INTERNATIONAL JWM&D

# International Journal of Water Management and Diplomacy

ISSN 2717- 8277

Volume: 1
Issue : 5
June 2022

Issue:5 2022
e-ISSN:2717-8277
International Journal of Water Management and Diplomacy



## Submission

The journal is an online journal and all manuscripts should be submitted electronically through Dergipark Online Submission and Peer-Review System : https://dergipark.org.tr/en/pub/ijwmd

Authors should prepare their papers in accordance with the current Guideline for Authours available at the same website.

# International Journal of
# Water Management and Diplomacy

Official Journal of the Hydropolitics Association

HYDROPOLITICS ASSOCIATION

## Editor-in-Chief

Dursun Yıldız

e-ISSN:2717-8277

# International Journal of

# Water Management and Diplomacy

Official Journal of the Hydropolitics Association

**Volume :1 Issue:5 June 2022**

**Contents**

JWMD Issue:5 2022
International Journal of Water Management and Diplomacy
e-ISSN:2717-8277

*Research Article*

# Water Resources in the Sao Paulo Metropolitan Area (RMSP): the underuse of Billings Reservoir

**Leandro Fernandes Miyazaki[1*], Luis Antonio Bittar Venturi[2]**

[1,2]*Department of Geography, University of Sao Paulo, Sao Paulo, Brazil*

*Corresponding Author, e-mail: leandro.miyazaki@usp.br

## Abstract

The aim of this paper was to highlight and analyze the factors that explain the underuse of the Billings Reservoir in the Sao Paulo Metropolitan Area, based on data that covered 5 years. This research was guided by hypothesis that the underuse is related to the pollution, due to domestic waste and/or non-household waste and garbage discharge. The method consisted of an evolutionary analysis of the Billings pollution levels and then on a dynamic and integrated analysis of the variables that support the hypotheses. Results showed that, in general, the Reservoir's water quality tends to worsen. In addition, the irregular garbage discharge into the Reservoir is still at high rates. In this sense, it was concluded that the variables analyzed (pollution levels, sewage, and garbage amount) provided favorable evidence for the confirmation of hypothesis. However, interviewees emphasized the membrane separation processes, such as ultrafiltration and nanofiltration, which together to other techniques may turn the water from Corpo Central (the most polluted area) fit for use. In other words, although pollution is the main problem, there are already modern technologies to treat such water.

**Keywords:** Natural Resources, Water Resources, Billings Reservoir, Underuse



HPA June 20 2022

JWMD Issue:5 2022 International Journal of Water Management and Diplomacy
e-ISSN:2717-8277



## 1. Introduction

Natural resources are essential for the development of human activities, both for their survival and for their comfort. From the simple extraction of wood by a farmer on his farm to make firewood, to the complex refinement of oil by a large company, these are examples of the many and varied possibilities of natural resources. From the 2nd World War onwards, there was an increasingly accentuated demand for natural resources and this great demand culminated, however, in the 1970s, in a broad discussion on economic production and environmental conservation.

The 1972 United Nations Conference on the Environment in Stockholm, or simply the Stockholm Conference, was a milestone in this debate. It drew the attention of the international community to environmental problems arising from the overexploitation of natural resources, which could compromise future generations. The Stockholm Conference, as well as other international meetings, also contributed to the consolidation of the concept of sustainable development in 1983, according to the report of the World Commission for the Environment (CMMAD) (RIBEIRO, 2001). According to the report, sustainable development "is that which meets the needs of the present without compromising the possibility of future generations meeting their own needs" (CMMAD,1988). In this way, natural resources came to be seen no longer as inexhaustible, but, in fact, as exhaustible.

In this context, water is also highly demanded, especially in densely populated areas. It is one of the most important components of the Earth, being essential in both biological and geological processes. As it is a vital liquid, humans, animals, and plants suffer in a few days if it is not ingested (approximately 70% of human beings' bodies are composed of water). It is indispensable for agriculture and for the maintenance of existing forests. Furthermore, it is a fundamental agent in the transformation of the planet's surface, modeling, for example, its morpho sculptures, whether by chemical and/or physical weathering, over geological time, in addition to promoting erosion (TEIXEIRA et al, 2009).

According to the Brazilian Institute of Geography and Statistics (IBGE, 2021), the Metropolitan Region of São Paulo (RMSP) has an estimated population of 22 million inhabitants. It is the most populous metropolitan region in the country, the 2nd largest in the Americas and the 10th largest in the world. It houses approximately 47% of the population of the state of São Paulo (46.6 million inhabitants) and around 10% of the total Brazilian population (213.3 million inhabitants).

According to the State Water Resources Plan (PERH), established by Law No. 7663/91, the water resources of the state of São Paulo must be managed based on the hydrographic basins. A total of 21 basins were defined. In this context, the RMSP is in the Alto Tietê Hydrographic Basin (BHAT), being the Water Resources Management Unit number 6 (UGRHI-6).

The UGRHI-6 is, when compared to all the other 21 UGRHIs in the state, the one that "has the lowest per capita water supply, totaling 130.68 m³/year per inhabitant, due to its small geographic area and high population concentration" (SIGRH, 2017), in addition to being in a headwater region, that is, close to the springs. Therefore, the task of water supply in the RMSP can be challenging, to say the least.

The largest water reservoir in the RMSP is Billings. Designed by the American engineer Asa White Kenney Billings, the construction of the reservoir began in 1925 and its filling started in 1927. Originally, the reservoir was built to generate electricity for the city of São Paulo through the Henry Borden plant, in Cubatão, and more recently, it has also been used to supply water to the population (EMAE, 2017).

The Billings Reservoir has a total storage capacity of around 1.1 billion m³ of water (EMAE, 2017). However, only the Rio Grande branch and, more recently, the Taquacetuba branch are used for supply. According to the Basic Sanitation Company of the State of São Paulo (SABESP, 2017), the Braço Rio Grande produces about 5m3/s of water, supplying 1.5 million people in the municipalities of Diadema, São Bernardo do Campo and Santo André (only 7% of the entire population of the RMSP). The Taquacetuba branch began operating in 2000, through a transposition to the Guarapiranga Reservoir, being able to withdraw from it up to 4m3/s of water, when necessary. According to estimates by the Secretariat of Environment of the State of São Paulo (SMA, 2010) Billings would have the capacity to supply water to approximately 4.5 million people.

As previously mentioned, the RMSP has a lower per capita water availability than any other UGRHI due to its high population concentration. In this way, it is at least contradictory that so little use of the largest water reservoir available in the region, through only three of its branches: Rio Grande (112 million m³ of total capacity and flow of 5 m³/s of water) and Taquacetuba and Rio Pequeno (whose total capacities are not even possible to be estimated, as they do not have a dam separating them from the central body, being possible to withdraw from both 4 m³/s of water, when necessary), totaling a flow of 9 m³ /s, with the total capacity of the Billings Reservoir being 1.1 billion m³ of water. For comparison purposes, the Cantareira System has a flow of 33 m³/s and supplies 5.3 million people, with a total capacity of 982 million m³ of water (SABESP, 2017).

In this sense, the aim of this research is to highlight and analyze the factors that explain the underuse of Billings Reservoir in the supply of the population in the Metropolitan Region of São Paulo, based on data that covered 5 years. To do so, this research was guided by hypothesis that the underuse is related to the pollution, due to discharge of domestic and/or non-domestic sewage, in addition to garbage.

## 2. Development

### 2.1 Billings Reservoir

The Billings Reservoir was designed by the American engineer Asa White Kenney Billings, having its construction started in 1925 and its filling started in 1927. The project was carried out by the former The São Paulo Tramway, Light and Power Company, Limited, with the objective of taking advantage of the waters of the Alto Tietê Basin to generate electricity at the Henry Borden Hydroelectric Power Plant, in Cubatão, through the unevenness of the Serra do Mar escarpment (EMAE, 2017).

**Figure 1 –** Construction of Pedreira Dam at the Rio Grande water course in 1928. Source: Capobianco & Whately (2002).

In the early 1940s, part of the waters of the Tietê River and its tributaries to Billings began to be diverted by reversing the Pinheiros River. This was possible thanks to the construction of the Pedreira and Traição Pumping Plants, in the late 1920s (CAPOBIANCO & WHATELY, 2002). (Figure 1,Figure 2).

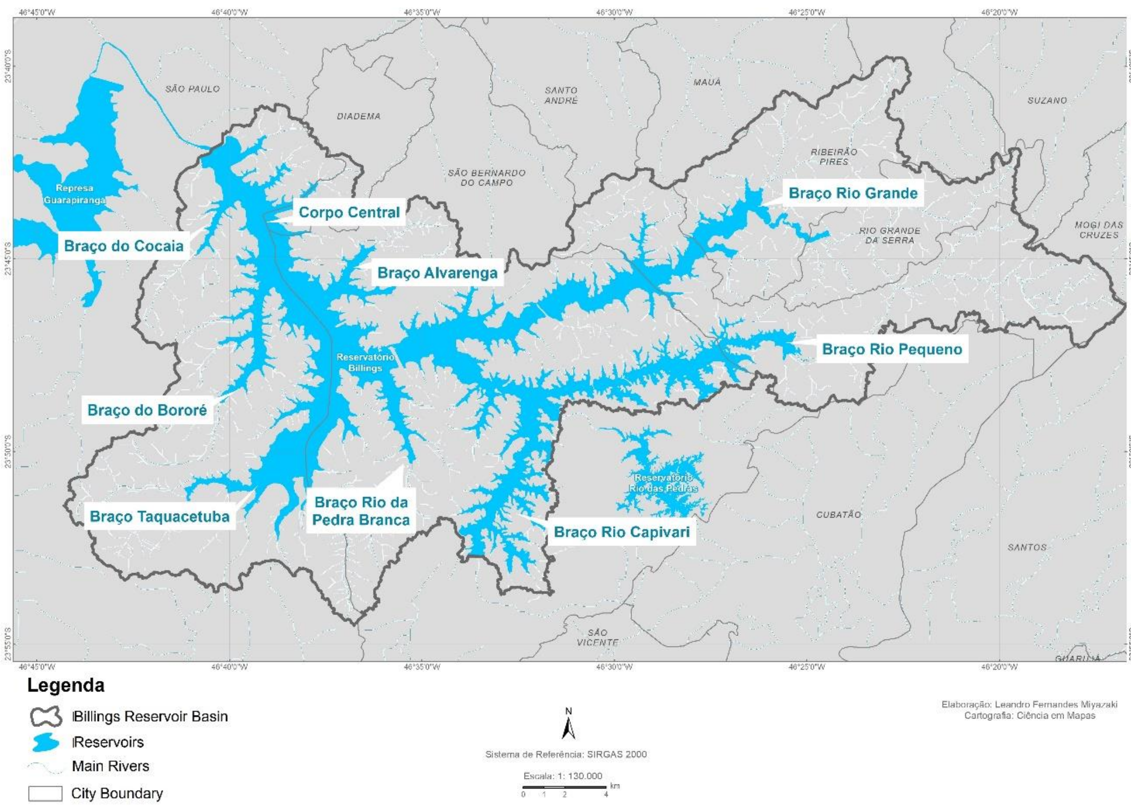



**Figure 2 –** Billings Reservoir River Basin and its arms (2018).

In addition, this operation also proved to be useful for controlling floods and the discharge of industrial effluents and sewage generated by the growing city of São Paulo. However, in the early 1970s, this pumping began to have serious consequences at Billings, with CETESB starting the anaerobic stain removal procedures (CAPOBIANCO & WHATELY, 2002).

## 2.2 Pollution, Sewage and Garbage

In 1982, due to the large amount of sewage in Billings, it is performed the interception of Braço Rio Grande, through the construction of the Anchieta Dam, to guarantee the supply of the ABC Paulista (cities of Santo André, São Bernardo do Campo, and São Caetano do Sul). The worsening of the conditions of the dam led to increased pressure from environmentalists to stop pumping water from Pinheiros River to Billings (one of the most important river that crosses São Paulo) (CAPOBIANCO & WHATELY, 2002).

During the first meeting of the State Council for the Environment (CONSEMA, 1983), the Billings situation was addressed. The next year, part of the waters of the Tietê River returned to its natural course, and CETESB started working on monitoring the water quality in the Reservoir, intending to manage pollution through its natural purification capacity (CAPOBIANCO & WHATLY, 2002).

According to Capobianco & Whately (2002), the water quality in Billings is severely compromised, both because of the pumping of polluted water from the Pinheiros River, as well as the resuspension of contaminated sediments and the irregular human occupation of its watershed.

The social and economic condition of the population in the basin is predominantly precarious. The urban expansion of the metropolis through an intense process of the establishment of irregular settlements, led to the emergence of clandestine subdivisions, invasions, and communities, in increasingly distant areas and with a lack of good urban infrastructure (PDPA BILLINGS, 2010).

**Figure 3 –** Water from the also polluted Pinheiros River being pumped into Billings (left) and Irregular Settlements alongside the Reservoir (right). ( Folhapress, 2015)

According to Capobianco & Whately (2002), the water quality in Billings is severely compromised, both because of the pumping of polluted water from the Pinheiros River, as well as the resuspension of contaminated sediments and the irregular human occupation of its basin (Figure 3).

The water characteristics of a reservoir are the result of a combination of several factors, including the nature ones, such as climatic cycles and ecological dynamics, or of an anthropic nature, such as irregular settlements being stablished in its surroundings, caused mainly by social exclusion (CAPOBIANCO & WHATELY, 2002).

In this way, the water concentration pollutants can be either due to external discharge, being dumped in the Corpo Central or in its tributaries, or by the internal discharge itself, through the resuspension of sediments contaminated by pollution. At Billings, the external discharge of pollutants consists of domestic and industrial sewage, in addition to garbage. On the other hand, the internal discharge is

e-ISSN:2717-8277

caused by the resuspension, as previously mentioned. The action of winds, rains or even a change in temperature causes the sediments to be moved in the water, causing the suspension of the accumulated pollutant discharges (CAPOBIANCO & WHATELY, 2002).

**Figure 4 –** Garbage discharged alongside the Reservoir. ( Folhapress, 2015.)

Other factors of concern regarding the quality of Billings water are eutrophication, the concentration of heavy metals, the presence of pathogenic microorganisms and algae that are highly toxic. Eutrophication occurs due to the intensification of the concentration of substances that contribute to the excessive increase of aquatic plants and algae. Critical eutrophication is verified at the Cocaia, Bororé, and Rio Grande arms as well as in some points of Taquacetuba and Corpo Central. Heavy metals were also identified at several points at the Reservoir, such as the Corpo Central and Cocaia, Bororé, Pedra Branca, Rio Pequeno, Taquacetuba and Rio Grande arms, caused by pumping polluted water from Pinheiros River and the remobilization of sediments contaminated with metals from the Reservoir (CAPOBIANCO & WHATELY, 2002). (Figure 4).

## 3. Materials and Methods

### 3.1 Method

Issue:5 2022
e-ISSN:2717-8277
International Journal of Water Management and Diplomacy

The method consisted of an evolutionary analysis of the Billings pollution levels and then on a dynamic and integrated analysis of the variables that supported the hypotheses.

## 3.2 Materials

### *3.2.1 Pollution Levels*

To determine pollution levels were used the Raw Water Quality Index (IQA) and the Raw Water Quality Index for Public Supply (IAP). IAQ was based and adapted from a study from the National Sanitation Foundation (NSF, 1970). A quality score (q) is established, ranging from 0 to 100, for each of the 9 variables considered in this index. Each variable is weighted (w) in relation to its importance and, finally, IQA is obtained by multiplying each component (qw). The IAP is the weighting product between IQA and the Index of Toxic and Organoleptic Substances (ISTO) (CETESB, 2021).[1](Figure 5).

| **Raw Water Quality Index (IQA) and Raw Water Quality Index for Public Supply (IAP)** | | |
|---|---|---|
| Range | Class | |
| IQA ≤ 19 | (purple) | Poor |
| 19 < IQA ≤ 36 | (red) | Bad |
| 36 < IQA ≤ 51 | (yellow) | Regular |
| 51 < IQA ≤ 79 | (green) | Good |
| 79 < IQA ≤ 100 | (blue) | Great |

**Figure 5** - Raw Water Quality Index (IQA) and Raw Water Quality Index for Public Supply (IAP).Source: CETESB (2021).

### *3.2.2 Total Amount of Domestic and/or Non-domestic Sewage and Garbage*

To determine the Total Amount of Domestic and/or Non-domestic Sewage was used the Sewage Collection and Treatability Index of the Municipality's Urban Population (ICTEM) (Figure 6), which portrays a situation that takes into account the effective removal of the biochemical oxygen demand (BOD), in relation to the potential BOD generated by the urban population without, however, failing to observe the importance of other elements that make up a sewage treatment system, such as the collection , removal and treatment. The indicator makes it possible to transform the nominal values of BOD into values for comparison between different situations in the various municipalities, reflecting the evolution

[1] For detailed variables explication see: https://cetesb.sp.gov.br/aguas-interiores/wp-content/uploads/sites/12/2021/09/Apendice-E-Indice-de-Qualidade-das-Aguas.pdf.

e-ISSN:2717-8277

or state of conservation of a public sewage treatment system. To determine the amount of garbage were consulted articles from the most reputed magazines in Brazil.

| **Sewage Collection and Treatability Index of the Municipality's Urban Population (ICTEM)** | | |
|---|---|---|
| Range | Class | |
| ICTEM ≤ 2,5 | | Poor |
| 2,5 < ICTEM ≤ 5,0 | | Bad |
| 5,0 < ICTEM ≤ 7,5 | | Regular |
| 7,5 < ICTEM ≤ 10,0 | | Good |

**Figure 6** - Sewage Collection and Treatability Index of the Municipality's Urban Population (ICTEM). Source: CETESB (2021).

*3.2.3 Interviews*

Interviews were conducted with experts in the field, PhD professors from the Department of Hydraulic and Environmental Engineering at Escola Politécnica da USP.

## 4. Results

### 4.1 Pollution Levels

Data were collected and analyzed for the period from August 1, 2012 to August 1, 2017. For the IQA and IAP Indexes the following water quality monitoring points (Table 1,Figure 7) were considered:

**Table 1 -** Water Quality Monitoring Points at the Billings Reservoir (2017).

| **Water Quality Monitoring Points** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Point Code** | **Water Resource** | **UGRHI** | **City** | **For Supply?** | **Latitude** | **Longitude** | **Operating Since** |
| BILL 02030 | Billings Reservoir | 6 | SÃO PAULO | No | 234304 | 463951 | 1/1/2007 |
| BILL 02100 | Billings Reservoir | 6 | SÃO PAULO | No | 234457 | 463852 | 1/1/1999 |
| BILL 02500 | Billings Reservoir | 6 | SÃO BERNARDO DO CAMPO | No | 234727 | 463554 | 1/1/1976 |
| BILL 02900 | Billings Reservoir | 6 | SÃO BERNARDO DO CAMPO | No | 234904 | 463123 | 1/1/1976 |
| BIRP 00500 | Arm Rio Pequeno | 6 | SÃO BERNARDO DO CAMPO | Yes | 234728 | 462814 | 4/14/2015 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| BITQ 00100 | Arm Ribeirão Taquacetuba | 6 | SÃO PAULO | Yes | 235041 | 463920 | 1/1/1999 |
| RGDE 02200 | Rio Grande Reservoir | 6 | RIBEIRÃO PIRES | No | 234423 | 462644 | 1/1/1983 |
| RGDE 02900 | Rio Grande Reservoir | 6 | SÃO BERNARDO DO CAMPO | Yes | 234616 | 463203 | 10/1/1974 |

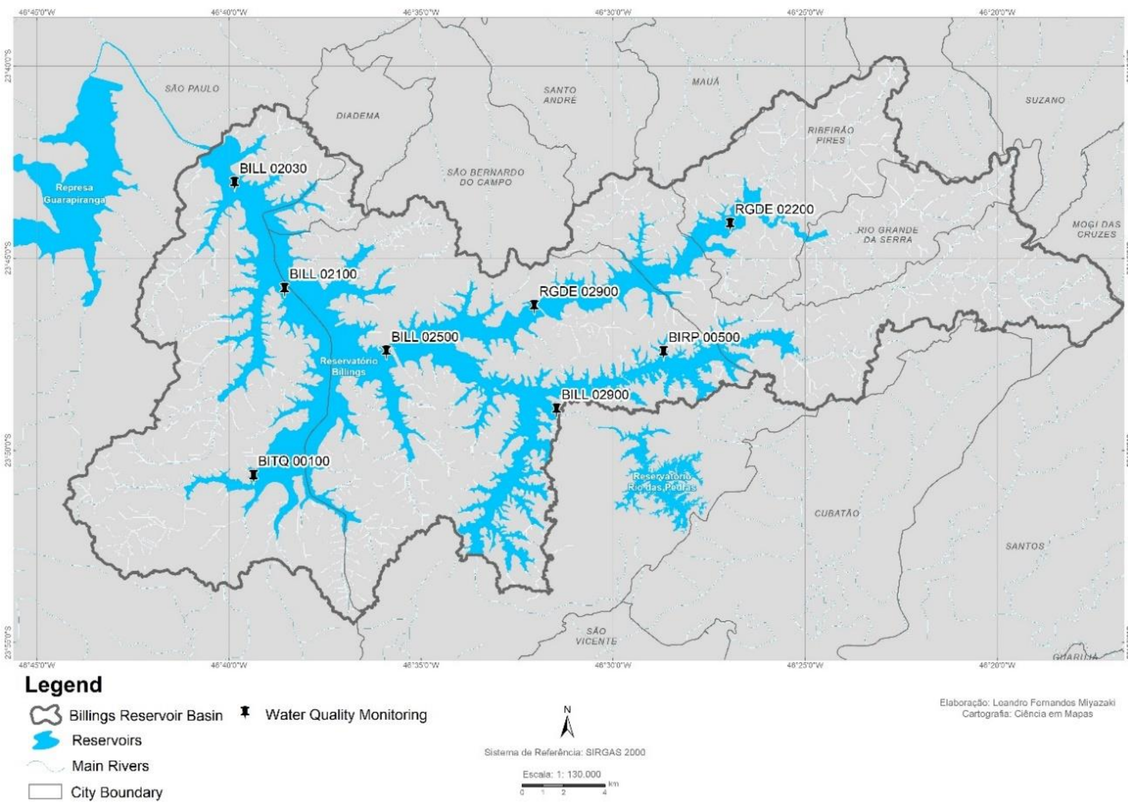



**Figure 7** - Water Quality Monitoring Points at the Billings Reservoir (2017).

Issue:5 2022
e-ISSN:2717-8277

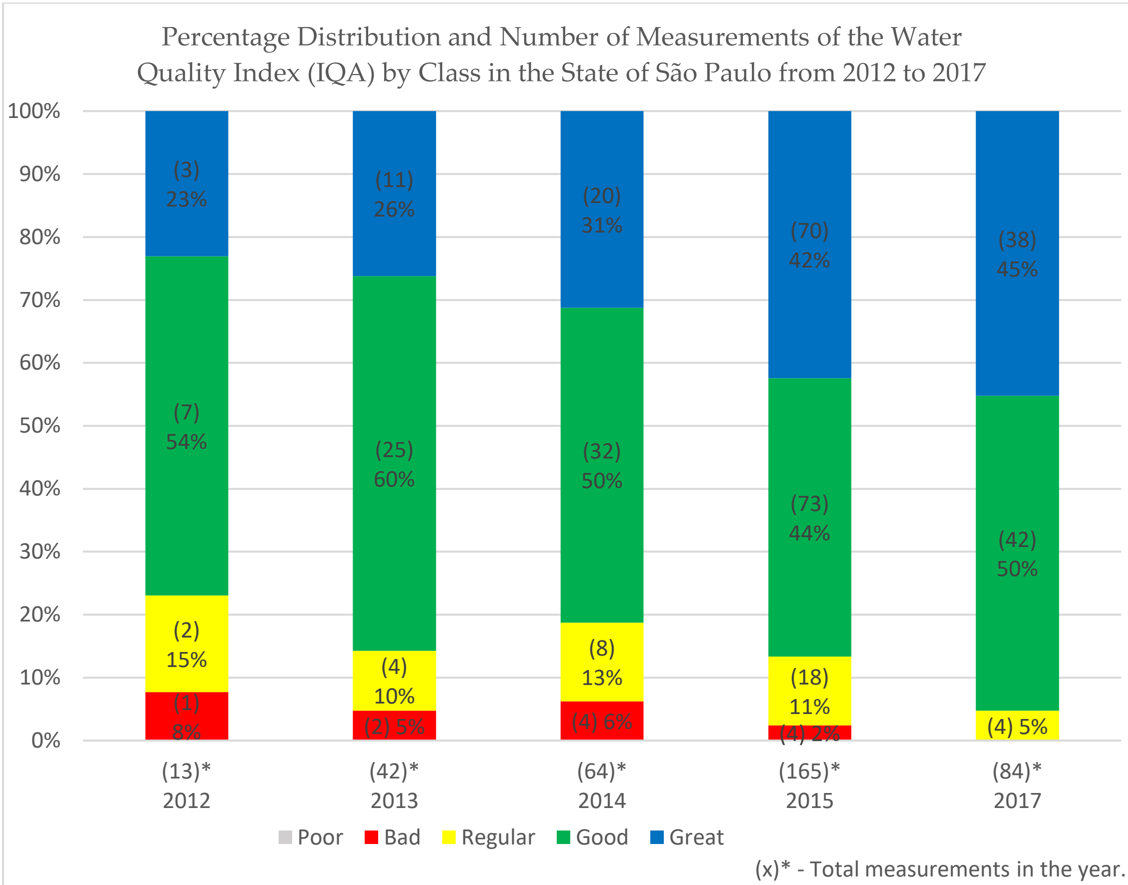



**Figure 8** - Percentage Distribution and Number of Measurements of the Raw Water Quality Index (IQA) by class at the Billings Reservoir from 2012 to 2017. Source: InfoÁguas (2017).

Figure 8 shows that water quality was predominantly classified as Good or Great, increasing the Great class from 23% in 2012 to 45% in 2017. In addition, the Poor class was not verified at any time, while the Bad class dropped from 8% in 2012 to 2% in 2015, not being verified in the 2017 measurements. In general, there was an overall improvement on the water quality.

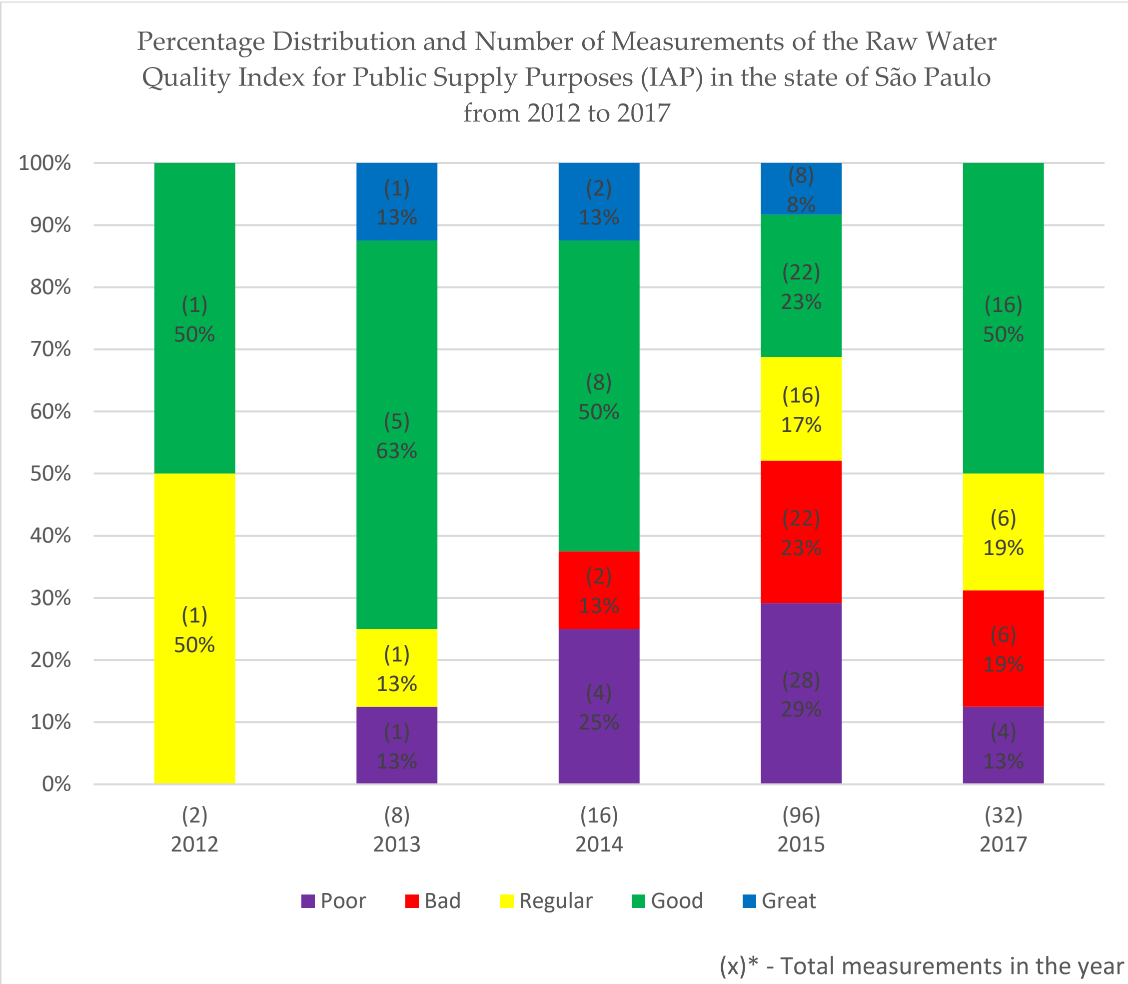



**Figure 9 -** Percentage Distribution and Number of Measurements of the Raw Water Quality Index for Public Supply (IAP) by Class in the Billings Reservoir from 2012 to 2017. Source: InfoÁguas (2017).

Figure 9 shows that there was great variation in the IAP classes. In 2012, despite not appearing the classes Poor or Bad, it is important to highlight that there were only two monitoring points, thus being a very restrictive result quantitatively. As of 2013, the total of monitoring points increased to 8, with most of them - 63% - presenting water quality as Good. Between 2013 and 2015, a deterioration in the quality of the IAP is observed (the Poor class goes from 13% to 29%), in addition to an increase in the number of monitoring points (from 8 to 96 in total). In general, the IAP index showed a worsening trend between 2012 and 2015, but in 2017 it showed some improvement (50% of the points were from the Good class).

## 4.2 Total Amount of Domestic and/or Non-domestic Sewage and Garbage

Table 2 shows that Diadema, Santo André and São Paulo have the highest rates of sewage collection among the cities at the Billings Basin. Ribeirão Pires and Rio Grande da Serra have the lowest rates, with the latter collecting less than half of its effluents. However, despite owning the best collection rates the cities of Diadema and Santo André are the ones with the lowest treatment rates. When it comes to the efficiency of the effluent treatment process, all of them present rates above 80%.

**Table 2 -** Collection, Treatment and Efficiency Rates of the Sewage Network of the Municipalities inside the Billings Basin – 2016. Source: CETESB (2016).

| **Collection, Treatment and Efficiency Rates of the Sewage Network from Cities at the Billings Basin - 2016** | | | | |
|---|---|---|---|---|
| City | Urban Population | Atendimento (%) | | Efficiency (%) |
| | | Collection | Treatment | |
| Diadema | 415,180 | 90 | 30 | 91 |
| Ribeirão Pires | 121,130 | 70 | 70 | 91 |
| Rio Grande da Serra | 48,861 | 49 | 85 | 91 |
| Santo André | 712,749 | 98 | 41 | 98 |
| São Paulo | 11,910,639 | 88 | 75 | 82 |

Table 3 shows that BOD and Urban Population are directly proportional variables, as the greater the population, the greater the BOD produced. Diadema (75%), Santo André (63%) and Rio Grande da Serra (61%) shows the highest remainder amount, being classified as Bad. Ribeirão Pires (55%) and São Paulo (46%), are classified as Regular and Good, respectively. Despite the largest population, the Good rate for São Paulo mean higher investments due to social and political pressure, since its magnitude results in stronger institutions. As the treatment rates do not follow the collection ones, the result is a lower rate in ICTEM.

Table 3. Sewage Collection and Treatability Index of the City's Urban Population (2016

| **Sewage Collection and Treatability Index of the City's Urban Population (2016)** | | | | |
|---|---|---|---|---|
| City | Urban Population | BOD (kg/per day) | | ICTEM |
| | | Potential | Remainder | |
| Diadema | 415,180 | 22,420 | 16,926 | 3.39 |
| Ribeirão Pires | 121,130 | 6,541 | 3,621 | 5.20 |
| Rio Grande da Serra | 48,861 | 2,638 | 1,630 | 4.50 |
| Santo André | 712,749 | 38,488 | 24,475 | 4.75 |
| São Paulo | 11,910,639 | 643,175 | 296,486 | 6.45 |

**Table 3 –** BOD and ICTEM from Cities at the Billings Basin – 2016. Source: CETESB (2016).

**Figure 10 –** Irregular settlements at the deactivated landfill Alvarenga in 2016 and Alvarenga landfill in the early 2000.

Figure 10 shows the Alvarenga landfill, a 40,000m$^2$ area that was used for the discharge

of heavy industrial waste and irregular debris for many years. According to the PDPA Billings (2010), since the establishment in 1972 to nowadays more than 2 million tons of garbage have been discharged in it. Although deactivated, it is estimated at 400 tons of garbage[2] being discharged every day at the Billings Basin. Besides this, the new irregular settlements at this area (result of weak housing policies) potentiates the pollution levels at the Billings basin.

## 4.3 Interviews

Questions like 'Why the water from the Corpo Central is not treated for supply' (the most polluted area) and 'Is there a technique available to treat water from the Corpo Central for supply' were asked. Answers mentioned that membrane separation processes, such as ultrafiltration and nanofiltration, can remove various contaminants present in the water and do not require chemical products continuously for their operation, which eliminates the generation of sludge. Photochemical oxidation process, which can eliminate organic pollutants such as residuals from drugs and other chemicals, can be used for complementary treatment (MIERZWA, 2018)[3].

Also, were asked questions such as 'If there is a technique available for treating the water from the Corpo Central, why it is not used?' and 'Would you like to add something that was not covered? Answers mentioned that reasons may rely on mainly due to the lack of knowledge about its potential compared to conventional water treatment technologies, as well as a misguided view of its implementation cost. It

[2] Veja Magazine (2015).

[3] PhD Professor at the Department of Hydraulic and Environmental Engineering at Escola Politécnica from University of Sao Paulo.

was pointed out that many people even those who work on this subject believe that bringing water from far away is cheaper than using this kind of technology. To wrap up, the interviewees added that problems related to water supply in highly urbanized regions are quite complex and require concerted actions to address them. Variables as reduction of water consumption, adoption of modern technologies for water treatment, expansion of sewage collection and treatment (MIERZWA, 2018) as well as the lack of interest of decision makers who prefer to import water from distant basins at high costs (HESPANHOL, 2018) [4]were brought up too.

## 5. Conclusion

IQA Index which was considered to provide an overview of water quality showed an improvement trend between 2012 and 2017. However, measurements for 2016 were not located to be analyzed. IAP Index, the most reliable index, was considered to have the quality of water for public supply purposes. In general, despite the variations in the number of measurements per year during the analyzed period (from only 2 in 2012, rising to 96 in 2015), it was possible to verify that the water quality has a worsening trend. In 2017, there was a fall again in the number of measurements points (32 in total), but when compared to 2015 (which had presented the worst rates) there was a fair trend of improvement. Data for 2016 was also not found to be analyzed.

BOD and Urban Population are directly proportional variables, as the greater the population, the greater the BOD produced. Regarding the performance of sewage collection and treatment systems (ICTEM), only São Paulo presented an index classified as Good. Ribeirão Pires was classified as Regular while Santo André, Rio Grande da Serra and Diadema were classified as Bad. This is a result, on the one hand of the low rate of sewage collection in some cities, such as in Rio Grande da Serra, and, on the other hand, of the low rate of treatment, such Diadema and Santo André. Thus, it is necessary that the collection and treatment rates go together, as this is the only way to have an effect. It is estimated that 400 tons of garbage is still discharged into Billings. Although Alvarenga landfill is officially deactivated its remediation has not started and the new irregular settlements potentiates the pollution levels.

In this sense, it was concluded that the variables analyzed (pollution levels, sewage, and garbage amount) provided favorable evidence for the confirmation of hypothesis. However, interviewees emphasized the membrane separation processes, such as ultrafiltration and nanofiltration, which together to other techniques may turn the water from Corpo Central fit for use. That means that the

[4] Late PhD Professor at the Department of Hydraulic and Environmental Engineering at Escola Politécnica from University of Sao Paulo. Founder of the International Reference Center on Water Reuse (CIRRA).

pollution is the main problem, but it is already possible to overcome this obstacle. For future research, it is recommended to explore the status quo around this subject to better understand these dilemmas.

## 6. References

BRASIL. Instituto Brasileiro de Geografia e Estatística. Diretoria de Geociências. **Vocabulário Básico de Recursos Naturais e Meio Ambiente.** 2. ed. Rio de Janeiro: Ibge, 2004. 332 p.

CAPOBIANCO, João Paulo Ribeiro; WHATELY, Marussia. **Billings 2000:** ameaças e perspectivas para o maior reservatório de água da Região Metropolitana de São Paulo. São Paulo: Instituto Socioambiental, 2002. 59 p.

Companhia Ambiental do Estado de São Paulo. Secretaria do Meio Ambiente. **Qualidade das Águas Interiores no Estado de São Paulo.** São Paulo: Cetesb, 2017. 282 p.

Companhia de Saneamento Básico do Estado de São Paulo. **Relatório de Sustentabilidade 2016.** São Paulo: Sabesp, 2016. 101 p.

Governo do Estado de São Paulo. Secretaria do Meio Ambiente. **Relatório de Qualidade Ambiental.** São Paulo: SMA, 2016. 300 p.

HESPANHOL, Ivanildo. Água e saneamento básico. In: REBOUÇAS, Aldo da Cunha (Org.). Águas doces no Brasil: capital ecológico, uso e conservação. 3. ed. São Paulo: Escrituras, 2006. Cap. 9. p. 269-324.

Instituto Brasileiro de Proteção Ambiental. **Relatório sobre a Vulnerabilidade Hídrica da Região Metropolitana de São Paulo.** São Paulo: PROAM, 2015. 28 p.

RODRIGUES, Raphael; MIERZWA, Jose Carlos; VECITIS, Chad D. Mixed matrix polysulfone/clay nanoparticles ultrafiltration membranes for water treatment. **Journal of Water Process Engineering**, v. 31, p. 100788, 2019.

VENTURI, Luis Antonio Bittar. The New Concept of Natural Resource and Its Derivations. **International Journal of Water Management and Diplomacy**, v. 1, n. 1, p. 48-60.

VENTURI, Luis Antonio Bittar. **Water's Flow of Peace**. Cambridge Scholars Publishing, 2020.

Received: 20 May 2022

Accepted: 08 June 2022

Issue:5 2022
International Journal of Water Management and Diplomacy
e-ISSN:2717-8277

*Research Article*

# Water pricing as a demand management option: dilemmas, challenges, and prospects

**Dr.Nuran Çakır Yıldız**
*Istanbul University-Cerrahpaşa, School of Social Sciences,*
*Marketing and Advertising Section*
*Email: nurcak@gmail.com*

## Abstract

This study starts with the economic policy of water, then the most basic difficulties encountered in water pricing are introduced It continues with studies on both the theory and applications of water pricing. Finally, it concludes with recommendations within the framework of the principles and logic of water pricing.

This study focuses on the subject that the improvement and dissemination of pricing services are substantial solutions for the effective use of water resources and the protection of the environment. It is also involved the issues like "economic dimension" of water, "right to water" and "economic value of water".
Related to the subject, it is expected to make two main contributions regarding both theory and practice of water pricing. (i) to provide an overview of the economics of water pricing; (ii) to illustrate the key dimensions and challenges of water pricing
The center of the study is to summarize important steps for policymakers seeking effective and efficient water pricing.

**Keywords:** Water pricing, Water demand management, Supply-side water management Environmental sustainability, Evolution of sustainable development

## 1. Introduction

In the report released after the International Conference on Water and Environment (ICWE) held in Dublin (Ireland) on January 26-31, 1992, the economic value of water was assessed, and then "full cost coverage" at the 2003 Kyoto World Water Forum approach and the "polluter pays" principle was brought to the agenda.
The definition of water as a fundamental human right in Principle 4 of the Dublin Conference paper was not a sufficient criterion.
In the General Comment 15th part of the conference, on the subject of the affordability of water, it is recommended that free usage or low-cost pricing policies, taking into account their own social and economic conditions and the principle of equity.

In addition to these, paragraph 11 emphasizes the importance of ensuring that the realization of the right to water is sustainable by pointing out that water is not only considered an economic good from a narrow perspective, but also a social and cultural good.

Despite the emerging efforts to recognize water as a human right in the international community, the understanding that water is an economic good also constitutes the other paradox of the issue.
According to the World Bank(WB), managing water as an economic good is necessary in terms of environmental sustainability (ecological outlook) and economic consideration, and these purposes are only possible by leaving supply-oriented management and adopting demand-oriented management. According to the WB, demand-oriented management is "limiting the demand for water by various means, such as setting price or quantitative limits".

Water pricing, which plays a key role in managing water demand and increasing water supply, has dimensions that simply do not fit into engineering, mathematics, and financial balance sheets. In July 2010, the UN General Assembly declared access to safe drinking water and sanitation a human right. But when water is considered an economic good, It is important to strike a balance between these two aspects of water to price water fairly and equitably and to maintain and expand the water and sanitation system.

In many countries, those who think that the income generated cannot cover (re)investment in infrastructure, as well as the operation and maintenance of water facilities because consumers pay very little for water services, advocate water pricing as an important economic tool.

Here, the same point of view highlights the need to price water to increase water use efficiency, ensure and develop social equality, and ensure the financial sustainability of water facilities and operators.
Relevant decision-makers are faced with the dilemma of how to provide water services reliably, now and in the future, that protect basic human needs and maximize the consumer surplus of water users. This requires not only engineering decisions about maintaining and increasing the water supply, but also making economic decisions about how to price water in ways that combine sustainability, efficiency, and equity.
All of the goals of combating poverty, health, education, and environmental sustainability within the Sustainable Development Goals make the right to water necessary (Jayyousi, 2007;330). All experts agree that the amount of water a person needs to survive should be subsidized. However, increasing political, economic, climatic and pollution pressures on water resources and the use of prices to reduce consumption become more acceptable putting water pricing reform on the agenda. Interest in effective and efficient water pricing is increasing day by day.

e-ISSN:2717-8277

**2. Basic Information on Water Use**

“The water provided for each person should be sufficient and continuous for personal and domestic use” (General Comment No: 15, 2002: paragraph 12).
Another statement was made in General Comment 15 (2002) paragraph 6: “Water is essential for many purposes, for personal and domestic use as well as for the realization of many of the rights contained in the Covenant. For example, water is essential for cooking (the right to adequate nutrition) and environmental health (the right to health). Water is also essential for people to earn a living (the right to earn a living by working) and to participate in various cultural activities (the right to participate in cultural legislation).

Whether water is formally expressed as a "human right" or a "commercial commodity", what is certain is the human need for water. The World Health Organization estimates the daily amount of water required for survival per person as 2.5 liters, U.S. The Environmental Protection Agency and the National Academy of Science define it as 2.0 liters (Gleick, 1996: 84). According to the research conducted by Gleick (1996), the amount of water required per person per day in total is 50 liters for drinking water, sanitation services, bathing, and cooking, regardless of climate, technology, and cultural influences. Therefore, within the scope of the social dimension of water allocation, necessary arrangements should be made to provide clean drinking water to people, ensure sanitation and food security and their basic social needs, and ensure the continuity of cultural identity.
According to the World Health Organization, access to water is not in question if it takes more than 1 kilometer in terms of distance and 30 minutes in terms of walking time. If it is reached within 100 meters in spatial terms and in 5 minutes in terms of time (at least one tap), we can talk about "medium level access". Finally, access to water in the house with more than one tap is considered optimal access.
The water use index (WEI), on the other hand, is obtained by dividing the average annual total amount of water withdrawn from fresh waters by the average total annual renewable freshwater resources at the country level and is expressed as a percentage.

According to projections, it is estimated that the amount of water per capita in Turkey, which was 1346 cubic meters in 2021, will decrease to 1116 cubic meters in 2040 with a population of 100 million. This figure indicates that according to the generally accepted criteria (Falkenmark index), Turkey will be a water-poor country. The decrease in the amount of water and the increase in population will continue at this rate, and in the 2050s, it will be a country that suffers from 'famine-drought' with 1069 cubic meters and below.
The amount of water consumed per person per day in Turkey is approximately 217 liters. In European Union member countries, this rate is 150 liters on average. Turkey is in the 4th rank among the 'most water consuming' countries in the world. Estonia, a European country of 1.3 million, ranks first with 355 liters per day, followed by the USA with 353 liters per day, and Greece with 282 liters. At its lowest usage, Israel is 38 liters and Lithuania is 30 liters

The amount of water consumed in the bathroom and toilet in Turkey constitutes 70 percent of the total water consumed at home. water in homes; 35 percent is used in the bathroom, 30 percent in the toilet, 20 percent in laundry and dishwashing, 10 percent in cooking and drinking water, and 5 percent in cleaning. liter and 173 liters for İzmir.

The world population is approximately 7.9 billion as of September 2021. 59.5 percent of the world's population lives in the Asian continent, where the world's most populated countries such as China and India are located. Although Africa has only 17.2 percent of the world's population, its population growth is 2.49 percent annually.
The global population is increasing by an average of 81 million people each year, the annual rate of increase has declined to 1.08% in 2020), and the world population is estimated to reach 9.8 billion people by 2050.
It is estimated that the world's food demand will be 60 percent higher in 2050, and therefore the water demand will increase at the same rate. There are two important components of water demand in the industry: Energy and manufacturing industry. The energy sector accounts for 75% of the water withdrawal in the industry and 25% of the manufacturing industry (United Nations Water:2018). It is stated that the use of water in residences and settlements will vary regionally but will increase at least three or four times (Boretti, and Rosa,2019, https://www.nature.com/articles/s41545-019-0039-9. Access Date: 14 October 2021).

## 3. The Political Economy Of Water

The acceptance of water as an economic good has caused a new debate among economists. Considering water as an economic good with the claim of water scarcity is effective in losing its public properties and becoming private property.
At the center of the debate is whether water is a right or a need.
If water is considered a human right, the idea that "no one can trade or sell it, or deprive anyone of this right because they cannot pay for it" comes to the fore.

If water is accepted as a need (acknowledged by the World Water Council and the World Bank), the idea that this need can be met by private companies as well as by public institutions is also accepted.

i. *The approach that defines water as an "economic good" demands that it be produced and sold under market conditions and that this service is provided by the private sector.*
ii. *The approach that defines water as a "fundamental human right" argues that everyone should have access to equal and safe water, and this can best be achieved by the public.*

The uneven distribution of water resources and the inequality created by political, economic, and administrative choices are at the root of the problems experienced in accessing water (Gleick, 1999: 495).

According to the UNESCO World Water Assessment Programme, reasons such as geographical limitations, economic difficulties, lack of capital-technology-information, and weakness of the state and its institutions can make it difficult to access existing resources in developing countries.

Even if access to water is provided, the poor quality of water (especially the use of water polluted by agricultural activities such as the use of fertilizers and pesticides) is considered as an important problem as access to water (Gleick, 1993: 91-92; Swain, 2004: 7).

**3.1. Public Good Aspect**

One of the most complex and blurred issues of public law, although it is the most important, is the concept of "public service". Today, the concept of "public service", which is one of the concepts in which economy and law are intertwined, is used as "functions/duties of the state" in the discipline of political sciences.

Legally, it is defined as "activities carried out to meet a general and collective need that arises at a certain time and place and needs to be satisfied continuously and regularly" (Gözübüyük and Smartoğlu, 1993:8 and Onar,1966:28). )

Public service according to one definition; is defined as continuous services that are offered equally to the society to meet general and common needs and that can vary according to the needs of the society.

According to another definition; services are provided to the public by a private enterprise, either by itself or under the close supervision of a public institution.
In summary, in light of the results, it is clear that water is a need that must be satisfied and consumed continuously and regularly.
Water has many features that indicate both public and economic properties.
First, the consequence of water is both a necessary and a non-substitute good is a public good.

The fact that the normal value of water is low does not mean that water can be privatized. The high social value of water is an important factor that prevents the purification of water. This is because water is both a necessary and a non-substitute good.
Secondly, the water sector is largely a public health sector. A clean drinking water supply and an extensive and reliable sewage system are required to avoid mass disease. The existence of clean water and clean water resources that can be accessed and the dangers that the society will face due to water and water are the responsibility of the states. Because the water sector is directly related to public health, the provision of water and wastewater services is seen as a necessity even in regions that are not economically profitable. With this feature, it is public property.
The simple definition of "economic good" for water is an effort to reconcile between those who advocate leaving the price and distribution of water to the functioning of the competitive market mechanism and those who argue that it should be seen as a basic need and excluded from the logic of market functioning. To the extent that the social benefits of water exceed the benefits from private consumption, it meets the criteria of being a valuable commodity (OECD 2002:7; Perry, Rock and Seckler 1997:6).

From this, it is concluded that water consumption, which is considered a basic human need, should be supported to reach the optimum consumption level in terms of society. Perry, Rock, and Seckler (1997, 6) stated that water, which should be considered a basic human need up to a certain amount, is private property after this amount, and whether it is subject to public or private supply can be evaluated according to these amounts.

A person's consumption of water specifically for cleaning can also provide protection (sanitation) against common infectious diseases. This protection has the same qualities as pure public goods. In this context, externality includes public goods as a special case (Cornes and Sandler 1986, 43-44). Since the market mechanism cannot internalize such elements in the decision-making mechanisms of individuals, the optimal level of supply will not occur. In this case, state intervention will appear in the form of subsidies for private expenditures.

While it is easily defined as a "common property" among the surface waters that are available to everyone, when only mains water is considered, it technically has the feature of exclusion, since access to this property depends on access to the network. At this point, if it is questioned whether exclusion is preferred or not, it will be concluded that the public feature of water is significant when it is considered that the inelastic nature of the demand for water and the low cost of taking the goods to an additional user to an individual after the supply network is established.

Another view is that water accessed from the network is a private good that has the characteristics of competition in consumption (because one person's consumption reduces the amount for others) and excludability from consumption (as only those who can pay can access the service), and efficiency in the distribution of resources can be achieved through proportional pricing (OECD 2002: 7).

The theory of public goods is also criticized because the criteria of competition in consumption and excludability from consumption cannot explain the distinction between public goods and private goods and those evaluations on this subject are based on value judgments. According to Malkin and Wildavsky (1991), the fact that all goods have both public and private characteristics makes it impossible to base the classification of public goods on objective criteria; Even if there are objective criteria, the classification to be made will not justify the state financing of the goods. This view emphasizes that the provision of public goods is a political process rather than a normative act (Malkin and Wildavsky 1991: 358).

As a result, the quality of water as a product in the ongoing debates is changing along the public-private line (Mehta 2002: 561).

More importantly, the increasing emphasis in these discussions on the properties of water that can be considered in the same category as private goods constitutes the first pillar of the changing nature of the industry. Questioning the concepts of public goods/valuable goods is one of the reasons for increasing pressures toward privatization (Çakal, 1996: 15).

In terms of future discussions, it is possible to say that the characteristics of water as a product are the main variables of the political decision-making process, as well as the characteristics that determine the industry in general.

### 3.2.Water as a Global Good

Globalization, in the simplest sense, can be defined as the increasing degree of communication and interaction between people, societies, and states living in different parts of the globe, within the framework of the concept of "interdependence".
Globalization; is the event of the integration of countries and peoples of the world, which reduces transportation and communication costs, and removes the barriers to goods, services, capital, and people crossing borders.
The concept of global public goods came to the fore for the first time with the study titled "Global Public Goods: International Cooperation in the 21. Century", prepared by the United Nations Development Program (UNDP). Therefore, the definition that should be addressed first in defining the concept of global public goods is the definition of global public goods in the aforementioned study. Accordingly, goods whose utility is largely universal for countries, people, and generations (present and future) are called global public goods.
Two criteria come to the fore in the UN Development Program's definition of global public goods. The first is that these goods are social, there is no competition in their consumption and no one can be excluded from their benefits, which are the main determinants of public goods. The second criterion is that its benefits are “quasi-universal", including all countries, people, present, and future generations.
In the definition of the World Bank, it is stated that there are cross-border externalities as the determinant of global public goods and that to obtain these externalities, countries should work together in the production of these goods and that insufficient production of such goods will be prevented by joint financing.
There are also global, international, and regional public goods concepts in the related literature. These expressions are interpreted according to the spreading areas of externalities (benefit or harm). If externalities are realized on a global scale, they are considered global goods. An example of this is the depletion of the ozone layer.
In principle, such goods and services benefit the entire global population, and the benefit is universal across countries, peoples, and generations. Accordingly, global public goods can be characterized as "benefits that can be obtained by all individuals (currently living individuals and future generations) in the world, where there is no competition and restriction in consumption, that everyone can benefit from and whose financing is provided globally". (Stiglitz,2006:31)

## 4. Theoretical Approach to Pricing

### 4.1. Value of Price

In practice, the terms price and value are sometimes used interchangeably. However, although these two concepts are related, they theoretically have different meanings.
Price is broadly defined as "value in money; It can be defined as the amount of money required to purchase goods or services that a seller wants to waive his right to goods or services" (Encyclopedia of Banking and Finance, 1962: 591). Considering the definitions in the literature, price is implicitly perceived

Issue:5 2022
e-ISSN:2717-8277

as a measure of value. However, price is not a value because it does not express the true value of a commodity. In the semantic term of the price, it usually has a temporary feature. It is the monetary price demanded (received) for goods and services. It is the sum of the values that consumers pay for the benefit resulting from owning or using a good or service.
Value is sometimes the total benefit or useful character of any good or service; sometimes it expresses the power to buy other goods or services provided by owning this thing, that is, the exchange power of a good or service against other goods or services (Encyclopedia of Banking and Finance, 1962: 591). The first is value in use; the latter is called exchange or exchange value.
Explaining the concept of value is one of the most complex problems and discussion topics in economics. The formation of prices, the existence of a relationship between price and value, or whether the goods have value independently of prices are extremely important issues for a well-functioning market mechanism (Ertuğrul, 2008: 148).

What value and price are and what constitutes a source for them have been studied by economists who put forward their theory of value.
According to Smith, the price of a good and the value of that good are two different things.
The value should be a fixed measure that does not change over time, while the price fluctuates over time. According to Adam Smith, the utility has nothing to do with exchange value. Because although water is more useful than diamond, diamond is more valuable than water. Accordingly, there is no relationship between utility and value. Useful is not valuable.

Adam Smith, in his book The Wealth of Nations, defined total utility as the value in use and the power of one good to purchase other goods as exchange value. When making a spending choice, the consumer takes into account the benefit (satisfaction obtained due to the fulfillment of the need) and makes his choice accordingly. The main purpose of the economically minded consumer is to spend his limited budget most beneficially.
In the same book, Adam Smith defined "the power of a good to buy other goods as its exchange value. The exchange value of a good is determined by the use-value of that good. Goods with a high use value also have a high exchange value. However, this proposition of classical economics does not always turn out to be true. There are also goods in life with a high use value and low exchange value, or goods with a low use-value and high exchange value. The most well-known example of this phenomenon is water and diamonds.

A commodity with a high use value (such as water) has a low exchange value, whereas a commodity with a low use value (such as a diamond) has a very high exchange value.
This; Although it is a consumer good with a very high use value, it is a luxury good with a very low exchange value and a very low use value, while diamond is good with a very high exchange value. This phenomenon is described as the "value paradox" in economics. Because the exchange value of a good is determined not by its total utility, but by its marginal utility, and consumers' purchase of the relatively

scarce diamond in very small quantities relative to water requires that the marginal utility, and hence exchange value, of diamonds relative to water, be much higher.

The law of diminishing marginal utility of William Stanley Jevons (1835-1882), the pioneer of Marginalist Thought, tried to explain the water-diamond paradox that preoccupied Classical economists.

The subjective pleasure or satisfaction expressed as the utility can be estimated simply by observing human behavior and listing human preferences. This approach, which is based on the fact that the benefit cannot be measured but can be ordered, is called ordinal utility. A single individual can compare the utility he receives when consuming successive units of a single good. A single individual can likewise compare the marginal benefits of various other goods.

The consumer who makes a rational choice, that is, who wants to maximize his utility, spends his monetary income (budget) in such a way that the marginal utility he will get from the last unit of all goods is equal.

The determinant of exchange value is utility. The utility is the capacity of a good to meet human needs. The utility comes from scarcity. Since the value of a good is determined by the marginal utility derived from that good, the product with low marginal utility is worthless, and the product with high marginal utility is valuable. Value is not a quality in a good, it is a feature that the buyer of that good attributes/gives to that good from outside.

It is not valuable because labor is used in the production of a good, it is valuable because the buyer of that good sees that it is useful, decides that it has a feature that will meet his needs, and more importantly, he finds that good worth buying. In other words, value is a subjective concept (Bocutoğlu,2012b,p.159)

The contribution of the marginalist school to this issue, with the emergence of the marginal utility theory, gave a different explanation to this paradoxical situation (diamond is more valuable than water). The main thing that determines the value of a good is the marginal utility it provides. It is a fact that the benefit of water consumption is enormous. However, another known fact is that as consumption increases, total utility increases, while marginal utility decreases (principle of diminishing marginal utility). (Çataloluk, 2014:872)

Therefore, while the marginal utility of the vitally important water consumed a lot is low, the total utility of the diamond that is consumed very little is low but the marginal utility is high.

Diamonds are rare; the cost to produce a new one is high; whereas water is relatively abundant and costs very little in many parts of the world. The total utility of water does not determine its price or demand.

Since water is abundant in nature compared to diamonds, it is deduced that it is cheap since no great effort is spent in obtaining it. After this explanation, it cannot be explained by the labor theory of value why the diamond piece found by chance in the forest or the desert without any effort is much more valuable. This situation is called the water-diamond paradox. To the classical economists' water-diamond paradox, marginalists tried to explain the law of diminishing marginal utility as follows. (Bocutoğlu, 2012, p.31)

The total utility of water is higher than the total utility of diamonds, whereas the marginal utility of water is smaller than the marginal utility of diamonds. Since the value of a good is determined by the marginal utility derived from that good, the product with low marginal utility is worthless, and the product with

high marginal utility is valuable. Because water is abundant and diamonds are scarce. This is why water is worthless and diamonds valuable. Water, which is vital and therefore valuable to all, is much cheaper than diamond, which is very expensive and has little usefulness. While the use-value of a diamond is relatively low, the use-value of water is high. On the other hand, the opposite is true for exchange values. If the amount of water and diamonds were the same on Earth, the marginal utility of water would be greater than that of diamonds. However, the value of the last unit of water (marginal utility of water) is lower since the amount of water is higher compared to the number of diamonds (marginal utility of diamonds). For example. Living in the drier part of the world increases the marginal utility of water.
Water has a vital property that has no substitute. However, even without diamonds, all living things can live in nature (nature itself). Therefore, in terms of the total benefit, water is vital and more beneficial than diamonds.
In the marginalist analysis, the rational consumer seeks to provide the maximum benefit. In Gossen's approach of diminishing marginal utility, the satisfaction of an individual who continues to satisfy a desire uninterruptedly until the saturation point decreases. As a result of a person's continuous consumption or use of a particular good, the benefit provided by each additional unit of good to that person decreases compared to the previous unit, because as the person satisfies his need, he will reach the full saturation point and after this point, the additional unit of goodwill no longer benefit. The marginal benefit obtained in the consumption of a glass of water begins to decrease with each additional glass and after a certain glass, it almost begins to harm the health of the body. In other words, the marginal utility of each additional drinking water decreases. However, no matter how much the number of diamond rings increases, the marginal utility does not decrease and the individual continues to buy. According to Jevons, the value of a good is determined by the marginal utility obtained from that good. The utility comes from scarcity.
In the marginalist analysis, according to Gossen's second law of utility maximization, in the mind of the consumer who acts rationally due to the scarcity of resources, he makes a preference order among the demands for goods that will benefit him. The individual aims to provide the most benefit while allocating the limited resources at his disposal to the satisfaction of his various wants. For this reason, when the consumer divides his income among the goods he will buy, if he gets the same marginal benefit from the last lira spent on each good, he maximizes the total utility of his total utility. (Gossen's 2nd law) According to Gossen's second rule, if consumers want to get the most benefit from their consumption expenditure, they should divide their current income among the different products in such a way that they cannot derive more utility from a new adjustment. Accordingly, a thirsty consumer will be prepared to spend relatively large amounts of money for the first glass; in the next glasses, the money he wants to spend will decrease with increasing saturation.

**4.2.The Logic of Calculating Price of Water over Marginal Cost**

Under perfect competition, it is considered as a way of maximizing consumer satisfaction and using society's limited resources effectively at the point where the price for economic efficiency is equal to the marginal cost of production.

A price based on Marginal Costs is assumed to transmit "price signals" that will lead to the efficient allocation of resources. (Conkling, 1999).

The producer, who wants to maximize his profit, will continue to produce until the marginal cost equals the market price. In other words, in the absence of externalities and other market imperfections, the market demand and supply curves will intersect at the point where marginal benefit equals marginal cost. This point is also the point at which total surplus (consumer surplus plus producer surplus) is maximized.

It states that if consumers are to make a rational choice between purchasing more or less of any product, the price they pay must equal the cost of supplying more or less of that product. This cost is the marginal cost of the product. If this cost is charged to consumers, optimum quantities will be purchased, maximizing consumer satisfaction. If they are charged more, less than optimal quantities will be purchased: the sacrifice of other forgone items will be exaggerated. If they are charged less, the output of the product will be greater than the optimum: the sacrifice of other forgone products will be underestimated.

There is also a reluctance to adopt marginal cost pricing. largely due to the inability to accurately estimate/calculate the marginal cost of water distribution to various end-users

According to economic rules, the price of water should be determined by calculating the marginal cost. That is, the amount that the consumer is ready to pay for the last unit of water should be taken into account.

In many countries, the management of the water cycle from beginning to end has been undertaken by public authorities, due to typical market disruptions such as natural monopolies, externalities, and public goods. High capital requirements and economies of scale create a natural monopoly on water infrastructure, requiring regulation to prevent overpricing. In addition, many investments in the sector produce joint goods such as electrical energy, flood control, and irrigation, which complicates pricing and distribution policies.

The public must intervene in the markets in an imperfectly competitive environment. Imperfect competition in the market reduces efficiency in both public and private production. There may be services that can become a natural monopoly in the provision of local services. Examples of such services are electricity, water, and public transport (metro). Service offerings can be realized in the form of increased efficiency, in other words, decreasing costs according to the scale.

In a perfectly functioning market system, prices will be approximately marginal costs. In practice, market distortions often require overt government intervention, which can take the form of public operation or regulation of services such as water supply, or interventions to correct the consequences of market failure, such as the use of pollution taxes or regulations. In such cases, marginal costs should be estimated and used as a basis for pricing to encourage efficient use of the relevant good or service. In practice, however, while market failure may indicate the need for compensatory action by the government, the opposite is often the case. Governments often provide incentives that encourage environmentally damaging behavior; For this reason, water and energy subsidies are frequently encountered, especially in developing countries.

"The relative utility and cost of the last unit of water determine the price of water. Why? Because individuals are free to take this last unit or not. If the price of water is higher than its final utility, it will continue to fall until it equals the utility of that last unit of water.
Moreover, since every unit of water is the same as every other unit, and since the price is odd in a perfectly competitive market, each unit will be sold at the price of the last least useful unit. (We should focus our attention on the marginal utility rather than the total.) Thus, as a good becomes abundant, the demand for the last small unit of that good decreases relatively, although the total utility increases with each additional unit. Thus, it is understood why large quantities of water have a low price. Or, one understands why air is a free good despite its vast benefits. Lots of later units change the market value of all units.
The economic value (EV) of a given level of water consumption is the benefits derived from its use. The EV value of water can be measured by the value of other goods and services or currencies that an individual is ready to barter for the amount of water consumed (Hanemann, 2006, pp. 78-80). or the price paid per unit for the service. When it comes to water, the price paid by most water consumers is not the market price, but a regulated price set by a water utility, regulator, or government. The economic cost (EC) of a given water resource is a clear compromise in other goods and services (or currencies) required to provide that water quantity and quality (Grafton, Chu, and Wyrwoll, 2020:87-88).
In the context of water supply, it includes private costs directly arising from capital investments, such as building a dam to store water and operating costs, such as water treatment and distribution costs. The EC also includes external costs that are not borne directly by the water supplier, but still incur costs to others. For example, external costs from building a dam may include reducing ecosystem services that could result from changing the timing, temperature, and volume of a downstream river's flow.
When water is charged at the marginal cost of delivery, the benefit from consuming the last unit of water is equal to the cost of supplying it. Applying this principle means measuring water consumption and increasing it as the consumption increases (volumetric charging). However, it is common for the minimum amount of water to be offered at low unit prices to promote equity and protect public health.
The price of water almost never equals its value and rarely covers its costs, explained by the special properties of water and how it is managed. Price almost never equals value because water typically cannot be transferred between competing uses where there are different marginal values. This may be due to regulatory restrictions on the transfer of water from agriculture to urban uses and the cost of transporting water (Hanemann, 2006, p. 74).

For different users dealing with seemingly the same water use, the dilemma between water values and water price may arise. This can occur when apportionment is made over the total amount of water that can be consumed by a household or when there are restrictions on certain uses, such as prohibiting outdoor water use (Grafton and Ward, 2008). Underrated, a water consumer may have a very high value for a particular outdoor use, such as watering a favorite tree, that greatly exceeds the value of some permitted indoor water use, as well as the price of water. This would be a case of water misallocation within a household because the consumer has a higher consumer surplus if he or she uses more water outside and less inside (for a constant overall level of water use), even if he has paid a higher water price for himself. it could be. outdoor use.

The second part of the dilemma (the price rarely pays off) comes from two factors. First, the external cost of water extraction, supply, and treatment placed on others is at best partially factored into the calculation of water supply costs. Regarding water, these external costs can include disruption of any of the ecosystem services.

Another reason why the water price rarely covers its costs is that fixed costs, such as the capital cost of water infrastructure, are, at best, only partially included in the water price applied in many countries (Hanemann, 2006, pp. 76– 7; OECD, 2012). The difference usually consists of transfers or subsidies to water suppliers paid from general revenues or taxes from local, state, or national governments. The inability to cover the full costs of providing water services can reduce incentives for utilities and other water providers to provide any additional water or even maintain existing water infrastructure. These undesirable consequences exacerbate water shortages over time, especially when water demand increases.

### 4.3. Pricing of Water at Marginal Cost

Water enterprises are "authentic" natural monopolies. The natural conditions of the area they serve and the condition of the water resources, the layout and layout of the city, the income level of the people, and the consumption culture determine the operating costs.

In general, marginal cost principles are accepted as the starting point for the affordable pricing of goods and services to guide consumers to efficient use of available resources and facilities (Monteiro, 2005:5.)

The water demand depends on the value in use. Consumers are willing to pay more for more valuable uses such as drinking or bathing. A higher willingness to pay can also be interpreted as having lower flexibility (responsiveness) to prices, but the willingness to pay (keeping income constant) decreases as consumption increases and additional water is put into lower value uses such as plumbing or landscaping. This idea is illustrated using a curved demand curve, which highlights how elasticity rises as the willingness to pay (value) falls.

The demand curve begins at the top left with inelastic demand for initial units of higher value uses (e.g. drinking), then to mid-value uses (e.g. sanitation) before reaching the final range of more elastic, lower value uses (e.g. landscaping). ) extends to This figure shows how price increases (from the ground up) reduce lower value uses, reducing demand from below.

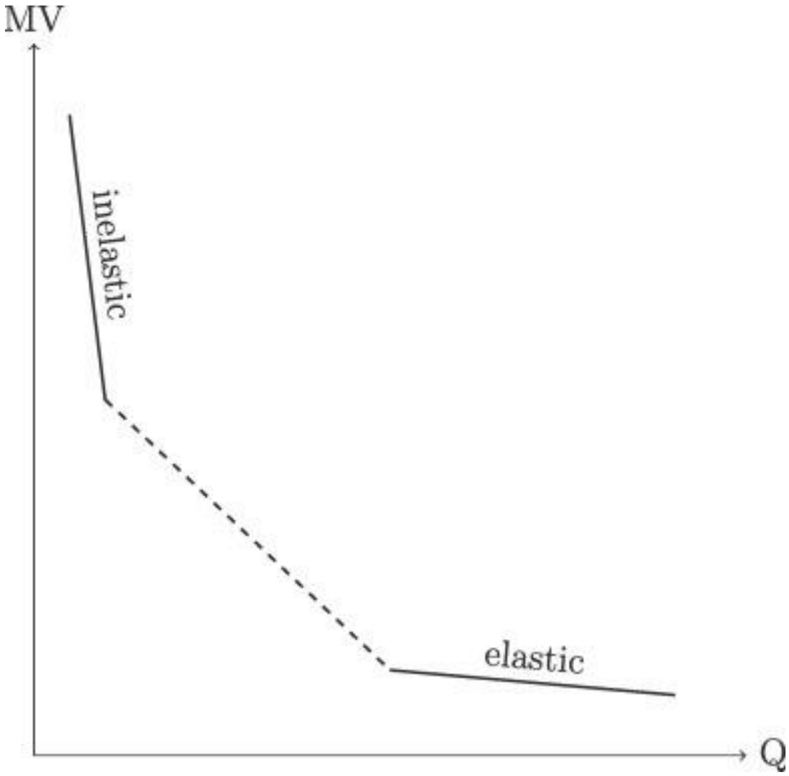



Chart 1: Water Demand Curve

This curve slopes downward from left to right, reflecting the diminishing marginal valuation with each additional increase in water demand.

The curved demand curve shows how the demand for water for each type of consumption differs in three different steps. The upper left step is for relatively price inflexible high marginal value indoor use. The lower right step is for low marginal value outdoor use and is relatively price flexible. The dashed line between these steps represents intermediate uses. The lack of water substitutes for most of the uses results in low price elasticity of demand.

Finally, it should be noted that there are serious regional differences in water demand within the same country, and these differences are significantly affected by the socio-economic structures of the regions in question, as well as geographical conditions. Johnstone, Wood, and Hearne (1999, 10) referred to studies that determined the income elasticity of water consumption in the range of 0.0-0.4 but emphasized that the demand function may show varying elasticities as the nature of the service provided with the product changes. For example, high-income segments who use water for luxury purposes (garden irrigation, car washing, etc.) may be more price sensitive. Therefore, it is among the findings that the price elasticity of demand changes according to the income level. Another factor affecting demand is

low-income elasticity. This means that especially low-income households allocate a significant part of their disposable income to water and wastewater services.
Walk up the demand curve after further price increases until we only use the higher value, the quantity wanted to decrease. It is very difficult to use prices to eliminate these high-value uses, which is why they are called inelastic. While this point may seem obvious, I'm trying to counter here a common complaint ("if prices go up, people won't be able to meet basic uses") that ignores the purpose (and outcome) of most price increases: reducing lower-value demands. This complaint is based on a fact (people die without water), which was mistakenly predicted by the claim that all water – not just drinking water – should be priced at zero "because we cannot live without water."
The demand curve reflects the marginal value of water consumed. Demand will therefore depend on usage (car wash vs drinking), time (now thirst vs. later), information (strong against weak price signals), and preferences (protection against consumption).
The supply curve reflects the marginal cost of providing water.
According to economic rules, the price of water should be determined by calculating the marginal cost. That is, the amount that the consumer is ready to pay for the last unit of water should be taken into account.

According to standard economic theory, prices should be determined at marginal cost (MC) because in the absence of externalities this maximizes economic welfare. This is because these prices reflect the costs involved in providing an additional amount of output. Where the user values an extra unit more than it costs to produce it, it is economically efficient to produce that unit and vice versa. Setting prices equal to MC means users will continue to purchase extra units until it is no longer economically efficient to produce them at that price. MC-based pricing, therefore, sends signals that encourage consumers and producers to balance the benefits derived from consuming a good or service with the costs of providing it.

JWMD Issue:5 2022
International Journal of Water Management and Diplomacy
e-ISSN:2717-8277

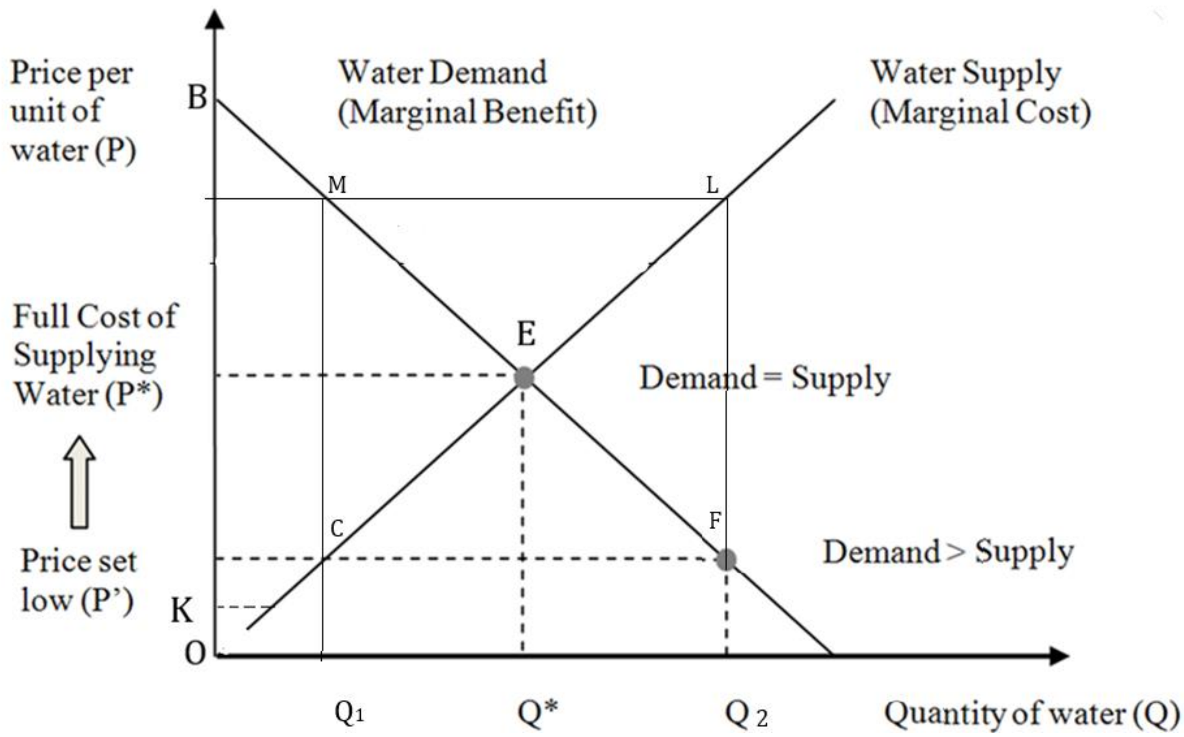



Figure 1: Market Equilibrium: Water Supply and Demand

Supply curve; It slopes upwards, reflecting that the increase in demand can only be met by the increase in costs in the water system.

As shown in Figure 1, net benefits are maximized when OQ* unit of water is produced at O P* OE price. The area between the demand curve and the supply curve, shown as KBE, represents the net benefit. If consumption is more than this, for example, let's assume that consumption is at point Q2', the cost of meeting the excess demand between Q* Q2 (area between Q*E Q2 L) exceeds the benefit Q*E Q2 F ' by ELF. On the other hand, if consumption drops to Q1 due to excessive price increases or severe restrictions, for example, the loss in consumer utility Q1MQ*E is greater than the cost savings Q1CEQ* and therefore this solution is not optimal either (Winpenny, 2005).

It is very difficult to talk about any equilibrium point in the water market in the traditional sense. Once an appropriate value system has been agreed upon, price-based instruments are particularly difficult to implement when it comes to water, because the flow of water through taps is highly complex and involves many externalities, market disruptions, and high transmission costs (Franks et al. 1997). Despite all this; Decisions in the market are based on the private costs and private benefits of the market participants. If consuming or producing goods and services creates an external cost or benefit to non-participants, the market supply and demand curves no longer reflect true marginal social benefit and marginal social cost. As a result, market equilibrium does not reflect social (Pareto) conditions.

**4.4.Pricing of Water at Marginal Cost and Externalities**

External economies can generally be defined as the positive or negative effects of the benefit and/or cost functions of other units as a result of the production and/or consumption activities of an economic unit. From another point of view, externalities are benefits and costs that are not reflected in the market mechanism. The external benefit or cost arising from the externality does not enter into the market price of the good produced or consumed. This situation necessitates state intervention as it hinders the effective allocation of resources.

One of the main reasons for the ineffective results of the market mechanism in the water industry is explained by externalities. Stiglitz defined externality as follows: a firm or an individual does not compensate for the costs it imposes on others (negative externality) or does not include the benefits it confers on others in its benefit function (positive externality), although it affects the decision-making mechanisms of other firms or individuals (Stiglitz 1988, 75).

In this context, one of the most common examples of negative externalities has been water pollution. Pollution of the above-ground sources from which water is extracted with the wastes produced by industrial or treatment plants, or the contamination of underground water sources with fertilizers and pesticides used in agriculture are typical examples of negative externalities. Regulating every stage of water supply in almost every region to protect public health naturally increases the cost (and risk) of treatment processes (Armstrong, Cowan, and Vickers 1994, 324).

In the case of positive external economies both in production and consumption, the social utility function in the economy is generally higher than the private utility function in the market. Therefore, the market price for the product in question will be lower than the price that would require the social optimum for producers, and higher than this price for consumers. In the case of negative external economies, the social cost function in the economy is higher than the private cost function in the market. In other words, costs measured in market prices do not reflect the actual costs incurred by the economy. In this case, the price that will occur in the market will be higher than the price that will realize the social optimum for producers and lower than this price for consumers.

Natural monopoly services are generally produced by the state rather than the private sector. Because, if such services are left to the private sector, the natural monopoly in the private sector can set its price at a level that will provide excessive profit by going beyond the marginal cost rule. Therefore, the state intervenes in areas where it has natural monopolies or keeps natural monopolies under its control by legal regulations.

Even if the conditions of perfect competition are fully realized in an economy, external economies prevent the market economy from providing the optimal resource allocation on its own.

The external benefit or cost arising from the externality does not enter into the market price of the good produced or consumed. This situation necessitates state intervention as it prevents effective resource allocation.

The state intervenes in production activities where externalities are concerned, by considering the benefit of society. For this purpose, the state tries to increase the positive/positive externalities and prevent the negative externalities. While activities with positive externalities will be undertaken by the state itself, private sector organizations that carry out these activities can be supported by subsidies from the budget.

The public must intervene in the markets in an imperfectly competitive environment. Imperfect competition in the market reduces efficiency in both public and private production. There may be services that can become a natural monopoly in the provision of local services. Examples of such services are electricity, water, and public transport (metro). Service offerings can be realized in the form of increased efficiency, in other words, decreasing costs according to the scale.

In a perfectly functioning market system, prices will be approximately marginal costs. In practice, market distortions often require overt government intervention, which can take the form of public operation or regulation of services such as water supply, or interventions to correct the consequences of market failure, such as the use of pollution taxes or regulations. In such cases, marginal costs should be estimated and used as a basis for pricing to encourage efficient use of the relevant good or service. In practice, however, while market failure may indicate the need for compensatory action by the government, the opposite is often the case. Governments often provide incentives that encourage environmentally damaging behavior; For this reason, water and energy subsidies are frequently encountered, especially in developing countries.

It is natural for pollution control to play a critical role in setting regulatory policies. However, the impact of the minimum water consumption of individuals (as well as the treatment and disposal of wastewater, and drainage of rainwater) on public health is also an example of a positive externality. This factor has decisive importance on the decisions and reactions of the public. It can be said that the effect of individual consumption on society, in general, is the dominant factor in the decisions at the stage of water supply. When we look at the discussions on the developments in the industry, it is seen that this element is "is water a public good or not?" seems to have moved into the question. In other words, on one side of the debate are those who say that water is a public good (which should be) accessible to all, and on the other side, some say that water should be managed as a scarce resource subject to competing uses. In the discussions in question, whether water should be accepted as a public good or not, this issue is tried to be explained by the criteria of "excludability in consumption" and "competitiveness in consumption" of the public economy (see Çakal 1996; Görer 2003; Görer 2000a; OECD 2002; DB 1993).

Taxes are at the forefront of the public measures to be taken to eliminate externalities. Taxes for regulatory purposes, also known as "Pigou-type taxes", are taxes used to ensure efficiency in resource allocation and are used especially in negative externalities. The idea of imposing a tax on goods that create an externality was first introduced by A.J. It has been suggested by Pigou.

In the graphic below, there is a formal representation of a tax applied before and after-tax, in terms of consumers and producers, in case of an externality.

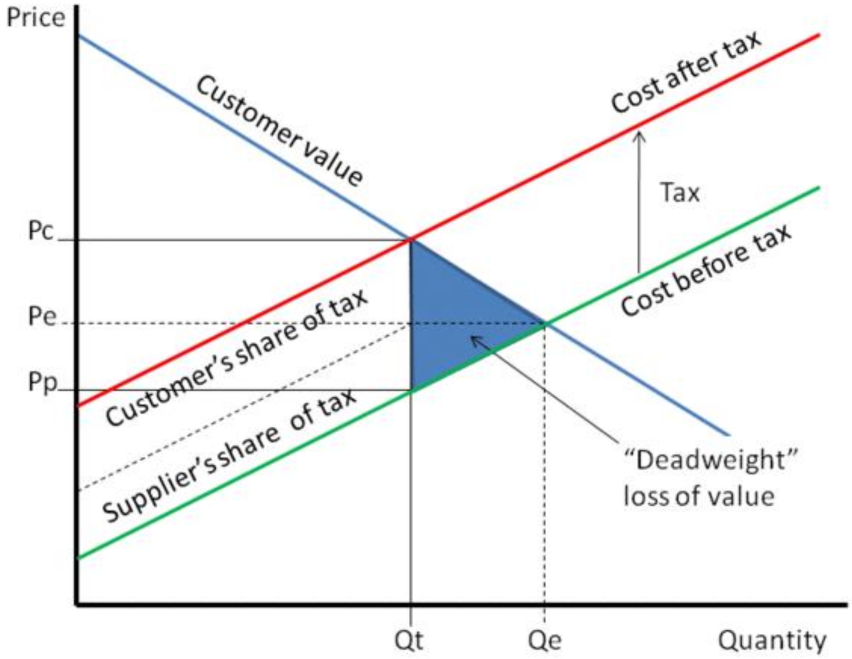



Figure 2: Pre-Tax and Post-Tax Supply Cost of External Cost

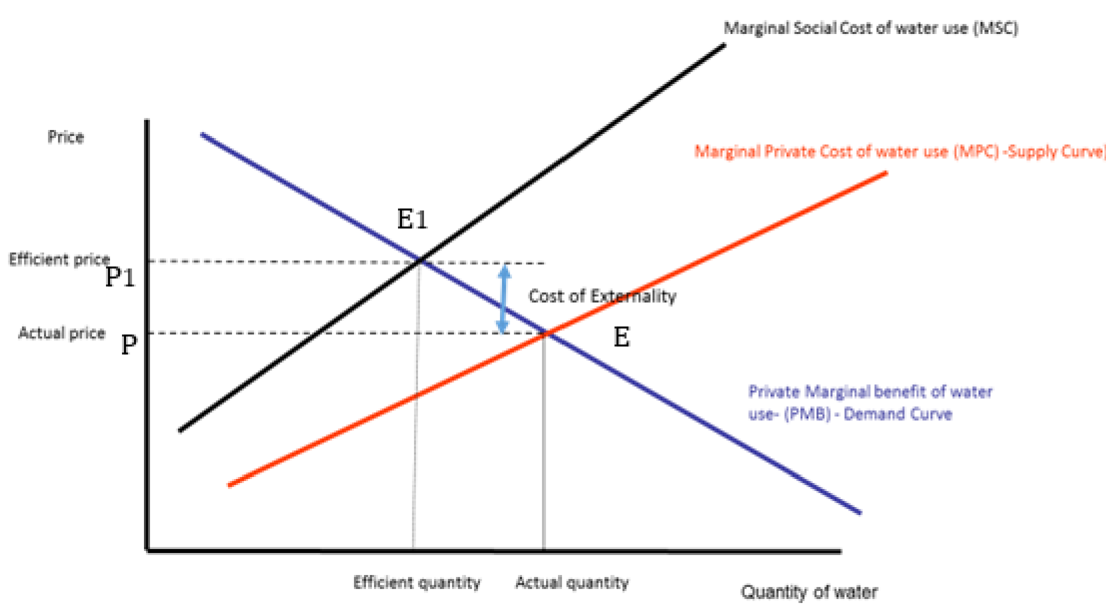


Figure 3: Reflection of External Cost on Marginal Benefit and Marginal Cost
*Source: Grafton, O., Pittock, J., Tait, M., White, C., (2013), Water Security, Economics, and Governance, Tilde University Press, Melbourne. ISBN: 978-0-7346-2006-4.*

The taxation of externality costs can be followed in the figure above. In Fig. MPC is the marginal private cost. It is the cost that directly concerns the producer of the good. MSC is the marginal social cost. Marginal social cost is the cost that includes the opportunity cost of all scarce resources, whether they are paid for or not. MSC = MPC + marginal external cost. The marginal utility of the good, MB, is equal to the demand curve.
The marginal private cost is MPC. Transportation service creates noise and environmental pollution. In this case, the marginal procurement cost of transportation exceeds the MPC. MSC > MPC. In competitive equilibrium, the output is an actual quantity (Q2), efficient price (P0), and marginal social cost MSC0. If producers are taxed enough to cover the marginal cost, the MSC curve will be the marginal cost curve over which the producer makes supply decisions. In this case, the price is P1, the supply in Q1.
Public activity in the water sector

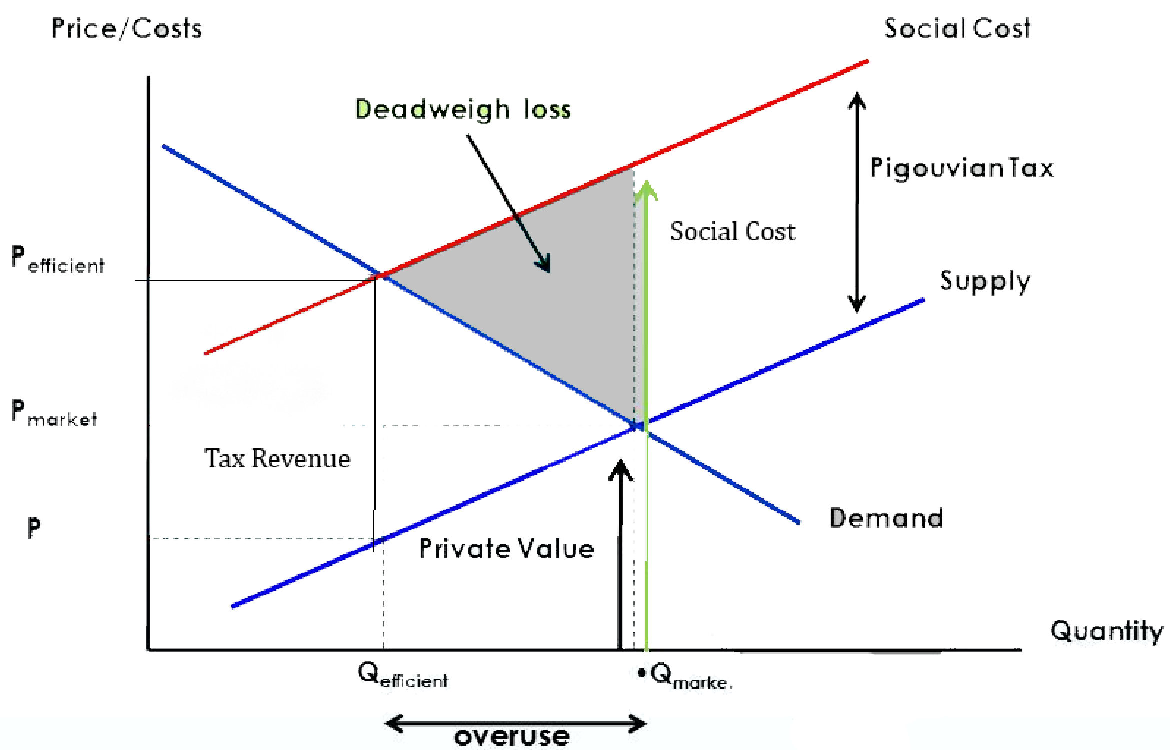



Figure 4: Reflection of Externalities on Taxes

In the illustration above, the demand curve shows the marginal utility a person receives as a result of producing one unit of water. The supply curve reflects the marginal cost of producing an extra unit of water produced. In the absence of an externality, the market equilibrium is fully effective. Marginal social cost is equal to marginal utility.

Now let's consider what happens when there is an externality. Marginal social cost is more than price. For example; where a user draws a large amount of water from nature, that user will likely have to pay the cost of transporting the water. However, this may result in costs for other water users that they do not have to pay for. As an example of the said costs; Less water is left for crop production, aquaculture, recreation, or biodiversity. These external effects are generally not reflected in market prices.

As a result, these effects are not reflected in the costs users have to pay, so users do not take these effects into account when deciding how much water to use. These effects are described as negative externalities and create a 'chock' (the support line drawn from its lower level and the resistance line drawn from its upper level forming a triangle shape) between the social and private marginal costs incurred by using a resource. If actual quantities are taken into account, the marginal social cost curve exceeds the price paid by consumers (White 2015). Because of negative externalities, water resources are often undervalued and overused compared to effective distribution that covers both private and external costs. It is also used more than effective distribution, which covers external costs.

As a result, it leads to a social welfare loss (deadweight loss). It is spent inefficiently and wastefully (rent-seeking expenses), leading to inefficiency and high costs in production (X-inefficiency).

Issue:5 2022
International Journal of Water Management and Diplomacy
e-ISSN:2717-8277

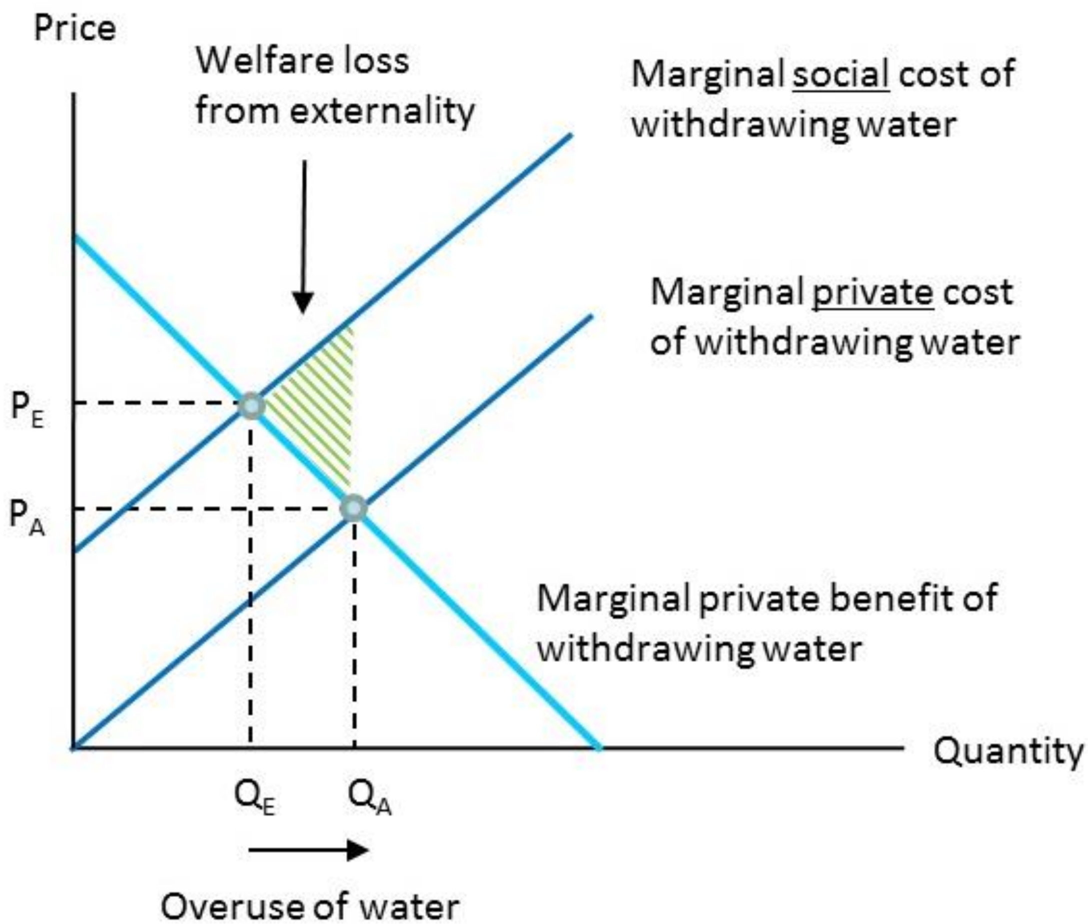



Figure 5: Loss of Welfare through the Reflection of Externalities in Taxes

In the case of positive external economies both in production and consumption, the social utility function in the economy is generally higher than the private utility function in the market. Therefore, the market price for the product in question will be lower than the price that would require the social optimum for producers, and higher than this price for consumers.

In the case of negative external economies, the social cost function in the economy is higher than the private cost function in the market. In other words, costs measured in market prices do not reflect the actual costs incurred by the economy. In this case, the price that will occur in the market will be higher than the price that will realize the social optimum for producers and lower than this price for consumers.

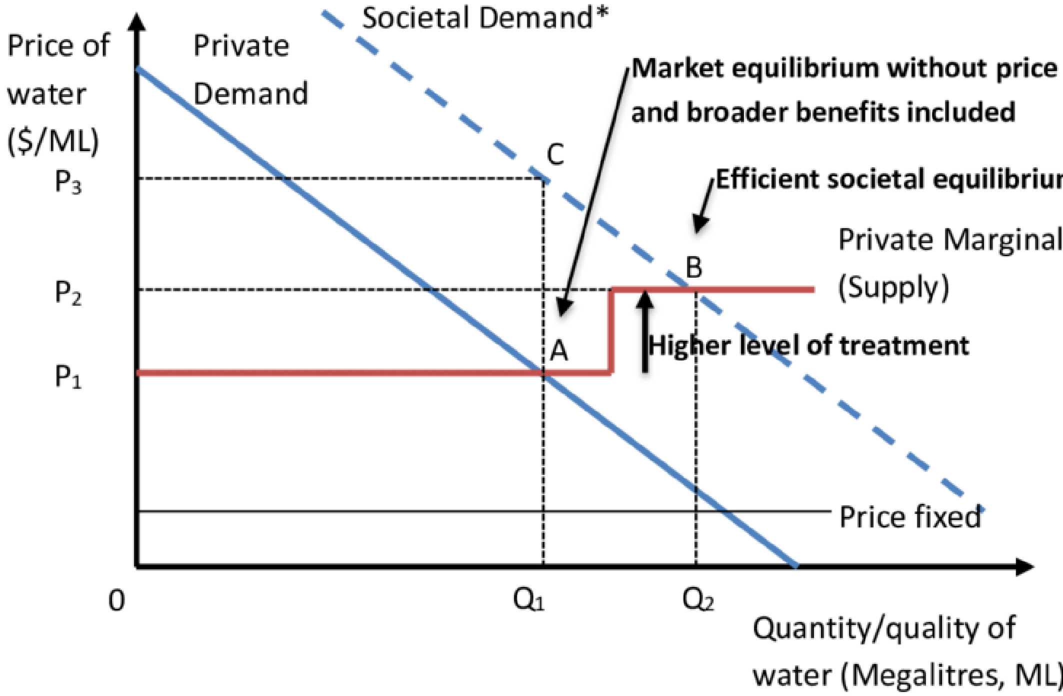



Figure 6: Demonstration of Leasehold and Social Benefit of Water

In the presence of externalities, inefficiency in resource allocation will occur and socially ineffective results will emerge in a market economy. In other words, since the firm does not bear some costs due to negative externalities, it will be able to produce more than necessary. Again, since no mechanism provides an additional advantage for the firm that creates positive externalities, less production will take place. Therefore, positive and negative externalities are frequently produced in competitive markets. This is also one of the reasons for market failure, as it leads to over-or under-allocation of resources.

Some authors, (Zarnikau, 1994), warn that marginal costs can fall below average costs; this is expected in capital-intensive industries such as water supply. Others, such as (Collinge, 1992), point out that although water utilities are commonly viewed as a natural monopoly due to their capital costs, it is not simply that the marginal cost falls below the average cost. Because cheaper water sources are used naturally before other more expensive sources, the marginal cost may exceed the average water supply cost. Therefore, marginal cost pricing can pose a problem for the water utility and its regulators, not because of insufficient revenue but because it will generate excessive profits. In a situation where the average cost is less than marginal cost, using marginal cost pricing can be an effective way to increase revenues. However, it is often not allowed, meaning it has a "declining incidence", hurting the poor the most because water expenditures have a greater weight in their budgets. Therefore, balancing the budget of the water network is a goal that is equally important as ensuring economic efficiency (Monteiro, 2005: 10).

**4.5. General Content of Pricing with the Full Cost Approach of Water**

Three different approaches can be adapted to meet the increasing demand for water resources in terms of both quality and quantity:

• Long-term fixed-presentation is an approach that has high environmental and economic costs, wastes public resources, and causes water resources to be perceived as too cheap.

• Supply management is an approach that aims to get more output from a particular system; However, the natural and economic resources required to sustain this policy are limited.

• Demand management is an approach that aims to reduce demand to supply. The general principles guiding this approach are pricing, regulation, training, the flexibility of water use rights, and operational control.

Today, in many parts of the world, water, together with its ownership and management, is monopolized by the public administration. In many regions, the management of water is "supply-side". In other words, water is offered "at low cost", "subsidized", and "regardless of its ability to pay", according to the principle of meeting the needs of social life unconditionally.

In the centralized supply-based approach, water is primarily treated as a "social quality" product. Its necessity in terms of health, its environmental and social importance, and an approach by central and local governments that this "product" should be provided free of charge can be considered reasonable. However, insufficient water resources limit the realization of this target by the administrations. While these administrations struggle to maintain a low-cost "minimal service" quality and reduce capital and water treatment costs, the approach is also not sustainable. Complaints about services are increasing in terms of both scope and quality (Garn, 1998: 6-7).

The demand-oriented approach, on the other hand, argues that water is an “economic commodity”. He argued that "water tariffs", which will ensure the repayment of the investment cost for the supply of water and the operating-maintenance expenses, will create a source for new investments and eliminate financing problems.

In the commercial and market approach, water should be priced. Urban drinking water and water used in agriculture and industry should be recycled without subsidizing costs. However, with this method, the waste of water and insufficient financing for water can be prevented within the framework of the market logic. The view, which argues that water is an "economic commodity", argues that "water tariffs", which will ensure the repayment of the investment cost and operation-maintenance expenses for the supply of water, will create a source for new investments and eliminate financing problems.

The method preferred by the OECD to meet the water demand in terms of both quantity and quality is the "demand management" method. In this method, the demand quantity is approximated by the supply quantity. Tools to be used for this purpose; regulation, pricing, education, the flexibility of water use rights, and operational control. Based on this view, it can be argued that OECD prefers market-oriented mechanisms in water management (TODAIE, 1999).

According to the World Bank, which is the most important actor among policy makers on water, it is preferable to abandon the centralized management of business and distribution systems in water resources management, cost-oriented pricing, the direct participation of interest groups in the management, accepting water as an economic good, and drawing a comprehensive policy framework. should be done. Considering these recommendations, it is seen that World Bank policies are in line with UN principles and OECD policies.

According to the World Bank, "the public sector, even in industrialized countries, let alone developing countries, will henceforth consider financial investment in water due to environmental costs (damage to irrigated lands and pollution of rivers and water supply, as well as the removal of wastewater by sewage systems). Due to limitations (increasing the need for water, increase in investment, operation and maintenance costs) and financial inadequacy (failure of the public in pricing and cost reimbursement, leaks in the networks, weaknesses in billing and collection systems, unstable payments of the majority of consumers and illegal use of the network, etc.) can't take it."

Decision-makers who are close to World Bank policies aimed to benefit from economic instruments based on market incentives such as "creation of water markets", "privatization", "water pricing" and "full return of water investment cost", "pollution fees". Similarly, it has been stated that financial instruments such as the introduction of "pollution charges" in line with the bank's "effective pricing" and "polluter pays" principles will also support the policy of water conservation and pollution prevention. (World Bank, 1993:55-56)

The demand for water to be sold through the market pricing system, taking into account the full cost, applies not only to drinking and utility water in the urban area but also to agricultural irrigation. Theorists, emphasizing the inevitability of commodification of water, state that "giving agricultural irrigation water to farmers far below the input costs leads to inefficient use of water".

**i. Full Economic Cost:**

The full economic cost is determined depending on whether the externalities are negative or positive. An example of a negative externality is that the source is used by being polluted by producers or consumers at the point where it starts, and as a result, consumers in the continuation of the water source are negatively affected.

Even if the conditions of perfect competition are fully realized in an economy, external economies prevent the market economy from providing optimal resource allocation on its own. External costs cannot be priced in the market process, so they are outside the market process.

Full Economic Cost = Full Cost of Supply + Opportunity Cost of Water + Economic Externalities

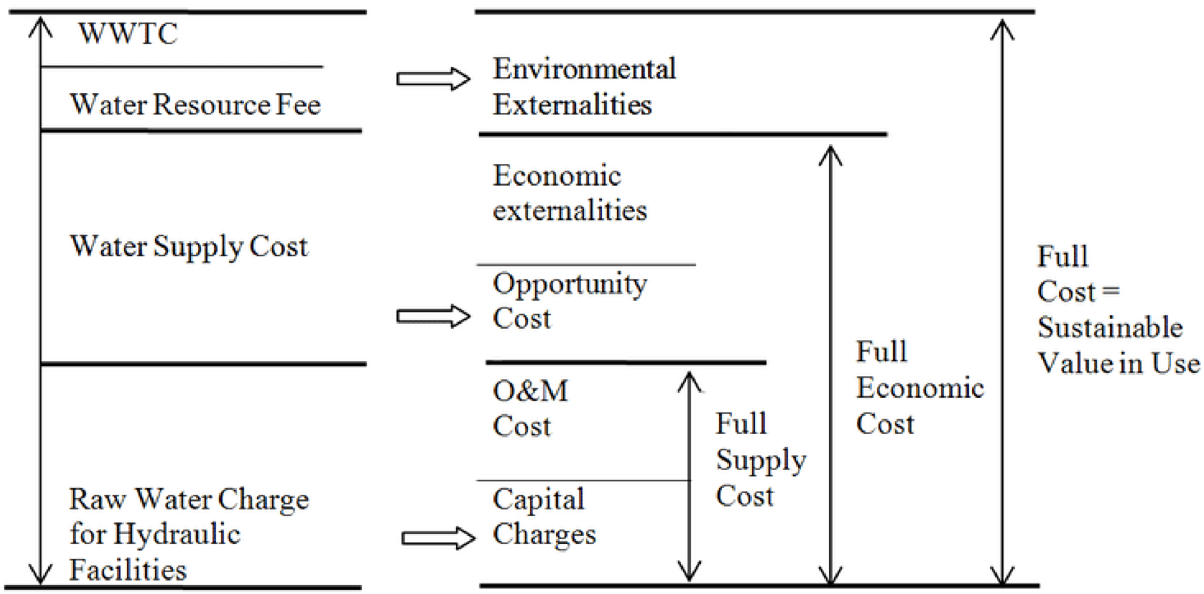



Figure 7 Full economic cost
Source: Rogers, P.P., Bhatia, R. & Huber, A. (1988) Economic Valuation of Water, Water Resources Management, Vol. 1.

The total cost of supply includes operating and maintenance costs and capital costs. Treatment consists of distribution, drainage and sewage collection and treatment, flood control capital, and recurring expenditure (Figure 7).
It is the cost of delivering water to consumers. While calculating this cost, externalities and alternative costs are not included in the calculation.
Operation and maintenance costs include raw water distributed, the electricity required for pumping, manpower spent, repair materials, and management and operating costs such as stocking, distribution, etc.

**ii. Capital expenses:**

Capital expenses are formed by calculating capital consumption and related costs such as warehouses, treatment facilities, transportation (transportation), and distribution systems.

**iii. Opportunity Cost of Water:**

Every natural resource has a value as an opportunity cost. This value is the cost corresponding to the value of options lost as a result of using water for a purpose. It is not possible to evaluate the content and financing of opportunity cost in regions where the world's water resources are abundant and in this context, the use of water for a particular use has no effect on other uses. It is possible to use an abundant natural resource in different ways and without creating any conflict of interest between these forms.

Opportunity cost is mentioned in areas where water is scarce or where the season is extremely dry. Opportunity cost is zero when water is plentiful and sufficient. It is the public cost of using water in a more costly and less efficient (profitable) business. A choice can be made between the opportunity cost of different uses of water (Rogers, Bhatia, and Huber, 1998).

According to this method, the real cost of water is the value of other products and services (industrial wood, secondary products, recreation, etc.) that are forgone due to water production and cannot be mass-produced.

Opportunity cost can also be thought of as the overall sacrifice incurred by the economy for water production. However, opportunity cost and monetary cost are not similar concepts. Monetary cost does not reflect opportunity cost.

Opportunity (alternative) costs are not added to the cost of water in supply-oriented management. If the water was sold on demand, its alternative costs would be included in the price. Since the property of public property is that it is open to everyone and no one can be excluded, it becomes difficult to collect the water supply cost and pollution fees fully from the consumers and polluters. The same conditions apply to groundwater and wastewater.

***The Opportunity Cost of Water is Difficult to Measure;*** In economics, opportunity cost is defined as the value of the best available alternative. Opportunity cost deals with the fact that by consuming water, a user deprives another user of water.

If the other user has a higher value for water, then there are some opportunity costs that society incurs due to this misappropriation of resources.

The opportunity cost of water is zero only when there is no alternative use (this is not a water shortage). As water becomes scarce, the opportunity cost increases dramatically. Because water is unevenly distributed in various areas, the opportunity cost is diverse. There is no shortage of water in the region where water is plentiful and the opportunity cost of water is zero. In areas where water is scarce, there is an opportunity cost.

The opportunity cost of water is different for different users. Because water is unevenly distributed in various areas, the opportunity cost is diverse and it is clear that the opportunity cost of water is difficult to measure. The determination of the opportunity cost of water is related to the socio-economic policies followed. Ignoring the opportunity cost of water undermines the principle of efficiency in allocating scarce water.

Recognizing that water is an economic commodity within the framework of opportunity costs requires pricing any direct or indirect use of water. In essence, this statement states that in practice, water prices and tariffs should cover not only the capital, operation, and maintenance costs of water infrastructures, but also the external costs incurred in other possible uses of water (domestic, industrial and environmental). However, it is difficult to say that external costs are fully reflected in water tariffs, even in many developed countries.

**iv. Environmental Externalities:**

Environmental criteria are the long-term effects of an individual's water use on ecosystems and the environment. Pollution fees are charged in proportion to the discharge of waste, the damage they cause to the environment, or the cost of protection and improvement, in accordance with the "polluter pays" principle. In practice, pollution charges are below that, only to cover monitoring and administrative costs. The pricing of water pollution is important in terms of its impact on demand. In addition, less pollution of water ensures that more resources are available.

Environmental costs are measured in marginal costs. It is the cost of removing an extra unit of a scarce resource. Environmental costs in the extraction or transformation of the resource into a product and its use are measured with the marginal external cost. This is the additional loss value that occurs in each unit of the resource that is converted into a product or used. The future exhausted benefits resulting from the use of the resource today are measured by the marginal user costs. That is the resource replacement costs that future generations have to bear. "User pays principle obliges these three costs to be considered together.

It is often necessary to choose between economic and environmental externalities. Environmental externalities are related to community health and ecosystem protection.

For this reason, the increase in the cost of production and consumption with population growth creates an economic externality, and the deterioration of public health or environmental factors creates an environmental externality. Environmental externalities are more difficult to calculate than economic externalities. Pollution charges are charged in proportion to the damage they cause to the environment or the cost of protection and improvement, in accordance with the principle of "polluter pays" for the discharge of waste.

In practice, pollution charges are below that, only to cover monitoring and administrative costs. The pricing of water pollution is important in terms of its impact on demand. In addition, less pollution of water ensures that more resources are available.

This is where the polluter pays principle comes into play. However, the difficulty of calculating additional criteria and environmental criteria often appears in the scientific literature. Water has a use-value. For example, this is how much harvest you get for 1m3 of water in agriculture or how much you produce for 1 ton of water in industry. An example of the net benefits created by water returning from use is the contribution of water used for irrigation to groundwater by infiltration or the recycling of water lost by evaporation back into the hydrological cycle through the rain.

Water has many externalities because it has the property of running away. One of the most common externalities is that of users at the starting point of the source to consumers downstream of the river or stream. The method generally applied to externalities is to internalize them.

## 5. Results and Evaluations

The pricing of water is used as an important policy tool in terms of water management. Due to the very special nature of water, social and political goals can take precedence over economic criteria. Conflicts or solutions on water become difficult due to its very important features listed below.

• It is a development issue.
• It is a vitally important resource with limited supply.

• "Clean and accessible water is the most basic human right.
• It includes the concepts of management, ecology, and justice.

While seeking answers for those who advocate the necessity of pricing water or for the opposing view, the water problem must be understood correctly.
The World Bank insistently calls for demand management to be adopted to prevent waste while giving a certain amount of use to the poor at very low or free cost. It will be ensured that a certain amount of water offered by demand management is distributed as closely as possible to its optimum use.
The rationale for calculating the water price in a demand-managed approach is as follows: as a result of increasing opportunity costs and increasing tariffs, consumers will reactively use less water. Pollution fees, that is, according to the polluter pays principle, suggest that waste should be charged in proportion to the damage they cause to the environment or the cost of protection and improvement.
Pricing the water is another important reason, it is of great importance in terms of meeting the infrastructure costs spent to take the water from the source and deliver it to the consumers, thus ensuring the better quality of the water or the preservation of the existing quality.
The theoretical approach to the pricing of water is based on the fact that the water supply is an "original" natural monopoly. Kahn defines a natural monopoly as when "the technologies of certain industries and the character of the service are such that services are provided by only one firm (in the extreme cases) or a select number of instruments with the least cost or the greatest net benefit to the consumer" (Kahn, 1998: 2). In other words, a natural monopoly is "a single firm meeting the demand in the industry more efficiently and at less cost than more than one firm".
In natural monopoly markets, the cost decreases as the demand increases, and the long-run average cost (UDOM) is at the lowest level since the demand is met by a single firm. Because the long-run average cost (UDOM) is decreasing, the long-run marginal cost (NAMM) is formed below the long-run average cost.
Ensuring that the water market works in accordance with the conditions of a perfectly competitive market may bring different results in this case. In a perfectly competitive market, the use of water will be higher, on the other hand, the price to be formed in the market will be lower than the price of the monopolist. The monopoly water market earns more profit than the water market operating under perfect competition conditions.

Monopoly markets are open to serious criticism because they disrupt the optimal allocation of resources (underproduction and high prices), that monopoly preserves its excess profits in the long run (always sells at a price above marginal cost), and the demand elasticity faced by the monopolist will increase as its profits decrease. Under normal circumstances, a monopolistic firm will market fewer products at a higher price.
This is particularly important when it comes to water. Due to the vital nature of water, demand elasticity is very low (in the range of 0.3-0.5 on average according to countries). The monopolist will want to maximize his profit by taking advantage of the low demand curve elasticity of this indispensable product. In this case, the public authority responsible for water pricing, taking into account the social

benefit, will also have the excess of the water enterprise with the monopoly power to provide financial support.

Another criticism is that businesses with monopoly power want to maximize their total profits by keeping their service areas limited and raising their prices. Therefore, it will not be profitable for these businesses to provide water services to poor neighborhoods. Because the population density per unit area is low, the investment cost is high in poor districts, the water consumption per subscriber is low, the loss-leakage rate is high, and collection is difficult.

The markets of water enterprises are limited to the region in which they operate. The fact that such businesses operate according to commercial rules requires that the least service be sold at the highest price.

In Turkey, the State Hydraulic Works (DSI) can take back the operation in such cases in the agreements it has made. Thus, the social dimension is brought to the fore. However, although DSI is a monopoly, it avoids controlling the quantity by setting low prices. Monopoly has to choose price and quantity control. DSI keeps the price low for social purposes instead of quantity control.

Water tariffs differ in agriculture, industry, and domestic use. In addition, monopolistic regional price discrimination can be applied. It may prefer price differentiation to provide cheaper water service to certain regions. In this sense, water pricing can be used as an effective tool to eliminate regional inequality. This may be a political choice or a social policy of public choice.

The state intervenes in production activities where externalities are concerned, by considering the benefit of society. For this purpose, the state tries to increase the positive/positive externalities and prevent the negative externalities.

While activities with positive externalities will be undertaken by the state itself, private sector organizations that carry out these activities can be supported by subsidies from the budget. What will polluters do? What is the size of the damage? Which activities cause how much pollution? How should the effects of the damage to the air and the environment be measured in terms of social, economic, and health? The answers to these questions constitute the most important sub-account item in the pricing of water, which is calculated with the full cost method.

Externalities make a difference between social costs and private costs, and between social and private benefits. A tax to be applied here in an appropriate combination would ensure that it reflects the real social costs of the actions of individuals and firms. Thus, marginal private costs will be equated to marginal social costs, and marginal private benefits will be equated to marginal social benefits. It is possible to realize this condition on a local scale and to explain it, especially with any production example that pollutes the air and water. For example, a polluting factory will produce at a point where it is equal to the marginal social cost of society. Thus, society will be freed from the negative externality cost that may arise from the overproduction of the producers. The imposition of a tax liability equal to the marginal cost of pollution per unit of a product by local governments will push the factory to produce at a socially efficient output level (Scitovsky, 1971:274).

It is recognized that pure marginal cost pricing may be undesirable for fairness, financial, political, or legal reasons. Those emphasizing the element of fairness are concerned that marginal cost pricing may overburden the poor. Where marginal cost falls below average cost, the revenue from marginal cost

pricing may not be sufficient to recover the costs that led to the water company's financial losses. On the other hand, if marginal costs rise above-average costs, excess profits through monopoly supply perceived as core goods may not be accepted by public or legal standards. To achieve the goal of efficient use of the resource and providing social benefit, it is recommended to use two-part tariffs, to adjust the fixed-wage to meet the income requirement, and to be priced higher than the consumers with less elastic demands.
Water pricing theory is further complicated by the intertemporal nature of water storage and delivery and the unpredictable nature of precipitation, water inflow, and water demands. Effective allocation often requires that marginal units (any good) be priced at their marginal costs. However, in the case of water, various complications arise. First, considering storage and distribution systems, the marginal cost of resources in the short run may be much lower than in the long run if the system capacity is not fully utilized. Second, given the increasing cost nature of the water industry, 'pricing all water at marginal cost would generate excess revenue for water authorities. Therefore, multi-part or incremental block tariff structures may be appropriate for nonprofit water authorities. (Hotelling 1931; Riley and Scherer 1979; Manning and Gallagher 1980).
In addition, marginal cost pricing will tend to constrain growth in the quantity demanded. There is some evidence that the price elasticity of demand for irrigation water is significantly greater. There is some debate about how best to approach efficient allocation in such situations. Pricing at long-run marginal cost will prolong the underutilization of capacity. On the other hand, it is quite possible that short-run marginal cost pricing will generate insufficient revenue to cover the fixed cost of existing facilities or to finance the next expansion (Starrett 1978). Pricing at short-run marginal cost will certainly give users false signals about water scarcity in the long run.
Water pricing is not the only way to recover the cost of water services. Priorities in the sectors where water pricing is applied are also changing.

- *In domestic consumption, priority is the principle of equality and fairness. Then comes the principle of effective distribution and the principle of income adequacy. The "affordable" expression used while analyzing the tariffs means that the share of water bills in family budgets is 3-5%. According to the World Health Organization, expenditures on water distribution and sanitary infrastructure only provide benefits for public health (4-12) times. Therefore, it is understood that the social costs and negative externalities of the public giving up providing water services will be very high. From this, it is possible to reach the following conclusion: Providing water service by the public is not only a social responsibility but also a rational necessity.*
- *Since water for industrial consumption is a part of the production, it will be among the water production costs. The priority here will be the principle of effective distribution and the principle of income adequacy.*

- *In agricultural consumption, since agricultural water pricing is a leading issue for agricultural and rural development policies, priority will be the principle of efficiency in water distribution. Following this principle will be the income adequacy principle. The principle of equality and fairness is not among the priorities here (Liu and Savenije, 2002: 216-217).*

In addition to the cost of delivering water to the consumer, reflecting the scarcity cost of consuming water to the price is one of these methods. In dry seasons when water is scarce, another pricing method is to determine the price of water by multiplying the amount used by the higher unit cost. In step pricing, which is another method, the water price is determined by multiplying with larger coefficients as the volume used increases. Thus, little water use is rewarded, while excessive water use is penalized financially.

A different method is to price the water according to the cost of noodles. For example, the price of water to be supplied to a high-altitude land will be much more expensive than land at or below sea level, which provides low-cost water because less energy is consumed. This kind of pricing method is the most preferred way to use water tariffs effectively.

## 6. References


1. Armstrong, M., Cowan, S. and Vickers, J. (1994). Regulatory Reform: Economic Analysis and British Experience, The MIT Press Cambridge, MA.

2. Ayman, O. (2010). "Hangi Kente Ne Kadar Su Kullanılıyor?", National Geographic, Nisan

3. Boretti, A., Rosa, L. (2019). "Reassessing the projections of the World Water Development Report", Nature, (31 Temmuz 2019), https://www.nature.com/articles/s41545-019-00

4. Bocutoğlu, E. (2012). "İktisat Teorisinde Emeğin Öyküsü: Değerin Kaynağı Olan Emekten Marjinal Faydanın Türevi Olan Emeğe Yolculuk", Hak İş Uluslararası Emek ve Toplum Dergisi, pp.128-150.

5. Cornes, R. and Sandler, T. (1986). The Theory of Externalities, Public Goods and Club Goods, Cambridge University Press, Cambridge.

6. Çakal, R. (1996). "Doğal Tekellerde Özelleştirme ve Regülasyon", Devlet Planlama Teşkilatı, No: 2455.

7. Çataloluk, C. (2014). "Yerel Hizmetlerin Fiyatlandırılmasında Etkinlik ve Sorunlar (Teorik Bir Çalışma)", İnsan Ve Toplum Bilimleri Araştırmaları Dergisi Cilt: 3, Sayı: 4.

8. Ertuğrul, M. (2008). "Değer-Fiyat Ayrımı Ve İşletme Değeri: Kuramsal Bir Bakış" Eskişehir Osmangazi Universitesi İİBF Dergisi, Ekim 2008, 3(2), 143-154.

9. Garn, M. (1998). "Managing Water as an Economic Good," in *Proceedings of the Community Water Supply and Sanitation Conference*, World Bank / UNDP-World Bank Water and Sanitation Program, Washington, D.C., May 5–8.

10. Gleick, P. (1999). *The Human Right to Water, Pacific Institute for Studies in Development, Environment, and Security*, Oakland, (First Edition: Water Policy, 1999, V: 1, N: 5 pp 487-503).

11. Görer, N. (2003). "Altyapı Hizmetlerinin Sağlanmasında Kamunun Değişen Sorumluluğu", M. A. Çukurçayir ve A. Tekel (der.), Yerel ve Kentsel Politikalar İçinde, Konya: Çizgi Kitabevi.

12. Görer, N. (2000a). "İçmesuyu ve Kanalizasyon Hizmetleri Sunumu Üzerine Bir Değerlendirme", B. A. Güler ve A. Sabuktay (edt.), Yerel Yönetimler Sempozyumu Bildirileri İçinde, Ankara:TODAİE.

13. Gözübüyük, Ş. and Akıllıoğlu, T. (1993) Yönetim Hukuku, Ankara.

14. Grafton, O., Pittock, J., Tait, M., White, C., (2013). Water Security, Economics, and Governance, Tilde University Press, Melbourne. ISBN: 978-0-7346-2006-4.

15. Grafton R, Q., Long C., Wyrwoll, P.(2020). The Paradox Of Water Pricing: Dichotomies, Dilemmas, And Decisions, Oxford Review Of Economic Policy, Volume 36, Issue 1, Spring 2020, Pages 86–107, https://doi.org/10.1093/oxrep/grz030.

16. Hanemann, W. M. (1997). 'Price and Rate Structures', in D. D. Baumann et al. (eds), Urban Water Demand Management and Planning, New York, McGraw-Hill, 137–79.

17. Henrique Monteiro, Water pricing Models: A Survey, August 2005, SSRN Electronic Journal, DOI: 10.2139/ssrn.899602 https://www.researchgate.net/publication/23748960_Water_Pricing_Models_A_Survey.

18. Kahn A. E.(1998). The Economics of Regulation, Volume II, The MIT Press.
19. Koncagül E. Suyun Değeri, DSİ, Oturum I http://eski.yerelnet.org.tr/yerel_hizmetler/su_atiksu/uluslararasipolitikalar.php

20. Malkin, J. and A. Wildavsky (1991). "Why the Traditional Distinction Between Public and Private Goods Should Be Abandoned", Journal of Theoretical Politics, Vol:3, No: 4.

21. Mehta, L. (2002). "Problem of Publicness and Access Rights: Perspectives from the Water Domain", I. Kaul, P. Conceiçao, K. Le Goulven ve R.U. Mendoza (der.) Providing Global Public Goods: Managing Globalization http://www.undp.org/globalpublicgoods/globalization/toc.html
22. Onar, S.S. (1996). İdare Hukukunun Umumi Esasları, İstanbul: Hak Kitabevi.

23. OECD (2002), Social Issues in the Provision of Water Services, OECD, Paris.

24. Ölmezsu, H. (2014). Hayatın Kaynağı (http://www.anorganik.org/wp-content/uploads/2014/11/su.pdf)
25. Pamukçu, K. (2000). Su Politikası, İstanbul: Bağlam Yayınları.
26. Perry, C. J., Rock, M., and Seckler, D (1997). "Water as an Economic Good: A Solution, or a Problem?", International Irrigation Management Institute, Research Report 14, Colombo.
27. Stiglitz, J. E. (1988). Economics of the Public Sector, Second Edition, New York.
28. Liu, J.; Savenije, H.H.G.; Xu, J.(2003). Water as an economic good and water tariff design: Comparison between IBT-con and IRT-cap. Phys. Chem. Earth 2003, 28, 209–217. [Google Scholar] [CrossRef] http://dx.doi.org/10.1016%2FS1474-7065(03)00027-5
29. Scitovsky, T. (1971). Welfare and Competition, USA: Richard D. Irwin, Inc.
30. Rogers, P., Bhatia, R., Huber, A.(1998).Water as a Social and Economic Good: How to Put the Principles into Practice, Stockholm: GWP.
31. United Nations Water, (2018). "World Water Development Report 2018", (19 Mart 2018), https://www.unwater.org/publications/world-water-development-report-2018/. (Access Date: October 14, 2021).
32. (UNDP 2006).
33. World Bank, (1993). "Water Resources Management", World Bank Policy Paper, Washington D.C.
34. Zetland, D. (2021). The role of prices in managing water scarcity Water Security Volume 12, April 2021, 100081 https://doi.org/10.1016/j.wasec.2020.100081.


Received: 08 June 2022

Accepted: 27 June 2022

Issue:5 2022
International Journal of Water Management and Diplomacy
e-ISSN:2717-8277

*Research Article*

# Assessment of crop water requirements by using cropwat for sustainable water resources management in agriculture (Akhisar-Manisa, Turkey)

**Fulya Aydin-Kandemir[1]*, Dursun Yıldız[2]**

*[1] Ege University Solar Energy Institute 35100 Bornova/İzmir, Turkey*
*[1]Hydropolitics Association, 06680 Kavaklidere/Ankara, Turkey*
*ORCID NO: 0000-0001-5101-6406*
*E-mail: fulya.aydin.kandemir@hpacenter.org*
*[2] Izmir Institute of Technology, 35430, Izmir, Turkey*
*[2]Hydropolitics Association, 06680 Kavaklidere/Ankara, Turkey*
*E-mail: dursunyildiz@hpacenter.org*
*ORCID NO: 0000-0001-5110-9960*
**Corresponding author: fulya.aydin.kandemir@hpacenter.org*

**Abstract**
This study was planned to assess the optimum water requirements of chosen crops and contribute to sustainable water management in Manisa-Akhisar Beyoba Region, which makes agricultural production with groundwater. A severe regional hydrological and agricultural drought for the past two years in this region has led to more use of groundwater. This resulted in a rapid decrease in groundwater levels. This study created a guide on the optimum water requirement of the crops to be grown for the sustainable use of groundwater in the region.

**Keywords:** optimum water requirement, sustainable water use, CROPWAT, CLIMWAT, FAO, climate change, agriculture

e-ISSN:2717-8277

## 1. Introduction

Groundwater is the primary source of freshwater in terms of volume. It is the source of the majority of our potable water (Schwarz and Zhang, 2003). It is also utilised for irrigation in several places (Siebert et al., 2010).

Being invisible causes groundwater to be used more uncontrolled. 67% of the groundwater withdrawn in Turkey is allocated for agricultural irrigation (Gunes et al., 2016). However, illegal withdrawals are made from many unauthorised wells (Aydin et al., 2020). This situation complicates the sustainable management of groundwater in terms of quality and quantity (Göçmez and İşçioğlu, 2004). So, it is essential to consider the optimum water demand of the crop, especially in agricultural lands under the threat of limited groundwater and climate change (Bhattarai and Shakya, 2020). Therefore, groundwater is an important resource for agricultural irrigation and drinking water, especially in dry periods. Without groundwater, surface waters would dry up and experience a decline in water quality and ecological health (Schwarz and Zhang, 2003).

In order to prevent this unsustainable water use, irrigation systems must be modernised and well-managed by properly evaluating water system requirements. To meet the irrigation demand, it is essential to understand crop water requirements (CWRs) and irrigation schedules (Ewaid et al., 2019).

To identify crop evapotranspiration, crop water requirement (CWR), and irrigation scheduling, researchers rely heavily on software modelling with packages such as CROPWAT 8.0. This software was created by the Food and Agriculture Organization (FAO) (Smith, 1996) to aid watering experts and farmers in doing the standard computations for water irrigation and in the design and management of irrigation systems (Clarke et al., 2001). This study creates a guideline for the irrigation water requirements of some agricultural products (wheat, maize, grape, cotton and barley) in Beyoba village (Akhisar–Manisa Province) of Turkey were analysed employing the CROPWAT model.

### 1.1. Study area

The study area was taken as Beyoba village in the Akhisar district of Manisa province in the west of Turkey (Figure 1).

e-ISSN:2717-8277


**Figure 1.** The study area (generated by using ArcGIS pro v2.18) The photos of the study area (right below) were obtained from the Beyoba Irrigation Cooperative (see acknowledgements).

Agricultural irrigation in the study area is carried out by using groundwater under the management of Beyoba Irrigation Cooperative. The irrigation area of Beyoba irrigation cooperative is 7500 decares, and maize, cotton and table grapes are grown in Figure 2. Approximately 5.5 million m³ of groundwater is drawn annually from 23 wells for agricultural irrigation.

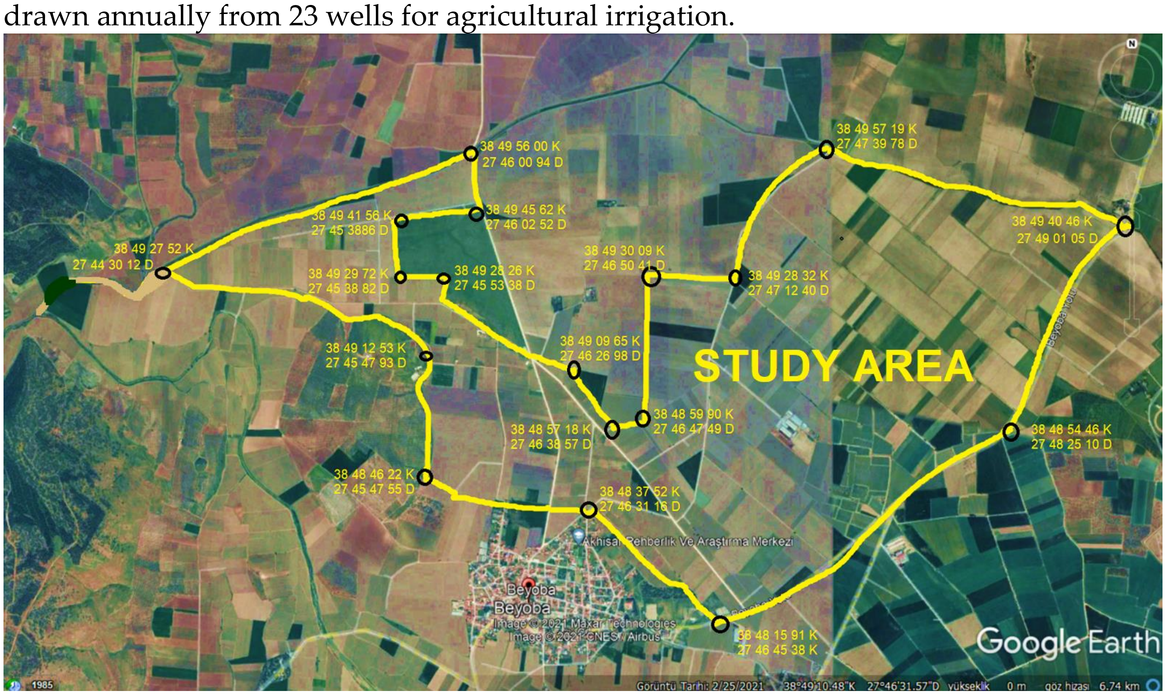



**Figure 2.** The irrigation area of Beyoba irrigation cooperative.

Issue:5 2022
International Journal of Water Management and Diplomacy
e-ISSN:2717-8277

## 2. Data and Method

### 2.1. ETo, ETc and Kc values by using CROPWAT

FAO created the CROPWAT computer tool for irrigation management and planning (FAO, 1992). Its fundamental duties include calculating reference evapotranspiration, agricultural water needs, and irrigation planning. (Allen et al., 1998; Rajput and Patel, 2006). By CROPWAT, the crops' coefficient (Kc), reference crop evapotranspiration (ETo) and finally crop evapotranspiration (Etc) can be considered for selected crop and irrigation requirements can be calculated under effective rainfall (or without considering effective rainfall) (CROPWAT, 2022).

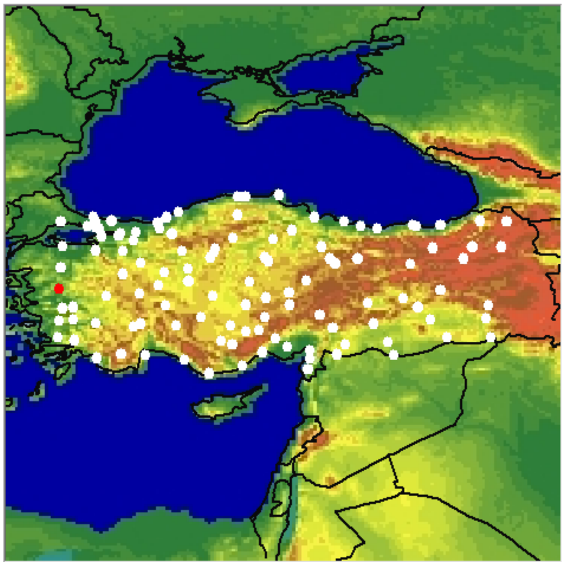
ETc relates to crop evapotranspiration from disease-free, well-fertilized crops produced in wide areas, under optimal soil water requirements, and attaining cultivation under specified climatic conditions (Allen et al., 1998; Vu et al., 2005). ETc is analyzed by multiplying the ETo by Kc as given:

$$\mathbf{ETc = Kc * ETo} \quad (1)$$

where Etc is mm/d; Kc is coefficient, and ETo is mm/d. ETo was analysed based on the FAO Penman-Monteith method (Allen et al., 1998; Vu et al., 2005). ETo is the amount of evapotranspiration from a proposed reference crop with a supposed crop height of 12 cm, a fixed canopy resistance of 70 sm-1, and an albedo of 0.23, which closely resembles the ET from a comprehensive surface of grass cover that is of suitable height, growing, totally shading the field, and receiving acceptable water (Allen et al., 1998; Vu et al., 2005). The FAO Penman-Monteith method needs solar radiation, maximum, minimum and means air temperatures, air humidity and wind speed data (Smith et al., 2002).

The Kc of plants is determined by climatic conditions and crop development phases. Changes occur in the plant cover, crop height, and leaf area as the crop matures. Due to changes in evapotranspiration during different growth stages, the Kc for a given crop alters over the growing period. The growing period can be separated into four different growing periods: initial, crop development, mid-season and late-season (Vu et al., 2005, Yarami et al., 2011).

In this study, the climate data (average for the 1970–2000 period (Ewaid et al., 2019): temperature, humidity, wind speed, sun hours and rainfall) were attained by CLIMWAT software attached to the CROPWAT software for Akhisar station (Manisa-Turkey) (Figure 3). According to temperature, humidity, wind speed, sun hours data, Monthly Radiation and Monthly ETo Penman-Monteith (Smith et al., 2002; Ewaid et al., 2019) values were calculated (Table 1). The effective rainfall values were also calculated based on the USDA soil conservation service (USDA, 1970; Tigkas et al., 2016; CROPWAT Software, 2022) (Table 2). According to Bokke and Shoro (2020) USDA soil conservation method is good for water-scarce areas.



| | | | | | |
|---|---|---|---|---|---|
| 81 | 35.03 | 37.26 | 230 | KARAISALI | TURKEY |
| 82 | 36.93 | 37.6 | 549 | KAHRAMANMARAS | TURKEY |
| 83 | 27.41 | 37.03 | 27 | BODRUM | TURKEY |
| 84 | 37.36 | 37.08 | 855 | GAZIANTEP | TURKEY |
| 85 | 27.2 | 37.83 | 22 | KUSADASI | TURKEY |
| 86 | 27.8 | 37.3 | 45 | MILAS | TURKEY |
| 87 | 27.85 | 37.85 | 57 | AYDIN | TURKEY |
| 88 | 38.28 | 37.75 | 678 | ADIYAMAN | TURKEY |
| 89 | 28.35 | 37.2 | 646 | MUGLA | TURKEY |
| 90 | 28.33 | 37.9 | 60 | NAZILLI | TURKEY |
| 91 | 38.76 | 37.13 | 547 | URFA | TURKEY |
| 92 | 29.08 | 37.76 | 428 | DENIZLI | TURKEY |
| 93 | 40.5 | 38.86 | 1177 | BINGOL | TURKEY |
| 94 | 30.53 | 38.75 | 1034 | AFYON | TURKEY |
| 95 | 31.38 | 38.35 | 1070 | AKSEHIR | TURKEY |
| 96 | 42.1 | 38.36 | 1559 | BITLIS | TURKEY |
| 97 | 32.95 | 38.66 | 969 | CIHANBEYLI | TURKEY |
| 98 | 43.3 | 38.96 | 1775 | ERCIS | TURKEY |
| 99 | 43.31 | 38.45 | 1661 | VAN | TURKEY |
| 100 | 44.01 | 38.05 | 2400 | BASKALE | TURKEY |
| 101 | 34.05 | 38.38 | 980 | AKSARAY | TURKEY |
| 102 | 34.71 | 38.61 | 1260 | NEVSEHIR | TURKEY |
| 103 | 35.5 | 38.38 | 1180 | DEVELI | TURKEY |
| 104 | 35.48 | 38.78 | 1054 | KAYSERI-ERKILET | TURKEY |
| 105 | 36.5 | 38.03 | 1340 | GOKSUN | TURKEY |
| 106 | 27.25 | 38.46 | 27 | BORNOVA | TURKEY |
| 107 | 27.98 | 38.26 | 122 | ODEMIS | TURKEY |
| 108 | 27.85 | 38.91 | 93 | AKHISAR | TURKEY |
| 109 | 27.08 | 38.58 | 20 | MENEMEN | TURKEY |
| 110 | 27.43 | 38.61 | 71 | MANISA | TURKEY |
| 111 | 27.16 | 38.43 | 25 | IZMIR | TURKEY |
| 112 | 28.31 | 38.3 | 150 | CESME | TURKEY |
| 113 | 38.08 | 38.43 | 849 | MALATYA-ERHAC | TURKEY |

**Figure 3.** Akhisar Manisa Station from CLIMWAT software.

**Table 1.** Akhisar station (LAT:38.91°N, LON:27.85°E; Altitude: 93 m.) climate data (average for 1970–2000 period), calculated monthly radiation and ETo Penman-Monteith (CROPWAT, 2022).

| **Month** | **Minimum Temperature** | **Maximum Temperature** | **Humidity** | **Wind** | **Sun** | **Radiation** | **ETo** |
|---|---|---|---|---|---|---|---|
| | **°C** | **°C** | **%** | **km/day** | **hours** | **MJ/m²/day** | **mm/day** |
| January | 2 | 10.8 | 79 | 112 | 4 | 7.3 | 0.85 |
| February | 2.8 | 12.3 | 74 | 121 | 5.1 | 10.3 | 1.27 |
| March | 4.2 | 15.9 | 66 | 138 | 5.9 | 14 | 2.13 |
| April | 7.7 | 21.4 | 61 | 112 | 7.3 | 18.5 | 3.14 |
| May | 11.8 | 26.8 | 59 | 104 | 8.6 | 22.1 | 4.2 |
| June | 15.6 | 31.7 | 51 | 130 | 11.4 | 26.6 | 5.77 |
| July | 18.5 | 34.1 | 48 | 164 | 13.2 | 28.7 | 6.8 |
| August | 18.4 | 34.2 | 48 | 156 | 12.4 | 26 | 6.26 |
| September | 14.5 | 30.8 | 51 | 121 | 10.6 | 20.7 | 4.51 |
| October | 10 | 24.4 | 62 | 95 | 7.7 | 13.7 | 2.53 |
| November | 5.7 | 18.1 | 77 | 61 | 5.5 | 9 | 1.18 |
| December | 3.6 | 12.7 | 80 | 78 | 4.2 | 6.8 | 0.77 |
| **Average** | 9.6 | 22.8 | 63 | 116 | 8 | 17 | 3.28 |

**Table 2.** Akhisar station rainfall data (average for 1970–2000 period) and calculated effective rainfall values based on USDA soil conservation service (USDA, 1970).

| Month | Rain (mm) | Eff rain (mm) |
|---|---|---|
| Jan | 96 | 81.3 |
| Feb | 81 | 70.5 |
| Mar | 63 | 56.6 |
| Apr | 53 | 48.5 |
| May | 29 | 27.7 |
| Jun | 15 | 14.6 |
| Jul | 5 | 5 |
| Aug | 7 | 6.9 |
| Sept | 14 | 13.7 |
| Oct | 35 | 33 |
| Nov | 72 | 63.7 |
| Dec | 124 | 99.4 |
| **Total** | 594 | 520.9 |

Here, five basic crops were selected to reveal the irrigation requirements in the study region. The selected crops are (1) wheat, (2) maize, (3) grape, (4) cotton, and (5) barley (table). For the determination of the Crop Water Requirements (CWR), each crop information is essential for further calculations, therefore the planting and harvesting dates of the selected crops were found for Turkey from USDA Foreign Agricultural Service (USDA IPAD, 2022) and Turkey Seed Union (TSU) (TSU, 2022) (in Table 3). After the integration of the harvesting dates of each crop, the CROPWAT have calculated the harvesting date (CROPWAT, 2022) according to the crop's distinct growing stages (in Table 4). All the crop information was given for the selected crops between Figure 4 to Figure 8 in this paper.

**Table 3.** The crops calendar for Turkey according to USDA Foreign Agricultural Service (USDA IPAD, 2022); for grapes, TSU was used to reference (TSU, 2022).

| **Turkey Crop Calendar** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wheat (spring) | | | Plant | Plant | Mid-season | Mid-season | Harvest | Harvest | | | | |
| Maize | | Plant | Plant | Plant | Mid-season | Mid-season | Mid-season | Mid-season | Harvest | Harvest | | |
| Grape | | Plant | Plant | Plant | Mid-season | Mid-season | Mid-season | Mid-season / Harvest | Harvest | Harvest | Harvest | Harvest |
| Cotton | | | / Plant | Plant | Plant | Plant / Mid-season | Mid-season | Mid-season | Mid-season / Harvest | Harvest | Harvest | |
| Barley | Mid-season | Mid-season | Mid-season | Mid-season | Mid-season | Harvest | Harvest | | | Plant | Plant | Mid-season |

| | |
|---|---|
| (green) | Plant |
| (orange) | Mid-season |
| (yellow) | Harvest |

**Table 4.** FAO's CROPWAT based planting and harvesting dates of the selected crops (Table 3 was considered for these dates).

| | Planting Date | Harvesting Date |
|---|---|---|
| Wheat | 01/03 | 08/07 |
| Maize | 01/02 | 28/10 |
| Grape | 01/02 | 31/01 |
| Cotton | 15/03 | 14/11 |
| Barley | 01/10 | 27/07 |

Wheat

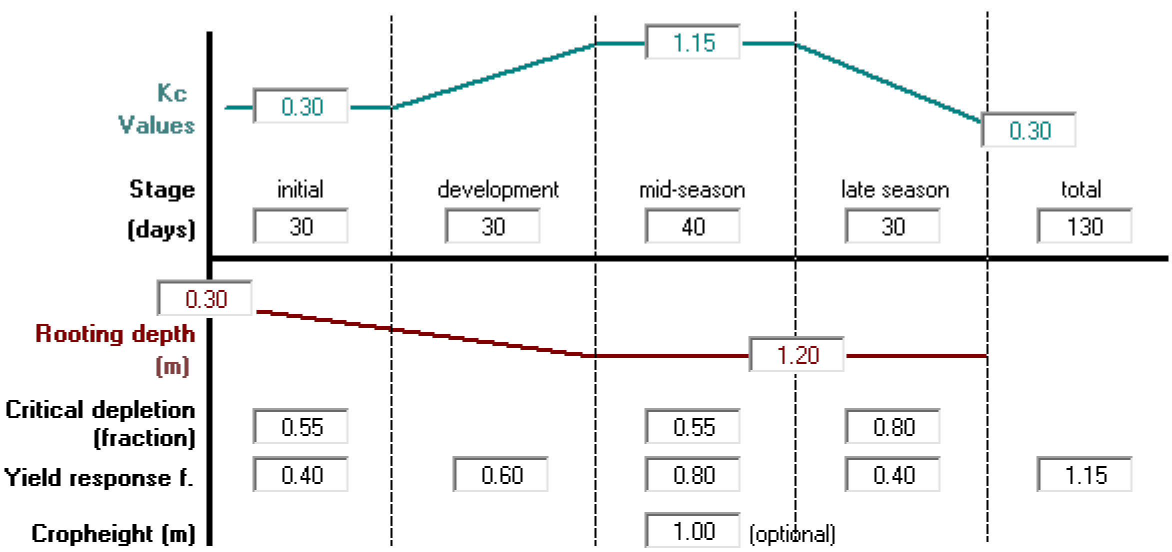



**Figure 4.** The crop properties of **wheat** from FAO CROPWAT.

Maize

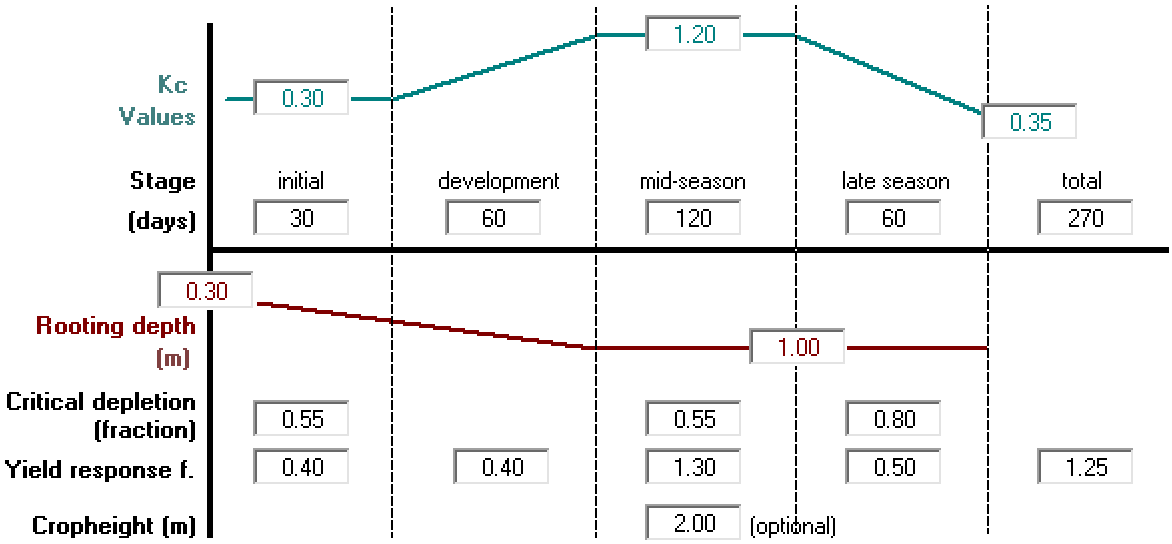



**Figure 5.** The crop properties of **maize** from FAO CROPWAT.

Grape

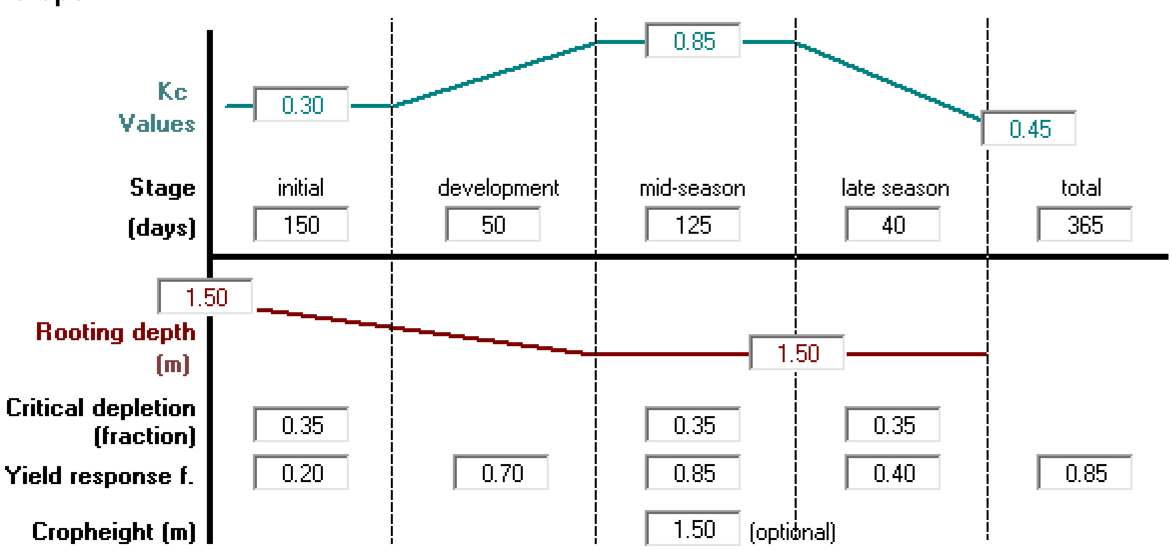



**Figure 6.** The crop properties of **grape** from FAO CROPWAT.

Cotton

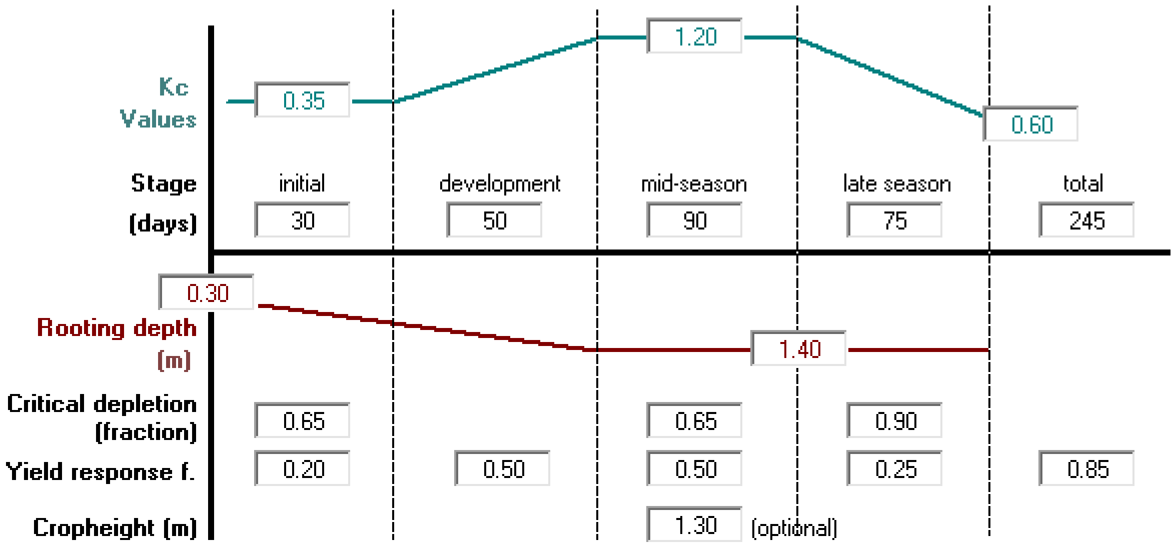



**Figure 7.** The crop properties of **cotton** from FAO CROPWAT.

**Barley**

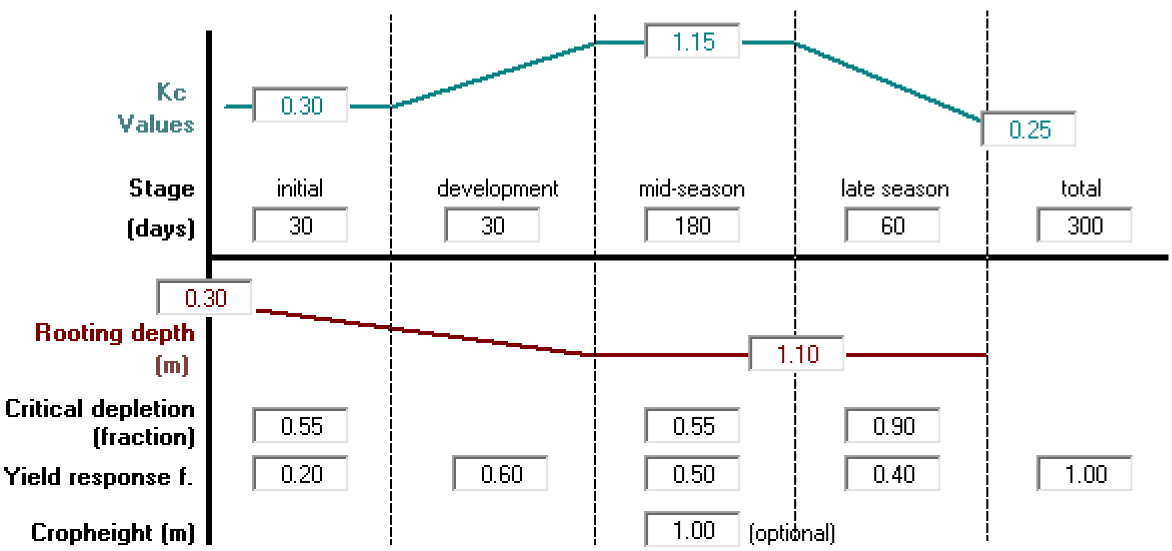



**Figure 8.** The crop properties of **barley** from FAO CROPWAT.

Included within the input provided in the CROPWAT and CLIMWAT programs were the Manisa Akhisar station data, the crop properties, the cultivation date, and the soil type. (Table 5). After all of the data were submitted to the software, it computed the crop's climatic characteristics, ETo, effective rainfall, and total irrigation needs.

**Table 5.** Optimal soil texture for wheat (NASA, 2022), maize (Eco Farming Daily, 2022), grape (Sommelier Choice Award, 2022), cotton (Wikifarmer, 2022) and barley (Valenzuela and Smith, 2022). The soil texture in this table is based on FAO soil texture classification (CROPWAT, 2022).

| | | **Soil Texture (FAO)** |
|---|---|---|
| | | Medium (loam) |
| Tot. avail. soil moist. | **mm/meter** | 290 |
| Max. rain infiltrat. rate | **mm/day** | 40 |
| Max. rooting depth | **cm** | 900 |
| Initial soil moist. deplet. (as % TAM) | **%** | 0 |
| Initial. avail. soil moist. | **mm/meter** | 290 |
| Crops | | Wheat, Maize, Grape, Cotton, Barley |

## 3. Results

### 3.1. Crop Water Requirements (CWR) of all crops

The crop's water requirement is the quantity (or depth) of water equal to the ET water loss. Crops have varying water needs according to location, climate, soil type, cultivation technique, effective rainfall, etc., and the full amount of water essential for crop development is not evenly distributed across its entire average lifespan (Azevedo et al., 2007; Ewaid et al., 2019). Tables 6–10 demonstrate the effective rain and the IR of wheat, maize, grape, cotton and barley computed by CROPWAT. Also, the irrigation requirements, which do not consider effective rainfall, were given in the same tables for selected crops. In tables, (Init, initial; Dev, development; Eff. Rain, effective rain; Irr. Req., irrigation requirements).

**Table 6.** CWR for spring **wheat** for (1) eff. rain. considered based on USDA soil conservation service and (2) no eff. rain. considered.

| **Month** | **Decade** | **Stage** | **Kc** | **ETc** | **ETc** | **Eff rain** | **Irr. Req.** | **Eff rain** | **Irr. Req.** |
|---|---|---|---|---|---|---|---|---|---|
| | | | **coeff** | **mm/day** | **mm/dec** | **mm/dec** | **mm/dec** | **mm/dec** | **mm/dec** |
| Mar | 1 | Init | 0.3 | 0.55 | 5.5 | 20.3 | 0 | 0 | 5.5 |
| Mar | 2 | Init | 0.3 | 0.64 | 6.4 | 18.6 | 0 | 0 | 6.4 |
| Mar | 3 | Deve | 0.3 | 0.75 | 8.2 | 17.8 | 0 | 0 | 8.2 |
| Apr | 1 | Deve | 0.48 | 1.36 | 13.6 | 17.4 | 0 | 0 | 13.6 |
| Apr | 2 | Deve | 0.77 | 2.4 | 24 | 16.7 | 7.3 | 0 | 24 |
| Apr | 3 | Mid | 1.04 | 3.65 | 36.5 | 14.2 | 22.3 | 0 | 36.5 |
| May | 1 | Mid | 1.15 | 4.41 | 44.1 | 11.3 | 32.8 | 0 | 44.1 |
| May | 2 | Mid | 1.15 | 4.82 | 48.2 | 8.9 | 39.3 | 0 | 48.2 |

**Table 6.** CWR for spring **wheat** for (1) eff. rain. considered based on USDA soil conservation service and (2) no eff. rain. considered.

| Month | Decade | Stage | Kc | ETc | ETc | Eff rain | Irr. Req. | Eff rain | Irr. Req. |
|---|---|---|---|---|---|---|---|---|---|
| | | | coeff | mm/day | mm/dec | mm/dec | mm/dec | mm/dec | mm/dec |
| May | 3 | Mid | 1.15 | 5.41 | 59.5 | 7.5 | 52 | 0 | 59.5 |
| Jun | 1 | Late | 1.14 | 5.97 | 59.7 | 6.3 | 53.4 | 0 | 59.7 |
| Jun | 2 | Late | 0.93 | 5.39 | 53.9 | 4.8 | 49.1 | 0 | 53.9 |
| Jun | 3 | Late | 0.65 | 3.99 | 39.9 | 3.7 | 36.1 | 0 | 39.9 |
| Jul | 1 | Late | 0.4 | 2.6 | 20.8 | 1.9 | 18.4 | 0 | 20.8 |
| | | | | | | | | | |
| | | | | Total | 420.2 | 149.5 | **310.7** | 0 | **420.2** |

**Table 7.** CWR for spring **maize** for (1) eff. rain. considered based on USDA soil conservation service and (2) no eff. rain. considered.

| Month | Decade | Stage | Kc | ETc | ETc | Eff rain | Irr. Req. | Eff rain | Irr. Req. |
|---|---|---|---|---|---|---|---|---|---|
| | | | coeff | mm/day | mm/dec | mm/dec | mm/dec | mm/dec | mm/dec |
| Feb | 1 | Init | 0.3 | 0.34 | 3.4 | 24.8 | 0 | 0 | 3.4 |
| Feb | 2 | Init | 0.3 | 0.38 | 3.8 | 23.6 | 0 | 0 | 3.8 |
| Feb | 3 | Init | 0.3 | 0.47 | 3.7 | 22 | 0 | 0 | 3.7 |
| Mar | 1 | Deve | 0.35 | 0.65 | 6.5 | 20.3 | 0 | 0 | 6.5 |
| Mar | 2 | Deve | 0.5 | 1.07 | 10.7 | 18.6 | 0 | 0 | 10.7 |
| Mar | 3 | Deve | 0.66 | 1.64 | 18 | 17.8 | 0.2 | 0 | 18 |
| Apr | 1 | Deve | 0.82 | 2.3 | 23 | 17.4 | 5.6 | 0 | 23 |
| Apr | 2 | Deve | 0.97 | 3.05 | 30.5 | 16.7 | 13.8 | 0 | 30.5 |
| Apr | 3 | Deve | 1.12 | 3.93 | 39.3 | 14.2 | 25 | 0 | 39.3 |
| May | 1 | Mid | 1.21 | 4.64 | 46.4 | 11.3 | 35.1 | 0 | 46.4 |
| May | 2 | Mid | 1.21 | 5.07 | 50.7 | 8.9 | 41.8 | 0 | 50.7 |

**Table 7.** CWR for spring **maize** for (1) eff. rain. considered based on USDA soil conservation service and (2) no eff. rain. considered.

| Month | Decade | Stage | Kc | ETc | ETc | Eff rain | Irr. Req. | Eff rain | Irr. Req. |
|---|---|---|---|---|---|---|---|---|---|
| | | | coeff | mm/day | mm/dec | mm/dec | mm/dec | mm/dec | mm/dec |
| May | 3 | Mid | 1.21 | 5.7 | 62.7 | 7.5 | 55.2 | 0 | 62.7 |
| Jun | 1 | Mid | 1.21 | 6.33 | 63.3 | 6.3 | 57 | 0 | 63.3 |
| Jun | 2 | Mid | 1.21 | 6.96 | 69.6 | 4.8 | 64.8 | 0 | 69.6 |
| Jun | 3 | Mid | 1.21 | 7.37 | 73.7 | 3.7 | 70 | 0 | 73.7 |
| Jul | 1 | Mid | 1.21 | 7.87 | 78.7 | 2.4 | 76.3 | 0 | 78.7 |
| Jul | 2 | Mid | 1.21 | 8.32 | 83.2 | 1.2 | 82.1 | 0 | 83.2 |
| Jul | 3 | Mid | 1.21 | 8.07 | 88.7 | 1.5 | 87.2 | 0 | 88.7 |
| Aug | 1 | Mid | 1.21 | 7.85 | 78.5 | 2 | 76.6 | 0 | 78.5 |
| Aug | 2 | Mid | 1.21 | 7.68 | 76.8 | 2.1 | 74.7 | 0 | 76.8 |
| Aug | 3 | Late | 1.2 | 6.91 | 76 | 2.9 | 73.1 | 0 | 76 |
| Sep | 1 | Late | 1.1 | 5.6 | 56 | 3.4 | 52.6 | 0 | 56 |
| Sep | 2 | Late | 0.96 | 4.32 | 43.2 | 4 | 39.2 | 0 | 43.2 |
| Sep | 3 | Late | 0.81 | 3.14 | 31.4 | 6.3 | 25 | 0 | 31.4 |
| Oct | 1 | Late | 0.67 | 2.14 | 21.4 | 8.5 | 12.9 | 0 | 21.4 |
| Oct | 2 | Late | 0.53 | 1.34 | 13.4 | 10.5 | 2.9 | 0 | 13.4 |
| Oct | 3 | Late | 0.4 | 0.83 | 6.6 | 10.2 | 0 | 0 | 6.6 |
| | | | | | | | | | |
| | | | | Total | 1159.5 | 273.1 | **971** | 0 | **1159.5** |

JWMD Issue:5 2022
e-ISSN:2717-8277
International Journal of Water Management and Diplomacy

**Table 8.** CWR for **grape** for (1) eff. rain. considered based on USDA soil conservation service and (2) no eff. rain. considered.

| Month | Decade | Stage | Kc | ETc | ETc | Eff rain | Irr. Req. | Eff rain | Irr. Req. |
|---|---|---|---|---|---|---|---|---|---|
| | | | coeff | mm/day | mm/dec | mm/dec | mm/dec | mm/dec | mm/dec |
| Feb | 1 | Init | 0.3 | 0.34 | 3.4 | 24.8 | 0 | 0 | 3.4 |
| Feb | 2 | Init | 0.3 | 0.38 | 3.8 | 23.6 | 0 | 0 | 3.8 |
| Feb | 3 | Init | 0.3 | 0.47 | 3.7 | 22 | 0 | 0 | 3.7 |
| Mar | 1 | Init | 0.3 | 0.55 | 5.5 | 20.3 | 0 | 0 | 5.5 |
| Mar | 2 | Init | 0.3 | 0.64 | 6.4 | 18.6 | 0 | 0 | 6.4 |
| Mar | 3 | Init | 0.3 | 0.74 | 8.1 | 17.8 | 0 | 0 | 8.1 |
| Apr | 1 | Init | 0.3 | 0.84 | 8.4 | 17.4 | 0 | 0 | 8.4 |
| Apr | 2 | Init | 0.3 | 0.94 | 9.4 | 16.7 | 0 | 0 | 9.4 |
| Apr | 3 | Init | 0.3 | 1.05 | 10.5 | 14.2 | 0 | 0 | 10.5 |
| May | 1 | Init | 0.3 | 1.15 | 11.5 | 11.3 | 0.2 | 0 | 11.5 |
| May | 2 | Init | 0.3 | 1.26 | 12.6 | 8.9 | 3.7 | 0 | 12.6 |
| May | 3 | Init | 0.3 | 1.42 | 15.6 | 7.5 | 8.1 | 0 | 15.6 |
| Jun | 1 | Init | 0.3 | 1.57 | 15.7 | 6.3 | 9.5 | 0 | 15.7 |
| Jun | 2 | Init | 0.3 | 1.73 | 17.3 | 4.8 | 12.5 | 0 | 17.3 |
| Jun | 3 | Init | 0.3 | 1.83 | 18.3 | 3.7 | 14.6 | 0 | 18.3 |
| Jul | 1 | Deve | 0.36 | 2.33 | 23.3 | 2.4 | 21 | 0 | 23.3 |
| Jul | 2 | Deve | 0.46 | 3.2 | 32 | 1.2 | 30.8 | 0 | 32 |
| Jul | 3 | Deve | 0.57 | 3.84 | 42.3 | 1.5 | 40.7 | 0 | 42.3 |
| Aug | 1 | Deve | 0.69 | 4.46 | 44.6 | 2 | 42.7 | 0 | 44.6 |
| Aug | 2 | Mid | 0.79 | 5.03 | 50.3 | 2.1 | 48.2 | 0 | 50.3 |
| Aug | 3 | Mid | 0.83 | 4.76 | 52.4 | 2.9 | 49.4 | 0 | 52.4 |
| Sep | 1 | Mid | 0.83 | 4.22 | 42.2 | 3.4 | 38.8 | 0 | 42.2 |
| Sep | 2 | Mid | 0.83 | 3.74 | 37.4 | 4 | 33.4 | 0 | 37.4 |
| Sep | 3 | Mid | 0.83 | 3.19 | 31.9 | 6.3 | 25.6 | 0 | 31.9 |
| Oct | 1 | Mid | 0.83 | 2.64 | 26.4 | 8.5 | 17.9 | 0 | 26.4 |
| Oct | 2 | Mid | 0.83 | 2.09 | 20.9 | 10.5 | 10.4 | 0 | 20.9 |
| Oct | 3 | Mid | 0.83 | 1.72 | 18.9 | 14.1 | 4.8 | 0 | 18.9 |
| Nov | 1 | Mid | 0.83 | 1.29 | 12.9 | 17.7 | 0 | 0 | 12.9 |

Issue:5 2022
International Journal of Water Management and Diplomacy
e-ISSN:2717-8277

**Table 8.** CWR for **grape** for (1) eff. rain. considered based on USDA soil conservation service and (2) no eff. rain. considered.

| Month | Decade | Stage | Kc | ETc | ETc | Eff rain | Irr. Req. | Eff rain | Irr. Req. |
|---|---|---|---|---|---|---|---|---|---|
| | | | coeff | mm/day | mm/dec | mm/dec | mm/dec | mm/dec | mm/dec |
| Nov | 2 | Mid | 0.83 | 0.89 | 8.9 | 21 | 0 | 0 | 8.9 |
| Nov | 3 | Mid | 0.83 | 0.81 | 8.1 | 25.1 | 0 | 0 | 8.1 |
| Dec | 1 | Mid | 0.83 | 0.75 | 7.5 | 30.8 | 0 | 0 | 7.5 |
| Dec | 2 | Mid | 0.83 | 0.64 | 6.4 | 35.6 | 0 | 0 | 6.4 |
| Dec | 3 | Late | 0.78 | 0.62 | 6.9 | 32.8 | 0 | 0 | 6.9 |
| Jan | 1 | Late | 0.67 | 0.55 | 5.5 | 28.9 | 0 | 0 | 5.5 |
| Jan | 2 | Late | 0.56 | 0.48 | 4.8 | 26.8 | 0 | 0 | 4.8 |
| Jan | 3 | Late | 0.45 | 0.44 | 4.9 | 25.7 | 0 | 0 | 4.9 |
| | | | | | | | | | |
| | | | | Total | 638.9 | 521.4 | **412.3** | 0 | **638.9** |

**Table 9.** CWR for **cotton** for (1) eff. rain. considered based on USDA soil conservation service and (2) no eff. rain. considered.

| Month | Decade | Stage | Kc | ETc | ETc | Eff rain | Irr. Req. | Eff rain | Irr. Req. |
|---|---|---|---|---|---|---|---|---|---|
| | | | coeff | mm/day | mm/dec | mm/dec | mm/dec | mm/dec | mm/dec |
| Mar | 2 | Init | 0.35 | 0.75 | 4.5 | 11.2 | 0 | 0 | 4.5 |
| Mar | 3 | Init | 0.35 | 0.86 | 9.5 | 17.8 | 0 | 0 | 9.5 |
| Apr | 1 | Init | 0.35 | 0.98 | 9.8 | 17.4 | 0 | 0 | 9.8 |
| Apr | 2 | Deve | 0.4 | 1.25 | 12.5 | 16.7 | 0 | 0 | 12.5 |
| Apr | 3 | Deve | 0.57 | 1.97 | 19.7 | 14.2 | 5.5 | 0 | 19.7 |
| May | 1 | Deve | 0.74 | 2.84 | 28.4 | 11.3 | 17.1 | 0 | 28.4 |
| May | 2 | Deve | 0.91 | 3.82 | 38.2 | 8.9 | 29.3 | 0 | 38.2 |

JWMD Issue:5 2022
e-ISSN:2717-8277
International Journal of Water Management and Diplomacy

**Table 9.** CWR for **cotton** for (1) eff. rain. considered based on USDA soil conservation service and (2) no eff. rain. considered.

| **Month** | **Decade** | **Stage** | **Kc** | **ETc** | **ETc** | **Eff rain** | **Irr. Req.** | **Eff rain** | **Irr. Req.** |
|---|---|---|---|---|---|---|---|---|---|
| | | | **coeff** | **mm/day** | **mm/dec** | **mm/dec** | **mm/dec** | **mm/dec** | **mm/dec** |
| May | 3 | Deve | 1.09 | 5.15 | 56.6 | 7.5 | 49.1 | 0 | 56.6 |
| Jun | 1 | Mid | 1.21 | 6.34 | 63.4 | 6.3 | 57.1 | 0 | 63.4 |
| Jun | 2 | Mid | 1.21 | 6.98 | 69.8 | 4.8 | 65 | 0 | 69.8 |
| Jun | 3 | Mid | 1.21 | 7.39 | 73.9 | 3.7 | 70.2 | 0 | 73.9 |
| Jul | 1 | Mid | 1.21 | 7.89 | 78.9 | 2.4 | 76.5 | 0 | 78.9 |
| Jul | 2 | Mid | 1.21 | 8.35 | 83.5 | 1.2 | 82.3 | 0 | 83.5 |
| Jul | 3 | Mid | 1.21 | 8.09 | 89 | 1.5 | 87.5 | 0 | 89 |
| Aug | 1 | Mid | 1.21 | 7.88 | 78.8 | 2 | 76.8 | 0 | 78.8 |
| Aug | 2 | Mid | 1.21 | 7.7 | 77 | 2.1 | 74.9 | 0 | 77 |
| Aug | 3 | Mid | 1.21 | 6.96 | 76.5 | 2.9 | 73.6 | 0 | 76.5 |
| Sep | 1 | Late | 1.16 | 5.94 | 59.4 | 3.4 | 55.9 | 0 | 59.4 |
| Sep | 2 | Late | 1.08 | 4.88 | 48.8 | 4 | 44.8 | 0 | 48.8 |
| Sep | 3 | Late | 1 | 3.85 | 38.5 | 6.3 | 32.1 | 0 | 38.5 |
| Oct | 1 | Late | 0.92 | 2.92 | 29.2 | 8.5 | 20.7 | 0 | 29.2 |
| Oct | 2 | Late | 0.83 | 2.11 | 21.1 | 10.5 | 10.6 | 0 | 21.1 |
| Oct | 3 | Late | 0.75 | 1.55 | 17.1 | 14.1 | 3 | 0 | 17.1 |
| Nov | 1 | Late | 0.66 | 1.03 | 10.3 | 17.7 | 0 | 0 | 10.3 |
| Nov | 2 | Late | 0.6 | 0.65 | 2.6 | 8.4 | 0 | 0 | 2.6 |
| | | | | | | | | | |
| | | | | Total | 1097.1 | 205 | **932.2** | 0 | **1097.1** |

**Table 10.** CWR for **barley** for (1) eff. rain. considered based on USDA soil conservation service and (2) no eff. rain. considered.

| Month | Decade | Stage | Kc | ETc | ETc | Eff rain | Irr. Req. | Eff rain | Irr. Req. |
|---|---|---|---|---|---|---|---|---|---|
| | | | coeff | mm/day | mm/dec | mm/dec | mm/dec | mm/dec | mm/dec |
| Oct | 1 | Init | 0.3 | 0.96 | 9.6 | 8.5 | 1 | 0 | 9.6 |
| Oct | 2 | Init | 0.3 | 0.76 | 7.6 | 10.5 | 0 | 0 | 7.6 |
| Oct | 3 | Deve | 0.3 | 0.63 | 6.9 | 14.1 | 0 | 0 | 6.9 |
| Nov | 1 | Deve | 0.48 | 0.75 | 7.5 | 17.7 | 0 | 0 | 7.5 |
| Nov | 2 | Deve | 0.75 | 0.81 | 8.1 | 21 | 0 | 0 | 8.1 |
| Nov | 3 | Mid | 1.02 | 1 | 10 | 25.1 | 0 | 0 | 10 |
| Dec | 1 | Mid | 1.12 | 1.01 | 10.1 | 30.8 | 0 | 0 | 10.1 |
| Dec | 2 | Mid | 1.12 | 0.86 | 8.6 | 35.6 | 0 | 0 | 8.6 |
| Dec | 3 | Mid | 1.12 | 0.89 | 9.8 | 32.8 | 0 | 0 | 9.8 |
| Jan | 1 | Mid | 1.12 | 0.92 | 9.2 | 28.9 | 0 | 0 | 9.2 |
| Jan | 2 | Mid | 1.12 | 0.95 | 9.5 | 26.8 | 0 | 0 | 9.5 |
| Jan | 3 | Mid | 1.12 | 1.11 | 12.2 | 25.7 | 0 | 0 | 12.2 |
| Feb | 1 | Mid | 1.12 | 1.27 | 12.7 | 24.8 | 0 | 0 | 12.7 |
| Feb | 2 | Mid | 1.12 | 1.43 | 14.3 | 23.6 | 0 | 0 | 14.3 |
| Feb | 3 | Mid | 1.12 | 1.75 | 14 | 22 | 0 | 0 | 14 |
| Mar | 1 | Mid | 1.12 | 2.07 | 20.7 | 20.3 | 0.4 | 0 | 20.7 |
| Mar | 2 | Mid | 1.12 | 2.39 | 23.9 | 18.6 | 5.3 | 0 | 23.9 |
| Mar | 3 | Mid | 1.12 | 2.77 | 30.4 | 17.8 | 12.6 | 0 | 30.4 |
| Apr | 1 | Mid | 1.12 | 3.14 | 31.4 | 17.4 | 14 | 0 | 31.4 |
| Apr | 2 | Mid | 1.12 | 3.52 | 35.2 | 16.7 | 18.5 | 0 | 35.2 |
| Apr | 3 | Mid | 1.12 | 3.92 | 39.2 | 14.2 | 25 | 0 | 39.2 |
| May | 1 | Mid | 1.12 | 4.31 | 43.1 | 11.3 | 31.8 | 0 | 43.1 |
| May | 2 | Mid | 1.12 | 4.71 | 47.1 | 8.9 | 38.2 | 0 | 47.1 |
| May | 3 | Late | 1.11 | 5.26 | 57.8 | 7.5 | 50.3 | 0 | 57.8 |
| Jun | 1 | Late | 1 | 5.23 | 52.3 | 6.3 | 46.1 | 0 | 52.3 |
| Jun | 2 | Late | 0.85 | 4.92 | 49.2 | 4.8 | 44.4 | 0 | 49.2 |
| Jun | 3 | Late | 0.71 | 4.32 | 43.2 | 3.7 | 39.5 | 0 | 43.2 |

**Table 10.** CWR for **barley** for (1) eff. rain. considered based on USDA soil conservation service and (2) no eff. rain. considered.

| Month | Decade | Stage | Kc | ETc | ETc | Eff rain | Irr. Req. | Eff rain | Irr. Req. |
|---|---|---|---|---|---|---|---|---|---|
| | | | coeff | mm/day | mm/dec | mm/dec | mm/dec | mm/dec | mm/dec |
| Jul | 1 | Late | 0.56 | 3.66 | 36.6 | 2.4 | 34.2 | 0 | 36.6 |
| Jul | 2 | Late | 0.42 | 2.87 | 28.7 | 1.2 | 27.6 | 0 | 28.7 |
| Jul | 3 | Late | 0.29 | 1.96 | 13.7 | 1 | 12.2 | 0 | 13.7 |
| | | | | | | | | | |
| | | | | Total | 702.8 | 500 | **401.1** | 0 | **702.8** |

Clearly, the cultivation of these five crops in the district represents a small-scale fraction of the national crop pattern; consequently, there is an immediate necessity to modify agriculture and irrigation infrastructure in order to increase output. As stated in Ewaid et al (2019), modernization of the watering system incorporates the latest techniques such as sprinkler and drip watering, with a focus on valuable products, water availability, and soil quality. It is crucial to educate farmers on the demand to conserve water and employ contemporary techniques.

## 4. Conclusions

The application of the FAO CROPWAT 8.0 technique produced an intriguing outcome. Due to the seasonal and ecological characteristics of the district, it is evident that crop watering needs were peculiar to the local research region. In this instance, maize had greater evapotranspiration and water demands than the other four crops in this order: Cotton > Grape > Barley > Wheat.

The findings of this study increase our knowledge of the water demand of a number of important crops in Manisa, Turkey; thus, strategies based on these results will assist in enhancing the management of water and crop yield.

Using scientific technologies such as CROPWAT and CLIMWAT, it is possible to evaluate CWRs with a reasonable level of precision and recommend crop patterns and crop rotations that growers are willing to acknowledge. The outputs of this study can be utilized by water resource administrators for planning activities, so aiding in the conservation of water in achieving CWRs, and by producers for determining the quantity of irrigation for the products under consideration.

A thorough approach should be developed to determine the CWRs for all districts without such research. Such a plan might serve as the foundation for agricultural operations. Moreover, testing must be conducted to validate the use of these software programs.

**Acknowledgement**
We would like to thank the General Director of Central Union of Turkey's Irrigation Cooperatives A. Halis Uysal and the Managers of Beyoba Village Irrigation Cooperative for their patient help and for providing data for this study effort.

**5.References**

Allen, R.G., Pereira, L.S., Raes, D., Smith, M. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. FAO - Food and Agriculture Organization of the United Nations, Rome.
Aydin, F., Erlat, E. & Türkeş, M. (2020) Impact of climate variability on the surface of Lake Tuz (Turkey), 1985–2016. Regional Environmental Change 20, 68. https://doi.org/10.1007/s10113-020-01656-z.
Azevedo, P.V., de Souza, C.B., da Silva, B.B., da Silva, V.P. (2007) Water requirements of pineapple crop grown in a tropical environment, Brazil. Agricultural Water Management, 88, 201–208.
Bhattarai, D.P., Shakya, N.M. (2020). Crop Water Requirements and Irrigation Scheduling for Major Crops in Kankai Irrigation System in Eastern Nepal. GSJ: Volume 8, Issue 8, ISSN 2320-9186.
Bokke, A.S., Shoro K.E. (2020). Impact of effective rainfall on net irrigation water requirement: The case of Ethiopia. Water Science. Vol. 34, No. 1, 155–163 https://doi.org/10.1080/11104929.2020.1749780
Clarke, D., Smith, M., El-Askari, K. (2001). CropWat for Windows: User Guide, University of Southampton: Southampton, UK.
CROPWAT Software, FAO, Land and Water Division (2022). Available online:
http://www.fao.org/land-water/databases-and-software/cropwat/en/ (Accessed on 20 January 2022).
FAO (1992) CROPWAT, a computer program for irrigation planning and management by M. Smith.
FAO Irrigation and Drainage Paper No. 26. Rome.
Eco Farming Daily (2022). Soil Requirements for Growing Corn.
"https://www.ecofarmingdaily.com/grow-crops/grow-corn/soil-requirements/". Accessed on 11 May 2022.
Ewaid, S.H., Abed, S.A., Al-Ansari, N. (2019). Crop Water Requirements and Irrigation Schedules for Some Major Crops in Southern Iraq. Water, 11, 756, doi:10.3390/w11040756.
Göçmez, G., İşçioğlu, A. (2004). Konya Kapalı Havzası'nda Yeraltı Suyu Seviye Değişimleri (In Turkish). Yeraltı suyunun Kullanımı, Problemler ve Çözüm Yolları. 22–24 Aralık. Konya, Turkey, pp 9–18
Gunes, M.S., Yildiz, D., Yildiz, D. (2016). Agricultural Groundwater Management in Turkey. Technical Report. Hydropolitics Association.
NASA (2022). Expert Group- Growing Wheat. "https://gpm.nasa.gov/education/sites/default/files/lesson_plan_files/water-for-wheaties/AG_MS_GrowingWheat.pdf". Accessed on 11 May 2022.

Rajput, T. B. S., & Patel, N. (2006). Determination of the optimal date for sowing of wheat in canal irrigated areas using FAO CROPWAT model. *Water Technology Centre, IARI, New Delhi, India*.

Schwartz, F.W. & Zhang, H. (2003). Fundamentals of Groundwater. John Wiley & Sons

Siebert, S., Burke, J., Faures, J. M., Frenken, K., Hoogeveen, J., Döll, P., & Portmann, F. T. (2010). Groundwater use for irrigation–a global inventory. Hydrology and earth system sciences, 14(10), 1863-1880.

Smith, M. (1996). CROPWAT: A Computer Program for Irrigation Planning and Management. FAO Irrigation and Drainage Paper No: 46, Rome.

Smith, M., Kivumbi, D., Heng, L.K. (2002) Use of the FAO CROPWAT model in deficit irrigation studies. In Deficit Irrigation Practices, FAO: Rome, Italy.

Sommelier Choice Award (2022). Soil Types That Matter For Grape Growing. "https://sommelierschoiceawards.com/en/blog/insights-1/soil-types-that-matter-for-grape-growing-164.htm". Accessed on 11 May 2022.

Tigkas, D., Vangelis, H., Tsakiris, G. (2016). Introducing a modified Reconnaissance Drought Index (RDIe) incorporating effective precipitation. Procedia Engineering 162: 332 – 339.

TSU (2022). Grape Farming Calendar [Turkish], "https://www.turktob.org.tr/tr/bagcilik-tarim-takvimi/4999". Accessed on 10 May 2022.

USDA SCS (1970). Irrigation water requirements. United States Department of Agriculture, Soil Conservation Service, Tech. Rel. No. 21, 88p.

USDA IPAD (2022). Crop Calendars for Middle East (Iran, Iraq, Syria) and Turkey, "https://ipad.fas.usda.gov/rssiws/al/crop_calendar/metu.aspx". Accessed on 10 May 2022.

Valenzuela, H., Smith, J. (2002). Barley. Sustainable Agriculture Green Manure Crops, Aug. 2002, SA-GM-3.

Vu, S.H., Watanabe, H., Takagi, K. (2005). Application of FAO-56 for evaluating evapotranspiration in simulation of pollutant runoff from paddy rice field in Japan. Agricultural Water Management 76(3):195-210pp.

Yarami, N., Kamgar-Haghighi, A.A., Sepaskhah, A.R., Zand-Parsa, S. (2011). Determination of the potential evapotranspiration and crop coefficient for saffron using a water-balance lysimeter. Archives of Agronomy and Soil Science. Volume 57, https://doi.org/10.1080/03650340.2010.485985.

Wikifarmer (2022). Cotton Growing Conditions. "https://wikifarmer.com/cotton-growing-conditions/". Accessed on 10 May 2022.

Received: 21 May 2022

Accepted: 18 June 2022

HPA