir. Delaware Nehir Havzası Komisyonu, Amerika Birleşik Devletleri'nde kurulan federal hükümetinde içerisinde olduğu ve eyaletler arası iş birliği özelliği taşıyan ilk komisyondur.

Delaware Nehir Havzası 13,600 mil kare büyüklüğündedir ve havzanın %15'i imarlı alan, %49'u ormanlık alan, %26'sı tarım alanı, %10'u ise sulak araziden oluşmaktadır (DRBC, 2013). Ormanlık alanlar genellikle havzanın üst kısmında, tarım alanları ise alt kısımlarda yoğunluklu bulunmaktadır. Amerika Birleşik Devletleri'nin populasyonunun yaklaşık %5'i havzanın su kaynaklarından yararlanmaktadır, ancak havzanın mevcut ve gelecekte ki yaklaşık su potansiyeli dikkate alındığında, havzada sürdürülebilir bir su yönetiminin uygulanmasının gerekliliği kaçınılmazdır. Havza da bulunan rezervuarların toplam su tutma kapasitesi 400 milyar galonun üzerindedir ve bu rezervuarlardan deşarj edilen sular, içme – kullanma, taşkın kontrol, hidroelektrik enerji üretimi, tuzluluk kontrolü ve çevresel ihtiyaç için kullanılmaktadır (HydroLogics, 2004).

Delaware Nehir Havzası Komisyonu'nun sorumluluğundaki New York'a içme ve kullanma suyu sağlayan, aynı zamanda alt havzalar için önemli bir su kaynağı olan, Cannonsville, Pepacton ve Neversink rezervuarları havzanın kuzeyinde yer almaktadır. Önceliği New York şehrine tüneller yardımı ile su sağlamak olan bu rezervuarlar, aynı zamanda çevresel akış ve alt havzada bulunan şehirlerin su ihtiyacı açsından da önemli bir yere sahiptir. Ayrıca, kurak dönemlerde tuzlu okyanus sularının Delaware Koyu'ndan havzaya girişi ile içme ve kullanma suyunun kalitesinin bozulması gibi problemler oluşmuş, bu sebeple rezervuarlardan yapılan kontrollü deşarjlar önem arz etmiştir.

Kontrollü deşarjlar havzada belirlenen sektörlerin su ihtiyacına bağlı olarak Cannonsville, Pepacton ve Neversink'in toplam hacmine göre yapılmaktadır. Bu sebeple, Delaware Nehir Havzası Komisyonu tarafından rezervuarların toplam hacmi dört ayrı aşamaya ayrılmış ve her bir rezervuardan deşarj edilen su miktarı kuraklık dönemlerine ve aylara göre sınırlandırılmıştır. Örneğin, üç rezervuarın ölçülen toplam hacmi 220 milyar galon ise, rezervuarlardan yapılan deşarjlar normal şartlar için belirlenen debilere bağlı yapılır. Ancak kurak dönemlerde, toplam hacim 60 milyar galona düşerse, deşarjlar kurak dönem için belirlenmiş debilere bağlı olarak yapılır. Ayrıca, kurak dönemlerde artan tuzluluk konsantrasyonunu önlemek amaçlı havzada belirlenen noktalarda istenen debinin sağlanması amacıyla da rezervuarlardan kontrollü deşarjlar yapılmaktadır.

Bu çalışmada, çoğunluğu Delaware Nehir Havzası Komisyonu tarafından yürürlüğe sokulmuş olan kanunlar derlenip, Stella isimli bir yazılım programına girilmiş ve New York Şehri Delaware Nehir Havzası (NYC-DRB) rezervuarları için hidrolik bir model geliştirilmiştir. Bu model ile birlikte, havza içi ve dışı içme suyu ihtiyacı belirlenmiş ve iklim değişikliğinin etkisi ile havzadaki su kullanımının sektörler üzerine etkisi ele alınmıştır. Rezervuarlara giren su miktarı hesaplandıktan sonra her bir sektörün su ihtiyacı belirlenmiş ve 25 yıllık rezervuar işletim kuralları temel alınarak, rezervuarlardan deşarj edilmesi gereken su miktarı Stella programında modellenmiştir. Ayrıca, rezervuar güvenliği açısından önemli bir yere sahip olan dolusavak yapısı dikkate alınmış ve dolusavak akımı modelde hesaplanmıştır. Bunula birlikte, 25 yıl havzada yaşanan kuraklık dönemleri boyunca uygulanan farklı senaryolar modele entegre edilmiştir. Daha sonra model çıktıları gözlem verileri ile karşılaştırılarak model validasyonu yapılmıştır.

Bu çalışma, su yönetimi stratejilerinin belirlenmesinde karar verme yetkisine sahip kişilere yardımcı olduğu gibi, havzada ki paydaşlar için de önemli bir adımdır. Bu çalışma ile havzadaki su taleplerinin karşılanmasında su kaynaklarının korunması ve sürdürülebilirliği sağlanmış olup, suyun sektörler arasında adil paylaşımının gerçekleşmesi hedeflenmiştir. Ayrıca, havzada ki doğal hayatın devamlılığı için önemli bir yere sahip olan çevresel akış çalışmaları kurak dönemler dikkate alınarak modele eklenmiş ve havzanın çevresel su ihtiyacı karşılanmıştır.

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e-mail: waterjournal@ormansu.gov.tr

Beştepe District Alparslan Türkeş Street No: 71 Yenimahalle/ANKARA
+90 (312) 207 50 00 • Fax: +90 (312) 207 51 87