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Research Article

Factors Affecting Per Capita Expenditure of Water and Sewerage Administrations in Türkiye

Türkiye'de Su ve Kanalizasyon İdarelerinin Kişi Başı Harcamalarını Etkileyen Faktörler

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Abstract

The per capita expenditure of water and sewerage administrations (WSAs) is an important indicator of their performance and characteristics. In this context, the effects of four parameters were investigated on the per capita expenditure of WSAs of thirty MMs in Türkiye. These parameters were determined as the service time, region, population size and budget of metropolitan municipalities (MMs). According to the results of the study, the WSAs with serving longer time and of high budget MMs had higher per capita expenditures than the others. Moreover, for the region parameter, it was determined that the per capita expenditure of the WSAs was the lowest in the Southeastern Anatolia Region while being the highest in the Marmara Region. A positive correlation was detected between the population size and per capita expenditures of WSAs. Moreover, it was assessed how much of the MMs budget was allocated to the budgets of WSAs for understanding differences among the regions. It was found that similar ratios, approximately 40% of the budgets of the MMs in the other regions except for those in the Black Sea and Central Anatolia Regions were allocated to the budgets of WSAs. On the other hand, a higher percentage of the budgets of Black Sea MMs was allocated to the budgets of the WSAs while allocating a lower percentage of the budgets of Central Anatolia MMs. According to the results, it was proposed that all WSAs should prepare master plans for at least 30 or 40 years to optimize their per capita expenditures and establish a balance between their capital and operating and maintenance costs.

Keywords: *budget allocation, capital cost, operating and maintenance cost, per capita expenditure, water and sewerage administration*

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Öz

Su ve kanalizasyon idarelerinin (SUKİ) kişi başına harcamaları, SUKİ'lerin performansları ve karakteristik özelliklerine dair önemli bir göstergedir. Bu çalışmada, hizmet süresi, bölge, nüfus ve büyükşehir belediyesi (BB) bütçesi olarak seçilen farklı parametrelerin Türkiye'deki otuz büyükşehir belediyesi SUKİ'lerinin kişi başı harcamaları üzerindeki etkileri incelenmiştir. Elde edilen sonuçlara göre hizmet süresi ve BB bütçesi daha yüksek olan SUKİ'lerin kişi başı harcamaları diğerlerine göre daha yüksektir. Ayrıca bölge bazında yapılan değerlendirmeye göre; Güneydoğu Anadolu Bölgesi'nin kişi başına düşen SUKİ harcamalarının en düşük, Marmara Bölgesi'nin ise en yüksek olduğu olduğu tespit edilmiştir. Nüfus ile kişi başına düşen SUKİ harcamaları arasında da pozitif korelasyon olduğu tespit edilmiştir. Aynı zamanda bölgesel farkları anlamak için BB bütçelerinden ne kadarının SUKİ bütçelerine tahsis edildiği değerlendirilmiştir. Karadeniz ve İç Anadolu bölgeleri hariç diğer tüm bölgelerin SUKİ'lere BB bütçesinden yaklaşık %40 gibi benzer oranlarda pay ayırdığı tespit edilmiştir. Karadeniz BB'leri SUKİ'lere en yüksek payda, İç Anadolu BB'leri ise SUKİ'lere en düşük payda bütçe ayırmaktadır. Çalışmada elde edilen sonuçlara göre, kişi başına harcamaları optimize etmek ve yatırım sermayesi ile işletme ve bakım maliyetleri arasında bir denge kurmak için SUKİ'lerin en az 30 veya 40 yıllk master planlar hazırlamaları önerilmiştir.

Anahtar sözcükler: *bütçe tahsisi, yatırım maliyeti, işletme ve bakım maliyeti, kişi başı harcama, su ve kanalizasyon idaresi*

Introduction

As a result of the pressure on infrastructural services caused by rapid urbanization and extreme weather events in the last century, water and sewage management has become outstandingly important. Water services are public services financed by local authorities under the control of the central government in most countries. In recent years, water services tend to get privatized with the practices such as public-private partnership (PPP) projects. Due to the involvement of private initiatives, many organizational structures in the water sector are developed recently depending on the specific conditions of the countries (Cinar, 2009). For instance, German Association for Water, Wastewater and Waste is defined as a politically and economically independent association, which promotes sustainable water management by conducting research and development (Association of Drinking Water from Reservoirs [ATT] et al., 2020). Water and sewerage works in the United States are handled by the Office of Water (OW), which is one of the headquarters offices of the United States Environmental Protection Agency. The OW is responsible to provide safe drinking water and restore and maintain oceans, watersheds, and their aquatic ecosystems to protect human health (The Office of Water [OW], 2022). In France, municipalities are legally responsible for water supply, wastewater and customer services. They are regulated by the state but autonomous to decide on two different possible management models based on the participation of the public sector. In the first model, municipalities choose to manage their water services and charge users directly. In the second model, municipalities own the facilities but sign PPP contracts with private companies that run water services (EurEau, 2020). Lee (2009) indicated that lack of funds, technological incapability and insufficient management skills have forced the water sector shift towards PPP model. As it is seen in Italy, there are different management systems for water services. About half of the population is served by the authorized public administration model, 36% by PPP, and 5% by state concessions. Water services are provided to the rest of the population by municipalities. In the United Kingdom, water services are regulated under special management models. Water companies have the right to carry out water management activities in their watersheds according to free market and trade rules. However, the compliance of these management activities with local, national and international legislation (Water Framework Directive, 2000) is monitored and audited by judicial institutions. Although water management in the Netherlands is organized at three levels such as national, state, and local; most powers are vested in local authorities (The Organisation for Economic Co-operation and Development [OECD], 2020).

According to Turkish Statistical Institute (TURKSTAT) projections, the population of Türkiye is forecasted to exceed 90 million in 2050 (Turkish Statistical Institute [TURKSTAT], 2013). The pressure on water resources will inevitably increase due to population increases and climate changes. Therefore, countries like Türkiye, which are not water-rich, should sustain water resources as well as water and sewerage services in the best way (Basa & Kurt, 2017). In the 1980s, the dramatically increasing population especially in her metropolitan provinces caused disruptions in water and wastewater services. Türkiye created and implemented a new service provision model for water in its metropolitan provinces in 1981 to overcome current problems. Water and sewerage administrations (WSAs) as independent budget institutions affiliated to metropolitan municipalities (MM) have been established in order to supply water, dispose wastewater and provide treatment services in their regions (Ozgun et al., 2018).

WSAs operate their activities by Law No. 2560 on the Establishment and Duties of the General Directorate of Istanbul Water and Sewerage Administration (The Law No: 2560, 1981). With a temporary article added to the aforementioned Law, the implementation of this Law was also ensured in WSAs to be established in other MM (Alıcı & Özaslan, 2018). In 2014, with Law No. 6360, the current district municipalities in the provinces of Aydın, Balıkesir, Denizli, Hatay, Malatya, Manisa, Kahramanmaraş, Mardin, Muğla, Ordu, Tekirdağ, Trabzon, Şanlıurfa, and also Van were transformed into MM. Moreover, the borders of the MM of Adana, Ankara, Antalya, Bursa, Diyarbakır, Eskişehir, Erzurum, Gaziantep, İzmir, Kayseri, Konya, Mersin, Sakarya and Samsun were determined as provincial administrative borders with the Law. Therefore, the number of WSAs in Türkiye significantly increased in

2014. The current number of total WSAs in Türkiye reached as thirty with the above mentioned Law (The Law No: 6360, 2012).

Generally, WSAs carry out their duties regarding water and sewerage services within the service areas of the MMs, and also their authorities on these issues are defined under the scope of the task of the related Law. For instance, 1) providing drinking, utility, and industrial water needs from all types of underground and surface water sources and distributing water to those in need; 2) carrying out studies and projects of all kinds of water facilities to transport water from the sources to the end users are some of the important basic duties of WSAs. Moreover, WSAs are also directly responsible for designing and building or causing to design and build facilities according to these projects, taking over and operating the established ones, and maintaining or having them repaired. One of their major responsibilities is carrying out studies and projects of all kinds of facilities to collect wastewater and stormwater. At last, another important duty of WSAs is preventing the pollution of water resources; sea, lake, river shores, and groundwater in the region from municipal and industrial effluents (The Law No: 2560, 1981).

Annual per capita expenditure allocated to water and wastewater management is an important indicator for both countries and provinces. The financial characteristics, geographical structure, climate conditions, and demographic structure of the countries and provinces affect the per capita expenditure allocated to water and wastewater management to different degrees. Moreover, per capita expenditures provide significant pieces of information about the characteristics of the WSAs. The effects of different factors on the per capita expenditures of WSAs in Türkiye have not been evaluated yet in any studies in the literature. In this study, factors affecting the per capita expenditures of thirty WSAs in Türkiye were investigated in detail. Accordingly, those were the service time of WSAs, region, size of population and budget of thirty MMs. In this study, the dynamics of per capita expenditures of WSAs were also discussed and the reasons for differences between them exist were investigated.

Method

Thirty Water and Sewerage Administrations

The WSAs in different regions of Türkiye are given in Table 1. Each WSA has been coded according to and shown by uppercase of the first letter of the name of the region, in which it is located.

Table 1

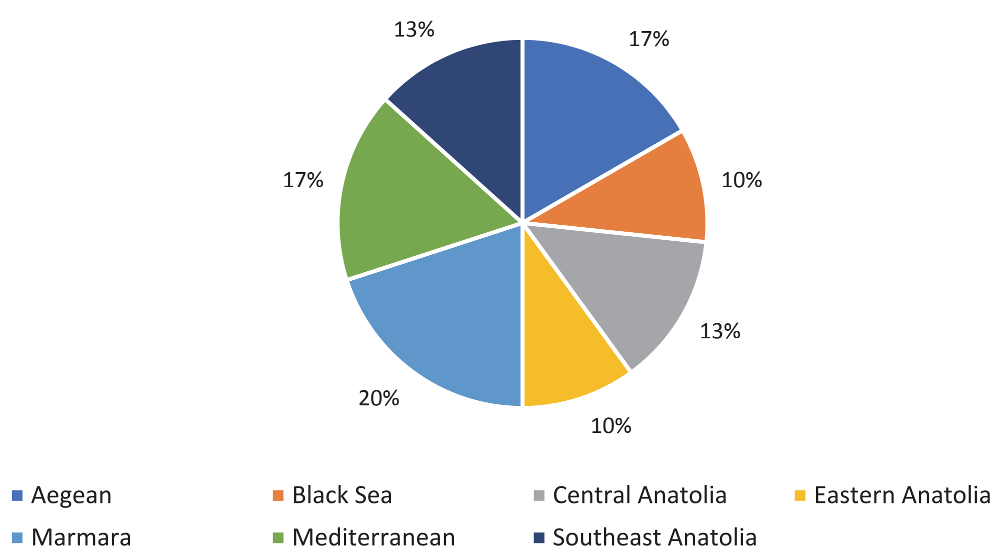
WSAs in Provinces in Different Regions

Regions	Aegean	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	Southeast Anatolia
	A_1	B_1	C_1	E_1	M_1	Me_1	S_1
	A_2	B_2	C_2	E_2	M_2	Me_2	S_2
	A_3	B_3	C_3	E_3	M_3	Me_3	S_3
	A_4		C_4		M_4	Me_4	S_4
	A_5				M_5	Me_5	
					M_6		

Moreover, it was calculated how much of the budgets of the MMs were allocated to the budgets of WSAs and average WSAs budgets based on regions, and compared the results. The distribution of the WSAs based on regions is demonstrated in Figure 1 by using a pie chart.

Figure 1

WSAs by Region



Per capita Expenditure Calculation

In this study, different parameters affecting the per capita expenditures of WSAs were taken into account. Accordingly, the total amount of annual expenditures of the WSA was divided by the total population of the province, served by the WSA, to calculate its per capita expenditures (Equation 1). The data used within the study belongs to the 2019 year of TURKSTAT. The total amount of annual expenditure of the WSA includes its capital, operational and maintenance costs of its investments and all other expenditures based on the duties of WSAs.

$$A = \frac{C}{N} \qquad \text{(Equation 1)}$$

where:
A: per capita expenditure of WSA (₺)
C: annual expenditure of WSA (₺)
N: population served by WSA (person)

Investigation of the impact of different elements was carried out by identifying four major factors such as service time of WSAs, region of WSAs, population served by WSAs, and budget of MMs, to which WSAs are affiliated.

Results and Discussion

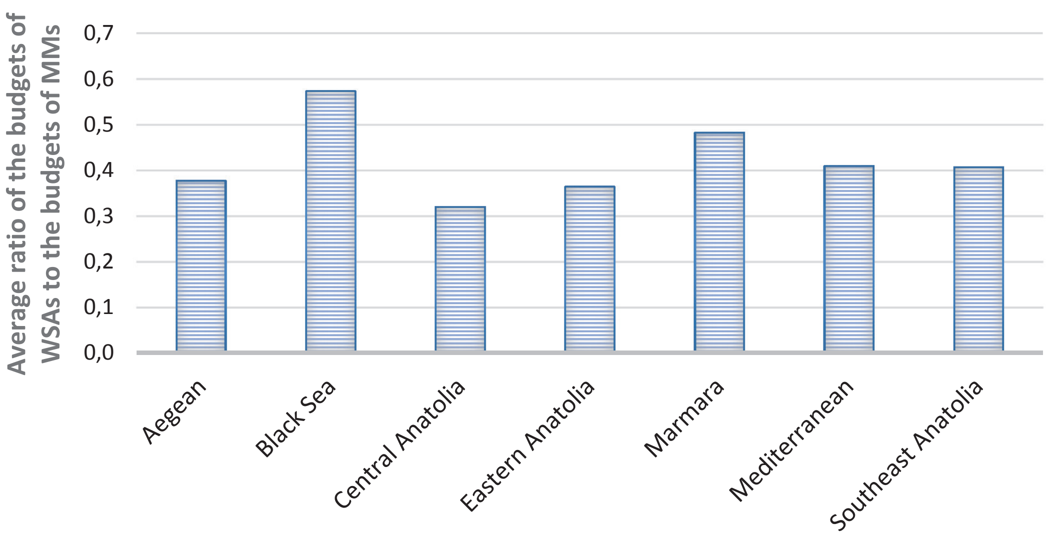
Assessment of the Budgets of WSAs Based on Their Regions

The average ratios of the budgets of WSAs to the metropolitan municipal budgets on a regional basis are given in Figure 2. According to the evaluation, the region with the highest average ratio of the budgets of WSAs to the budgets of MMs was the Black Sea Region. In the Black Sea Region, 57% of the total MMs budget was allocated to the budgets of WSAs. This might be either explained by its geographical conditions that have led to increasing infrastructure costs for transporting water and wastewater and also investment costs for preventing natural disasters such as flooding caused by heavy rain events. Bene et al. (2010) indicated that the cost of the electrical energy of pumping water is the major portion of the total operating cost of waterworks. The amount of energy for pumping water significantly increases when the land areas are rugged or/and the slope of land is steep (Adamiak & Spychalski, 2021). Therefore, the rugged land of the Black Sea Region is one of the most important factors that increase the overall expenditure of WSAs. The Black Sea Region receives the highest average annual precipitation in Türkiye varying from 1250 to 2500 mm/year. Considering the average annual precipitation of Türkiye, which is 574 mm/year, the microclimatic conditions of the Black Sea Region are more evident. On the other hand, the Central Anatolia Region receives the least precipitation in Türkiye with an average annual precipitation of 250 to 300 mm (State Hydraulic Works [DSI], 2022). Therefore, Central Anatolia was the region with the lowest average ratio of the budgets of WSAs to the budgets of MMs. In the Central Anatolia Region, 32% of the total budget of the MMs was allocated to the budgets of WSAs. There is no rugged land and extreme climate condition in Central Anatolia compared to the Black Sea Region. Moreover, Central Anatolia is a region where a high risk of drought exists (Bacanli et al., 2010). Thus, WSAs in the Central Anatolia Region might not need great investments contrary to those in the Black Sea Region. However, it would be important for WSAs in the Central Anatolian Region to make investments in line with the necessary precautions against the risk of drought.

The budget of M_4 in the Marmara Region was 88% budget of its MM due to either the geotechnical properties of the city or the costs caused by the water supply and wastewater disposal of the city. The Marmara Region was detected as the second highest average annual rate of the budgets of WSAs to the metropolitan municipal budgets. However, excluding the M_4 Province, the average ratio of the budgets of WSAs to the budgets of MMs in the Marmara Region was found close to both of those in the Mediterranean and Aegean Regions. As a result of evaluating the budgets of WSAs and MMs together, except for those in the Black Sea and Central Anatolia Regions, and also M_4, the percentage of the budgets of all other regions MMs allocated to the budgets of WSAs were similar (~40%). These results were higher than expectations due to the expenditures of WSAs in Türkiye which are mainly composed of capital costs. The initial capital costs are usually high, which is why the expenditures of WSAs constitute a high percentage of the total metropolitan municipal budget. Contrarily, WSAs expenditures in developed countries include mainly operational and maintenance costs and thus reasonable percentages of their metropolitan municipal budgets are allocated to the budgets of WSAs. It can be expected that this ratio of 40% might be decreased in Türkiye over the coming years.

Figure 2

The Average Ratios of the Budgets of WSAs to the MM Budgets on a Regional Basis



Assessment of Factors Affecting Per Capita Expenditures of WSAs

The average annual expenditures per capita of WSAs by providing services for different period of times are shown in Table 2. According to the results, the average expenditure per capita of WSAs by providing services for a short period of time (0-10 years) was determined as 357.72±132.93 ₺, while WSAs by providing services for a moderate period of time (10-30 years) have per capita expenditure of 415.15±115.83 ₺ on average. In the last category, WSAs with services for a long period of time (>30 years) have spent 472.96±107.27 ₺ per capita on average. According to the results, it was said that per capita expenditures have been increased slightly as the WSAs services for a period of time increases. It is expected that WSA services for a period of time and development level of MM are directly proportional. For instance, WSAs of three major MMs in Türkiye were established a long time ago than the others. The MMs of the three most populous and wealthy provinces have WSAs that have been serving for many years and already completed primary water and wastewater works in the past years. It is obvious that WSAs, that have been serving for many years, should direct their investments to improve their performance by constructing large and mega infrastructures such as advanced biological wastewater treatment plants (WWTPs) or separate sewer systems. Accordingly, WSAs, that have been serving for a short time, should direct their investments to solve urgent waterworks and relatively small infrastructure. In other words, WSAs serving for a long period of time or the

MMs of the three most populous and wealthy provinces have spent more money per capita on water and sewerage works in their provinces.

Table 2

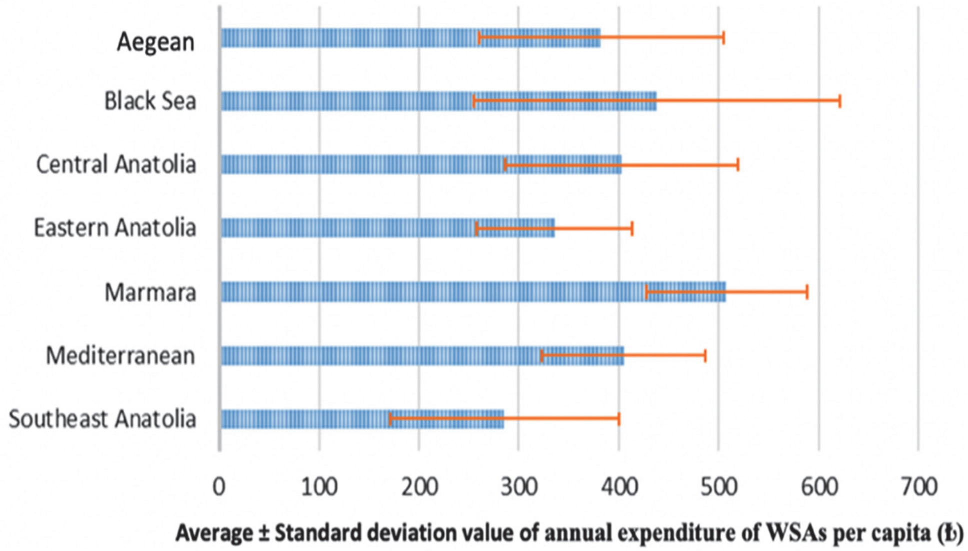
Average Annual Expenditures Per Capita of WSAs by Serving for a Period of Time

Serving time (years)	Average ± Standard deviation value (₺)
0-10	357.72±132.93
10-30	415.15±115.83
>30	472.96±107.27

Average annual expenditures per capita of WSAs on the regions in Türkiye are illustrated in Figure 3. The Marmara Region has the highest per capita expenditure with 507.85±80.05 ₺. Considering the ongoing various wastewater collection, stormwater collection, transmission line projects, and advanced biological WWTP constructions in the Marmara Region, the high per capita expenditure is reasonable. Moreover, land acquisition costs in the Marmara Region are higher than those in other regions. Environmental problems such as eutrophication or mucilage blooms may be caused by the high nutrient introduction to the receiving water bodies attributed to the poor performance of WWTPs. Especially, the coasts of Marmara Sea faced massive mucilage problems in 2021. To prevent such environmental problems in the future, Ozturk and Seker (2021) suggested some measures for WSAs in the Marmara Region. One of the measures was to increase the number of advanced biological WWTPs in the region. Therefore, per capita expenditures of WSAs in the Marmara Region might increase in the future because of the forthcoming possible investments for building advanced WWTPs. The lowest per capita expenditure with 285.50±114.85 ₺ was found for WSAs in Southeast Anatolia. This result is reasonable since the financial development level of Southeast Anatolia is relatively lower than the rest of the regions in Türkiye (Unsal & Sulku, 2020). The results for other regions were similar in terms of the average annual expenditure of WSAs per capita.

Figure 3

Annual Expenditure of WSAs Per Capita on Regions



The average annual expenditure per capita of WSAs on population size was evaluated in three categories: 1) between 0-2 million people, 2) between 2-4 million people and 3) >4 million people. According to Table 3, the average annual per capita expenditures of WSAs for the population size between 0 and 2 million was 375.14±128.60 ₺. For the population size of more than 4 million it was determined as 572.35±7.05 ₺. Therefore, per capita expenditures of WSAs increase in line with the increases in population size. Contrarily, their per capita expenditure is expected to decrease when they serve a great population. For instance, Tuna and Kınacı (1999) calculated per capita wastewater collection system construction costs depending on the population size and showed that the per capita costs have been decreased by the population growth. The opposite situation observed in WSAs showed that the expenditures of WSAs in Türkiye were still about capital investment costs such as constructing WWTPs. In addition, high energy prices and large population in major metropolitan areas cause an increase in per capita expenditures of local governments. Three major MMs of Türkiye have a population of more than 4 million people. Due to wider range of job opportunities in developed provinces, their population is so high. Therefore, the per capita expenditure of WSAs in the least populated cities is reasonable by considering major WSAs located in the most crowded cities. These WSAs should provide more extensive water and sewerage works.

Table 3

Average Annual Expenditure Per Capita of WSAs on Population Size

Population (million people)	Average ± Standard deviation value (₺)
0-2	375.14±128.60
2-4	410.04±102.48
>4	572.35±7.05

Table 4 shows the average annual expenditure per capita of WSAs by the metropolitan municipal budgets. The volume of metropolitan municipal budgets were studied at three intervals; between 0 and 2, between 2 and 4, and higher than 6 billion TRY. Average per capita expenditure was determined as 361.29±127.34 ₺ for MMs, that have annual budget between 0 and 2 billion TRY. On the other hand, it was determined as 572.35±7.05 ₺ for the MMs, that have annual budget more than 4 billion TRY. The results show that expenditures per capita of WSAs increase as the budget of MM increases. In general, the volume of metropolitan municipal budgets is proportional to the economic development of the provinces. It is also expected that the volume of the budgets of MMs is related directly with the average income per capita by provinces. WSAs in provinces that per capita income is higher than the others, might have huge budgets due to the big volume of metropolitan municipal budgets. Therefore, the number of investments and projects conducted by WSAs will increase. Consequently, WSAs of big volume budgets of MMs have higher per capita expenditures than the others having small budgets.

Table 4

Average Annual Expenditure Per Capita of WSAs by Metropolitan Municipal Budgets

Annual budget (billion TRY) of MMs	Average ± Standard deviation value (₺)
0-2	361.29±127.34
2-4	457.65±68.12
>4	572.35±7.05

Even if there are factors affecting the per capita expenditures of WSAs, in some cases it cannot be explained by these factors. The investment and inspection mechanisms for WSAs should be rearranged and their activities should be regulated by the auditing organizations. There are many examples of auditing authorities around the world such as Water Administrations Association-VEWIN in the Netherlands and Water Environment Research Foundation-WERF in USA. This organizational structure is also beneficial in order to optimize per capita expenditures, develop fast and low-cost solutions, carry out joint Research & Development studies and sharing knowledge and experiences. It is also recommended to establish a WSAs Union to solve their common problems. By the time a WSAs Union will be established in Türkiye, a unit might be established in the Union of Municipalities of Türkiye (Sarıkaya et al., 2019) to facilitate administrative operations, improve their investments and optimize their per capita expenditures.

The WSAs need to prepare a master plan for drinking water, wastewater, and stormwater works in line with their strategic goals and obligations in order to perform their duties more effectively. A well-prepared master plan would be a roadmap for the administrations for the next ~30-40 years. Due to the importance of master plans in water and wastewater management, in some countries, the preparation of master plans is either required or handbooks are prepared at the national level for the aim of support the WSAs. For example, in Bulgaria it is obligatory for Regional Water and Sanitation Associations to prepare a master plan for their region, and in Romania the national handbook provides the principles and procedures for preparing a master plan (Sarıkaya et al., 2022). As it is seen from national and international experiences, the WSAs get many benefits from a well-prepared master plan so the costs of preparing a master plan might be ignored. Preparing master plans by the WSAs should be obligatory as it is practiced in some countries. In addition, considering the investment, operational and maintenance costs to be calculated within the scope of the master plan, the policies for pricing their water and wastewater services will be determined in light of the master plan. There is no guide for the preparation of master plans on drinking water, wastewater, and stormwater management in Türkiye. In this regard, it is recommended to prepare a guide for the administrations to develop their organizational capacity. Moreover, preparing a master plan and transitioning to energy efficiency based on smart water management technologies may contribute to establishing a balance between per capita expenditures and enhancing the performance of WSAs (Sarıkaya et al., 2022).

Conclusions

The performance and characteristics of WSAs are significantly influenced by their per capita expenditures. This study investigated how various factors affect the per capita expenditure of WSAs. The results showed that per capita expenditures are considerably high in WSAs that have been serving for many years and were of large volume budgets of MMs. According to the region-based evaluation, it was found that WSAs in the Marmara Region had the highest per capita expenditures with an annual average of 507.85±80.05 ₺. On the other hand, per capita expenditures of WSAs located in the Eastern Anatolia Region were determined as the lowest value with an annual average of 285.50±114.85 ₺. Moreover, the population serving by WSA and per capita expenditures of WSAs are positively correlated. When ratios of the budgets of WSAs to the budgets of MMs were investigated, it was found that MMs in the Black Sea Region allocate the highest percentage of their budgets to the budgets of WSAs in the region. On the other hand, MMs in Central Anatolia allocate the lowest percentage of their budgets to the budgets of WSAs in the region. According to the results, it was proposed that the investment and inspection mechanisms of WSAs should be separated and their activities should be controlled by auditing authorities to optimize their expenditures per capita and establish a balance between their services and expenditures. It was also recommended to prepare a master plan which could be a roadmap for the administrations based on 30-40 year periods, so that both per capita WSAs expenditures and the budgets allocated by MMs to WSAs may not significantly differentiate over the years and induce high differences based on the region. In different examples across the world, the benefits of the master plans to the administrations are more than the costs of the resources allocated for the preparation of a master plan. Therefore, it was suggested that the preparation of a master plan should be an obligation for WSAs.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Türkiye'de Su ve Kanalizasyon İdarelerinin Kişi Başı Harcamalarını Etkileyen Faktörler

Artan nüfusun ihtiyacı olan su ve atıksu gibi altyapısal hizmetler, çevre ve insan sağlığı da gözetilerek 2560 sayılı kanunda düzenlendiği şekliyle büyükşehir belediyeleri bünyesinde kurulan su ve kanalizasyon idareleri (SUKİ) tarafından yürütülmektedir. SUKİ yatırım ve hizmetlerinden kaynaklı harcamaların sunulan hizmetin niteliğinden ve öneminden dolayı araştırılması gerekli alanlardan biridir. Yatırım ve hizmetlerinden kaynaklı harcamalarının hizmet ettikleri bölge nüfuslarına oranı SUKI'lerin kişi başı harcamaları olarak tanımlanmaktadır. Kişi başı harcamaları SUKİ'lerin etkinliğini ortaya koyan önemli bir performans göstergesidir. Kurumsal, demografik, iklimsel ve coğrafyaya bağlı koşullar kişi başı harcamaları etkileyen çeşitli faktörler arasında bulunmaktadır. Bu faktörlerin kişi başı harcamalara ayrı ayrı etkileri olduğu ve her bir SUKİ için farklı değerler aldığı gözlenmektedir. Bu doğrultuda; çalışmada seçilen farklı parametrelerin SUKİ'lerin kişi başı harcamalarına olan etkileri incelenmiş ve tartışılmıştır. Bu parametreler SUKİ hizmet süresi, SUKİ'nin hizmet ettiği bölge ve nüfus ile SUKİ'nin bağlı olduğu büyükşehir belediyesi (BB) bütçesi olarak seçilmiştir. Çalışma kapsamında Türkiye'de faaliyetlerine devam etmekte olan otuz SUKİ incelenmiş ve farklı parametreler bazında kişi başı harcamaları değerlendirmeye tabi tutulmuştur. SUKİ'ler %20 ile en fazla Marmara Bölgesi'nde mevcutken, %10 ile en az Doğu Anadolu Bölgesi'ndedir. Kişi başı harcama, SUKİ'nin yıllık toplam harcaması SUKİ'nin hizmet ettiği nüfusa bölünerek Türk Lirası (₺) cinsinden hesaplanmıştır. Bununla birlikte; SUKİ'lerin bölgeler bazında finansal özelliklerinin anlaşılabilmesi amacıyla SUKİ bütçelerinin BB bütçelerine oranları yüzdesel ve bölgesel olarak hesaplanmıştır. Buna göre; Karadeniz Bölgesi'nde bulunan BB'lerin toplam bütçesinin %57'si bölgede bulunan SUKİ'lere ayrılmıştır. Diğer yandan, İç Anadolu Bölgesi'nde bulunan BB'lerin toplam bütçesinin %32'si bölgede bulunan SUKİ'lere ayrılmıştır. Özellikle Karadeniz bölgesinin coğrafi özellikleri ve iklimsel yapısı nedeniyle SUKİ yatırımlarının BB bütçesinde önemli bir yer tuttuğu tahmin edilmektedir. Örneğin; Karadeniz Bölgesi yıllık ortalama 1250 ila 2500 mm yağış almaktadır. Son yıllarda iklim değişikliğinin bir sonucu olarak meydana gelen aşırı yağış kaynaklı sel ve taşkınlar da bölgenin altyapısı üzerindeki baskıyı arttırmaktadır. Sonuç olarak bölgede bulunan SUKİ'lerin altyapıya yönelik yatırımlarının gelecekte de artması beklenmektedir. İç Anadolu Bölgesi'nde gerek coğrafi şartlar gerekse iklimsellik Karadeniz Bölgesi'nde olduğu gibi zorlayıcı ve yüksek yatırım gerektirecek özellikte değildir. Dolayısıyla BB'ler tarafından SUKİ'lere ayrılan bütçe yüzdesel olarak Karadeniz ve diğer bölgelere göre daha düşüktür. Marmara Bölgesi'nde ise çalışma kapsamında M_4 olarak kodlandırılan büyükşehire bağlı SUKİ bütçesinin toplam BB bütçesine oranı %88 gibi çok yüksek bir değer olarak hesaplanmıştır. Bu SUKİ'ye ait veri değerlendirilmeye alınmadığı takdirde; Maramara Bölgesi, Ege Bölgesi, Akdeniz Bölgesi, Doğu Anadolu Bölgesi ve Güneydoğu Anadolu Bölgesi için bölgelerde bulunan SUKİ'lerin bağlı oldukları BB bütçelerine oranlarının %40 civarında olduğu görülmüştür.

Kişi başı harcamalara SUKİ hizmet sürelerinin etkilerinin de incelendiği çalışmada, SUKİ'ler düşük (0-10 yıl), orta (10-30 yıl) ve uzun (30 yıldan daha fazla) hizmet süreli olmak üzere üç grupta sınıflandırılmıştır. Hizmet süresi düşük SUKİ'lerin (0-10 yıl) yıllık kişi başına ortalama 357.72±132.93 ₺, orta hizmet süreli SUKİ'lerin (0-30 yıl) yıllık kişi başına ortalama 415.15±115.83 ₺ ve son kategori olan uzun hizmet süreli SUKİ'lerin (>30 yıl) ise yılık kişi başına ortalama 472.96±107.27 ₺ harcadığı tespit edilmiştir. Dolayısıyla hizmet süresi arttıkça SUKİ'lerin kişi başı harcamalarının arttığı sonucuna varılmıştır. Bunun en önemli sebeplerinden biri; uzun hizmet süreli SUKİ'lerin düşük maliyetli birincil yatırımlarını tamamlamış olmaları ve örneğin ileri biyolojik atıksu arıtma tesisleri ya da ayrık toplama sistemleri gibi daha büyük bütçeli yatırımlar yapıyor olmalarıdır. Kişi başı harcamalara bölge etkisi ise Türkiye'de bulunan yedi farklı coğrafi bölge üzerinden incelenmiştir. Sonuçlara göre; Marmara

Bölgesi'nde bulunan SUKİ'lerin kişi başı harcamaları yıllık ortalama 507.85±80.05 ₺ ile en yüksek olarak tespit edilmiştir. Bununla birlikte; Güneydoğu Anadolu Bölgesi'nde bulunan SUKİ'lerin kişi başı harcamaları yıllık ortalama 285.50±114.85 ₺ ile en az yatırım yapan idareler olarak tespit edilmiştir. Bu farklılığın en önemli nedenlerinden birinin bölgeler arasındaki ekonomik gelişmişlik farkı olduğu öne sürülmüştür. Nüfus etkisini incelemek için SUKİ'ler hizmet verdikleri nüfusa göre üç farklı kategoride değerlendirilmiştir. Buna göre; hizmet verdiği nüfus 0-2 milyon kişi arasında olan SUKİ'ler kişi başı 375.14±128.60 ₺, 2-4 milyon kişi arasında olan SUKİ'ler kişi başı 410.04±102.48 ₺, 4 milyon kişiden daha fazla olan SUKİ'ler kişi başı 572.35±7.05 ₺ harcamaktadır. Dolayısıyla daha fazla nüfusa hizmet veren SUKİ'lerin kişi başı harcamalarının daha yüksek olduğu sonucuna varılmıştır. Son olarak BB bütçesinin etkileri incelenmiş ve daha yüksek bütçeli BB'lere bağlı SUKİ'lerin kişi başı harcamalarının da daha yüksek olduğu sonucuna varılmıştır. BB bütçesi ve SUKİ kişi başı harcaması arasındaki pozitif korelasyonun ana nedenlerinden birinin ekonomik gelişmişlik seviyesinden kaynaklı hayata geçirilen yüksek yatırımlar olduğu sonucuna varılmıştır.

Çalışma kapsamında elde edilen sonuçlara göre, kişi başı harcamaların optimize edilmesi ve harcamalar arasında bir dengenin kurulması için SUKİ'lerin yatırım ve kontrol mekanizmasının ayrıştırılması ve faaliyetlerinin oluşturulacak merkezi bir yönetim altında kontrol edilmesi önerilmiştir. Kişi başı SUKİ harcamalarının ve BB'lerin SUKİ'lere ayırdığı bütçelerin yıllar içerisinde aşırı artışlar göstererek bölge bazında yüksek farklılıklar yaratmaması amacıyla 30-40 yıllık dönemler için idareye yol gösterecek master planlar hazırlanması tavsiye edilmiştir. Dünyadaki farklı örneklerden de görüleceği üzere master plan çalışmasının idareye kattığı faydalar, master plan hazırlama maliyetinden daha fazladır. Dolayısıyla SUKİ'lerin master plan hazırlamasının zorunlu olması sonucuna varılmıştır.

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Research Article

Detection of Biofilm Layer in Water Plumbing and Determination of its Effect on Water Quality

Sıhhi Tesisatlarda Biyofilm Tabakası Tespiti ve Su Kalitesine Etkisinin Belirlenmesi

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Abstract

In this study, biofilm formation on the plumbing, the presence of pathogenic microorganisms in biofilms and their effects on water quality were examined by membrane filtration with dehydrated medium method in 22 different buildings in a facility's water network. A relation with biofilm formation and water quality deterioration with the age of the plumbing and the pipe material was also studied. The results were expressed as colony forming units (CFU). According to the results of the galvanized metal pipes, the average colony count was determined as >200 CFU/250 mL, average pathogen count was calculated as 107 CFU/250 mL and the highest deterioration in the water quality were observed. For the Polyethylene (PE) pipes, the average colony count was found as >200 CFU/250 mL and the average pathogen count was found as 145 CFU/250 mL. No physical and chemical changes in water quality were observed. For the Polypropylene Random Copolymer (PPRC) pipes, neither physical/chemical change in water quality nor pathogenic growth were observed. The total colony count was found as 34 CFU/250 mL. Biofilm formation was detected at 15 points in the network. *Pseudomonas aeruginosa* was the most common detected pathogens in plumbing as 12 points from 22 buildings. The highest colony formation was *Escherichia coli*, which was detected in four of 22 plumbing as 600 CFU/250 mL colonies. It has been observed that more accumulations occurred in galvanized metal pipe surfaces, and microbiological growth was higher than PE and PPRC pipes.

Keywords: *plumbing, water quality, biofilm, pathogen microorganisms*

Öz

Çalışmamızda, bir işletmeye ait içme suyu şebekesine bağlı 22 binanın sıhhi tesisatlarında biyofilm oluşumu ve biyofilm içindeki patojenlerin varlıkları membran filtrasyon ve hazır kurutulmuş besiyeri yöntemiyle incelenmiş, su kalitesine etkileri tespit edilmiştir. Biyofilm oluşumu ve su kalitesindeki bozulma ile sıhhi tesisat yaşı ve boru malzemesi arasındaki ilişki de ayrıca incelenmiştir. Sonuçlar koloni oluşturan birim (CFU) olarak ifade edilmiştir. Yapılan analiz sonuçlarına göre galvaniz metal

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tesisatlarda ortalama koloni sayısı >200 CFU/250 mL, ortalama patojen sayısı 107 CFU/250 mL olarak tespit edilmiştir ve su kalitesindeki en yoğun bozulma görülmüştür. Polietilen (PE) tesisatlarda ortalama koloni sayısı >200 CFU/250 mL, ortalama patojen sayısı 145 CFU/250 mL olarak ölçülmüştür. Fiziksel ve kimyasal açıdan su kalitesinde değişim görülmemiştir. Polipropilen Rastgele Kopolimer (PPRC) tesisatlarda su kalitesinde değişim görülmemiş, ortalama koloni sayısı 34 CFU/250 mL olup patojen çoğalması gözlemlenmemiştir. Tesisatlarda 15 noktada biyofilm oluşumu tespit edilmiştir. En çok tespit edilen patojen tür 22 noktanın 12'sinde görülen *Pseudomonas aeruginosa* olmuştur. En fazla koloni oluşumu ise 22 noktanın 4'ünde tespit edilen ve toplamda 600 CFU/250 mL'nin üzerinde koloni sayımı yapılan *Escherichia coli* olmuştur. Galvaniz metal tesisatlarda daha fazla birikim oluştuğu, bu yüzeyler üzerinde mikrobiyolojik çoğalmanın PE ve PPRC'ye göre daha fazla olduğu görülmüştür.

Anahtar sözcükler: *sıhhi tesisat, su kalitesi, biyofilm, patojen mikroorganizmalar*

Introduction

Access to safe drinking water is a fundamental human right and a vital component of an effective health protection policy. Some physical, chemical and microbiological water parameters can affect the aesthetic parameters of water (such as appearance, odor, taste etc.) and the quality and acceptability of the water for the consumer (World Health Organization [WHO], 2017). In order to provide high quality water that complies with international standards and regulations, it is necessary to have an integrated water production and distribution process. This process starts from the water source, continues with the transmission lines, drinking water treatment plants, water distribution structures and finally ends with the plumbing of the end users. The most important step of this process in terms of having a direct effect on the end user is the indoor water plumbing and the water tanks.

The quality of the tap water may deteriorate due to inappropriate plumbing installations, wrong material selection, reverse and cross connections in plumbing, unmaintained and uncleaned domestic water tanks. In such cases the color, odor and taste of the water may change, the concentrations of heavy metals (depending on the pipe material like iron, manganese, copper, zinc, lead etc.) may increase and pathogenic microorganisms may be encountered in the water (WHO, 2017; Gray, 2008). Microorganisms can always be found in drinking water systems no matter how strict precautions and treatment processes are applied in the production and distribution stages of water. Both chemical and biological quality changes can occur in drinking water supplied to the network (Boe-Hansen, 2001). Factors such as the amount of organic nutrients in the water, initial bacterial concentration, water age in the network, hydraulic effects, pipe and connection materials, pipe corrosion, sediment accumulation on the pipes affect the bacterial growth in pipelines (Acehan, 2007). High alkalinity values promote the accumulation on the pipes and suitable environment for bacterial growth (Küçükgül et al., 2004). Most of the naturally occurring microorganisms in the water network do not pose a risk to human health (Skjevrak et al., 2004). However, when the microorganisms multiply in the water and start to form colonies, they can cause some consumer complaints such as taste, odor or appearance problems (Türetgen, 2005). These bacterial colonies are called as biofilms that adhere to a living or inanimate surface and spread in a gel-like layer of polymeric structure that they produce (Costerton et al., 1995). The biofilm formed in drinking water systems is mainly composed of bacteria and exopolymeric substances (EPS) secreted by bacteria. EPS ensures the coexistence of bacteria and acts as a barrier that protects microorganisms against environmental stresses and external factors (Freeman & Lock, 1995). Especially, water networks and tanks that are not cleaned and disinfected become a suitable environment for bacteria to form a biofilm (LeChevallier et al., 1988). Microorganisms are constantly multiplying in a biofilm layer. Microorganisms can detach from the biofilm by the flow rate and mix with the water. Those colonies are immediately replaced in the biofilms. Depending on the flow rate of the water, a single cell can break away from the biofilm layer, as well as a cell cluster with a diameter of 500 µm (Telgmann et al., 2004). Some pathogenic microorganisms can also develop and multiply in biofilms (Liu et al., 2016; Zhang et al., 2009; Boe-Hansen, 2001). With the detachment from the biofilm, the microorganisms can pass into the aquatic environment and finally into the human body. As a result, pathogens in the biofilms cause a potential health risk for the consumers and needs to be carefully examined in terms of drinking water quality and human health.

Many studies and researches have been carried out on the microorganisms in the biofilm layers formed in domestic and industrial water systems with different water sources and pipeline materials. The materials used in the water distribution systems and plumbing affect the biofilm formation. Biofilm can form in all types of materials, but each pipe material creates different conditions for microorganisms to attach, form biofilm and multiply. Pietrzyk et al. (2017) found that galvanized steel is particularly susceptible to the adhesion of microorganisms. Niquette et al. (2000) stated that iron pipes support microbiological growth 10 to 45 times more than plastic pipes. Camper (2003) also stated that in the presence of high organic matter, there is much more bacterial growth in cast iron pipes than in other pipe materials. In the study conducted by Türetgen (2005), it was observed that a high rate of biofilm formation was observed on galvanized steel and copper surfaces, while less bacteria and EPS were found in plastic pipes. According to Keskin and Kahveci (2019), a thin biofilm layer was formed on the inner surface of polyethylene pipes under the same conditions, while a very thick biofilm layer was formed in iron pipes. The studies on the biofilms in water networks are generally lab-scale pilot systems, which are modeled in laboratory conditions. Analysis of existing biofilms and microorganisms in actively operated water networks is also necessary in terms of detecting and minimizing current risks for consumers. There is no universal directive or guide on when and how often samples should be taken from plumbing for microbiological monitoring. However, monthly, 3-month, 6-month and annual samples can be taken for *Pseudomonas aeruginosa* monitoring (Hong et al., 2017). Since each region has different water qualities, environmental conditions, characteristics, water treatment, distribution and plumbing systems, the biofilm formations and pathogen microorganism compositions should be analyzed and investigated separately.

There are several ways to detect bacterial growth in a sample. However, membrane filtration is one of the most effective methods that can be used in the analysis of samples with volumes such as 100 mL - 250 mL, especially in the analysis of samples containing very few microorganisms in potable water. Since the entire sample is filtered, all microorganisms in it can be easily counted without the need for any estimation or escalation. (Akpınar et.al., 2019; Sartorius, 2014).

In order to detect the biofilm layer formation in water plumbing and determine its effect on water quality according to the pipe material types and plumbing ages, this paper examines bacterial colony count on pipe surfaces in an operating water network via membrane filtration method. To achieve this, a separate water network is used rather than the main water supply network of Ankara but both networks supply water from the same water source. It is aimed that the outcomes of our study can give an idea for the buildings using similar water plumbing throughout the Ankara Province. In this study, the effects of plumbing age, galvanized metal, polyethylene (PE) and polypropylene random copolymer (PPRC) pipe types used in plumbing on biofilm formation, presence of pathogenic microorganisms and also the quality of water are examined individually. To observe biofilm formation and the presence of pathogens, the indicator microorganisms are determined. In the plumbing; total colony, total coliform, *Pseudomonas aeruginosa*, *Salmonella* spp., *Staphylococcus aureus, Enterococci* and *Escherichia coli (E. coli)* species are studied together with physical and chemical analysis of water. The aim of this study are to (1) detect the biofilm formation and pathogenic microorganisms in biofilms, to (2) observe the highest colony formation on the pipe surfaces and to (3) record the highest deterioration in the water quality according to the pipe materials and plumbing ages in the selected drinking water network in Ankara Province.

Materials and Methods

Study Area and Sampling

The selected water network belongs to a facility in Ankara Province. The facility has totally 70 buildings inside and serves nearly 20.000 people. It has its own water treatment plant, wastewater treatment plant and water distribution network apart from the Ankara Province. This network was selected as a model for Ankara Province's similar settlements. The facility gets raw water directly from the Çamlıdere Dam. The treatment plant of the facility has the five units: Coagulation, flocculation, sedimentation, filtration, and disinfection as the other conventional treatment systems. Galvanized metal, PE and PPRC pipes are used in the water distribution network and plumbing systems in the buildings. PE pipes are used in raw water and some main lines, and also at the outlet of the treatment plant. Treated water from the wastewater treatment plant is used as irrigation water in the facility.

In the study, 22 buildings of different ages and pipe materials out of 70 buildings in the network have been analyzed. Samples were collected from the raw water at inlet of the treatment plant, the effluent treated water at the outlet of the water treatment plant and from 20 different plumbing in the water network. The sampling points were selected according to pipe types, plumbing ages, and locations.

The plumbing system in a building in the network is shown in Figure 1.

The distribution of the 22 buildings and layout of the network are represented in Figure 2.

Plumbing systems were evaluated in three categories: 1) Sampling points, 2) pipe types and 3) age category, given in Table 1.

Figure 1

Indoor Plumbing System of a Building

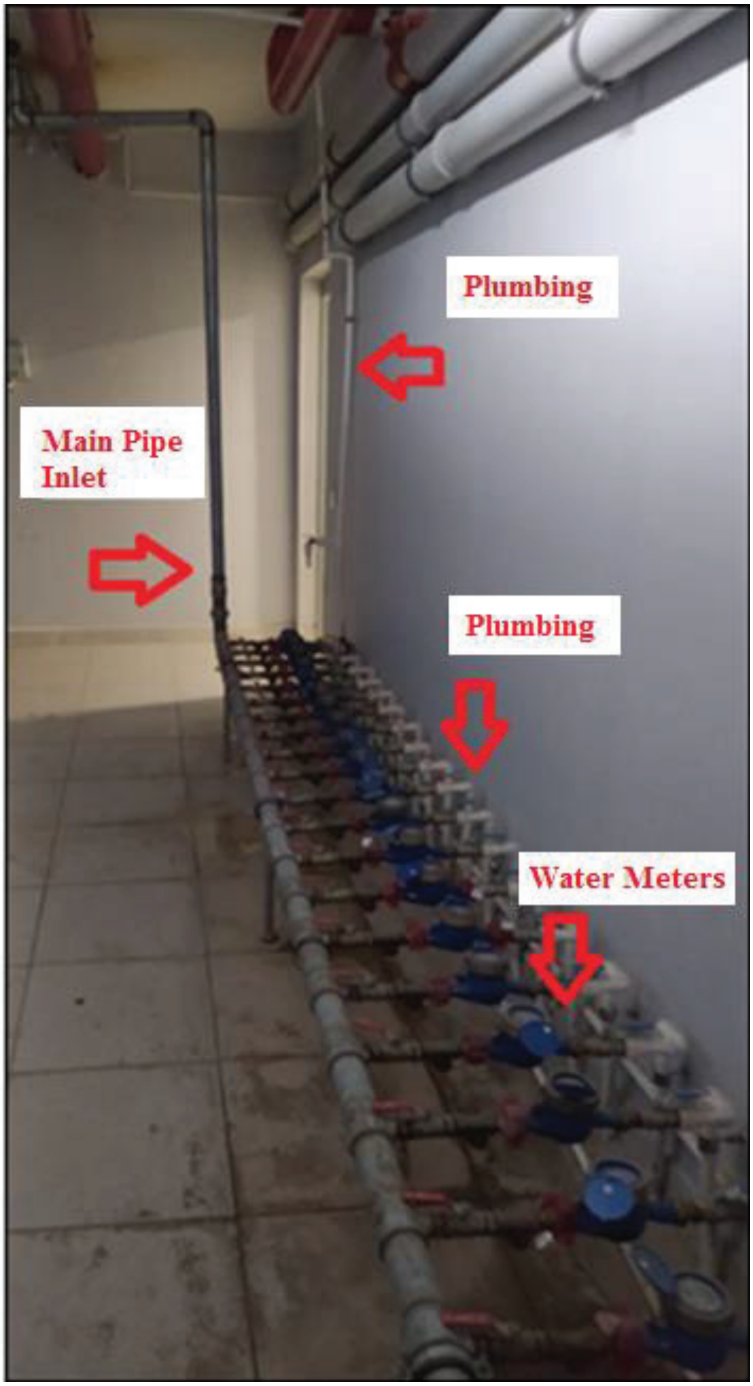
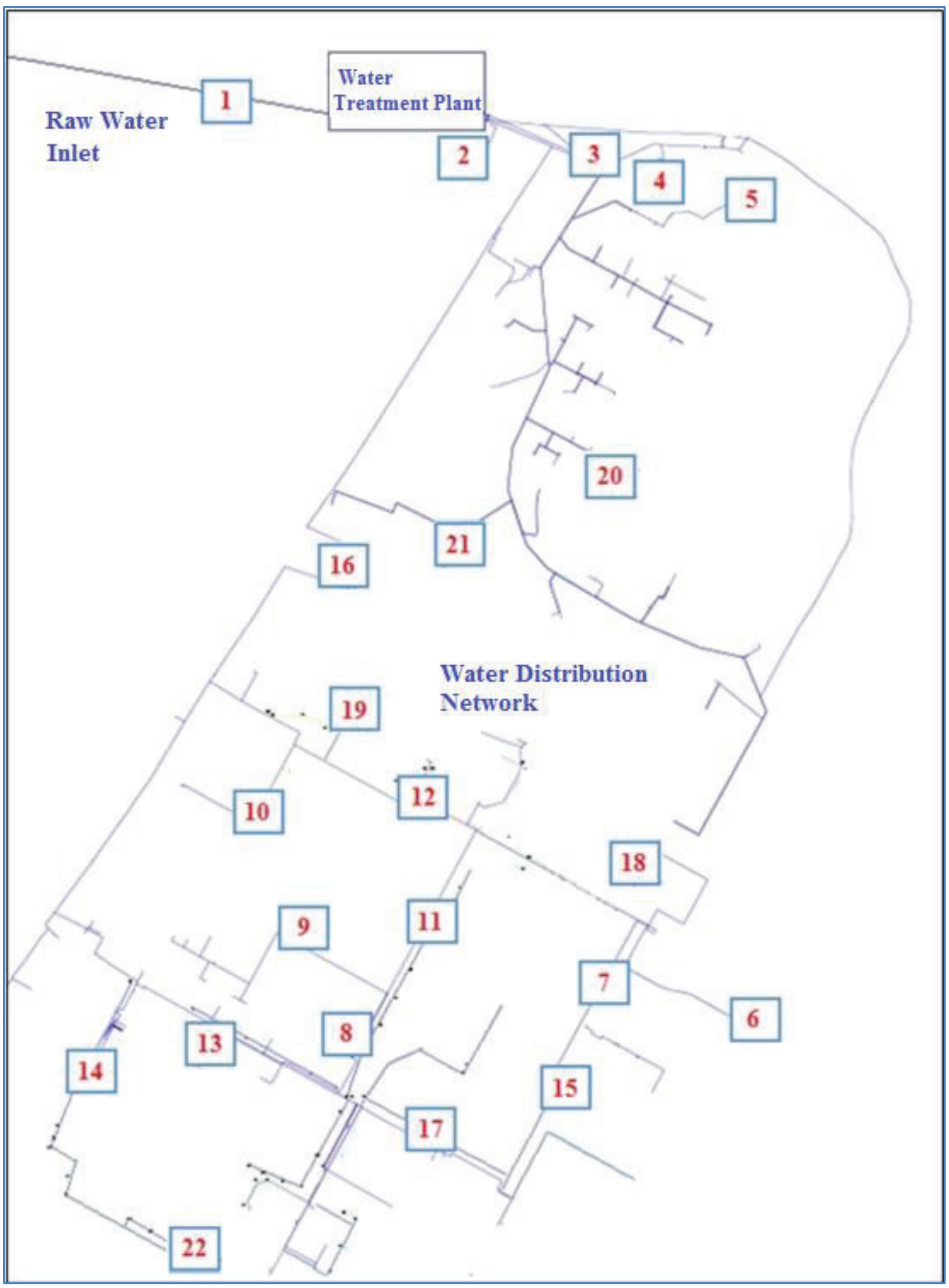


Figure 2

Layout of the Network and Buildings



Note. Due to the security restrictions, images of the study area cannot be given.

Table 1

Sampling Points and Their Characteristics

Building No	Pipe Types	Water Usage	Sampling Points	Plumbing Age Category
1	PE	Raw Water	Sample Tap	III***
2	PE	Potable	Sample Tap	II**
3	PPRC	Potable	Plumbing	II
4	PPRC	Potable	Plumbing	II
5	Galvanized	Potable	Plumbing	III
6	PE	Potable	Inlet Collector	II
7	PE	Potable	Inlet Collector	II
8	PPRC	Potable	Plumbing	I*
9	Galvanized	Operational	Plumbing	III
10	Galvanized	Potable	Inlet Collector	III
11	PPRC	Potable	Inlet Collector	I
12	Galvanized	Potable	Plumbing	III
13	Galvanized	Potable	Plumbing	II
14	Galvanized	Potable	Plumbing	II
15	Galvanized	Potable	Plumbing	I
16	Galvanized	Potable	Inlet Collector	II
17	Galvanized	Potable	Inlet Collector	II
18	Galvanized	Potable	Inlet Collector	I
19	PPRC	Potable	Plumbing	I
20	Galvanized	Potable	Inlet Collector	III
21	Galvanized	Potable	Plumbing	III
22	PPRC	Potable	Plumbing	I

* the age of plumbing in the new buildings is between 0 and 5 years.

** the age of the plumbing in the middle-aged buildings is between 6 and 15 years.

*** the age of plumbing in the old buildings is over 15 years.

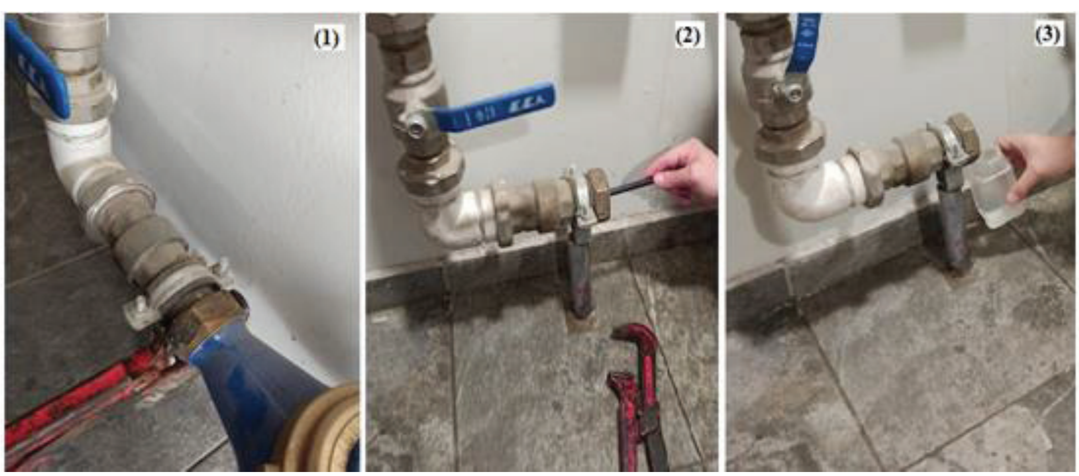
For the number 1, sample was taken from the raw water inlet. For the number 2, sample was taken from the effluent treated water. For the numbers between 3 and 22, samples were collected from the different points on the water distribution network in the buildings. In this study, a simple random sample was taken from each point annually. Total hardness, total alkalinity, iron, turbidity, pH, odor and total organic carbon load were also examined in terms of microbial growth stimulation.

At each sampling point, sample was firstly taken from tap water flowing in order to determine the current water quality. These samples were called as "Before". After disassembling the pipes, the accumulations on the pipe surface were scraped by a sterilized rod and the water sample was taken by providing the transition of the substances on the pipe surfaces into the water phase. These samples were named as "After". In this way, the effect of those accumulations on the physical, chemical and bacteriological quality of the water was examined and biofilm formations were studied.

The method of taking the samples from the pipes is shown in Figure 3.

Figure 3

Water Sampling Method



Note. (1) Disassembling the tap/water meter, (2) Scraping the inner surface of the pipes with a sterile rod, (3) Sampling from the flowing water.

Water samples containing the detached layers were transferred into the laboratory for the microbiological analysis on the same day under. Furthermore, in order to determine changes in physical and chemical characteristics of the water, additional control samples were taken and analyzed in the laboratory. The microbiological samples were incubated according to the incubation duration and temperatures. The results were preserved on the filter papers.

Microbiological Analysis

In this study, dehydrated nutrient sets developed by Sartorius Company were used as the medium, referred as "Nutrient Pad Set (NPS)". It consists of media and membrane filter sets, each of which is impregnated with an absorbent pad by the manufacturer, then dehydrated and placed in sterile Petri dishes (Sartorius, 2014).

Membrane filtration method was used in the study for the detection of pathogens in the biofilm layer. Sterile sample containers (with Sodium Thiosulfate), vacuum pump, vacuum hose, glass vacuum flask, stainless steel filter holder, filter body, dosing syringe, stainless steel forceps and 0.2 nm pore size membrane filters were used in the membrane filtration process. In order to observe bacterial growth on filter papers, samples were placed in the incubator.

Different media, incubation durations and temperatures were used for the examined microbial species. "Yeast NPS" for total colony (germ count) detection, "Chromocult NPS" for total coliform detection, "Endo NPS" for *E. coli* detection, "Cetrimide NPS" for *Pseudomonas aeruginosa* detection, "Bismuth Sulfite NPS" for *Salmonella* spp. detection, "Chapman NPS" for *Staphylococcus aureus* detection and "Azide NPS" for *Enterococci* detection were used. The incubation conditions of the media and species are given in Table 2:

Table 2

Species and Incubation Conditions

Media Name (NPS)	Species	Incubation Temperature (ºC)	Incubation Duration (h)
Yeast	Total Colony	37	48
Chromocult	Total Coliform	36	24
ENDO	*E. coli*	36	24
Cetrimide	*Pseudomonas aeruginosa*	42	48
Bismuth Sulfide	*Salmonella* spp.	36	48
Chapman	*Staphylococcus aureus*	30 - 35	72
Azide	*Enterococci*	36	48

When calculating the colonies formed in the medium in the microbiological evaluations, it is accepted that each colony consists of a single microorganism. Therefore, the result can be expressed as colony forming units (CFU). When the number of aerobic microorganisms that can grow at a certain temperature and hour is expressed as "n CFU/ 250 mL", the results of the microbiological analyzes were calculated as follows:

- If $n = 0$, result = 0 CFU/ 250 mL
- If $1 < n < 200$, result = n CFU / 250 mL
- If $n > 200$, result = 200 CFU / 250 mL

Physical and Chemical Analysis

Total hardness, total alkalinity, iron, turbidity, pH and odor parameters were analyzed in "Before" and "After" samples taken from the water network. Also, total organic carbon (TOC) was measured in the water samples. Total hardness was determined by titrimetric method according to EPA130.2. The alkalinity analysis was performed using the titrimetric method according to ISO 9963. Iron analysis was carried out in accordance with ISO 6332-1998, DIN 38406 E1-1 using the LCK 521 Kit on a spectrophotometer device (Hach Lange DR 6000). Turbidity analyzes were performed on a turbidimeter device (Hach Lange 2100N) according to ISO 7027. pH analyzes were performed using a pH meter (Hach Sension1) according to TS 3263 and ISO 10523. TOC were analyzed in accordance with TS 8195 EN 1484 with a TOC analyzer (Shimadzu TOC -L) operating with combustion catalytic oxidation method at 680°C.

Results

Raw Water Analysis Results

TOC results of the raw water are given in Table 3.

TOC values for Çamlıdere Dam water correspond to A2 category (water that becomes drinkable after physical treatment, chemical treatment and disinfection).

Table 3

Raw Water TOC Values

							May 2020	April 2021
					Sample Date			
Parameter	Unit	Limit Values			Method	Raw Water Source	Results	
		A1	A2	A3				
Total Organic Carbon	mg/L	4	4.7	10	TS 8195 EN 1484	Çamlıdere Dam	7.41	4.04

Note. A1, A2, A3 are categories in Turkish Regulation on the Quality and Purification of Drinking Water Supply.

The alkalinity and hardness values of raw water are given in Table 4:

Table 4

Raw Water Alkalinity and Hardness Values

Parameters	Results
P Alkalinity ($CaCO_3$)	0 mg/L
M Alkalinity ($CaCO_3$)	75 mg/L
Total Hardness ($CaCO_3$)	78 mg/L

The physical and chemical analysis results of raw water were given in Table 5. The results for Çamlıdere Dam water also correspond to A2 category.

Table 5

Physical and Chemical Water Quality of Raw Water

Parameters	Unit	Result
Odor		Rusty
Total Hardness	mg/L $CaCO_3$	78
Total Alkalinity	mg/L	75
Iron	µg/L	361
Turbidity	NTU	10.28
pH		7.93

Microbiological analyzes were carried out in raw water and pathogen species were examined via membrane filtration method. The samples of raw water were diluted 50% in microbiological analyzes, so the number of colonies counted in the medium was multiplied by two. The result of the microbiological analysis of raw water were stated in Table 6.

Table 6

Raw Water Microbiological Analysis Results

Sample Name	Media (NPS)	Species	Dilution Coefficient	Result (CFU/250 mL)
1. Point (Raw Water)	Yeast	Total Colony	0.5	200
	Chromocult	Total Coliform	0.5	120
	Azide	*Enterococci*	0.5	10
	Cetrimide	*Pseudomonas aeruginosa*	0.5	14
	Chapman	*Staphylococcus aureus*	0.5	200
	Endo	*E. coli*	0.5	112
	Bismuth Sulfide	*Salmonella* spp.	0.5	4

Distribution Network (Plumbing) Analysis Results

Although TOC values in water distribution network changed periodically, the average values were above 3 mg/L. In the period of May 2021, samples were taken from the raw water, the treatment plant effluent, sample point 6 (as the middle point of distribution network), sample point 22 (as the last point of distribution network) and the TOC values were examined. The results were stated in Table 7.

Table 7

TOC Values in the Water Network

	Results (mg/L)			
Sample Period	Raw Water	Treated Water Effluent	Plumbing No.6 (from network)	Plumbing No.22 (from network)
May 2021	4.37	3.35	3.66	3.45

Samples were taken as "Before" and "After" at each point in the plumbing and the physical, chemical and microbiological quality changes were examined. Physical and chemical analysis results of "Before" and "After" water samples were given in Table 8. Microbiological results were given in Tables 9 and 10.

Table 8

Physical and Chemical Analysis Results of "Before" and "After" Water Samples

Plumbing No	Pipe Material	Plumbing Age[1]	TOC mg/L	Odor		Turbidity (NTU)		pH		Hardness (mg/L CaCO3)		T. Alkalinity (mg/L)		Iron (µg/L)		Deterioration in Water Quality[2]
				"Before" Sample	"After" Sample	"Before" Sample	"After" Sample	"Before" Sample	"After" Sample	"Before" Sample	"After" Sample	"Before" Sample	"After" Sample	"Before" Sample	"After" Sample	
1	PE	III	4.37	Rusty	Rusty	10.28	10.28	7.93	7.93	78	78	75	75	361	361	-[3]
2	PE	II	3.35	Normal	Normal	0.1	0.1	7.4	7.41	79	78	55	58	11	27	A
3	PPRC	II	-	Normal	Normal	0.09	0.12	7.45	7.45	86	86	70	75	10	20	A
4	PPRC	II	-	Normal	Normal	0.1	0.1	7.55	7.54	89	89	58	57	10	20	A
5	Galvanized	III	-	Normal	Normal	0.1	0.59	7.5	7.51	79	80	55	72	10	57	B
6	PE	II	3.66	Normal	Normal	0.44	0.78	7.55	7.53	77	77	57	66	36	40	A
7	PE	II	-	Normal	Normal	0.4	0.62	7.54	7.55	86	78	57	64	20	28	A
8	PPRC	I	-	Normal	Normal	0.1	0.42	7.5	7.51	79	80	58	70	10	26	A
9	Galvanized	III	-	Normal	Rusty	0.1	0.73	7.5	7.51	79	78	58	70	10	151	B
10	Galvanized	III	-	Normal	Rusty	0.21	1.78	7.55	7.55	80	77	64	66	24	539	D
11	PPRC	I	-	Normal	Normal	0.3	0.33	7.5	7.51	79	79	60	65	14	16	A
12	Galvanized	III	-	Normal	Rusty	0.44	5.28	7.55	7.55	77	76	59	58	46	656	D
13	Galvanized	II	-	Normal	Normal	0.4	1.29	7.5	7.51	76	78	50	51	30	134	C
14	Galvanized	II	-	Normal	Normal	0.21	1.23	7.55	7.55	78	78	63	70	26	151	C
15	Galvanized	I	-	Normal	Normal	0.21	0.32	7.5	7.51	78	80	63	63	10	13	A
16	Galvanized	II	-	Normal	Normal	0.24	0.43	7.5	7.51	76	78	58	64	26	43	A
17	Galvanized	II	-	Normal	Normal	0.4	0.7	7.55	7.51	78	78	57	57	10	510	D
18	Galvanized	I	-	Normal	Normal	0.44	0.43	7.55	7.55	76	78	58	60	26	26	A
19	PPRC	I	-	Normal	Normal	0.5	0.57	7.51	7.51	78	76	57	58	60	60	A
20	Galvanized	III	-	Normal	Rusty	0.64	6.98	7.55	7.51	80	80	64	66	10	2126	D
21	Galvanized	III	-	Normal	Rusty	0.2	1.52	7.5	7.51	76	78	50	49	11	200	D
22	PPRC	I	3.45	Normal	Normal	0.09	0.12	7.5	7.51	78	80	63	64	10	11	A

Note 1. I: New buildings (plumbing age: 0 - 5 years), II: Middle-aged buildings (plumbing age: 6 - 15 years), III: old buildings (plumbing age: over 15 years).

Note 2. Level A: No change in water quality, Level B: Deterioration did not exceed the regulation limit values, Level C: Deterioration with one parameters exceeding the limit values, Level D: Too much deterioration in water quality and at least two parameters exceed the limit values.

Note 3. Raw water (untreated) sample. Before and After values are same.

Table 9

Microbiological Analysis Results of "Before" Water Samples

Sampled Plumbing No	Pipe Material	Plumbing Age[1]	Number of Counted Colonies (CFU/250 mL)										
			Total Colony	Other Species[2]	Total Coliform	Other Species[3]	Enterococci	*Pseudo. aer.*	Other *Pseudo.*[4]	*Staphyl. aur.*	*E. coli*	Other Species[5]	*Salmonella* spp.
1	PE	III	0	0	0	0	0	0	0	0	0	0	0
2	PE	II	0	0	0	0	0	0	0	0	0	0	0
3	PPRC	II	0	0	0	0	0	0	0	0	0	0	0
4	PPRC	II	0	0	0	0	0	0	0	0	0	0	0
5	Galvanized	III	0	0	0	0	0	0	0	0	0	0	0
6	PE	II	0	0	0	0	0	0	0	0	0	0	0
7	PE	II	0	0	0	0	0	0	0	0	0	0	0
8	PPRC	I	0	0	0	0	0	0	0	0	0	0	0
9	Galvanized	III	0	0	0	0	0	0	0	0	0	0	0
10	Galvanized	III	0	0	0	0	0	0	0	0	0	0	0
11	PPRC	I	0	0	0	0	0	0	0	0	0	0	0
12	Galvanized	III	0	0	0	0	0	0	0	0	0	0	0
13	Galvanized	II	0	0	0	0	0	0	0	0	0	0	0
14	Galvanized	II	0	0	0	0	0	0	0	0	0	0	0
15	Galvanized	I	0	0	0	0	0	0	0	0	0	0	0
16	Galvanized	II	0	0	0	0	0	0	0	0	0	0	0
17	Galvanized	II	0	0	0	0	0	0	0	0	0	0	0
18	Galvanized	I	0	0	0	0	0	0	0	0	0	0	0
19	PPRC	I	0	0	0	0	0	0	0	0	0	0	0
20	Galvanized	III	0	0	0	0	0	0	0	0	0	0	0
21	Galvanized	III	0	0	0	0	0	0	0	0	0	0	0
22	PPRC	I	0	0	0	0	0	0	0	0	0	0	0

NOTE 1. I: New buildings (plumbing age: 0 - 5 years), II: Middle-aged buildings (plumbing age: 6 - 15 years), III: old buildings (plumbing age: over 15 years).

NOTE 2. Shows other microorganisms formed on Yeast NPS medium rather than total colony bacteria.
NOTE 3. Shows other microorganisms formed on Chromocult NPS medium rather than total coliform bacteria.
NOTE 4. Shows other *Pseudomonas* species that do not show fluorescence under a UV lamp with a wavelength of 365 nm.
NOTE 5. Shows other coliforms formed on Endo NPS medium rather than *E. coli.*

Table 10

Microbiological analysis results of "After" water samples

Sampled Plumbing No	Pipe Material	Plumbing Age[1]	Deterioration in Water Quality[2]	Number of Counted Colonies (CFU/250 mL)										
				Total Colony	Other Species[3]	Total Coliform	Other Species[4]	Enterococci	*Pseudo. aer.*	Other *Pseudo.*[5]	*Staphyl. aur.*	*E. coli*	Other Species[6]	*Salmonella* spp.
1	PE	III	-	200	0	120	0	10	14	200	200	112	0	4
2	PE	II	A	0	0	0	0	0	0	0	0	0	0	0
3	PPRC	II	A	0	0	0	0	0	0	0	0	0	0	0
4	PPRC	II	A	0	0	0	0	0	0	0	0	0	0	0
5	Galvanized	III	B	13	0	0	0	0	1	0	0	0	0	0
6	PE	II	A	200	0	0	0	200	1	0	32	0	200	0
7	PE	II	A	3	0	0	0	0	0	0	2	0	0	0
8	PPRC	I	A	197	0	0	0	0	0	0	0	0	0	0
9	Galvanized	III	B	200	0	0	0	0	2	0	7	0	0	0
10	Galvanized	III	D	200	0	200	0	0	7	0	12	200	0	0
11	PPRC	I	A	0	0	0	0	0	0	0	0	0	0	0
12	Galvanized	III	D	200	0	0	0	0	2	0	1	1	1	0
13	Galvanized	II	C	200	200	0	0	0	1	0	1	0	0	0
14	Galvanized	II	C	200	54	0	0	0	1	0	7	0	0	0
15	Galvanized	I	A	200	0	200	0	0	0	0	0	200	0	0
16	Galvanized	II	A	29	200	1	6	0	1	0	0	0	0	0
17	Galvanized	II	D	38	2	0	1	0	2	1	11	0	0	0
18	Galvanized	I	A	200	0	0	0	0	0	0	0	0	0	0
19	PPRC	I	A	4	0	0	0	0	0	0	0	0	0	0
20	Galvanized	III	D	200	0	0	0	0	1	0	0	0	0	0
21	Galvanized	III	D	200	0	200	0	0	2	2	13	200	0	0
22	PPRC	I	A	0	0	0	0	0	0	0	0	0	0	0

NOTE 1. I: New buildings (plumbing age: 0 - 5 years), II: Middle-aged buildings (plumbing age: 6 - 15 years), III: old buildings (plumbing age: over 15 years).
NOTE 2. Level A: No change in water quality, Level B: Deterioration did not exceed the regulation limit values, Level C: Deterioration with one parameters exceeding the limit values, Level D: Too much deterioration in water quality and at least two parameters exceed the limit values
NOTE 3. Shows other microorganisms formed on Yeast NPS medium rather than total colony bacteria.
NOTE 4. Shows other microorganisms formed on Chromocult NPS medium rather than total coliform bacteria.
NOTE 5. Shows other *Pseudomonas* species that do not show fluorescence under a UV lamp with a wavelength of 365 nm.
NOTE 6. Shows other coliforms formed on Endo NPS medium rather than *E. coli.*

Results According to the Pipe Materials

The "Before" and "After" analyzes were also compared according to the pipe materials. In microbiological analysis, the averages of total colony and total pathogen numbers were taken. The age of the plumbing and the degree of deterioration in water quality were also considered during the calculations. The results and average values of the all samples with respect to galvanized metal, PE and PPRC pipe materials were given in Tables 11, 12 and 13 as follows:

Table 11

Results of the "After" Samples for the "Galvanized Metal" Plumbing

Sampled Plumbing No	Pipe Material	Plumbing Age	Deterioration in Water Quality	Total Colony Count (CFU/250 mL)	Total Pathogen Count (CFU/250mL)
5	Galvanized Metal	III	B	13	1
9	Galvanized Metal	III	B	>200	9
10	Galvanized Metal	III	D	>200	419
12	Galvanized Metal	III	D	>200	4
13	Galvanized Metal	II	C	>200	2
14	Galvanized Metal	II	C	>200	8
15	Galvanized Metal	I	A	>200	400
16	Galvanized Metal	II	A	>200	8
17	Galvanized Metal	II	D	40	15
18	Galvanized Metal	I	A	>200	0
20	Galvanized Metal	III	D	>200	1
21	Galvanized Metal	III	D	>200	417
AVERAGE		II	C	>200	107

Table 12

Results of the "After" Samples for the "PE" Plumbing

Sampled Plumbing No	Pipe Material	Plumbing Age	Deterioration in Water Quality	Total Colony Count (CFU/250 mL)	Total Pathogen Count (CFU/250mL)
2	PE	II	A	0	0
6	PE[1]	II	A	>200	433
7	PE	II	A	3	2
AVERAGE		II	A	>200	145

Note 1. Infiltration from the pipe leakage into the water network has been detected.

Table 13

Results of the "After" Samples for the "PPRC" Plumbing

Sampled Plumbing No	Pipe Material	Plumbing Age	Deterioration in Water Quality	Total Colony Count (CFU/250 mL)	Total Pathogen Count (CFU/250mL)
3	PPRC	II	A	0	0
4	PPRC	II	A	0	0
8	PPRC[1]	I	A	197	0
11	PPRC	I	A	0	0
19	PPRC	I	A	4	0
22	PPRC	I	A	0	0
AVERAGE		I	A	34	0

Note 1. The sample was taken from a tap in the toilets.

Discussion and Conclusion

In this study, the pipe materials and the age of the plumbing were associated with biofilm formation, presence of pathogenic microorganisms and deterioration in water quality. The results obtained have been helpful in terms of realizing the effect of biofilms on water quality, factors affecting biofilm formation on plumbing in Ankara city conditions, detection of biofilms and pathogenic microorganism via dehydrated NPS media. It was concluded that biofilm formations could be detected in indoor plumbing by using total colony count on Yeast NPS medium. At 15 points in the network, biofilm formation was detected by this way. It has also been found that once biofilms detached from pipe surfaces and mix with water, they are deteriorating the quality of treated tap water. The necessity of examining the presence of pathogenic microorganisms in the network after the initial detection of biofilm formation was pointed out.

Inappropriate Plumbing Conditions

In this study, it was observed that the inlet of the pipes left opened during the replacement of broken pipes at one point. When the new or repaired pipes are put into service directly without cleaning and flushing, pathogens and other microorganisms from the outer environment (like soil) can enter the water network and quickly form a biofilm layer on suitable surfaces. Microbiological water qualities may deteriorate even the disinfection is applied to the water network. So one of the causes of the bacterial growth and biofilm formation in the network was the inappropriate pipe replacement works.

At sample point 6, biofilm layers and pathogen microorganisms resulting from pipe leakages and infiltrations from the environment was detected. At sample point 8, it is considered that since the sample is taken from the toilets, the microorganisms in the environment might reach the pipe surface with the effect of negative pressure. At the sample point 18, it was revealed that the treated irrigation water was connected to the drinking water collector with a valve and a cross-connection in the network was formed. Although it was a new building, a biofilm layer formed on the pipe surface due to that cross connection. Pathogenic microorganisms may enter the clean water networks due to cross connections and may form biofilms on pipe surfaces.

Effect of Pipe Material on Water Quality

When the results are evaluated according to the pipe types, in the 12 buildings with galvanized metal plumbing, it was observed that the physical, chemical and microbiological parameters of the waters in “Before” samples complied with the “TS 266 Water Intended for Human Consumption Standard” limit values. However, in the “After” samples taken by scraping the pipe surfaces, it was observed that the physical and chemical qualities of the water samples deteriorated significantly (Level C and D). Iron and turbidity parameters exceeded the TS 266 standard values at 7 points. In addition, the average total colony was counted as >200 CFU/250 mL in those 12 galvanized plumbing, and the average number of different types of pathogens was calculated as 107 CFU/250 mL.

In the PE plumbing, also the physical, chemical and microbiological parameters of the waters in “Before” samples complied with the TS 266 standard. For the “After” samples, the average total colony count of the PE plumbing was >200 CFU/250 mL and the average pathogen colony was 145 CFU/250 mL. Only one point in PE pipes, a bacterial growth was observed which was resulting from the infiltration caused by a pipe leakage detected at sample point 6. Therefore, intense bacterial growth was detected at this point. Different types of pathogens can enter the water plumbing due to such pipe leaks from the soil with backpressure and maintain their existence by forming a biofilm on the pipe surface. No significant change was observed in the physical and chemical qualities of the "Before" and "After" water samples (Level A).

PPRC plumbing, on the other hand, were counted as the least microbial growth and water quality deterioration with respect to the other pipe types. The physical, chemical and microbiological parameters of the waters in “Before” samples complied with the TS 266 standard. For the “After” samples, the average total colony count was 34 CFU/250 mL, and no pathogenic species were found at those six plumbing. Only at sample point 8, total colony formation was observed. At that point, the water sample was taken from a PPRC type in the toilets, so it was considered as the source of microorganisms. No significant change was observed in the physical and chemical qualities of the "Before" and "After" samples (Level A).

More accumulations and scums occurred in galvanized metal pipes, and microbiological growth on this residue was higher when compared with PE and PPRC pipes. Especially at the network age of II. and III. category, more bacterial growth and deterioration in water quality were detected in galvanized metal pipes. In the buildings with the same plumbing age, biofilms formed more in galvanized metal pipes according to the total colony count results. It was concluded that biofilm formation deteriorates the physical, chemical and microbiological quality of water. In general, although total colony detection and biofilm formation were observed in PE and PPRC pipes, the colony number and diversity of pathogen species in galvanized metal pipes was much higher. These results were corresponded to the previous studies of Niquette et al. (2000), Camper (2003), Türetgen (2005) and Keskin and Kahveci (2019).

Effect of TOC on Biofilms

TOC values were found as 4.37 mg/L in raw water and as 3.35 mg/L, 3.66 mg/L, 3.45 mg/L in the water network respectively. There was no carbon removal unit (ozonation, membrane filters, etc.) in the water treatment plant. For this reason, the organic carbon in the raw water was reaching to the water network with partial removal and bringing an organic load to water. The amount of organic matter in the network was an important source for the biofilm formation and bacterial growth. Organic carbon should be removed in treatment plants in order to limit the bacterial growth and biofilm formation in the water networks.

Effect of Pipe Age on Water Quality

The plumbing age of total 70 buildings in the study area was mainly II. category (between 6-15 years) and plumbing materials were galvanized metal. Similarly, the plumbing age of 22 points selected within the scope of this study was same as II. category and pipe types were galvanized metal generally.

When the results are evaluated according to the plumbing ages, it has been determined that in the old plumbing, which are in the third category in terms of building age, the accumulations on the pipe surfaces were denser than the second and first category plumbing. Over the years, the accumulation on the pipe surfaces increases for the hard and high-alkalinity waters because of the minerals inside, which forms a suitable environment for the microorganisms to attach the surface and form biofilms. Galvanized metal plumbing was used in the second and third category building ages in the facility. Since PE and PPRC materials are used in networks recently, they were found only in buildings with first and second category network age in the study area. Biofilm and pathogen formation in PE and PPRC pipes in I. and II. category buildings were lower than galvanized metal pipes. The highest water quality deterioration and the most intense corrosion was observed in galvanized metal pipes in III. category buildings.

Detected Pathogens in Plumbing

The results were also evaluated in terms of the detected pathogens. Total colony formation was detected in 16 of the 22 plumbing examined, and pathogenic microorganism colonies was observed in 13 of these points. *Pseudomonas aeruginos*a, a chlorine-resistant pathogen, can escape the final chlorination and disinfection processes in the treatment plants and survive in biofilms in the water networks. In this study, *Pseudomonas aeruginos*a was the most detected pathogens, which was counted at 11 of the 22 plumbing on drinking water network. Percival et al. (1998) isolated also *Pseudomonas* sp. from stainless steel plumbing and Critchley et al. (2003) isolated from copper plumbing. The highest colony formation was *E. coli*, which was detected in 4 of 22 plumbing and counted over 600 CFU/250 mL in total. *Enterococci* are relatively resistant to chlorine and chemicals. Therefore, the remaining cells after disinfection at the treatment plant can multiply again in biofilms on the pipe surfaces. *E. coli* and *Straphylococci* are not as resistant to chlorine and are usually removed by disinfection. It is considered that *Enterococci, Straphylococci* and *E. coli* entered the network from the soil with backpressure. Those pathogens can enter the water network from soil or outer environment due to the leakages or pipe repairing works. Salmonella species are not resistant to chlorine, and no growth was detected in the network.

In conclusion, it has been observed that more accumulations occurred in galvanized metal pipe surfaces, and microbiological growth was higher in galvanized metal pipes than PE and PPRC pipes. The highest water quality deterioration and biofilm formation was observed in galvanized metal pipes in III. category buildings (plumbing age over 15 years). More aged galvanized metal plumbing promotes more biofilm formation. *Pseudomonas aeruginosa* was the most common detected pathogens in plumbing. The highest colony formation was *Escherichia coli*. High total colony counts detected on Yeast NPS medium during the study showed the presence of biofilms on the pipe surfaces. It is considered that the total colony analysis on Yeast NPS medium with membrane filtration method can be used to make a preliminary assessment for biofilm formations on the plumbing. In cases where the total colony results exceed the TS 266 standard limit values, additional pathogen type analysis can be performed in the plumbing. Biofilms in drinking water distribution networks are an important issue that should be carefully examined in terms of human health due to the pathogenic microorganisms they contain and their negative effects on drinking water quality. This study and methodology can be applied to water networks of different cities in order to reveal the plumbing situation and their effect on water quality. Another study for the water tanks in the water networks can be carried out to detect the biofilm formation and pathogen microorganisms in similar way. In addition, a plumbing water quality risk analysis method can be developed with the results obtained in this study in order to increase the awareness of the consumers about the effect of plumbing on water quality and to minimize the possible health problems related to them.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Sıhhi Tesisatlarda Biyofilm Tabakası Tespiti ve Su Kalitesine Etkisinin Belirlenmesi

Arıtma tesislerinde arıtılan içme suyunun kalitesini bozan ve insan sağlığı açısından risk teşkil eden hususlardan birisi de su dağıtım sistemlerinde oluşan biyofilm tabakası ve içeriğindeki patojen mikroorganizmalardır. Bu çalışmada bir işletmedeki binaların sıhhi tesisatlarında biyofilm varlığı, biyofilmlerdeki patojen mikroorganizmaların tespiti ve biyofilmlerin içme sularının fiziksel, kimyasal ve mikrobiyolojik kalitesine etkisi araştırılmıştır. Mikrobiyolojik incelemelerde biyofilm varlığı ve patojenlerin tespiti için membran filtrasyon yöntemi ve hazır kurutulmuş besiyerleri kullanılmıştır. "Nutrient Pad Set (NKS)" olarak da adlandırılan bu sistem, üretici tarafından her biri absorban pede emdirildikten sonra kurutulup, steril olarak petri kutularına yerleştirilmiş besiyerleri ve membran filtre setlerinden oluşmaktadır. Çalışmada ağırlıklı olarak indikatör mikroorganizmalar incelenmiştir. Türlerin tespitinde hazır kurutulmuş besiyeri kullanıldığı için üretici firma tarafından besiyeri temini yapılabilen Toplam Koloni, Toplam Koliform, Enterokoklar, *Pseudomonas aeruginosa, Salmonella* spp*., Staphylococcus aureus* ve *E. coli* türleri çalışmaya dahil edilmiştir. Biyofilm ve içerdiği mikroorganizmalar ile ilgili yapılan çalışmalarda yaygınlıkla laboratuvarda kontrollü ortamda boru üzerinde biyofilm oluşumu gözlenirken, bu çalışmada doğrudan canlı ve aktif bir şebeke üzerinde var olan biyofilmler ve içerikleri incelenmiştir. Numune noktalarındaki su kalitesinin analizi yapılırken barajlardan gelen ham sudan başlanarak içme suyu arıtma tesisi çıkışı ve iç tesisatın son noktasında su kalitesindeki değişim incelenmiştir. Demir, toplam sertlik, toplam alkalinite, pH ve bulanıklık değerleri ile suların görüntü ve kokusu, musluktan akan su (öncesi) ve boru yüzeyi kazındıktan sonra akan su (sonrası) olmak üzere değerlendirilmiş ve su kalitesine yönelik fiziksel ve kimyasal etkiler de analiz edilmiştir.

Sıhhi tesisatlarda kullanılan boru türü ve tesisat yaşı ile biyofilm oluşumu, patojen mikroorganizma varlığı ve su kalitesindeki değişimler ilişkilendirilmiştir. Elde edilen sonuçlar, ülkemiz şartlarında içme suyu şebekelerinde gelişen biyofilm tabakaları içinde mevcut olabilecek patojen mikroorganizma türleri ve bu türlerin hazır kurutulmuş besiyerleriyle tespit edilebilmesi açısından yol gösterici olmuştur. Özellikle Yeast besiyeri kullanılarak iç tesisatta biyofilm oluşumlarının tespit edilebildiği gözlemlenmiştir. Ayrıca biyofilmlerin bozulup suya karıştığında arıtılmış şebeke suyu kalitesini değiştirdiği de tespit edilmiştir. Biyofilm oluşumunun tespit edilmesinin akabinde şebekede patojen mikroorganizma varlığının incelenmesinin gerekliliği de ortaya çıkmıştır.

Şebekede boru patlakları, çevreden infiltrasyonlar, çapraz bağlantılar, ters basınç, boru yenileme çalışmalarından kaynaklı kirlenmeler vb. dış etmenlerden kaynaklı biyofilm ve patojen mikroorganizma varlığı da gözlemlenmiştir. İncelenen 22 tesisatın 16'sında toplam koloni oluşumu tespit edilmiş olup bu noktaların 13'ünde de patojen mikroorganizma çoğalması görülmüştür.

Yapılan analiz sonuçlarına göre galvaniz metal tesisatların ortalama şebeke yaşı kategorisi II (6 - 15 yıl arası), suyun fiziksel ve kimyasal kalitesindeki bozulma derecesi C seviyesi (su kalitesinde bozulma var, en fazla bir parametrede sınır değer aşılmış), ortalama toplam koloni sayısı >200 CFU/250 mL, ortalama patojen sayısı 107 CFU/250 mL olarak tespit edilmiştir. PE tesisatlarda fiziksel ve kimyasal açıdan su kalitesinde değişim görülmemiş, ortalama şebeke yaşı kategorisi II (6 - 15 yıl arası), ortalama toplam koloni sayısı >200 CFU/250 mL, ortalama patojen sayısı 145 CFU/250 mL olarak ölçülmüştür. PE tesisatlardaki patojen sayısının yüksekliğinin nedeni, şebekede meydana gelen boru patlağından kaynaklı şebeke suyuna çevresel su sızıntısı (infiltrasyon) olarak tespit

edilmiştir. PPRC tesisatlarda da su kalitesinde değişim görülmemiş, ortalama şebeke yaşı kategorisi I (0 - 5 yıl arası) ortalama toplam koloni sayısı 34 CFU/250 mL olarak ölçülmüştür. PPRC tesisatlarda herhangi bir patojen mikroorganizma çoğalması gözlemlenmemiştir.

Patojen türleri açısından değerlendirildiğinde çalışma yapılan şebekede *Pseudomonas aeruginosa*, *Staphylococcus aureus, E. coli,* Toplam Koloni, Toplam Koliform ve Enterokok türleri farklı sayılarda tespit edilmiştir. Ham suda tespit edilen *Salmonella* spp. türüne ise arıtılmış şebeke suyunda rastlanmamıştır. Bina içi şebekelerde numune alınan tesisatlarda en çok tespit edilen patojen tür 12 noktada koloni oluşturan *Pseudomonas aeruginosa* olmuştur. En fazla koloni oluşumu ise 4 noktada tespit edilen ve toplamda 600 CFU/250 mL'nin üzerinde koloni sayımı yapılan *E. coli* olmuştur.

Tesisatlar boru türüne göre incelendiğinde galvaniz metal tesisatlarda daha fazla tortu ve birikim oluştuğu, bu tortu üzerinde mikrobiyolojik çoğalmanın diğer boru türlerine göre (PE ve PPRC) daha fazla olduğu görülmüştür. Özellikle şebeke yaşı II. ve III. kategori olan binaların tesisatlarında galvaniz metal borularda daha fazla çoğalma ve su kalitesinde bozulma tespit edilmiştir. Tesisat yaşı aynı olan binalarda galvaniz metal tesisatlarda daha hızlı biyofilm oluşmakta ve boru yüzeyinde mikroorganizma çoğalmaktadır. Biyofilm oluşumunun suyun fiziksel, kimyasal ve mikrobiyolojik kalitesini bozduğu tespit edilmiştir. III. kategori olan eski binaların galvaniz metal tesisatlarında yoğun korozyon nedeniyle boru bağlantı noktalarının boruya kaynadığı gözlemlenmiştir. Bu tür korozyona uğramış galvaniz borularda bağlantı yerinden boru sökülmeye çalışıldığı zaman boru tamamen kopabilmekte ve deforme olabilmektedir. Bu nedenle bazı noktalarda korozyona uğrayan boru sökülememiş ve boru yüzeyi gözlemlenememiştir. Çalışmada PE ve PPRC borularda da toplam koloni tespiti ve biyofilm oluşumu gözlemlense de galvaniz metal borularda patojen tür sayısı ve çeşitliliği diğer boru türlerine göre daha fazla tespit edilmiştir.

Bina yaşı açısından değerlendirildiğinde I. ve II. kategori binalarda PE ve PPRC borularda biyofilm ve patojen oluşumu galvaniz metal tesisatlara göre daha düşüktür. En yüksek kirlilik en yoğun korozyonun da gözlendiği galvaniz metal tesisatlarda ve III. kategori binalarda tespit edilmiştir.

Şebeke suyunda toplam organik karbon (TOK) değerleri dönemsel olarak değişmekle birlikte 3 mg/L'nin altına düşmemektedir. TOK değerleri ham suda 4.37 mg/L ve su şebekesinde sırasıyla 3.35 mg/L, 3.66 mg/L, 3.45 mg/L olarak tespit edilmiştir. İçme suyu arıtma tesisinde organik karbon için bir giderim ünitesi (granüler aktif karbon, ozonlama, membran filtre vs.) bulunmamaktadır. Bu nedenle ham sudaki organik karbon kısmi bir giderimle şebekeye ulaşmakta ve şebeke suyuna organik yük getirmektedir. Şebekedeki organik madde miktarı mikroorganizmaların biyofilm oluşturması ve çoğalması için önemli bir kaynak oluşturmaktadır. Arıtma tesislerinde organik karbonun giderilmesi gerekmektedir.

Çalışma sırasında Yeast besiyeri üzerinde tespit edilen yüksek toplam koloni sayıları, tesisat borularının iç yüzeyinde biyofilm varlığının göstergesidir. Boru yüzeylerinden alınan numunelerde toplam koloni sayısı analizinin, ön değerlendirme yapmak ve boruda biyofilm oluşumunu gözlemlemek için kullanılabileceği değerlendirilmektedir.

İçme suyu dağıtım şebekelerindeki biyofilmler, içerdikleri patojen mikroorganizmalar ve içme suyuna olumsuz etkileri nedeniyle insan sağlığı açısından dikkatle araştırılması gereken bir konudur. Farklı su kaynaklarına, farklı arıtma tesisleri ve su dağıtım sistemlerine göre içme suyu şebekelerinde biyofilm oluşumunun ve patojen varlığının incelenmesi gerekmektedir. Bu konudaki teknik bilgi ve farkındalık düzeyleri yetersiz olan tüketicilerin, olumsuz bina içi tesisat koşulları nedeniyle yaşanabilecek su kalite problemlerinden ve buna bağlı gelişecek sağlık sorunlardan etkilenmeleri kaçınılmazdır.

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Case Study

A Case Study on the Estimation of Flood Flows in Rivers with Different Methods

Akarsulardaki Taşkın Debilerinin Farklı Yöntemlerle Tahmini Üzerine bir Durum Çalışması

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Abstract

The estimation of the flood discharges of rivers that do not have streamflow measurements is one of the important issues in hydraulic engineering. For the safety of the structures to be built on these rivers, it is necessary to accurately estimate the possible flood discharges for some periods. Many methods have been developed on this subject. With the methods developed based on the catchment and rainfall characteristics, it is possible to make accurate estimations about the catchment without flow measurement. In this study, an evaluation was made on the estimation success of the methods by trying to determine the flood discharges of a river flowing through a 336 km^2 catchment area with indirect and direct methods based on rainfall. Compared rainfall-runoff estimation methods showed that Synthetic Method was the least reliable one among all other estimations. On the other hand, with the discharges of Q_{10} = 77 m^3/s, Q_{100} = 193 m^3/s and Q_{500} = 273 m^3/s, Mockus emerged as the most consistent one through all evaluated peak flow discharges methods. It is also intended that this study will be a guide for those who work on the subject.
Keywords: *flood discharge estimation, rainfall-runoff relationship, runoff estimations, probability distributions*

Öz

Akım ölçüm verileri bulunmayan akarsuların taşkın debilerinin tahmin edilmesi su mühendisliğinin önemli konularından biridir. Bu akarsular üzerinde yapılacak yapıların güvenliği için belirli periyotlarda gelmesi muhtemel taşkın debilerinin doğru bir şekilde tahmin edilmesi gerekir. Bu konuda birçok yöntem geliştirilmiştir. Havza ve yağış özelliklerine bağlı olarak geliştirilen bu yöntemler sayesinde akış verileri olmadan havza hakkında doğru tahminler yapmak mümkündür. Bu çalışmada, 336 km^2'lik bir havza alanı içerisinden akan bir akarsuya ait taşkın debileri çeşitli dolaylı yöntemler ve akış verilerine dayalı doğrudan yöntemlerle belirlenmeye çalışılarak yöntemlerin tahmin başarısı üzerinde değerlendirme yapılmıştır. Karşılaştırılan yağış-akış tahmin yöntemleri, Sentetik Yöntemin yapılan tahminler arasında en az güvenilir olanı olduğunu göstermektedir. Diğer yandan, Q_{10} = 77 m^3/s, Q_{100} = 193 m^3/s ve Q_{500} = 273 m^3/s'lik debi değerleri ile Mockus Yöntemi, değerlendirilen yöntemler arasından en güvenilir yöntem olarak belirlenmiştir. Bu çalışmanın konuyla ilgili uygulamada çalışanlar için bir rehber olması da amaçlanmıştır.
Anahtar sözcükler: *taşkın debisi tahmini, yağış-akış ilişkisi, akış tahminleri, olasılık dağılımları*

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Introduction

Floods seen in streams after heavy rains are among the most common natural disasters in Türkiye and the province of Bitlis, where the study area is located (Ekinci et al., 2020; Işık & Özlük, 2012). Especially considering the current topographic situation of the province, the study area is among the provinces with the highest flood damage (Kadıoğlu, 2008). In this context, the region is in a very vulnerable position in terms of natural disasters. A catchment is a system which the surface waters are collected in the form of a network and the direction of the greatest slope, and are also transferred to sea or lake as the main branch such as a stream, creek or river. In other words, it can be considered as an operator that converts rainfall into runoff. The neighboring catchments are separated from each other by borders called drainage divides, water divides, divides, ridgelines, watersheds, or water partings. The flood risk is strictly related to the characteristics of the catchments. Features such as a catchment area, average slope of the catchment, shape factor and bifurcation rate are important parameters that characterize a catchment. Additionally, vegetation, soil structure, rainfall intensity and flood-frequency in a catchment are foremost factors in creating floods. It is required to determine the peak flood discharge brought by a river for the calculation and design of dam reservoir operations, waterpower facilities, streamflow arrangements and flood control structures. While the highest discharge value observed over the years may be accepted as the design flow for some planning activities, it is desirable to know the return period of discharges that will not be possible to measure in the most engineering designs where flood controls are momentous. These discharges can be determined by various statistical methods and/or empirical equations (Samantaray & Sahoo, 2020). Their return period can be 50, 100 and 500 yearly depending on the importance of engineering applications. When determining flood discharges, it is necessary to have the streamflow measurements for many years. The stream flow data are collected from Streamflow Monitoring Stations (SMS) installed in the rivers. The data are recorded instantaneously, daily, weekly, monthly and yearly. However, the data are either not available or insufficient in some streams, creeks and brooks (Gao et al., 2017). Various methods such as Rational, Mc-Math, Synthetic, Mockus and Snyder Methods can be applied to estimate the peak flood discharges (Gulbahar, 2016; Semerci et al., 2020). For these methods, firstly, it is essential to obtain and analyze rainfall data. Another important aspect is the determination of effective parameters for the rainfall-runoff (RR) relationship. In order to determine the flow heights, it is required to know the runoff coefficient and RR parameters which depend on the catchment structure, slope and vegetation density.

In this study, the runoff data performances of the methods mentioned above are evaluated trying to estimate directly and indirectly the flood discharges of a river. Calculations of flow estimation methods, which are frequently used in hydrology, are shown in detail and frequency analyzes are made. The most appropriate method is specified for medium-sized catchments and it is concluded that it could be also used safely in catchments of similar size. It is also intended that the study will be a guide for those who work on the subject in practice.

Material and Method

Study Area

Formed by tectonic origin, Lake Van is the world's largest soda lake, as well as being the world's fourth largest closed lake. It is also the largest lake in Türkiye. Lake Van basin, which is a closed basin, has an area of approximately 20,000 km^2 and 3713 km^2 of the basin (roughly 20%) is the lake surface area. It is about 1740 m above sea level, its deepest point is calculated as 450 m, and the volume of the lake is approximately 607 km^3 (Litt et al., 2009). The Yeniköprü Stream catchment, the study area, within the borders of the Ahlat District of Bitlis is located in the Ahlat-Ovakışla sub-basin of the closed drainage area of Lake Van (Figure 1). The starting point was accepted as the 25-010 SMS of State Hydraulic Works (DSI) at the 1769 m elevation of Kınalıkçı Village on Süfresur Creek, and the catchment area of 336 km^2 of the basin has been studied. 28 years of flow data and Maximum Annual Instantaneous Flow (MAIF) data between 1963-1990 have been gathered from DSI's 25-010 numbered SMS (General Directorate of State Hydraulic Works [DSİ], 1994). Lake Nazik at 1815 m elevation, is connected to Yeniköprü Stream via Suçikan Creek and drains into Lake Van at 1647 m elevation. The study area, which has a volcanic structure due to close to the Nemrut Caldera, is relatively flat and has been turned into agricultural lands over time. The northeastern valleys, where the main stream extends, are more mountainous and sloped than the other parts of the study area.

Figure 1

Yeniköprü Stream Catchment

Note. Google Earth

Catchment Characteristics

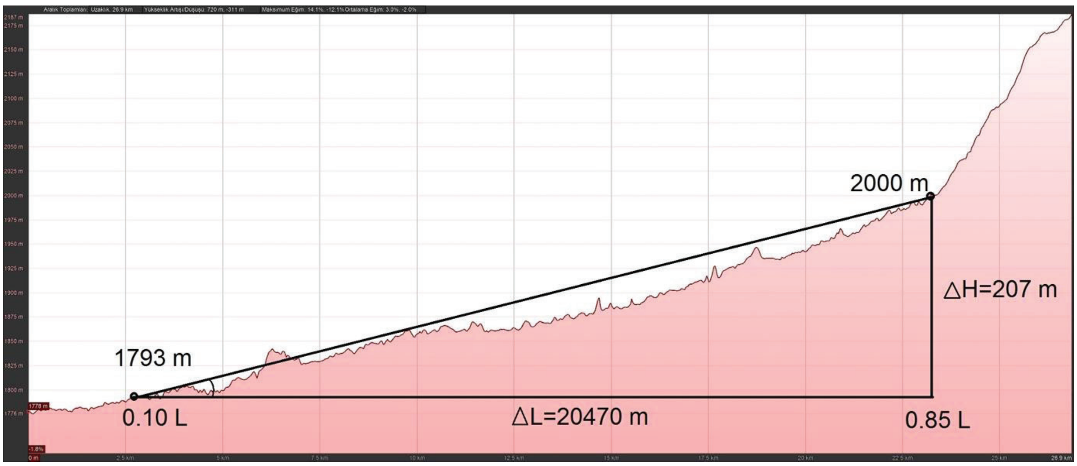
Benson's slope equation was used to determine the catchment slope. In this method, 10% to 85% of the length of the main stream is marked on the map and the slope of the line between two points is calculated (Figure 2):

$$Benson\ Slope = \frac{\Delta H}{\Delta L} = \frac{207}{20470} = 0.010$$

$$S = 0.010 \times 1000 = 10\ m/km$$

Figure 2

Benson's Slope of the Study Area



The characteristics of the Yeniköprü Catchment were determined approximately as in Table 1.

Table 1

The Catchment Characteristics

Catchment Area, A (km^2)	Main Stream Length, L (m)	Elevation Difference H (m)	Catchment Slope S (m/km)
336	27300	410	10

Methodology

The study consists of three main sections as the rainfall analysis, the rainfall-runoff (RR) relationships and the flow frequency analysis.

First, the rainfall of the area must be analyzed to predict the runoff in streams having no gauging stations. The rainfall can be converted into streams with the help of RR relations and used in the design of water structures. The relations known as Intensity–Duration Frequency (IDF) curves are widely used in the design of engineering structures and have various calculating equations and formulas developed in literature (Chen, 1983; Koutsoyiannis et al., 1988). As the importance of the structure to be built grows, and structures that will cause serious damage in case of collapse, data with large return period should be used. As the return period increases, the magnitude of the rainfall intensity to be used also increases. The Gumbel distribution is generally used for rainfall frequency analysis (Chow et al., 1988). The annual maximum rainfall for each selected duration is taken from the rainfall records, and frequency analysis is then applied to the annual data. Frequency analysis test and distribution graphs according to Gumbel distribution of maximum rainfall of different durations are given in Figures 3 and 4, respectively. Rainfall intensity also depends on its duration. Duration of the rainfall increases, the total rainfall height increases, but intensity decreases. The relation $i=\Delta P/\Delta t$ gives the rainfall intensity (mm/h), in which Δt: rainfall duration (h), and ΔP: rainfall height during this duration (mm).

The second step is the determination of the RR relationship. For this aim, five different methods were used: Rational Method, McMath Method, Synthetic Method, Mockus Method and Snyder Method.

As a third step, frequency analysis was carried out by taking into account the Maximum Annual Instantaneous Flow (MAIF) values for each year of WMS numbered 25-010 of SWW, which was accepted as the starting point of the study area (DSİ, 1994). In the study, two well-known distribution functions for hydrological processes (Long-normal and Gumbel) were used for flow frequency analysis. These distributions were applied to the flow data based on Bayazıt et al. (2009) and Bayazıt (2011).

The details related to these methods are given in the Results and Discussion section.

Results and Discussions

Rainfall Analysis

Just a rainfall measurement station 17810 in Bitlis-Ahlat of the General Directorate of Meteorology (MGM, 2022) close to the study area has hourly total rainfall data for many years. Assuming the rainfall was distributed uniformly in the catchment and the IDF curves were obtained depending on the rainfall data.

Figure 3

Gumbel Distribution Test Results of Rainfall of Different Durations

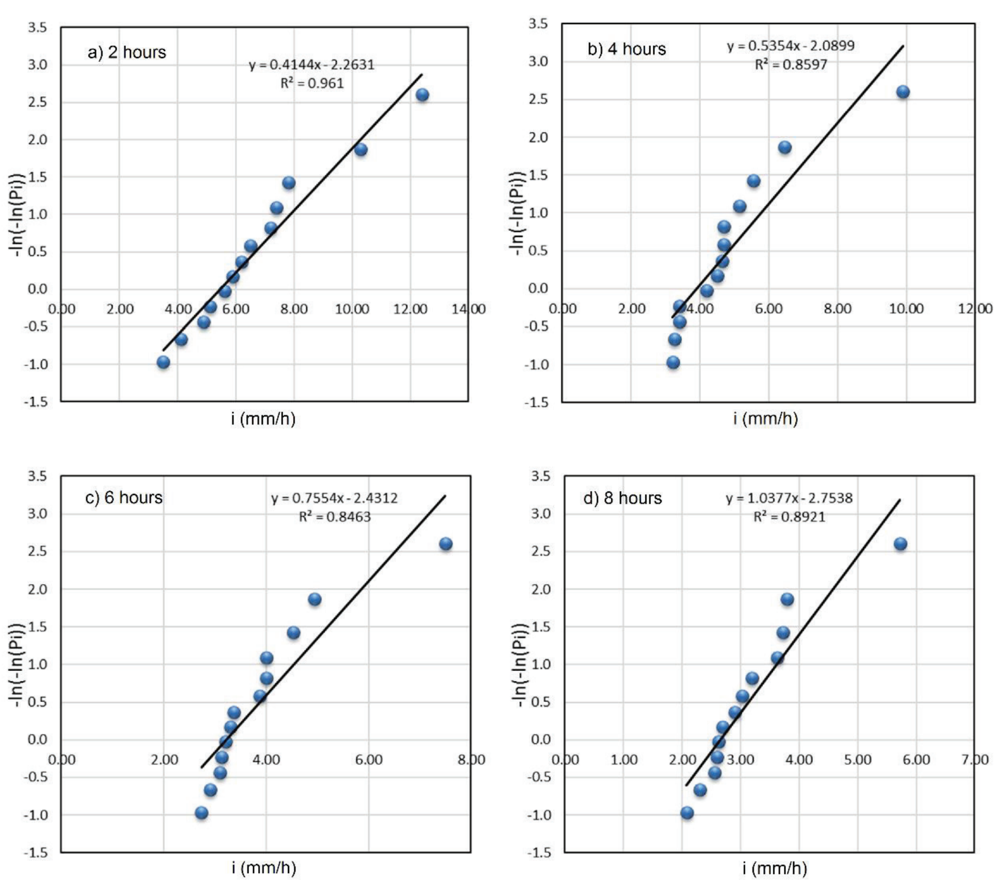


Figure 4

Gumbel Distribution Probability Density Function (PDF) and Cumulative Distribution Function (CDF) of Rainfall of Different Durations

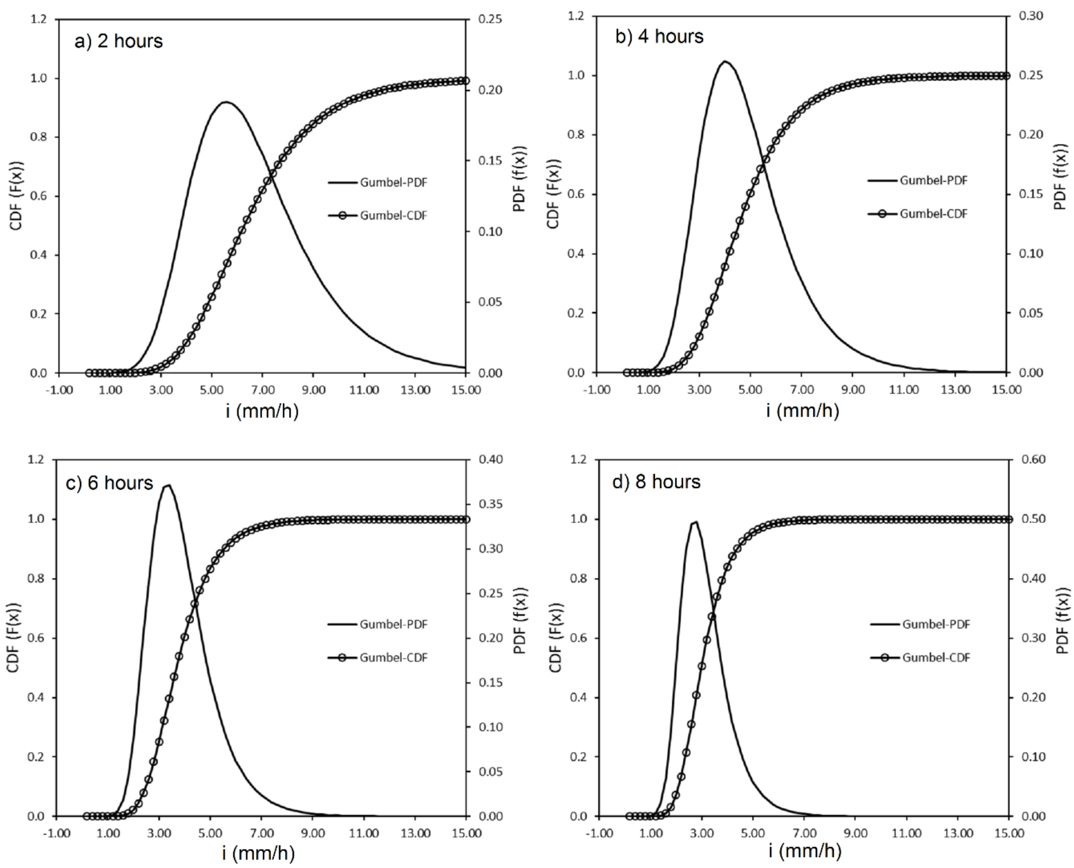
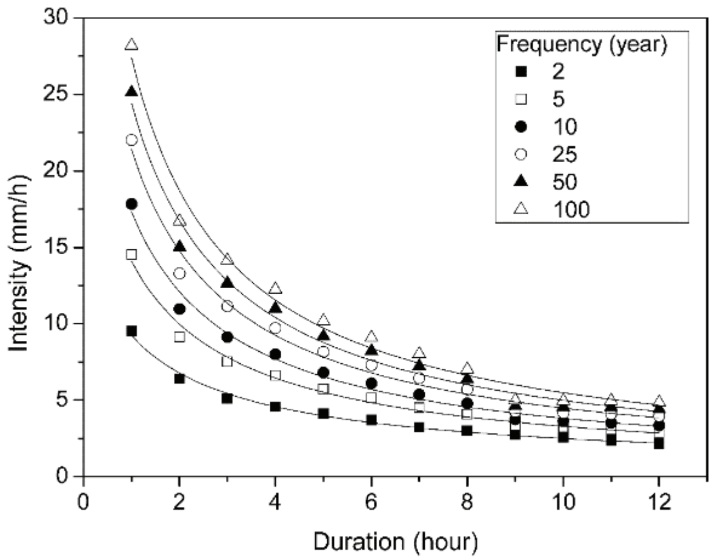


Figure 5

Intensity-Duration Frequency Relations of Station No: 17810



As shown in Figure 5, the intensity-duration frequency curves for Ahlat station were obtained with R^2=98-99% accuracy by the relation given with Eq. 1.

$$i = \frac{a}{(1+t)^b} \tag{1}$$

Where, *i*: rainfall intensity (mm/h), *t*: rainfall duration (h), *a* and *b* are coefficients depending on location and frequency, and the coefficients obtained by curve fitting for rainfall data are given in Table 2.

Table 2

Coefficients of Eq. 1 for Station No: 17810

T (year)	2	5	10	25	50	100
a	15.75	25.47	32.01	40.34	46.54	52.68
b	0.77	0.85	0.89	0.92	0.93	0.94

The data for Eq. (2) was obtained from Ahlat station and Eq. (2) was calculated by using the IDF relationship suggested by Chow et al. (1988) based on Wenzel's (1982) approach:

$$i = \frac{c \times T^m}{t + f} = \frac{23.23 \times T^{0.22}}{t + 1.33} \tag{2}$$

Here; *i*: rainfall intensity (mm/h), *t*: rainfall duration (h) *T*: frequency (year) and *c* and *f* are location dependent coefficients. The coefficients were calculated as *c*=23.23, *m*=0.22 and *f*=1.33 for station 17810 by curve fitting using the least-squares method. The compatibility of the function obtained with these coefficients with the real data was successful at the rate of R^2=98% (Figure 6). IDF relationship can also be given in logarithmic scale as in Figure 7, so that it can be easily read from the graphs. McCuen (1998) also determined a detailed mathematical representation of IDF curves.

Figure 6

Comparison of Equation (2) Calculation Values with Observation

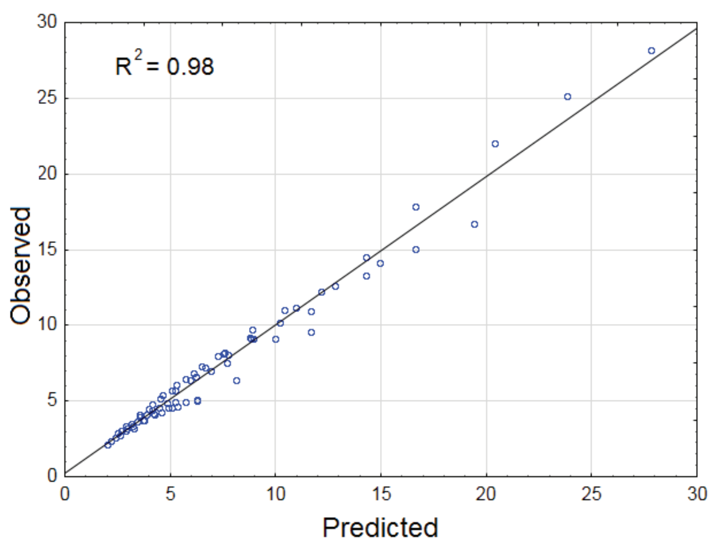
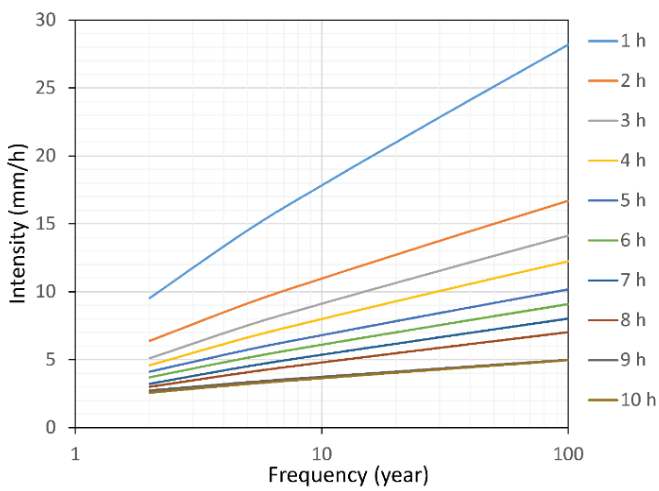


Figure 7

Intensity-Duration Frequency



RR Prediction Methods

Rational Method

The rational method, which dates back to the middle of the nineteenth century, is still a widely used method for the design of storm sewers today (Pilgrim, 1986; Linsley, 1986). The method is used with a maximum drainage area of 25 km^2 but it is generally used in drainage areas up to 15 km^2. According to some other references, this limit could be reduced to 1 km^2. Even though the investigated drainage area (336 km^2) is rather larger than its limit value, the method was used for testing its success in the study. The total discharge through the runoff during a rainfall is calculated by the following equation (Eq. 3) (Özbek, 1989).

$$Q = \frac{CiA}{3.6} \quad (3)$$

where, Q: discharge (m^3/s) i: rainfall intensity (mm/h), C: runoff coefficient, A: drainage area (km^2). Rainfall time will be taken as the time of concentration of the water. Time of concentration (T_c, min) can be calculated based on the maximum length of travel of water (L, m) and catchment slope (S) with the following set of equations (Eq. 4):

$$T_c = 0.0195K^{0.77}, K = \frac{L}{S^{1/2}} \quad (4)$$

$$K = \frac{27300}{0.010^{1/2}} = 273000, T_c = 0.0195 \times 273000^{0.77} = 300\ min = 5\ hours$$

The runoff coefficient (*C*) varies according to the catchment terrain and slope, and the flood frequency. Approximately 70% of the Yeniköprü catchment area is flat (<2%) and 30% is moderately sloped (2% - 7%) and consists mostly of cultivated land:

10 years flood C_{10} = 0.70 x 0.36 + 0.30 x 0.41 = 0.38

100 years flood C_{100} = 0.70 x 0.43 + 0.30 x 0.48 = 0.44

Runoff intensities corresponding to the time of concentration T_c=5 hours were calculated by the methods mentioned previously and showed in Table 3. From the Table 3, Equation (2) gave results closer to the values read from the curves in Figure 7 (prepared with the actual data). In other words, Equation (2) gave more successful results than Equation (1).

Table 3

The Rainfall Intensity Obtained by the Different Methods Corresponding the Concentration Time

Method	T_c (hour)	i_{10} (mm/h)	i_{100} (mm/h)
Equation (1)	5	6.50	9.78
Equation (2)	5	6.09	10.11
Figure 6	5	6.81	10.18

$$Q_{10} = \frac{0.38 \times 6.81 \times 336}{3.6} = 241\ m^3/s$$

$$Q_{100} = \frac{0.44 \times 10.18 \times 336}{3.6} = 418\ m^3/s$$

Depending on the Q_{10} and Q_{100} discharges, the discharge from Q_{500} was also calculated with the following equation (Eq. 5) (Kumanlıoğlu & Ersoy, 2018).

$$Q_T = Q_{10} + ZT \times (Q_{100} - Q_{10}) \tag{5}$$

$$ZT = 0.99 \times \log T - 0.98 = 0.99 \times \log 500 - 0.98 = 1.69$$

$$Q_{500} = 241 + 1.69 \times (780 - 241) = 540\ m^3/s$$

McMath Method

McMath (1887) method gives good results in determining the capacity of surface drainages on flat lands of any expanse. The flood discharge is calculated in m^3/s with the following equation (Eq. 6) (Özbek, 1989):

$$Q = 0.0023.C.i.S^{1/5}A^{4/5} \tag{6}$$

Here; C: a coefficient giving the catchment features depending on vegetation, soil and topography, i: rainfall intensity according to time of concentration and selected frequency (mm/h), S: catchment slope x 1000; A: catchment area or rainfall area (ha). The C coefficient was taken as C=0.30+0.12+0.06=0.48, with the vegetation cover of the land is bare (C_1=0.30), soil type is light (C_2=0.12) and topography is slightly inclined (C_3=0.06). The time of concentration T_c (min) was calculated as:

$$T_c = 0.0195 \times \left(\frac{L^3}{H}\right)^{0.385} \tag{7}$$

$$T_c = 0.0195 \times \left(\frac{27300^3}{410}\right)^{0.385} = 256\ min = 4.26\ hours$$

If the rainfall intensities corresponding to this time were calculated from Equation (2): i_{10}=6.90 mm/hour, i_{100}=11.45 mm/hour were obtained.

$$Q_{10} = 0.0023 \times 0.48 \times 6.90 \times 10^{1/5} \times 336000^{4/5} = 318\ m^3/s$$

$$Q_{100} = 0.0023 \times 0.48 \times 11.45 \times 10^{1/5} \times 336000^{4/5} = 528\ m^3/s$$

$$Q_{500} = 318 + 1.69 \times (528 - 318) = 673\ m^3/s$$

Synthetic Method

This method can be used to find flood discharges in rivers where long-term flow measurements are not available. The following steps are applied in the method (Özbek, 1989):

1. Rainfall periods leading to floods are predicted. The period was generally accepted as 2 hours. The rainfall intensity was multiplied by time to obtain rainfall height: P_{10}=2x10.98=21.96 mm, P_{100}=2x16.71=33.42 mm.

2. The curve number (CN) is determined from the relevant tables (SCS, 1972 and 1986) according to the land features and vegetation of the drainage area. It was considered CN=80 for this study.

3. Rainfall height (P) and runoff height (h_a) by curve number are obtained from RR curves. According to this; Rainfall and runoff heights were calculated for P_{10}= 21.96, h_a= 2 mm, and for P_{100}=33.42 mm, h_a= 8 mm.

4. Catchment features are determined such as drainage area and main stream length as in Table 1 for this study. The distance between the projection of the center of gravity of the rainfall area on the main collector and the point where the collector leaves the rainfall area was assumed to be (L_c) ≈ 8 km. Additionally, the harmonic slope, which is the slope of the catchment, was calculated and shown in Table 4 with the following equation.

5.

$$S = \left(\frac{10}{\sum \frac{1}{\sqrt{s_i}}} \right)^2 \tag{8}$$

6. q_p=35 lt/s.km^2.mm was obtained from synthetic unit hydrograph graphs with the help of $\frac{L \times L_c}{\sqrt{s}} = \frac{27.3 \times 8}{\sqrt{0.0102}} = 2162$ and area.

7. The discharge value is obtained by the following equation depending on the q_p:

$$Q = A \times q_p \times h_a \times 10^{-3} \tag{9}$$

$$Q_{10} = 336 \times 35 \times 2 \times 10^{-3} = 24\ m^3/s$$

$$Q_{100} = 336 \times 35 \times 8 \times 10^{-3} = 94\ m^3/s$$

$$Q_{500} = 24 + 1.69 \times (94 - 24) = 142\ m^3/s$$

Table 4

Harmonic Slope Calculations

No	Elevation (m)	Heigth h (m)	Distance L_i (m)	$S_i = h/L_i$	$(s_i)^{1/2}$	$1/(si)^{1/2}$
0	1777	-	-	-	-	-
1	1794	17	2730	0.0062	0.0789	12.67
2	1811	17	2730	0.0062	0.0789	12.67
3	1840	29	2730	0.0106	0.1031	9.70
4	1861	21	2730	0.0077	0.0877	11.40
5	1872	11	2730	0.0040	0.0635	15.75
6	1900	28	2730	0.0103	0.1013	9.87
7	1935	35	2730	0.0128	0.1132	8.83
8	1977	42	2730	0.0154	0.1240	8.06
9	2071	94	2730	0.0344	0.1856	5.39
10	2185	114	2730	0.0418	0.2043	4.89
		Total	27300			99.25
					S=	0.0102

Mockus Method

Mockus (1949) proposed a method for catchments without SMS. According to this method, it is stated that runoff estimates can be based on information and data such as soil, land use, previous rainfall, duration of storm, and average annual temperature. The time of concentration is calculated in hours with the following equation according to this method (Özbek, 1989).

$$T_c = 0.00032\frac{L^{0.77}}{S^{0.385}} \quad (10)$$

Here, for L= 27300 m and S=0.0102, T_c=4.87 hour, unit downpour time D (hour):

$$D = 2\sqrt{T_c} = 2 \times \sqrt{4.87} \cong 5\ hours$$

In practice, the nearest integer greater than D is taken for the rainfall time (hours) corresponding to the time of concentration. However, if $T_c \leq 1, D = 1$ was taken. The time of rise of the hydrograph was: $T_p = 0.5D + 0.6T_c = 0.5 \times 5 + 0.6 \times 4.87 = 5.42\ hours$.

The recession time of the water: $T_r = 1.67T_p = 1.67 \times 6.7 = 9.05\ hours$ the flood period: $T_s = T_p + T_r = 5.42 + 9.05 = 14.5\ hours$, D= 5 hours of rainfall versus rainfall heights: for i_{10}= 6.81 mm/hour, P_{10}=5x5.74=34.05 mm, for i_{100}=10.18 mm/hour, P_{100}= 5x10.18=50.90 mm. If CN=80 was taken, from the RR curves: for P_{10}=34.05 mm, h_a=6 mm, and for P_{100}=50.90 mm, h_a=15 mm were found (Bayazıt et al., 2009). Accordingly, peak flood discharges were calculated with the following equation.

$$Q_p = \frac{0.208 \times A \times h_a}{T_p} \tag{11}$$

$$Q_{10} = \frac{0.208 \times 336 \times 6}{5.42} = 77\ m^3/s$$

$$Q_{100} = \frac{0.208 \times 336 \times 15}{5.42} = 193\ m^3/s$$

$$Q_{500} = 77 + 1.69 \times (193 - 77) = 273\ m^3/s$$

Snyder Method

Snyder (1938), who conducted a study of catchments ranging in size from about 10 to 10,000 mi^2 (30 to 30,000 km^2) in the Appalachian Highlands of the United States, found synthetic relationships for some properties of the standard unit hydrograph. It can be applied by dividing large catchments into small areas. This method was applied as follows (Özbek, 1989).

Peak time of the hydrograph in hours is calculated by the following equation (Eq.12):

$$T_p = C_t \times (L \times L_c)^{0.30} \tag{12}$$

C_t is a coefficient depending on the soil type and was taken from Table 5 given below (C_t=1.50).

$$T_p = 1.50 \times (27.3 \times 8)^{0.30} = 7.5\ hours$$

Table 5

C_t Coefficients Depending on Soil Type (Özbek, 1989)

Soil Type	C_t	C_p
Very Sandy	1.65	0.56
Moderately sandy clay	1.50	0.63
Very clayey or rocky	1.35	0.69

Downpour time per unit hydrograph, T_y, was calculated as follows and taken as the nearest hour.

$$T_r = T_y = \frac{T_p}{5.5} = \frac{7.5}{5.5} = 1.36 \cong 1\ hour$$

By taking C_p=0.63 from Table 5, drainage efficiency was calculated with the following equation (Eq. 13).

$$q_v = 276 \times \frac{C_p}{T_p} \tag{13}$$

$$q_v = 276 \times 0.63/7.5 = 23.2\ lt/s/km^2/mm$$

Unit hydrograph peak discharge:

$$q_p = A \times q_v \times 10^{-3} = 336 \times 23.2 \times 10^{-3} = 7.80\ m^3/s.m$$

Unit hydrograph volume:

$$V_b = A \times 1 \times 10^3 = 336 \times 10^3\ m^3$$

The hydrograph time is calculated by the equation below (Eq.14).

$$T_s = 3 + \frac{3T_p}{24} \tag{14}$$

T_{w75} and T_{w50} values were read from the Snyder chart, depending on their q_v values (for $0.75q_p$ and $0.50q_p$). Rainfall intensity versus T_y=1-hour duration was read from the IDF curves and flow heights were found. If the runoff heights corresponding to this flow height were obtained from the RR chart according to the curve number (CN=80): for i_{10}=17.84 mm/h and P_{10} = 2x17.84 = 35.68 mm, and for i_{100}=28.19

mm/h and P_{100} = 2x28.19 = 56.38 mm, h_a≈6 mm and h_a≈16 mm were obtained, respectively. Accordingly, flood peak discharges:

$$Q_{10} = A \times q_v \times h_a \times 10^{-3} = 336 \times 23.2 \times 6 \times 10^{-3} = 47\, m^3/s$$

$$Q_{100} = A \times q_v \times h_a \times 10^{-3} = 336 \times 23.2 \times 16 \times 10^{-3} = 125\, m^3/s$$

$$Q_{500} = 47 + 1.69 \times (125 - 47) = 179\, m^3/s$$

Flow Frequency Analysis

Lognormal Distribution Function

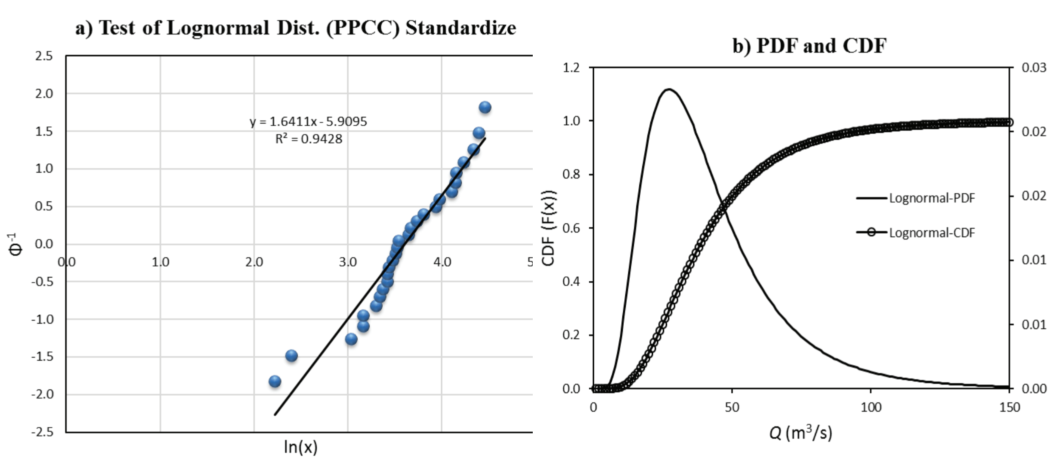
Hydrological variables generally are skewed distribution. Since it has only positive values and the distribution is skewed (C_s>0), this distribution is frequently used for hydrological variables. Lognormal distribution results are given in Figure 8 by using the MAIF values of numbered 25-010 SWW for WMS.

According to the Lognormal distribution, the peak flood discharges of this station were:

$$Q_{10} = 73\, m^3/s\, , Q_{100} = 129\, m^3/s, Q_{500} = 174\, m^3/s$$

Figure 8

Lognormal Distribution Function

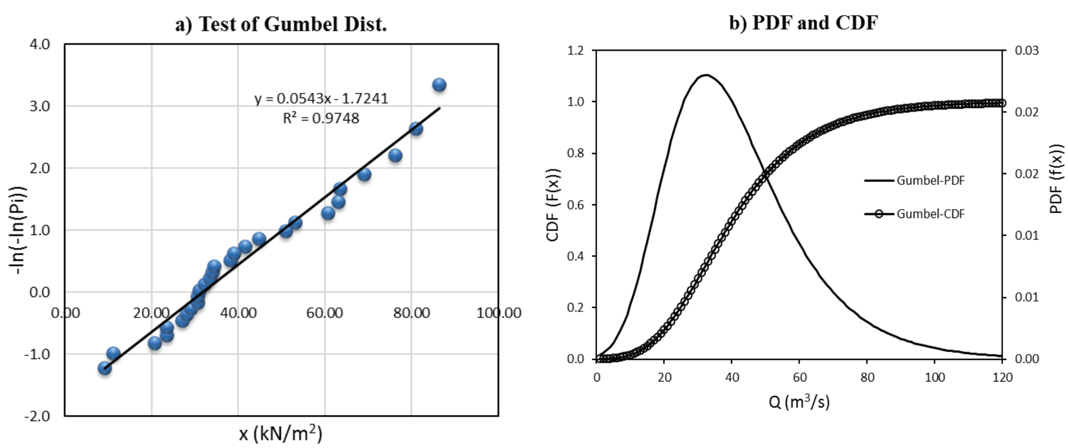


Gumbel Distribution

Another widely used skew distribution function in hydrology is the Gumbel Distribution. Gumbel Distribution results are given in Figure 9 by using the MAIF values of numbered 25-010 SWW for WMS.

Figure 9

Gumbel Distribution



According to the Gumbel distribution, the peak flood discharges of this station were:

$$Q_{10} = 73\ m^3/s, Q_{100} = 117\ m^3/s, Q_{500} = 147\ m^3/s$$

The results obtained by applying the methods are summarized comparatively in Table 6. The first five methods in Table 6 are direct methods based on precipitation data, while the last two are direct methods based on flow measurement data. The WMS values in the 6th and 7th lines of the table can be used as a reference since they are obtained from the actual flow measurement values.

Table 6

Comparison Table of Peak Flood Discharges

No	Methods	Flood Discharges (m^3/s)		
		Q_{10}	Q_{100}	Q_{500}
1	Rational Method	241	418	540
2	Mc-Math Method	318	528	668
3	Synthetic Method	24	94	142
4	Mockus Method	77	193	273
5	Snyder Method	47	125	179
6	WMS-Lognormal	73	129	174
7	WMS-Gumbel	73	117	147
	Average	122	229	303
	Max. Q	318	528	668

Conclusion

The performances of the methods frequently used in the practice to determine peak flood discharge in rivers were evaluated in this study. It focused on calculating the flood discharge in rivers with limited measured data. For this purpose, the study evaluated under three main section as the rainfall analysis, the rainfall-runoff (RR) relationships and the flow frequency analysis. The study was performed using indirect (RR analysis) and direct (flow-frequency analysis) approaches in a designated area to determine the performance of the methods. According to the results of the study;

The methods with highest values were the Mc-Math and Rational Methods. It was already stated that the Rational Method would not be appropriate for the given catchment scale (336 km^2). However, it can be said that the Mc-Math method, which gives higher values than the Rational Method, does not give appropriate values in these catchment scales. The method with lowest value was the Synthetic Method. Therefore, it can be said that the Synthetic Method can yield smaller values than expected for a basin of this scale. Although the Snyder Method gave results that are close to WMS values, especially in 500-year return-period, the accuracy of this method was very sensitive to the selected parameters, so care should be taken in its use. Among these methods, it was seen that the Mockus method was the most reliable. Although it gave higher results than WMS values at high return-periods, it can be said that this method gave better results than other methods, since it remained on the safe side. In line with these explanations, the methods in the 3rd, 4th and 5th rows in Table 6 can be used for medium-sized basins for which flow data are not available or limited. As another approach, these results may be averaged after eliminating the extreme values as frequently used in statistics. In future studies, the methods used in this study can be applied in larger and smaller basins in order to see model performances.

Acknowledgement

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Akarsulardaki Taşkın Debilerinin Farklı Yöntemlerle Tahmini Üzerine bir Durum Çalışması

Akarsu havzaları en büyük eğim doğrultusunda yüzeysel suları bir ağ şeklinde toplayarak ana kol (dere, çay, nehir gibi) halinde deniz ve göllere aktaran sistemlerdir. Diğer bir ifadeyle yağışları akışa çeviren operatörlerdir. Su toplama havzaları, drenaj alanı olarak da adlandırılan akarsu havzaları bu özellikleriyle su ayrım çizgisi denilen kesin sınırlarla birbirilerinden ayrılırlar. Akarsuların taşkın debileri drenaj havzalarının özellikleriyle yakından ilişkilidir. Havza alanı, havzanın ortalama eğimi, şekil faktörü, çatallaşma oranı gibi özellikler havzaları karakterize eden önemli özellikleridir. Bununla birlikte havzadaki bitki örtüsü, toprak yapısı, yağış tekerrür aralıkları, yağış şiddeti gibi parametreler de yağışların taşkına dönüşmesinde en önemli etkenler olarak nitelendirilir. Baraj hazne işletmesi, su kuvvetleri tesisleri, akarsu düzenlemesi ve taşkın koruma yapılarının hesap ve tasarımları için akarsuların getirebileceği maksimum debilerin tespiti gerekir. Bazı tasarımlar için yıllar içinde gözlenen en büyük debiler tasarım debisi olarak kabul edilebilirken, taşkınların önemli olduğu mühendislik tasarımlarının çoğunda ölçülmesi mümkün olmayacak zaman aralıklarındaki tekerrür debilerinin bilinmesi istenir. Bu debiler bazı istatistik yöntemler ve/veya tecrübe formülleriyle belirlenebilir. Bunlar, mühendislik uygulamasının önemine göre 50, 100 ve 500 yılık tekerrürlü debiler olabilmektedirler. Debi ölçümleri DSİ tarafından akarsu üzerine kurulan akım gözlem istasyonları (AGİ) aracılığıyla yapılmaktadır. Bu ölçümler anlık, günlük, haftalık, aylık ve yıllık olarak kayıt altına alınmaktadır. Ancak özellikle, dere ve çay sınıfında bazı akarsularda bu ölçümler ya hiç yapılmamakta ya da yeterli miktarda veri elde edilmemektedir. Bu gibi akarsuların taşkın debilerinin ölçülmesinde Rasyonel Yöntem, Mc-Math Yöntemi, Sentetik Yöntem, Mockus Yöntemi, Snyder Yöntemi gibi çeşitli yöntemler geliştirilmiştir. Bu yöntemlerin kullanımında öncelikle yağış verilerinin elde edilmesi ve analiz edilmesi oldukça önemlidir. Diğer önemli bir husus da yağışın akışa geçmesinde etkili parametrelerin belirlenmesidir. Akış yüksekliklerinin belirlenmesi için arazi yapısı, eğimi, bitki örtüsü gibi etkenlere göre akış katsayısı, yağış-akış gibi ilişkilerin bilinmesi gerekir.

Bu çalışmada, bir akarsuya ait taşkın debileri çeşitli dolaylı yöntemler ve akış verilerine dayalı doğrudan yöntemlerle belirlenmeye çalışılarak yöntemlerin performansları değerlendirilmiştir. Bu çalışmanın konuyla ilgili uygulamada çalışanlar ve ihtiyaç duyanlar için bir rehber olması amaçlanmıştır. Çalışma alanı olarak Van Gölü kapalı havzası içerisindeki Ahlat ilçe sınırlarındaki Yeniköprü Çayı havzası seçilmiştir. Çıkış noktası, Süfresur Deresi üzerinde Kınalıkçı Köyü mevkii 1769 m kotundaki DSİ'ait 25-010 Akım Gözlem İstasyonu (AGİ) kabul edilerek havzanın 336 km^2'lik drenaj alanı dikkate alınmıştır. Çalışmada, yapılan tahminler ile gerçek akım verilerinin, frekans analizleri kullanılarak karşılaştırılması amaçlanmıştır. Bu noktaya yakın DSİ'nin 25-010 numaralı AGİ'ye ait 1963-1990 yılları arası 28 yıllık Yılda Anlık Maksimum Akım (YAMA) verileri temin edilmiştir. Nemrut Kalderası nedeniyle volkanik bir yapıya sahip olan çalışma alanı nispeten düzlük bir alandır ve zaman içinde tarımsal kullanıma açılmıştır. Akarsuyun ana kolunun uzandığı kuzeydoğu vadileri havzanın diğer kesimlerine göre daha fazla dağlık ve eğimlidir.

Akım istasyonu olmayan akarsulardaki akışları tahmin etmek için öncelikle bölgenin yağış verilerinin analiz edilmesi gerekir. Elde edilecek yağış verileri yağış-akış ilişkileri yardımıyla akışa çevrilerek su yapılarının tasarımında kullanılabilir. Şiddet – Zaman – Tekerrür (Intensity – Duration Frequency, IDF) eğrileri olarak bilinen bağıntılar mühendislik sistemlerinin tasarımında oldukça

yaygın olarak kullanılmaktadır. Yapılacak yapının önemi büyüdükçe ve yıkılması durumunda ciddi zararlara neden olacaksa tekerrür aralığı büyük seçilmelidir. Tekerrür süresi büyüdükçe kullanılacak yağış şiddetinin büyüklüğü de artar. Yağış tekerrür analizlerinde genel olarak Gumbel dağılımı kullanılır (Chow vd., 1988). Seçilen her süre için yıllık maksimum yağış yüksekliği yağış kayıtlarından çıkarılır ve daha sonra frekans analizi yıllık verilere uygulanır. Farklı süreli maksimum yağışların Gumbel dağılımına göre frekans analizi test ve dağılım grafiklerine de çalışmada yer verilmiştir. Yağış şiddeti ayrıca yağış süresine bağlıdır. Süregelen yağış süresi arttıkça toplam yağış yüksekliği artar fakat yağış şiddeti azalır.

Çalışma alanına yakın Meteoroloji Genel Müdürlüğü'nün Bitlis-Ahlat ilçesindeki 17810'nolu yağış ölçüm istasyonunun uzun yıllara ait saatlik toplam yağış verileri mevcuttur. Çalışmada bu yağışların havzaya üniform dağıldığı kabul edilerek Şiddet – Süre – Tekerrür eğrileri yağış verilerine bağlı olarak elde edilmiştir. Çalışmada ayrıca farklı yöntemlerle elde edilen farklı tekerrürlü taşkın pik debileri tablolar ile karşılaştırmalı olarak verilmiştir. Bu tablolarda AGİ değerleri gerçek akım ölçüm değerlerinden elde edildiğinden referans olarak kullanılabilir. Sonuç olarak, elde edilen değerler arasında en yüksek değerleri veren metotlar Mc-Math ve Rasyonel Yöntemler olmuştur. Rasyonel Yöntemin verilen havza ölçeğinde (336 km^2) uygun olmayacağı bir gerçektir. Ancak çalışmada bu yönteme de yer verilerek çıkan sonuçlar karşılaştırılmıştır. Çalışmada, Rasyonel Yönteme göre daha büyük değerler veren Mc-Math yönteminin de bu havza ölçeğinde uygun değerler vermediği tespit edilmiştir. Kullanılan metotlar arasında en düşük değeri veren metot ise Sentetik Metot olmuştur. Dolayısıyla bu ölçekteki bir havza için Sentetik yöntemin beklenenden daha küçük değerler verebileceği söylenebilir. Snyder Yöntemi özellikle 500 yıllık tekerrürde AGİ değerlerine yakın sonuçlar verse de bu yöntemin doğruluğu seçilen parametrelere çok fazla duyarlı olduğundan kullanımı dikkat gerektirmektedir. Kullanılan tahmin yöntemleri arasında en güvenilir sonuç veren ise Mockus Yöntemi olmuştur. Bu metot her ne kadar yüksek tekerrür sürelerinde AGİ değerlerinden büyük sonuçlar verse de güvenli tarafta kaldığından bu yöntemin diğer yöntemlere göre daha iyi sonuç verdiği söylenebilir. Bu açıklamalar doğrultusunda akım ölçümleri yapılmayan orta ölçekli havzalar için kullanılacak yöntemler belirtilmiştir. Bir başka yaklaşım olarak uç değerleri çıkartıp ortalama değeri kullanmak da istatistikte sıkça kullanılan bir yoldur.

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Research Article

Development of A Multimetric Index Based on Benthic Macroinvertebrates for Rivers (BMIR) in Türkiye

Türkiye'deki Nehirler İçin Bentik Makroomurgasızlara Dayalı Bir Multimetrik İndeks (BMIR) Geliştirilmesi

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Abstract

Stream types determined according to altitude, slope and alkalinity in six different hydrobiogeographic regions of Türkiye were taken as the basis of the study. In line with the European Water Framework Directive, a macroinvertebrate-based multimetric method was tested for Turkish rivers as a potential assessment. In this study, benthic macroinvertebrate data (1875 taxa obtained from 1925 stations with reference points) were used to create a multimetric index for all river types in the hydrobiogeographic regions of Türkiye. Nine biological metrics were evaluated and index development criteria were chosen to capture meaningful results at the ecosystem, community, and individual levels. The metric combinations were chosen to show the best distinction between areas with no or only very minor anthropogenic disturbances and stressed areas (with discrimination efficiency values). The multimetric index including three different metrics from three different metric categories distinguishes reference or slightly distorted areas from stressed areas with an efficiency close to 100%. Index values were divided at a five-scale system between one (High) and zero (Bad) for biological evaluation. Further testing and research can be done so that the index will provide a more useful result as a bioassessment tool for decision-makers in hydrobiogeographic regions. Also, the index can provide a basis for methods by which river status is assessed based on stress factors.
Keywords: *Türkiye, EU Water Framework Directive, benthic macroinvertebrates, multimetric index, streams*

Öz

Türkiye'nin altı farklı hidrobiyocoğrafik bölgesinde rakım, eğim ve alkaliniteye göre belirlenen akarsu tipleri çalışmada temel alınmıştır. Avrupa Su Çerçeve Direktifi ile uyumlu potansiyel bir değerlendirme olarak Türkiye nehirleri için makroomurgasız tabanlı bir multimetrik yöntem test edilmiştir. Bu çalışmada, Türkiye'nin hidrobiyocoğrafik bölgelerindeki tüm nehir tipleri için bir multimetrik indeks oluşturmak amacıyla 1925 istasyondan, referans noktaları dahil, 1875 takson içeren bentik makroomurgasız verileri kullanılmıştır. Ekosistem, komunite ve bireysel düzeylerde anlamlı sonuçlar elde etmek için dokuz biyolojik metrik değerlendirilmiş ve indeks geliştirme kriterleri seçilmiştir. Metrik kombinasyonları, antropojenik etkilerin hiç olmadığı veya çok küçük

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olduğu alanlar ile stresli alanlar arasındaki en iyi ayrımı (ayrışma değerleriyle) gösterecek şekilde belirlenmiştir. Üç farklı metrik kategorisinden üç farklı metriği içeren multimetrik indeks, %100'e yakın bir verimlilikle referans veya hafif stresli alanları stresli alanlardan ayırır. İndeks değerleri biyolojik değerlendirme için bir (Çok iyi) ve sıfır (Kötü) arasında beş ölçekli bir sisteme bölündü. İndeksin hidrobiyocoğrafik bölgelerdeki karar vericiler için bir biyo-değerlendirme aracı olarak daha faydalı bir sonuç sağlaması için daha fazla test ve araştırma yapılabilir. Ayrıca indeks, stres faktörlerine dayalı olarak nehir durumunun değerlendirildiği yöntemler için bir temel sağlayabilir.

Anahtar sözcükler: *Türkiye, su çerçeve direktifi, bentik makroomurgasızlar, multimetrik indeks, akarsular*

Introduction

The EU Water Framework Directive (WFD) (The EU Water Framework Directive [WFD], 2000/60/EC) demands member states and other participating countries to prevent further degradation, conserve and advance the condition of surface waters and recover all categories of water bodies that are not in good ecological status. For sustaining the aquatic ecosystems which harbour biodiversity and provide the services and products that humans rely on, good ecological status is essential (Munné et al., 2015; Everard, 2012). Introducing reference conditions as a unifying concept for not heavily modified water bodies enables the determination of ecological status. In the WFD assessment, the relationships between the biota and the hydromorphological and chemical components are used to determine the ecological status of water bodies. The WFD requires that bioassessments to be stated as a proportion (Ecological Quality Ratio, EQR) at a five-grade framework ranging between 0 (Bad) and 1 (High). The EQR is the ratio of the observed value for a given water body type to the expected value for the same types under reference conditions. Benthic macroinvertebrates, macrophytes, diatoms, phytoplankton, and fish are used in the biological assessment to determine the ecological quality status of surface water bodies according to the WFD. Benthic invertebrates have long been employed to evaluate the impacts of human-based activities in coastal, transitional and freshwater habitats and are known to be susceptible to varying degrees of local disturbance (Zeybek, 2017; Birk et al., 2012; Hellawell, 2012; Medeiros et al., 2012; Borja et al., 2011; Chainho et al., 2008; Chaves et al., 2005). In the implementation of the WFD the parameters (i) taxonomic composition and abundance, (ii) diversity, and (iii) ratio of disturbance sensitive to insensitive species for benthic macroinvertebrate quality element should be addressed.

Biological indices, which are aimed to be developed based on three basic approaches, are used to evaluate biological integrity: the first step is regionalization (Omernik, 1987, 1995), the second step is a multimetric approach (Barbour et al., 1996; Davis & Simon, 1995; Karr et al., 1986; Karr & Dudley, 1981) and third, the determination of reference conditions (Hughes, 1995; Hughes et al., 1986).

Regionalization is the categorization of ecologically separate units based on physiography, soil type, climate, vegetation, geology, and land use. The presupposition that geophysical settings together with biogeographic processes are ecologically beneficial classification, is one of the pillars of regionalization (Karr & Chu, 1999). The geographical distinction of homogeneity within region and heterogeneity between regions has become a fundamental aspect of bioassessment (Hawkins et al., 2010; Hawkins & Norris, 2000). To establish a similar basis in ecological assessment, the final classification level must meet sufficient classes and provide a means of demonstrating the biological status of an area. Measurements must incorporate a variety of factors due to complex biological systems and major anthropogenic impacts on aquatic populations. The individual, community, and landscape-scale metrics are some of these numerous aspects. Individual measurements, or metrics, may be generated from functional traits like feeding patterns and life histories, structural components of communities like species composition and abundance, and measures of condition (e.g. presence or absence of tolerant organisms and individual health). Multimetric indices are made up of ecologically based measurements with recognized reactions to disturbances brought on by human (Sorrano et al., 2011; Butcher et al., 2003). The ratio of the observed assessment value to the expected value is utilized as the reference condition for determining the degree of anthropogenic effect. Reference conditions are defined as basic measurements of ecological variables that represent an ecosystem where there is no anthropogenic impact or at a level of concern (Stoddard et al., 2006; Miller et al., 1988). Land use, the physicochemical features of water bodies, habitat quality, monitoring data on water quality, and expert opinion can be used to quantify reference conditions in determining ecological status (Pardo et al., 2012; Herlihy et al., 2008; Whittier et al., 2007).

There is a need for the establishment of stream typology and the creation of an evaluation system based on a multimetric index emerges with the implementation of the WFD. As a EU candidate country, Türkiye requires an assessment method that reveals the quality status of aquatic ecosystems concerning benthic macroinvertebrates. In light of the WFD's implementation, the creation of a new multimetric index has been planned. When determining the state of an ecosystem, a multimetric index uses more than one variable (metric). These metrics, which evaluate ecosystem quality from different aspects, are combined into a single index value. The advantages of multimetric indices are that they are adaptable, convenient to add and eliminate metrics, and that the metric scoring system can be easily changed (Gabriels et al., 2010). Many countries have established multimetric indices that use different organisms, including macroinvertebrates, to assess natural and unnatural effects on water quality, and there are some studies in this direction in

Türkiye as well (Odabaşı et al., 2022; Akay & Dalkıran, 2020; Dügel, 2016; Allan, 2004; Barbour et al. 1996). Therefore, the development of a type-specific multimetric index based on macroinvertebrates for Turkish rivers is a potential mean to meet WFD requirements. The new index, known as the Benthic Macroinvertebrate Multimetric Index for River (BMIR), enables the score criteria to be modified for each river type in all hydrobiogeographic regions to reflect the relative distance to the reference conditions. This document provides an overview of the BMIR and its development process for all river types in Türkiye.

The objectives of this study include: (1) to determine reference conditions for the river types in hydrobiogeographic regions based on the benthic macroinvertebrate community and (2) to develop a multimetric index for benthic macroinvertebrate communities using metrics.

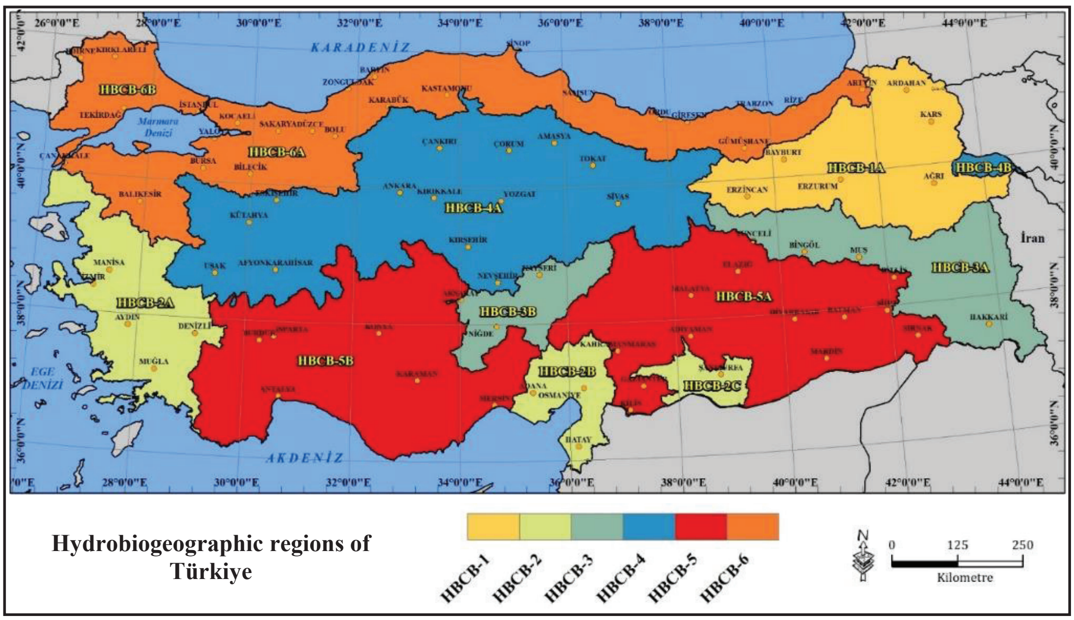
Methods

Hydrobiogeographic Regions and Typology

The hydrobiogeographic regions and typologies of streams of Türkiye were determined with the project named Digitizing Water Resources, Preparation of Monitoring Programs by Performing Typology, Water Body, and Risk Assessment (Digitizing Project, 2022). This project was carried out by the General Directorate of Water Management between 2017-2021. Within the scope of the project, water bodies and water body typologies were determined using the water resources base created in the project, and the basin monitoring programs were updated by determining the risk situation based on pressure for each water body. According to the Digitizing Project (2022), in the regionalization study carried out in Türkiye, meaningful abiotic factors determining the habitat conditions of aquatic organisms were determined and used to reflect the structure and functioning of the aquatic ecosystems more accurately. As a result of the regionalization studies carried out with the determined five significant abiotic factors (average temperature, relative humidity, sunshine intensity, closure, and altitude), six hydrobiogeographic regions were obtained (Fig. 1). In this study, these six hydrobiogeographic regions determined for Türkiye were used.

Figure 1

Map of Türkiye

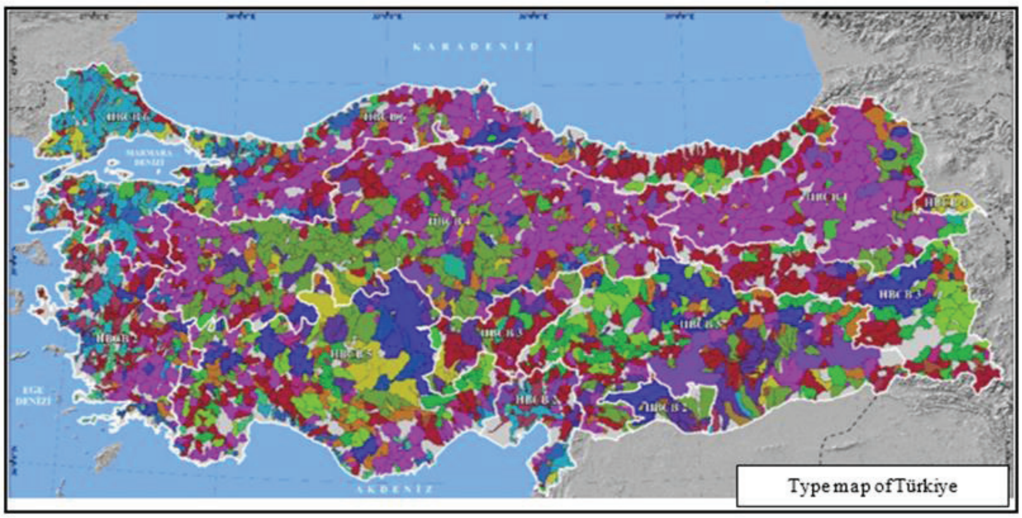


Note. Adapted from "Digitizing Project, 2022."

Type criteria (altitude, slope, and alkalinity) by selecting benthic macroinvertebrates distributed in the rivers of each hydrobiogeographic region and their associated, significant abiotic environmental parameters, were determined in the Digitizing Project (2022). Class boundary values of the types were determined for each hydrobiogeographic region, taking into account the environmental parameter ranges preferred by benthic macroinvertebrates, as well as the groupings (aggregations) that occur while dispersing within these ranges and the breaking points of these aggregations (Digitizing Project, 2022). The BMIR is a hydrobiogeographic region-based type-specific index, which means that index calculation depends on the type of river a sampling site belongs to. The river typology system in Türkiye (Fig. 2) developed by the project named Digitizing Project (2022) was used in this study.

Figure 2.

Map of River Types of Türkiye's Hydrobiogeographic Regions



Note. Adapted from "Digitizing Project, (2022)".

An overview of the types used in BMIR, class limits, features and abbreviations are presented in Table 1.

Table 1

The Types of Rivers in The Hydrobiogeographic Regions as Used Within The BMIR, and Class Boundaries

	Hydrobiogeographic Region-1			Hydrobiogeographic Region-2			Hydrobiogeographic Region-3		
Types	ABX, BAB, BAX, BBA, BBB, BBX, CBA, CBB, CBX			AAA, AAB, AAX, ABA, ABB, ABX, BAA, BAB, BAX, BBA, BBB, BBX, CBA, CBB, CBX			BAA, BAB, BAX, BBA, BBB, BBX, CAB, CAX, CBA, CBB, CBX		
Class boundaries	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
altitude (m)	<800	800-2500	>2500	<400	400-1300	>1300	<800	800-2000	>2000
slope (%)	<6	>6		<9	>9		<6	>6	
alkalinity (mg $CaCO^3$/L)	<60	>60		<200	>200		<170	>170	

Table 1

(Continued)

	Hydrobiogeographic Region-4			Hydrobiogeographic Region-5			Hydrobiogeographic Region-6		
Types	AAB, AAX, ABA, ABB, ABX, BAA, BAB, BAX, BBA, BBB, BBX			AAA, AAB, AAX, ABA, ABB, ABX, BAA, BAB, BAX, BBA, BBB, BBX, CAA, CAB, CAX, CBA, CBB, CBX			AAA, AAB, AAX, ABA, ABB, ABX, BAA, BAB, BAX, BBA, BBB, BBX, CBA, CBB, CBX		
Class boundaries	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
altitude (m)	<600	600-2500	>2500	<500	500-1300	>1300	<400	400-1500	>1500
slope (%)	<8	>8		<8	>8		<10	>10	
alkalinity (mg $CaCO^3$/L)	<130	>130		<150	>150		<120	>120	

Note. Adapted from "Digitizing Project, (2022)".

In triple-type notation, the first letter represents altitude, the second is slope, and the last is alkalinity parameter. X was used for the parameters whose class values could not be determined.

Sampling, Sorting, Identification and Counting

Data were handed from the Türkiye National Monitoring Program of surface water quality, supplied by the General Directorate of Water Management, Republic of Türkiye the Ministry of Agriculture and Forestry. The data on benthic macroinvertebrates between the years 2014-2020 for analyses were used. The collected data are at family, genus and species level. Altogether, 1875 taxa from 1925 monitoring sites were analyzed.

Sampling is done in spring and late summer or early autumn. To provide a reliable water quality assessment, it is recommended to avoid macroinvertebrate sampling during the winter months to avoid extreme conditions such as both the hydrological regime and temperature. Per-site samples are taken in different seasons using a multi-habitat approach (Biological Monitoring Communiqué, 2019; Hering et al., 2004). A multihabitat method is used as the sampling method, in which the main habitats covering more than 5% area in the sampling area are proportionally sampled. Benthic macroinvertebrates are systematically gathered from all in-river habitats in the sample area. A total of 20 samples are taken from the microhabitats detected in the sampling area and an area of approximately 1.25 m^2 is sampled. For example, if 50% of the in-river microhabitats are gravel, 10 sampling samples are taken from that microhabitat. It is ensured that all living individuals obtained are identified at the species level as much as possible. A list of all taxa taken into consideration for the BMIR is consisting of 1875 taxa. For each identified taxon, the number of individuals sampled and the number of individuals per square meter in that sample are recorded. The database contained taxa lists of the macroinvertebrate fauna with the number of individuals per square meter and data on hydrobiogeographic region and river types of each site. The measurements in the database are divided by hydrobiogeographic regions and river types in hydrobiogeographic regions respectively.

Metric Selection and Calculation of Metrics

ASTERICS (AQEM/STAR Ecological River Classification System) program with a large number of metrics such as richness/diversity metrics, composition/abundance metrics, and sensitivity/tolerance metrics (Furse et al. 2006; The Development and Testing of an Integrated Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates [AQEM], 2002) were reviewed.

Various monitoring studies have been carring out in accordance with the EU Water Framework Directive in order to determine both reference and degraded areas (e.g Project on Establishment of Reference Monitoring Network in Türkiye [Reference Project], 2020) and appropriate metrics in Türkiye, and multimetric indices containing different metrics have been developed for eight of twenty five river basins (Dügel 2016; Akay & Dalkıran, 2020). In the multimetric index development process, metrics in ASTERICS, which were assigned by Dügel (2016) for the eight basins were used. These evaluated and analyzed candidate metrics were given in Table 2. The requirements for these metrics to be able to make calculations (e.g. ecological trait scores of taxon, tolerance scores, etc.) were examined.

Table 2

The List of the Metrics Evaluated and Analyzed Firstly

Candidate metrics	Metric type
Biological Monitoring Working Party, BMWP (1978) Spanish version (BMWP-S)	Tolerance / intolerance measures
Shannon-Wiener (H') (1949)	Diversity measures
Margalef (1951)	Diversity measures
%EPT	Composition measures
%Type Aka Lit Psa	Substratum type measures
%Epirithral	Zonation measures
%Littoral	Zonation measures
%Hyporithral	Zonation measures
%Grazers-scrapers	Functional/Trophic measures

Using the biological data (taxa lists, abundance) nine candidate biological metrics were calculated in all hydrobiogeographic regions. The software package Excel Data Analysis ToolPak was used for metric calculation, statistical analysis, and graphical visualization. For metrics operating at the species level, taxa identified at the genus level in the calculations were entered as genus sp.

Removal of Redundant Metrics

Some metrics were eliminated due to lack of data, such as having not available (NA) or operating within a very narrow range of values. For the metrics to be potentially useful, their ability to make a clear distinction between quality classes was taken into account (Barbour, 1999). Descriptive statistics such as central tendency, range, distribution, and outliers were used to reveal the metric performances in determining the quality of observed areas versus reference areas.

Those with highly correlated and linear gradients between metrics generally provide the same information (Barbour et al., 1996; Karr, 1991; Karr et al., 1986). Among the candidate metrics, pairwise correlation analysis (Pearson product-moment correlation) was used in order not to increase the effect in the same direction and to eliminate them. The upper limit of the correlation coefficient was defined as r = 0.75. As stated earlier, highly correlated metrics were eliminated because they contributed in the same direction.

The nine metrics (Table 2) were tested to determine the degree to which they discriminate between reference points and disturbing points in stream types located in hydrobiogeographic regions. By visualizing the distribution of the metrics within the quality classes, the discrimination capacities of the metrics were assessed. We used box plots to visualize the distinct values of the metrics between the reference points and the degraded points. The metrics with the highest degree of divergence were evaluated as the most appropriate metrics. Metrics with insufficient separation degrees between the reference and disturbed areas were eliminated.

To aggregate the final metrics into the multimetric index, special attention was paid to selecting metrics to include at least three primary metric types and to show the ability to distinguish between degraded fields and undisturbed or slightly degraded fields (Karr & Chu, 1999).

Standardization of Final Metrics and Calculation of BMIR Index

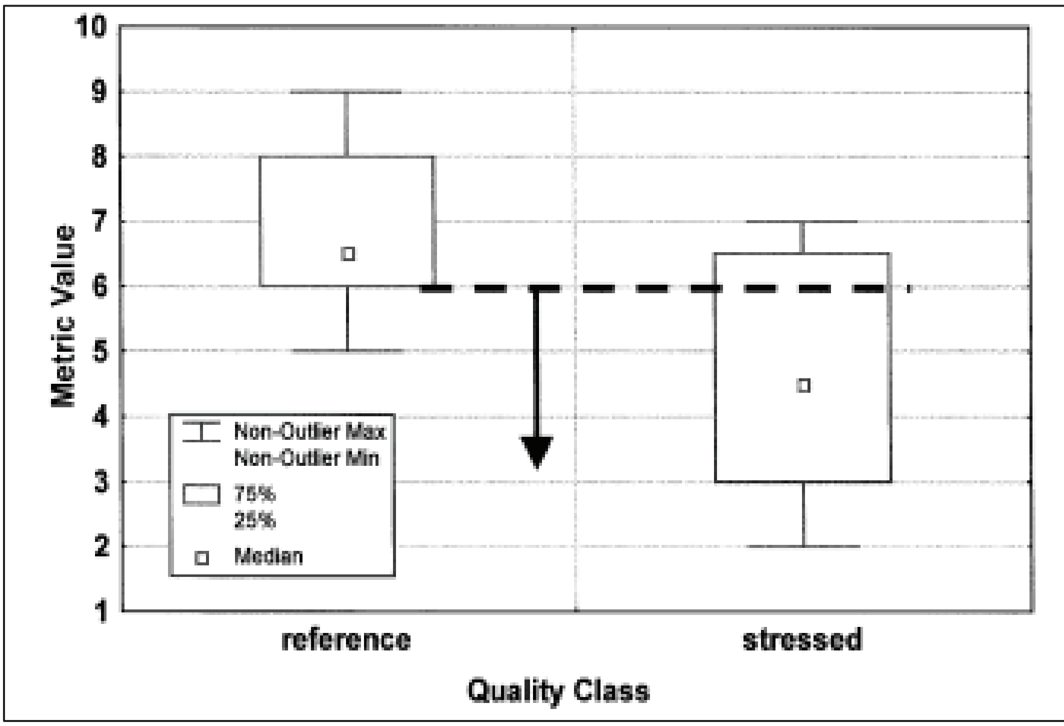
Multimetric indices are used in order to obtain an integrated and common meaning from the information obtained through biological metrics. To integrate, scores from the final metrics need to be normalized by converting them to scores in the same range of values. It is ensured through standardization that each metric has the same value and importance. The method followed in this study United States - Environmental Protection Agency's Rapid Bioassessment Protocols (Barbour, 1999): The score obtained at all sampling points (including reference points) of each metric is based on the distribution of values. The 95^{th} percentile of the distribution of score values for each metric was used to eliminate discrete values. Standardization was performed by calculating the metric scores as a percentage of the 95^{th} percentile. As a result, metric scores near the 95^{th} percentile were valued higher, while metric scores deviating from this percentile by a greater percentage were lower. Metric scores exceeding the 95^{th} percentile were scored as 1. The resulting index value is calculated using the average of the metric values obtained.

The Discrimination Efficiency of Index

Discrimination efficiency (DE) (Karr & Chu, 1999) values were estimated to see the strength of the index.

Figure 3

Discrimination Efficiency



The DE was calculated as the percentage of stressed samples with metric values lower than the 25th percentile of reference values for decreasing metrics, and higher than the 75th percentile for increasing metrics, respectively (Fig. 3).

As part of the WFD, data from reference areas according to the index were combined and tested against degraded areas, as this would help us decide whether action is needed to improve the quality of a river area (Directive, 2000/60/EC). Due to insufficient data on interactions between quality changes and hydromorphological features, final reference conditions based on macroinvertebrate data were used to develop a multimetric index (Buffagni et al., 2004).

Class Boundary Values

Class boundary values have been created based on index ranges, thus allowing for differentiation between different stress conditions. Many different methods have been developed in the literature to determine class limit values

(Barbour, 1999). In this study, a four-class boundaries of five quality grades was used to meet the requirements of the WFD;

- 95th percentile High and Good quality class,
- 60th percentile Good and Moderate quality class,
- 30th percentile Moderate and Poor quality class,
- 5th percentile Poor and Bad quality class.

Class boundary values suggested in the BMIR index were defined using unequal intervals. The fit of the thresholds was verified using index performance (DE) and precision estimates.

Results

Benthic Macroinvertebrate Fauna

Of the 1875 taxa analyzed, 1373 were at the species level, 410 at the genus level, and 92 at the family level. For metrics operating at the species level, taxa identified at the genus level in the calculations were entered as genus sp.

Elimination and Selection of Metrics

By visualizing the distribution of the metrics within the quality classes, the discrimination capacities of the metrics were assessed (Fig. 4). Metrics with insufficient separation degrees between the reference and disturbed areas were eliminated.

The metrics with the highest degree of discrimination are %Epirithral, BMWP-S, Shannon-Wiener, %EPT and Margalef. Among the candidate metrics, pairwise correlation analysis (Pearson product-moment correlation) was used (Table 3) in order not to increase the effect in the same direction and to eliminate them. Highly correlated metrics were eliminated because they contributed in the same direction.

Figure 4

The Discrimination Efficiency Degrees of the Metrics Between the Reference and Stressed Areas

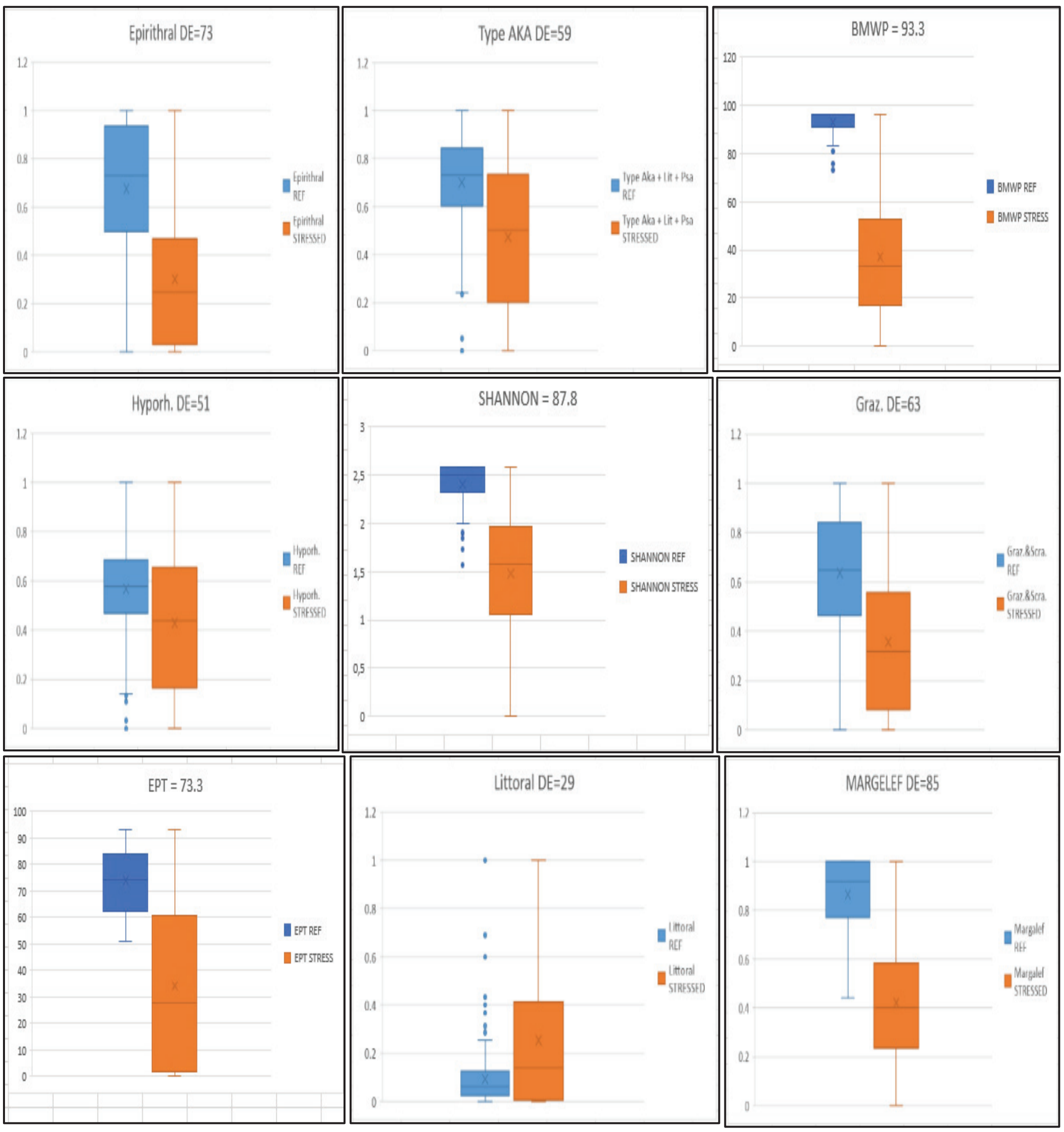


Table 3

The Correlation Degrees of the Metrics

Metrics	*BMWP-S*	*Shannon-Wiener*	*Margalef*	*%EPT*	*%Epirithral*	*%Littoral*	*%Hyporithral*	*%Grazers-scrapers*	*%Type Aka Lit Psa*
BMWP-S	1								
Shannon-Wiener	0,6679	1							
Margalef	0,7936	0,8675	1						
%EPT	0,3993	0,2585	0,2522	1					
%Epirithral	0,4088	0,2164	0,2368	0,5032	1				
%Littoral	-0,288	-0,1182	-0,1628	-0,4003	-0,4751	1			
%Hyporithral	0,1559	0,0458	0,0547	0,3346	0,2850	-0,3809	1		
%Grazers-scrapers	0,2122	0,1365	0,1458	0,3803	0,4268	-0,1871	0,2829	1	
%Type Aka Lit Psa	0,3106	0,1652	0,1681	0,4603	0,6070	-0,4335	0,5192	0,2054	1

The Margalef metric was eliminated as it showed high correlation with both BMWP-S and Shannon-Wiener. Lastly, among these metrics, the %Epirithral metric was eliminated on the assumption that the %Epirithral score values of the species in Türkiye were insufficient.

Final Metrics

Finally, the metrics that can reach the score values of species in Türkiye, that is, enable the calculations, and the metrics with the highest discriminant values were selected. The metrics that could be used in the final index after the metric eliminations were called final metrics. The discrimination efficiency values of the final metrics are shown in Fig. 5.

For the composition measures %EPT taxa were selected, which have high discriminatory power in all hydrobiogeographic regions. Within tolerance/intolerance measures the BMWP-S showed very useful results in all hydrobiogeographic regions. Among the diversity indices tested, the Shannon-Wiener diversity index gave the best results in all hydrobiogeographic region types.This resulted in a final list of three metrics. The final metrics comprised in the BMIR are, the Percentage of Ephemeroptera, Plecoptera and Trichoptera Taxa (%EPT), the Shannon-Wiener Diversity Index and the BMWP-S (Table 4).

Table 4

The List of Final Metrics Comprised in the BMIR

Metrics		Metric type
BMWP-S	Biological monitoring working party-Spanish version	Tolerance / intolerance measures
Shannon-Wiener	Shannon-Wiener diversity index	Diversity measures
%EPT	Percentage of Ephemeroptera, Plecoptera and Trichoptera taxa	Composition measures

Figure 5

The Discrimination Efficiency Values of Final Metrics in All Hydrobiogeographic Regions

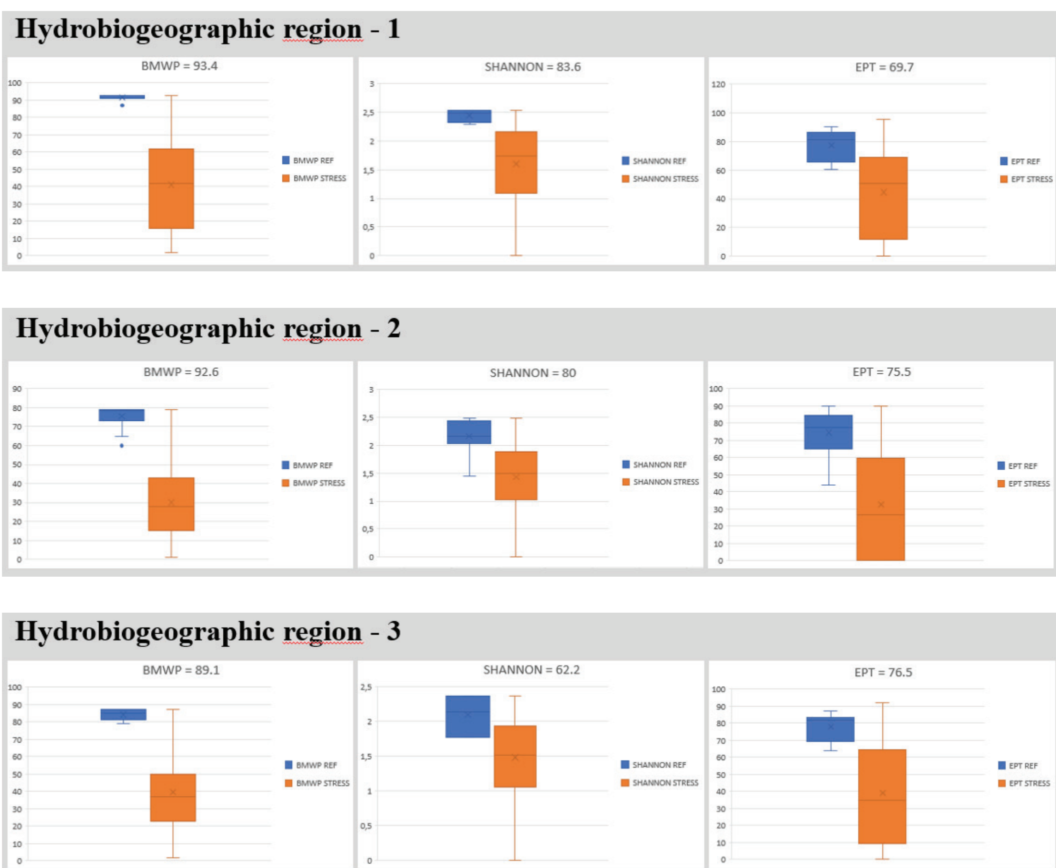
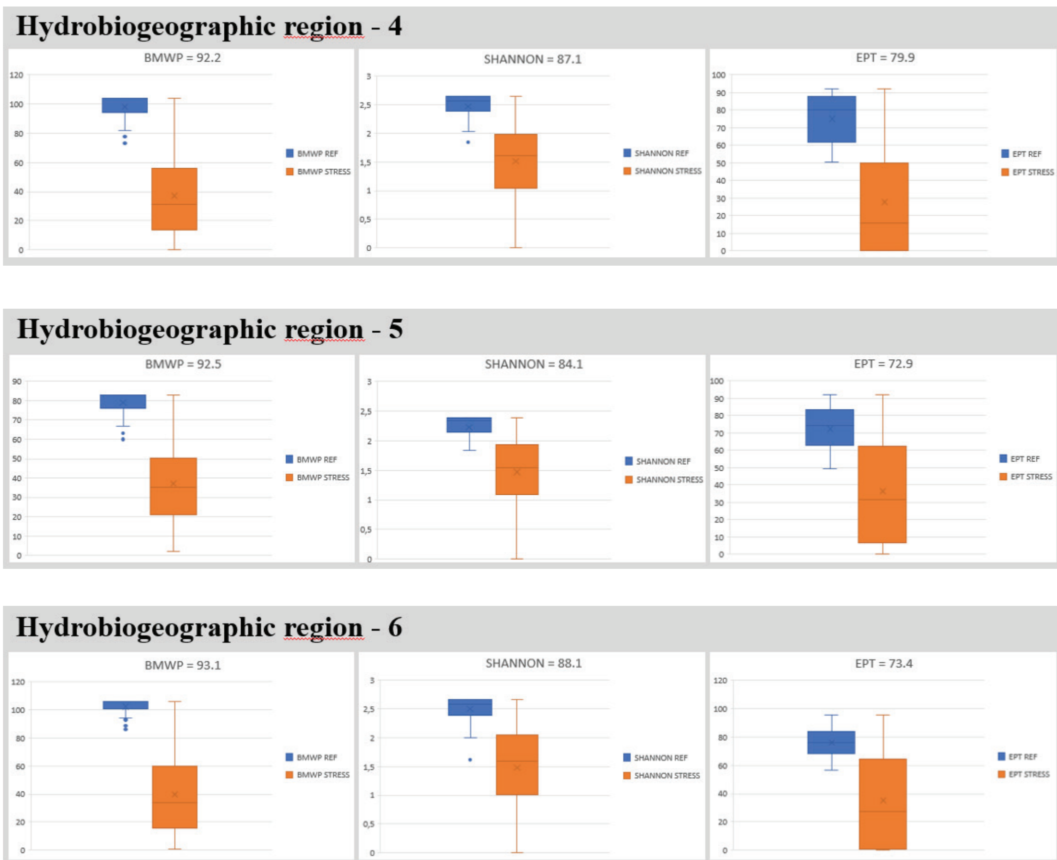


Figure 5

(Continued)



Reference Values of BMIR and Index Calculation

Reference values of three metrics were created for all types in each hydrobiogeographic region. These values were derived from the 95th percentile of the metric scores at the sampling points belonging to each type of hydrobiogeographic region. However, there was insufficient data on some types within hydrobiogeographic regions. For these types, a single reference value was produced from the data set created by combining the data of all types in the hydrobiogeographic regions they belong to. The reference values of three metrics for all types are summarized in Table 5.

Table 5

Metric Reference Values of Types in Hydrobiogeographic Regions

	Reference Values of Hydrobiogeographic Region-1 Types		
Metrics	*BBA*	*BBB*	*BAB, BBX, ABX, BAX, CBA, CBB, CBX*
BMWP-S	98,95	98,49	98
Shannon-Wiener	2,69	2,52	2,62
%EPT	90,72	97,75	95,39

	Reference Values of Hydrobiogeographic Region-2 Types						
Metrics	*AAA*	*AAB*	*ABA*	*ABB*	*BBA*	*BBB*	*BAA, AAX, BAB, BBX, ABX, CBA, BAX, CBB, CBX*
BMWP-S	61,01	55,30	75,76	98	85	76,03	78,41
Shannon-Wiener	2,47	2,19	2,53	2,27	2,62	2,45	2,48
%EPT	85,24	81,01	81,10	86,92	94,83	94,45	90,08

	Reference Values of Hydrobiogeographic Region-3 Types		
Metrics	*BBA*	*BBB*	*CBB, CBA, BAB, BAA, BAX, BBX, CAB, CAX, CBX*
BMWP-S	85	88,81	87
Shannon-Wiener	2,37	2,44	2,37
%EPT	93,16	72,15	92,39

	Reference Values of Hydrobiogeographic Region-4 Types				
Metrics	*BBA*	*BBB*	*BAB*	*BAA*	*ABB, BBX, BAX, AAB, AAX, ABA, ABX*
BMWP-S	115,69	104,41	76,5	61	104
Shannon-Wiener	2,67	2,67	2,31	2,28	2,65
%EPT	92,12	93,49	66,16	41,84	92,31

Table 5

(Continued)

Reference Values of Hydrobiogeographic Region-5 Types									
Metrics	*CBA*	*BBB*	*BBA*	*CBB*	*BAA*	*BAB*	*ABA*	*ABB*	*AAB, AAA, BAX, CBX, CAB, ABX, CAX, BBX, CAA, AAX*
BMWP-S	93,71	67,81	91	83	67,52	47,88	67,94	79,38	83
Shannon-Wiener	2,52	2,31	2,39	2,41	2,29	2,05	2,25	2,31	2,39
%EPT	96,68	94,69	85,96	95,76	59,99	80,37	77,81	100	91,86

Reference Values of Hydrobiogeographic Region-6 Types									
Metrics	*BBA*	*AAB*	*BBB*	*CBA*	*ABB*	*ABA*	*AAA*	*BAB*	*AAX, ABX, CBB, BBX, BAA, BAX, CBX*
BMWP-S	116,64	63,42	123,09	108,02	71,12	95,72	85	80,05	105,56
Shannon-Wiener	2,62	2,43	2,77	2,73	2,25	2,62	2,20	2,20	2,66
%EPT	100	72,58	97,36	100	85,12	93,43	86,40	84,27	95,73

The multimetric index calculation of a sampling point is explained below:

- Three metrics (BMWP-S, Shannon-Wiener, %EPT) are calculated separately.
- The metric scores obtained are divided by the reference value of those metrics determined for that type.
- The score values (between 0 and 1) obtained from each metric are summed up and averaged.
- The result of the multimetric index is obtained (BMIR value).

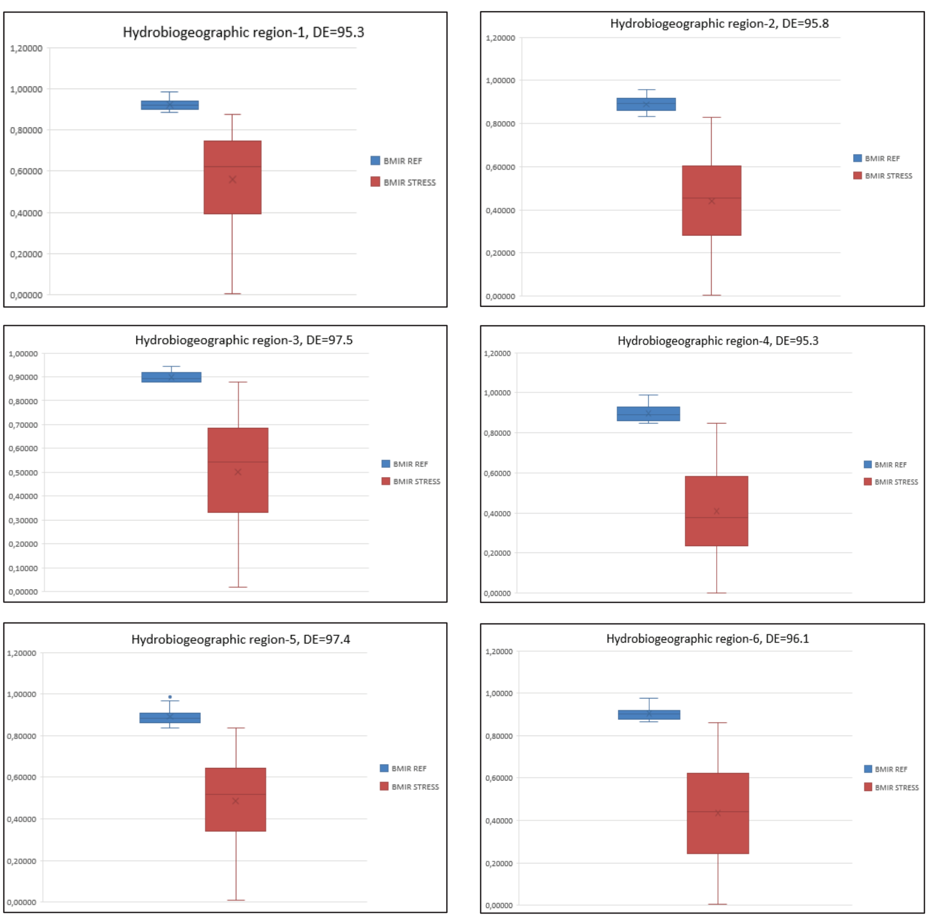
DE Values of BMIR

The final index that discriminated best between the different stages of disturbance is summarized in Figure 6 including calculated DE's.

The resulting index comprises three metrics from three metric categories (composition, tolerance/intolerance, and diversity measures) and distinguishes reference/slightly disturbed sites from stressed sites with probabilities between 95.3% and 97.5%.

Figure 6

Discrimination Efficiency Values of BMIR (final index) in Hydrobiogeographic Regions



Quality Class Boundary Values of BMIR

BMIR, as mentioned above, produces a score ranging from 0 to 1 by averaging the three metric scores. This means that for the BMIR value to be 1, all metric values must be close to the type-specific reference values for these metrics. Therefore, the BMIR index result can be used as an EQR.

The quality class boundaries were derived from the percentile of index scores in the sampling sites belonging to each type in all hydrobiogeographic regions. Variable class ranges were defined for proposed class boundary values in the BMIR indices. Quality class thresholds were obtained by dividing BMIR index scores into five classes based on percentiles. These percentiles are 95^{th} (High-Good), 60^{th} (Good-Moderate), 30^{th} (Moderate-Poor) and 5^{th} (Poor-Bad) percentile. Proposed class boundary values are summarized in Table 6.

As mentioned in the methodology section, there was insufficient data on some types in hydrobiogeographic regions. For these types, common class boundary ranges were produced from the data set created by combining the data of all types in the hydrobiogeographic regions they belong to.

Table 6

BMIR's Class Boundary Values for the Types in All Hydrobiogeographic Regions

	Class Boundaries of Hydrobiogeographic Region-1 Types		
Quality classes	*BBA*	*BBB*	*BAB, BBX, ABX, BAX, CBA, CBB, CBX*
High	0,89-1,00	0,91-1,00	0,88-1,00
Good	0,72-0,89	0,67-0,91	0,68-0,88
Moderate	0,53-0,72	0,50-0,67	0,50-0,68
Poor	0,19-0,53	0,15-0,50	0,15-0,50
Bad	0,00-0,19	0,00-0,15	0,00-0,15

Table 6

(Continued)

Class Boundaries of Hydrobiogeographic Region-2 Types							
Quality classes	*AAA*	*AAB*	*ABA*	*ABB*	*BBA*	*BBB*	*BAA, AAX, BAB, BBX, ABX, CBA, BAX, CBB, CBX*
High	0,79-1,00	0,86-1,00	0,78-1,00	0,74-1,00	0,83-1,00	0,86-1,00	0,83-1,00
Good	0,46-0,79	0,41-0,86	0,46-0,78	0,50-0,74	0,54-0,83	0,63-0,86	0,53-0,83
Moderate	0,28-0,46	0,21-0,41	0,29-0,46	0,30-0,50	0,36-0,54	0,46-0,63	0,33-0,53
Poor	0,12-0,28	0,05-0,21	0,03-0,29	0,05-0,30	0,07-0,36	0,19-0,46	0,08-0,33
Bad	0,00-,012	0,00-0,05	0,00-0,03	0,00-0,05	0,00-0,07	0,00-0,19	0,00-0,08

Class Boundaries of Hydrobiogeographic Region-3 Types			
Quality classes	*BBA*	*BBB*	*CBB, CBA, BAB, BAA, BAX, BBX, CAB, CAX, CBX*
High	0,88-1,00	0,81-1,00	0,88-1,00
Good	0,64-0,88	0,56-0,81	0,62-0,88
Moderate	0,42-0,64	0,29-0,56	0,39-0,62
Poor	0,14-0,42	0,14-0,29	0,13-0,39
Bad	0,00-0,14	0,00-0,14	0,00-0,13

Class Boundaries of Hydrobiogeographic Region-4 Types					
Quality classes	*BBA*	*BBB*	*BAB*	*BAA*	*ABB, BBX, BAX, AAB, AAX, ABA, ABX*
High	0,88-1,00	0,85-1,00	0,82-1,00	0,77-1,00	0,85-1,00
Good	0,63-0,88	0,54-0,85	0,39-0,82	0,44-0,77	0,49-0,85
Moderate	0,36-0,63	0,35-0,54	0,21-0,39	0,24-0,44	0,27-0,49
Poor	0,16-0,36	0,13-0,35	0,04-0,21	0,09-0,24	0,08-0,27
Bad	0,00-0,16	0,00-0,13	0,00-0,04	0,00-0,09	0,00-0,08

Table 6

(Continued)

Class Boundaries of Hydrobiogeographic Region-5 Types									
Quality classes	*CBA*	*BBB*	*BBA*	*CBB*	*BAA*	*BAB*	*ABA*	*ABB*	*AAB, AAA, BAX, CBX, CAB, ABX, CAX, BBX, CAA, AAX*
High	0,85-1,00	0,84-1,00	0,82-1,00	0,86-1,00	0,91-1,00	0,79-1,00	0,88-1,00	0,79-1,00	0,84-1,00
Good	0,62-0,85	0,59-0,84	0,52-0,82	0,66-0,86	0,48-0,91	0,48-0,79	0,60-0,88	0,61-0,79	0,59-0,84
Moderate	0,44-0,62	0,45-0,59	0,33-0,52	0,55-0,66	0,31-0,48	0,24-0,48	0,35-0,60	0,48-0,61	0,39-0,59
Poor	0,21-0,44	0,09-0,45	0,12-0,33	0,29-0,55	0,13-0,31	0,06-0,24	0,16-0,35	0,29-0,48	0,12-0,39
Bad	0,00-0,21	0,00-0,09	0,00-0,12	0,00-0,29	0,00-0,13	0,00-0,06	0,00-0,16	0,00-0,29	0,00-0,12

Class Boundaries of Hydrobiogeographic Region-6 Types									
Quality classes	*BBA*	*AAB*	*BBB*	*CBA*	*ABB*	*ABA*	*AAA*	*BAB*	*AAX, ABX, CBB, BBX, BAA, BAX, CBX*
High	0,87-1,00	0,76-1,00	0,85-1,00	0,90-1,00	0,76-1,00	0,79-1,00	0,77-1,00	0,88-1,00	0,86-1,00
Good	0,59-0,87	0,42-0,76	0,62-0,85	0,77-0,90	0,44-0,76	0,63-0,79	0,50-0,77	0,46-0,88	0,53-0,86
Moderate	0,40-0,59	0,18-0,42	0,41-0,62	0,68-0,77	0,27-0,44	0,47-0,63	0,30-0,50	0,25-0,46	0,30-0,53
Poor	0,11-0,40	0,01-0,18	0,12-0,41	0,42-0,68	0,05-0,27	0,20-0,47	0,07-0,30	0,13-0,25	0,06-0,30
Bad	0,00-0,11	0,00-0,01	0,00-0,12	0,00-0,42	0,00-0,05	0,00-0,20	0,00-0,07	0,00-0,13	0,00-0,06

Discussion and Conclusion

In the assessment of the ecological status of a water body under the EU Water Framework Directive, biological quality element indices, which show changes such as the composition and abundance of type-specific taxa, are of central importance and imply that biota rather than abiotic conditions are prioritized. When there is no alteration in quality over the sampling period, an efficient index should not vary much and show only minor differences between comparable sites of the same type (Karr et al., 1987). The choice of final metrics depended on several factors; it should be suitable for use for all water body types, contain metrics from more than one metric category, be effective in evaluating water quality, and meet WFD criteria. The fact that the metrics to be selected are also data that can be used effectively and that are easy to select and measure can provide convenience in practice. In order to shed light on future studies, it is necessary to produce the ecological traits score values of the species (specific to Türkiye), so that aquatic ecosystem assessments can be made more soundly.

All hydrobiogeographic region types utilized the same set of metrics, however scoring thresholds varied by type-specific. This allowed for typological differences to be considered in an index's calculation while maintaining clarity and simplicity. Butcher et al. (2003) took a similar technique by altering the threshold values of some measures linearly with the natural logarithm of stream width to differentiate the Benthic Community Index.

In this study, nine metrics representing diversity, composition, and tolerance, including functional metrics, were included in the evaluation of benthic macroinvertebrate based ecological status (Odabaşı et al., 2022; Dügel, 2016) for the Türkiye's hydrobiogeographic regions. The BMIR was developed with three key metrics selected from metric groups. According to the Dügel (2016), for eight river basins of Türkiye, several metrics such as BMWP-S, EPT [%], Margalef, Shannon-Wiener, Gra+Scr [%], epirhithral [%], littoral [%], hyporhithral [%], and Type Akal+Lithal+Psammal were found as appropriate. Among these metrics, BMWP-S, Shannon-Wiener and EPT [%] took part in the metric development process for Türkiye. Multimetric indices integrate different metrics into a single evaluation. In this manner, multiple dimensions of ecosystem functioning or diverse measures of ecological integrity are expected to be integrated into a more comprehensive assessment. At least one metric related to the metric group (composition/abundance, richness/diversity, sensitivity/tolerance, and functions) should be utilised for estimating the functionality of the freshwater groups (Hering et al., 2004). In addition, it is commonly assumed that combining several metrics improves the reliability and efficiency of an index because accidental outliers of one metric can be smoothed out by the other metrics (Gabriels et al., 2010). Compared to the individual metrics, the multimetric index provides more reliable and consistent findings, showing higher discrimination efficiency. There are three different metric types in three different metric categories in the multimetric index, thus increasing the capacity of the index to discriminate against different stress intensities. The calculation of the chosen metrics was based on the number of taxa and the number of taxa per square meter within taxonomic groups.

Richness or diversity metrics are generally implemented as indicators of ecological integrity. Diversity metrics are based on the assumption that disruption of the aquatic ecosystem or stress on communities reduces biodiversity (Gabriels et al., 2010). Moreover, richness metrics indicate the diversity of an aquatic community and are recognized as the most useful indicator of deterioration (Resh et al., 1995). Detection of the elimination of taxa from a naturally diversified system can be done easily (Barbour et al., 1996). In particular, species belonging to the insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) are widely considered to be susceptible to perturbation, and the loss of taxonomic richness within this group implies impairment (Wallace et al., 1996). According to Guerold (2000), Shannon-Wiener index, one of the diversity indexes, can be used to illustrate the changes of the ecosystem condition. In this study, we used the Shannon-Wiener index as a measure of diversity and provided accurate results in all stream types. This metric contributes to the index of all stream types. The use of sensitivity metrics in macroinvertebrate-based water quality studies is widespread. Metrics based on sensitivity have the benefit over richness and diversity metrics, in that taxon-specific features can be included. The principle that varied taxa respond to disturbance in different ways, is base for these metrics (Gabriels et al., 2010). The majority of macroinvertebrate-based assessment systems incorporate this principle (Gabriels et al., 2010; Armitage et al., 1983). Measurements of composition give information on the relative contribution of taxonomic groups to the total fauna. A healthy and stable assemblage will have reasonably consistent proportional representation, according to the premise (Barbour et al., 1996). According to Ode et al. (2005), %EPT is sensitive to anthropogenic stress in aquatic ecosystems, measures the response of Ephemeroptera, Plecoptera, and Trichoptera taxa to pressures. This study, %EPT taxa composition measures promoted to the index: High discriminatory power was found for %EPT taxonomic composition measurements across all stream types and hydrobiogeographic regions. Pollution-tolerant and intolerant taxa or percent composition are included in the content of Tolerance/Intolerance measures (Barbour, 1999). In this study, BMWP-S was used for that measure. In many countries around the globe, the BMWP metric or a modification thereof has been widely used, and in many published reports, its efficiency for water quality studies has been demonstrated (Arslan et al., 2016; Wyżga et al., 2013; Yu et al., 2004; Mustow, 2002; Junqueira & Campos, 1998). Also, Dügel (2016) suggested that the BMWP-S index is one of the most appropriate tolerance metric for Türkiye. This was confirmed by our results, where the BMWP-S results were responsive in all hydrobiogeographic regions.

On benthic macroinvertebrates of Turkish rivers, many metric-based studies are done for some river basins to date (Arslan & Mercan, 2020; Akay & Dalkıran, 2020; Zeybek, 2017; Arslan et al., 2016; Dügel, 2016; Kalyoncu & Zeybek, 2011; Kazancı & Türkmen, 2010; Kazancı et al., 2010; Duran, 2006). However, most of them assess biological quality on the basis of a single metric rather than a multimetric approach. To our knowledge, this article is the first in the literature to evaluate multimetric-based benthic macroinvertebrates covering the whole of Türkiye. For this reason, the BMIR index is expected to be valuable for international researchers as well as helping in the ecological status assessment of Turkish rivers.

In conclusion, the tested multimetric approach was found to be useful and effective for assessing the ecological status of Türkiye's running rivers. The index developed in this study was quite specialized, for a unique combination of hydrobiogeographic regions and stream types; furthermore, the data size of some stream types in each hydrobiogeographic region was necessarily smaller than the data size of hydrobiogeographic regions. Index development for full implementation in Türkiye, it will be necessary to build stressor-specific indices or to generalize to multiple stressor types. Combining measurements considered suitable for individual stressors or developing hydrobiogeographic-specific indices can facilitate generalization. For nationwide index use, it is not necessary to develop a separate index for each river water body type. Separate indices or separate class boundaries may only be used for regions with great faunal variation, such as ecoregions. This study aimed to create a general index for all hydrobiogeographic regions based on a certain metric group, as well as to derive the reference and class boundary ranges of the index specific to the types within the regions. Here, a general index was developed containing the same metrics for all ecoregions, in addition, changes were made to the reference values of the metrics and class boundary ranges for each ecoregion. For each stream type, the final threshold values and reference values can be calibrated. It is thought that the developed BMIR index will help decision makers in determining the ecological quality of Turkish rivers.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Türkiye'deki Nehirler İçin Bentik Makroomurgasızlara Dayalı Bir Multimetrik İndeks Geliştirilmesi (BMIR)

AB Su Çerçeve Direktifi (SÇD) (Directive, 2000/60/EC), üye devletlerden ve diğer katılımcı ülkelerden yüzey sularının daha fazla bozulmasını önlemelerini, mevcut durumlarını korumalarını ve iyi durumda olmayan tüm su kütlelerini iyileştirmelerini talep etmektedir. SÇD, su kütlelerinin ekolojik durumunu belirlemek için biyota ile hidromorfolojik ve kimyasal bileşenler arasındaki ilişkileri kullanmakta ve biyolojik değerlendirmenin 0 (Kötü) ile 1 (Çok İyi) arasında değişen beş sınıflı bir gösterimle oransal (Ekolojik Kalite Oranı, EKO) olarak belirtilmesini istemektedir. EKO, bir su kütlesi tipi için gözlemlenen değerin, referans koşullar altında aynı tip için beklenen değere oranıdır. SÇD'de yüzey suyu kütlelerinin ekolojik kalite durumunu belirlemek için biyolojik değerlendirmede bentik makroomurgasızlar, makrofitler, diatomlar, fitoplanktonlar ve balıklar kullanılmaktadır. Bentik makroomurgasızlar, kıyı, geçiş ve tatlı su habitatlarında insan temelli faaliyetlerin etkilerini değerlendirmek için uzun süredir kullanılmakta ve çeşitli derecelerdeki bozulmalara duyarlı oldukları bilinmektedir (Zeybek, 2017; Birk ve diğerleri, 2012; Hellawell, 2012; Medeiros ve diğerleri, 2012; Borja ve diğerleri, 2011; Chainho ve diğerleri, 2008; Chaves ve diğerleri, 2005).

SÇD'nin uygulanmasıyla birlikte nehir tipolojisinin belirlenmesi ve multimetrik indekse dayalı bir değerlendirme sisteminin oluşturulması ihtiyacı ortaya çıkmaktadır. Türkiye nehirleri için makroomurgasızlara dayalı tipe özgü bir multimetrik indeksin geliştirilmesinin, SÇD gerekliliklerini karşılamak için potansiyel bir araç olacağı düşünülmektedir. Nehir Bentik Makroomurgasız Multimetrik İndeksi (BMIR) olarak bilinen bu yeni indeks, tüm hidrobiyocoğrafik bölgelerdeki her nehir tipi için belirlenen sınıf sınır aralıklarını referans koşullara göreli mesafeyi yansıtacak şekilde değiştirilmesine olanak sağlamaktadır.

Biyolojik değerlendirmede kullanılmak için geliştirilen biyolojik indeksler üç temel yaklaşıma dayanmaktadır. (i)Bölgeselleşme (Omernik, 1987, 1995), (ii)multimetrik yaklaşım (Barbour ve diğerleri, 1996; Davis ve Simon, 1995; Karr ve diğerleri, 1986; Karr ve Dudley, 1981) ve (iii)referans koşullarının belirlenmesidir (Hughes, 1995; Hughes ve diğerleri, 1986). Çalışma bu üç temel üzerine kurulmuştur.

Bu çalışmada kullanılan veriler, Su Yönetimi Genel Müdürlüğü tarafından yürütülen Su Kalitesi İzleme Programı'ndan elde edilmiştir. Ayrıca, Su Kaynaklarının Sayısallaştırılması, Tipoloji, Su Kütlesi ve Risk Değerlendirmesi Yapılarak İzleme Programlarının Hazırlanması Projesi (Digitizing Project, 2022) kapsamında Türkiye için belirlenen 6 hidrobiyocoğrafik bölge ve nehir tipoloji sistemi kullanılmıştır. Elde edilen veritabanı, metrekare başına düşen birey sayısı ile birlikte makroomurgasız faunanın takson listelerini ve hidrobiyocoğrafik bölge ve her bölgenin nehir tipleri hakkındaki verileri içermektedir.

Metrik seçimlerinde çeşitlilik, bolluk, tolerans gibi çok sayıda metrik içeren ASTERICS programı gözden geçirilmiştir. İlk olarak dokuz aday metrik değerlendirilmiş ve analiz edilmiştir. Bu metriklerin hesaplama yapabilmesi için gereksinimler (örn. türlerin ekolojik özellik skorları, tolerans

değerleri vb.) incelenmiştir. Biyolojik veriler kullanılarak tüm hidrobiyocoğrafik bölgelerde dokuz aday metrik hesaplanmıştır. Metrik hesaplama, istatistiksel analiz ve grafik görselleştirme için Excel Data Analysis ToolPak kullanılmıştır.

Gözlemlenen alanların kalitesini referans alanlara göre belirlemede metrik performanslarını ortaya koymak için merkezi eğilim, aralık, dağılım ve aykırı değerler gibi tanımlayıcı istatistikler kullanılmıştır. Aday metriklerden etkiyi aynı yönde artırmamak ve ortadan kaldırmak için ikili korelasyon analizi (Pearson çarpım-moment korelasyonu) kullanılmıştır. Korelasyon katsayısının üst sınırı r = 0.75 olarak tanımlanmıştır. Referans noktaları ve bozulmuş noktalar arasındaki metriklerin ayrım değerlerini görselleştirmek için kutu grafikleri (box-plot) kullanılmıştır.

Türlerin ekolojik isterleri açısından değeri belirlenememiş veya çok dar bir değer aralığında çalışan bazı metrikler elenmiştir. Aynı yönde katkı sağladıkları için yüksek korelasyonlu metrikler ve referans ve bozulmuş alanlar arasında yetersiz ayrışma derecesine sahip metrikler elimine edilmiştir. Yüksek ayrışma derecesine sahip metrikler, uygun metrikler olarak değerlendirilmiştir. Son olarak, Türkiye'deki türlerin ekolojik skor değerlerine ulaşabilen yani hesaplamaları mümkün kılan metrikler ve ayrışma değerleri en yüksek olan metrikler nihai metrikler olarak seçilmiştir. Nihai metriklerin seçiminde ayrıca farklı metrik kategorilerinden metrik seçimine de özen gösterilmiştir (Karr ve Chu, 1999).

Her bir metrik tüm örnekleme noktalarında (referans noktaları dahil) hesaplanmıştır. Elde edilen skor değerler yüzdelik dilimlere bölünmüştür. Ayrık değerleri elimine etmek için her bir metrik için skor değerleri dağılımının 95. yüzdelik dilimi kullanılmıştır. Standardizasyon, metrik skorlarının 95. yüzdelik diliminin yüzdesi olarak hesaplanmasıyla gerçekleştirilmiştir. 95. yüzdelik dilimi aşan metrik skorları 1 olarak hesaplanmıştır. Nihai metrik (3) değerlerin ortalaması alınarak indeks değeri hesaplanmıştır.

İndeks aralıklarına dayalı olarak sınıf sınır değerleri oluşturulmuştur, böylece farklı stres koşulları arasında ayrım yapılmasına olanak sağlanmıştır. Literatürde sınıf sınır değerlerini belirlemek için birçok farklı yöntem geliştirilmiştir (Barbour, 1999). Bu çalışmada, SÇD'nin gereksinimlerini karşılamak için beş sınıflı bir kalite sınıfı aralığı kullanılmıştır;

- 95. persentil Çok İyi ve İyi kalite sınıf sınırı,
- 60. persentil İyi ve Orta kalite sınıf sınırı,
- 30. persentil Orta ve Zayıf kalite sınıf sınırı,
- 5. persentil Zayıf ve Kötü kalite sınıf sınırı.

İndeksi oluşturan metriklerden, kompozisyon metriği için yüksek ayrım gücüne sahip %EPT metriği seçilmiştir. Tolerans/hassas metrikleri için seçilen BMWP-S tüm hidrobiyocoğrafik bölgelerde çok faydalı sonuçlar göstermiştir. Test edilen çeşitlilik indeksleri arasında Shannon-Wiener çeşitlilik indeksi tüm hidrobiyocoğrafik bölge tiplerinde en iyi sonuçları vermiştir. BMIR'de nihai olarak 3 metrik seçilmiştir, bunlar, Ephemeroptera, Plecoptera ve Trichoptera Takson Yüzdesi (%EPT), Shannon-Wiener Çeşitlilik İndeksi ve BMWP-S'dir.

Her bir hidrobiyocoğrafik bölgede tüm tipler için 3 metriğin referans değerleri, her bir hidrobiyocoğrafik bölge tipine ait örnekleme noktalarındaki metrik skorlarının 95. yüzdelik diliminden türetilmiştir. Ancak, hidrobiyocoğrafik bölgelerdeki bazı tipler hakkında yeterli veri bulunmamaktadır. Bu tipler için ait oldukları hidrobiyocoğrafik bölgelerdeki tüm tiplerin verilerinin birleştirilmesiyle oluşturulan veri setinden tek bir referans değer üretilmiştir.

Bir örnekleme noktasının BMIR indeks hesaplaması aşağıda açıklanmıştır:

- 3 metrik (BMWP-S, Shannon-Wiener, %EPT) ayrı ayrı hesaplanır.
- Elde edilen metrik skorlar, o tip için belirlenen metriklerin referans değerine bölünür.
- Her bir metrikten elde edilen skor değerleri (0 ile 1 arasında) toplanır ve ortalaması alınır.
- Multimetrik indeksin sonucu elde edilir (BMIR değeri).

BMIR, yukarıda bahsedildiği gibi, 3 metrik skorunun ortalamasını alarak 0 ile 1 arasında bir değer üretir. Bu nedenle, BMIR indeks sonucu EKO olarak kullanılmaya uygundur.

Sonuç olarak, test edilen multimetrik yaklaşımın Türkiye'nin akarsularının ekolojik durumunu değerlendirmede faydalı ve etkili olacağı tahmin edilmektedir. Geliştirilen indeks, hidrobiyocoğrafik bölgelerin ve akarsu tiplerinin bentik makroomurgasızlar açısından kalite durumunu ortaya koymada hassastır. Türkiye'de ileri seviye bir uygulama için, stres faktörüne özel indeksler oluşturmak veya birden fazla stres faktörünü genelleyerek indeks geliştirmek bir sonraki çalışma olabileceği düşünülmektedir. Bu çalışmanın amacı, belirli bir metrik grup bazında tüm hidrobiyocoğrafik bölgeler için genel bir indeks oluşturmak ve ayrıca bölgeler içindeki tiplere özel indeksin referans ve sınıf sınır aralıklarını türetmektir. Burada, tüm hidrobiyocoğrafik bölgeler için aynı metrikleri içeren genel bir indeks geliştirilmiş, hidrobiyocoğrafik bölgelerdeki nehir tiplerine ait farklı referans değerler ve sınıf sınır aralıkları üretilmiştir. Her nehir tipi için nihai sınıf sınır değerleri ve referans değerleri kalibre edilebilir özelliktedir. Geliştirilen BMIR indeksinin Türkiye nehirlerinin ekolojik kalitesinin belirlenmesinde karar vericilere yardımcı olacağı düşünülmektedir.

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Research Article

On the Changing Snow Contribution to Runoff across Türkiye

Türkiye Genelinde Kar Erimesinin Akışa Katkısındaki Değişimin İncelenmesi

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Abstract

Contribution of snowfall to runoff is especially important in snow-dominated regions where hydrological processes are mostly influenced by snowmelt. In this study, the contribution of snowfall to runoff in Türkiye for the last 21 years was examined in the light of the hydrological model results globally provided by National Aeronautics and Space Administration. The model outputs of the Global Land Data Assimilation System v2.1, in which observed and remote sensing products are assimilated, were used in this study. The snow dominant regions of Türkiye for the last 21 years were revealed, and the ratio of the spatially averaged maximum snow water equivalent to runoff (Rsr) values, an indicator showing snowmelt contribution to runoff, were calculated for a period of 11-years from 2000 to 2021 (period 1:2000-2010, period 2: 2011-2021). These Rsr values were compared across Türkiye to see whether they were decreasing or increasing in the snow-dominated regions. According to the results of the analysis, Rsr values are decreasing in all snow-dominated regions. Rsr values decreased by up to 50 percent in the last 11-year period in the regions receiving high snowfall, such as the upper Euphrates basin.
Keywords: *hydrology, snow, runoff, climate change, global warming*

Öz

Hidrolojik süreçlerin çoğunlukla kar erimesinden etkilendiği kar baskın bölgelerde, kar yağışının yüzey akışına katkısı oldukça önemlidir. Bu çalışmada, Ulusal Havacılık ve Uzay Dairesi'nin küresel hidrolojik model sonuçları ışığında Türkiye'de son 21 yılda kar yağışının yüzey akışına katkısı incelenmiştir. Bu çalışmada, gözlemlenen ve uzaktan algılama ürünlerinin asimile edildiği Global Land Data Assimilation System v2.1 model çıktıları kullanılmıştır. Türkiye'nin son 21 yıldaki kar baskın bölgeleri ortaya çıkarılmış ve kar erimesinin akışa katkısı göstergesi olan alan ağırlıklı ortalama maksimum kar suyu eşdeğerinin akış değerlerine oranı (Rsr) iki ayrı 11 yıllık dönem için hesaplanmıştır (2000-2010, 2011-2021). Bu Rsr değerleri, kar yağışlı bölgelerde azalma olup olmadığını görmek için Türkiye genelinde karşılaştırılmıştır. Analiz sonuçlarına göre, kar baskın tüm bölgelerde Rsr değerlerinin düştüğü sonucuna varılmıştır. Yukarı Fırat Havzası gibi yüksek kar yağışı alan bölgelerde son 11 yılda Rsr değerleri yüzde 50'ye varan düşüş göstermiştir.
Anahtar sözcükler: *hidroloji, kar, akış, iklim değişikliği, küresel ısınma*

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Introduction

Snowpack is highly sensitive to temperature changes. The sensitivity against temperature is more observable by the change of runoff characteristics with respect to the increase in temperature at snow-dominant regions where winter precipitation is dominated by snowfall. In these snow-dominant regions, the decrease in snowfall in the winter season results in a decreasing amount of snowpack that would melt in the spring and summer months. In addition, increasing temperatures accelerates the snow melting, thus can pull back the period of the snow melting by a couple of weeks. Earlier seasonal snowmelt and lesser amount of snowfall considerably reduces the water availability in the summer months when water usage is at its peak. This poses the risk of insufficient reservoir capacities in dry seasons, endangering many water-dependent sectors. Barnett et al. (2005) review some case studies in which some water problems are associated with shifts in the seasonality of runoff, such as possible future reductions in hydroelectric production or severely damaging the fish populations. These kinds of water problems associated with snow losses are monetarily quantified at a trillion dollars level (Sturm et al., 2017).

Variability in the volume and seasonal variation of snowpack is well examined with hydrologic analysis and observational data. For example, Adam et al. (2009) conclude that projected losses in the snowpack and warm-season runoff are linked to warming temperatures in snow-dominated regions. It is observed from the remote sensing data that snow-water equivalent (SWE) values in mountain systems have a negative trend for both the continental scale and mountain systems (Bormann et al., 2018). Analyzes of the timing of snowmelt at the observation stations in the snow-dominated regions show that the peak times of snow-related runoff are shifted to earlier times away from warmer months (Tan et al., 2011; Dudley et al., 2017; Uzun et al., 2021). Jain et al. (2010) use remote sensing data in order to estimate the snowmelt runoff under different warming climate scenarios and find that more snowmelt runoff occurr earlier due to the increased snow melting, although there is not much change in total runoff.

The effect of snowmelt on the runoff is analyzed by a variety of methods, such as the ratio of snowfall to the total precipitation (Barnett et al., 2005), snowfall to total runoff (Barnett et al., 2005), and degree-day approaches (Kayastha & Kayastha, 2020). According to studies of Kang et al. (2014) and Islam et al. (2017) on SWE contribution to runoff generation, significant decreases are found in the ratio of snowmelt contribution to runoff in the snow-dominant regimes.

Türkiye has snow-dominated regions due to the abundance of mountainous areas. Especially in the Eastern Anatolia Region of the country, where the mountainous regions are dense, snowfalls are heavy and the amount of runoff in the warmer months strongly depends on the snowmelt. The effects of climate change on water resources in these regions are investigated in some projection-based studies. For example, according to the study conducted in the Upper Euphrates Basin, which constitutes 50 percent of the Euphrates Basin, snowmelt occurs earlier and the runoff decreases in warmer months as the projected temperature increases in the basin ("Assessment of Climate Change Impacts on Snowmelt and Streamflows Project, 2019). According to a hydrological sensitivity study on another snow-dominated region, Upper Kızılırmak River Basin, the surface runoff decreases in warmer months with the increased temperature (Cevahir, 2019). The relationship between snowmelt and temperature on a regional is examined in such studies in Türkiye (e.g. Yucel et al., 2015). Even though these studies are based on the projections, there is a need for a observation-based study across Türkiye on the change in the contribution of snowmelt to runoff.

The objective of this study is to examine the change in the snowmelt contribution to runoff generation in Türkiye for the last 21 years with the data provided by NASA's (National Aeronautics and Space Administration) Global Land Data Assimilation System v2.1 (GLDAS v2.1).

Method

NASA's GLDAS v2.1 provides monthly global hydrological and meteorological data (spatial resolution of 0.25° x 0.25°) forced with a combination of model and observation data from 2000 to present (Beaudoing & Rodell, 2020; Rodell et al., 2004). The more detailed information for the data products are released in NASA website (NASA GES DISC, 2020). Please also see "Readme" document of the GLDAS (Rui & Beaudoing, 2019).

To examine the dependence of the runoff on snowmelt in Türkiye, a ratio of snow contribution to runoff generation (Rsr) was quantified for each water year (Déry et al., 2005; Kang et al., 2014). Rsr is calculated by (Eqn. 1):

$$R_{sr} = \frac{SWE_{melt}}{\sum_{t=1}^{N} R_t} \#(1)$$

where R is runoff (mm/day) and N is 365 or 366, depending on whether a given year is a leap year or not. In order to account for the water years, t=1 marks 1 October of the given year. SWE_{melt} is calculated by (Eqn. 2):

$$SWE_{melt} = SWE_{max} - SWE_{min} \#(2)$$

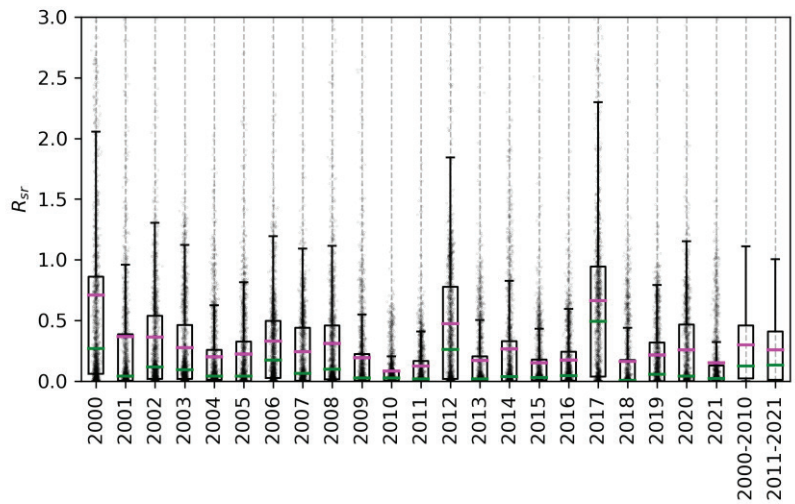
where SWE_{max} is the maximum snow water equivalent of the year, and SWE_{min} is the minimum snow water equivalent of the year. For this study, SWE is 3-hourly instantaneous data, which is given at the end of each 3-hour period. Snow water equivalent and total runoff are the outputs of the dataset from GLDAS v2.1 between 2000 and 2021. In the dataset, SWE is stated as "snow-depth water equivalent" (kg/m^2). Total runoff is the sum of "subsurface runoff" (kg/m^2/3hr) and "surface runoff" (kg/m^2/3hr). To compute monthly total runoff, the sum of subsurface runoff (kg/m^2/3hr) and surface runoff (kg/m^2/3hr) is multiplied by 240 (8{3hr/day} * 30{days}). The years 2000 to 2021 were divided into two 11-year periods. Rsr values were calculated for the years between 2000-2010, and 2011-2021 (including 2000 and 2021).

Results and Discussion

Figure 1 showed the country average of Rsr values calculated for each year between 2000 and 2021 in Türkiye. In Figure 1, small gray dots represented the value in each GLDAS pixel, magenta lines represented the mean values and green lines represented the median values. From Figure 1, it can be seen that apart from the peaks occurring in 2012 and 2017, the Rsr values showed a decrease in the second period (see the comparison of the periods at the bottom-right corner in Figure 1). The Rsr values calculated for the two periods (2000-2010 and 2011-2021) and the comparison of these periods across Türkiye were shown in Figure 2. Figure 3 showed the Rsr values of each basin for two periods. From Figure 2 and 3, generally, Fırat-Dicle (Euphrates – Tigris), Aras (Araks), Çoruh (Chorokhi), Eastern Black Sea Region, around the city of Sivas, which is the upstream of the Kızılırmak Basin and Yeşilırmak, Eastern and Southern parts of the Western Black Sea Basins were the regions where the runoff was heavily fed by snowfall (Rsr >0.50). Conversely, the western side of Türkiye, the western part of the Central Anatolian region, the Aegean and Mediterranean were outside the snow-dominated regions (Rsr<0.50). Rsr values lower than 0.50 were excluded to assess in the current study as the effect of snow on the runoff were negligible.

Figure 1

Box Plot for The Change of Rsr Values of Türkiye-Wide Averages from 2000 to 2021



Note. Magenta lines represent the mean values and green lines represent the median values.

Overall, among the snow-dominated regions, the Rsr values decreased in the upstream regions of the Upper Euphrates, Lake Van, Upper Kızılırmak, Eastern Black Sea, northern parts of Seyhan, and the eastern parts of Tigris basins in the last 11-year period, compared to period of 2000-2010. The decrease in the Rsr values in these regions are also apparent in Figure 3, where there are more scatter points below the diagonal line. The decrease in Rsr is consistent with the results of the climate projections in Türkiye. In the climate change projections of these basins, a quite amount of snowfall will be replaced by rainfall in the future (Climate Change Impacts on Water Resources Project, 2016). Particularly in the Upper Euphrates basin, the decrease in Rsr values of up to 50 percent in the last 11 years is remarkable compared to the first 11-year period. The SWE in these regions, such as the Western and Southern parts of the Palandöken Mountains, Mercan, Tecer and Tahtalı Mountains, decreased in the last 11 years, compared to the first 11-year period (Figure 4 and 5). Rsr values show a decrease in these regions mostly due to decreases in SWE.

Figure 2.a

The Averages of the Rsr Values for the Period of 2000-2010

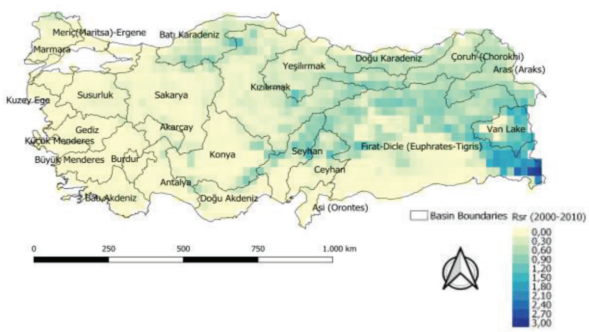


Figure 2.b

The Averages of the Rsr Values for the Period of 2011-2021

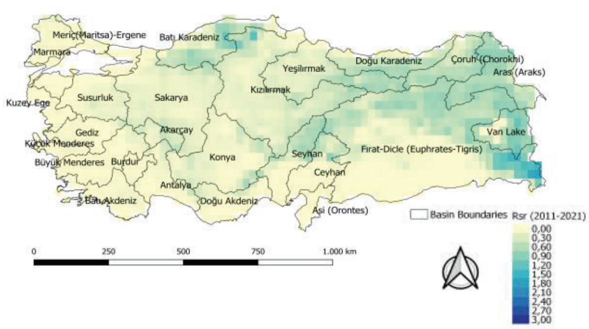


Figure 2.c

The Percentage Change of the Mean Values of Rsr Whose Values Are Greater Than 0.50

Between These Two Periods Across Türkiye

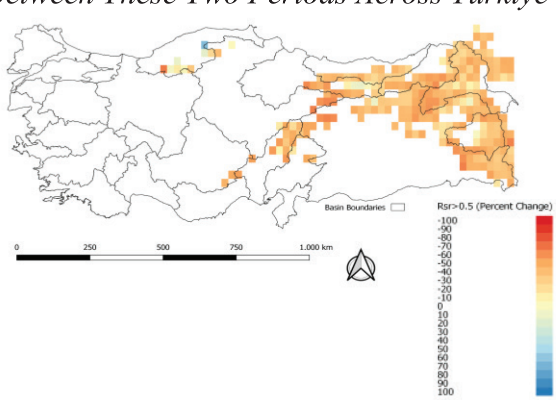
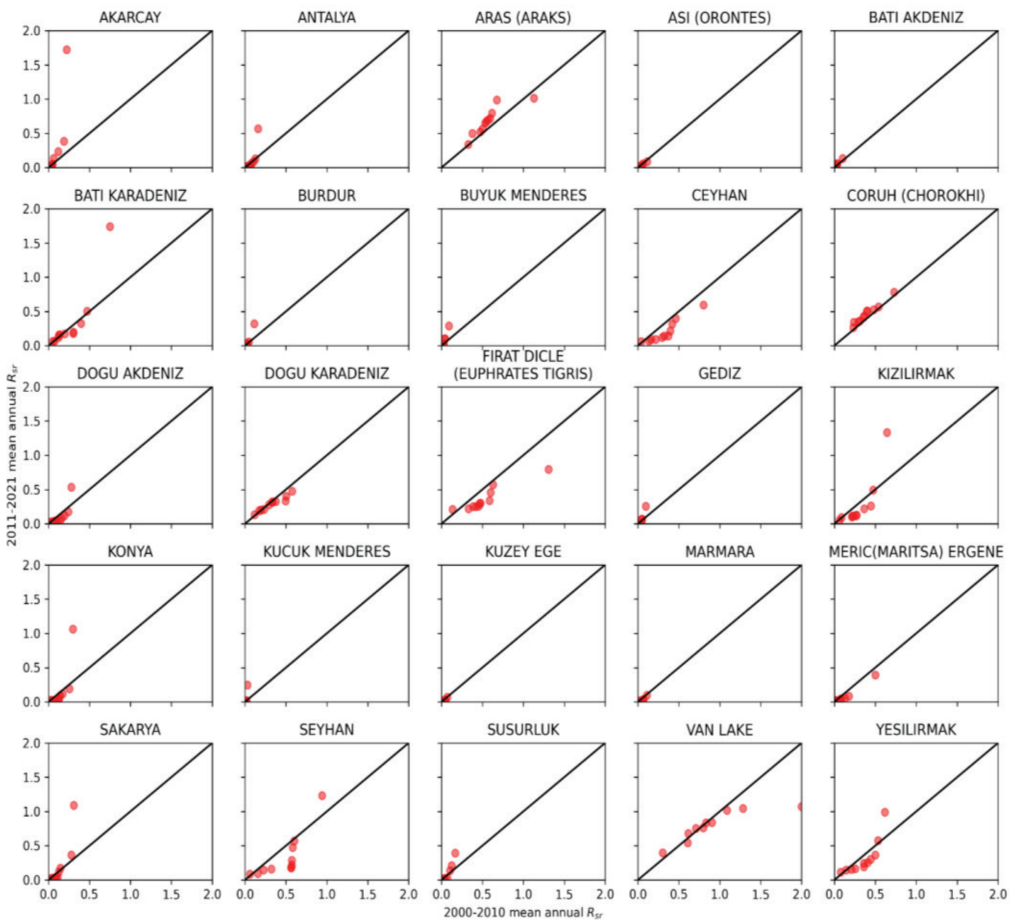


Figure 3

Scatter Plots of Rsr Values Calculated For Both Periods of All Basins in Türkiye



Note. Each dot shows the average Rsr value of each basin for each year (x-axis for the first

10 years, y-axis for the second 10 years). The X axis shows annual average for each year between 2000-2010, and the Y axis shows annual average for each year between 2011-2021.

Figure 4

The Percentage Change of SWE Between the Averages of Period of 2000-2010 and the Averages of Period of 2011-2021 Across Türkiye

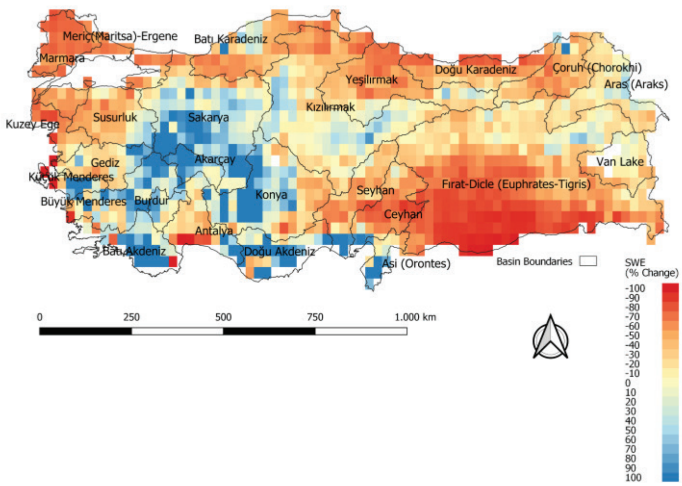
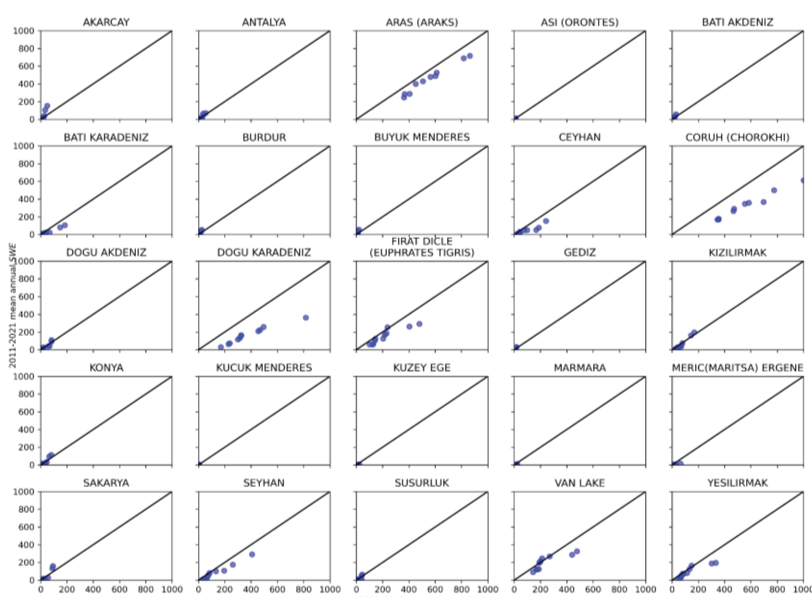


Figure 5

Scatter Plots of SWE (Kg M-2) Values for Both Periods of All Basins in Türkiye



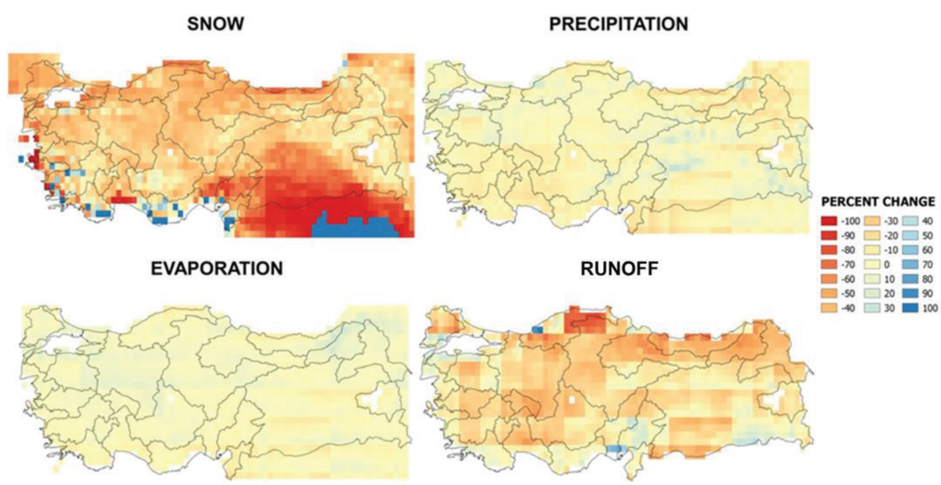
Note. The X axis shows annual average for each year between 2000-2010, and the Y axis shows annual average for each year between 2011-2021.

Additionally, From Figure 6, it is noteworthy that the runoff values decreased significantly (i.e. more than roughly 20 percent fall in the black sea cost) in the last 11-year period for the most parts of Türkiye. The decreases in the runoff values, especially on the western side of the middle of the Black Sea coast, in the Çoruh (Chorokhi), Eastern Black Sea, Yeşilırmak and Western Black Sea Basins, stood out compared to other regions. The decreases amount of runoff in these regions was related to decreases in total precipitation as well as decreases in snow water equivalent. For other basins, such as parts of the Central Anatolian, Aegean and Mediterranean Regions, where mountainous regions are scarce and snow is not dominant form of precipitation, the decreases in the runoff values are due to decreased rainfall or increased evaporation (Figure 6).

The results in the current study, which are mostly in line with the climate projections of the Coupled Model Intercomparison Project 5 (CMIP5) (Taylor et al., 2011) [except for the slightly decreased about 10 percent precipitation trend estimated by the current study in the Eastern Black Sea Region where the amount of precipitation was shown to be a moderate increase at the future projections according to the most Global Climate Models (Demircan et al., 2017)], showed that the water availability in the snow-dominated regions of Türkiye were adversely affected in the last decade compared to earlier period. The decrease in the Rsr values, which has manifested itself in the last 11 years, can be expected to accelerate in the future, where record temperatures have been experienced recently almost every year. Since the energy generation is reliant on snow-fed freshwater resources in the snow-dominated regions of the Fırat (Euphrates), Dicle (Tigris), Eastern Black Sea, Yeşilırmak, and Kızılırmak Basins, the concern of insufficient electricity production may be encountered in the not-too-distant future.

Figure 6

The Percentage Changes of Snow, Precipitation, Evaporation and Runoff Values Between the Averages of These Two Periods Across Türkiye



Conclusion

This study sought to identify the snow-dominated regions in Türkiye with the model outputs data globally shared by NASA GLDAS v2.1 for the last 21 years and to compare the changes in snow contribution to runoff in these regions over 11-year periods. For this purpose, Rsr values for the years 2000 and 2011, and 2011-2021 were calculated and the averages of the Rsr values for these periods were spatially represented in Türkiye. Then, the changes of Rsr values in both periods were also shown and analyzed.

According to the results, in accordance with the climate projections of the CMIP5 (Taylor et al., 2011, p. 5) , there has been a decrease in SWE in the most of the snow-dominated regions in the 2011-2021 period compared to the period of 2000-2011. The Rsr values generally decreased in almost all snow-dominated regions. In addition, it has been observed that the runoff decreased in the last 11-year period in the most area of Türkiye, regardless of whether the region is snow-dominated or not. All these results generated based on NASA GLDAS v2.1 model outputs can be seen as another indication for the predictions that there will be insufficient water availability in the future in snow-dominated regions where the hydrological energy potential are high.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Türkiye Genelinde Kar Erimesinin Akışa Katkısındaki Değişimin İncelenmesi

Kar örtüsü, sıcaklık değişimine karşı oldukça hassastır. Kış yağışlarında kar yağışlarının hâkim olduğu kar baskın bölgelerde sıcaklığa karşı duyarlılık, daha fazla gözlemlenebilir. Kar yağışının yoğun olduğu bu bölgelerde, artan sıcaklıklarla beraber, kış mevsiminde kar yağışının azalması, ilkbahar ve yaz aylarında eriyecek olan kar miktarının azalmasına neden olur. Ayrıca artan sıcaklıklar karın erimesini hızlandırmakta, dolayısıyla karın erime zamanını daha sıcak aylardan daha soğuk aylara çekebilmektedir. Karların erken erimesi ve daha az kar yağışı, su kullanımının en yoğun olduğu yaz aylarında su miktarını önemli ölçüde azaltır. Bu durum, kurak mevsimlerde yetersiz rezervuar kapasitesi riskini ortaya çıkararak suya bağımlı birçok sektörü tehlikeye atmaktadır. Bu konuda yapılan çalışmalar göstermektedir ki bazı suya bağlı sorunlar (gelecekte hidroelektrik üretiminde olası azalmalar veya balık popülasyonlarına ciddi zararlar gibi) akıntının mevsimselliğindeki değişimlerle ilişkilidir ve kar kayıplarıyla ilişkilendirilen bu tür su sorunları, maddi olarak trilyon dolar düzeyinde ölçülmektedir.

Türkiye'de dağlık alanların bol olması nedeniyle yoğun kar yağışı alan birçok bölge bulunmaktadır. Özellikle dağlık bölgelerin yoğun olduğu Doğu Anadolu Bölgesi bol kar yağışı alır ve sıcak aylardaki yüzeysel akış miktarı kış aylarında yağan karların erimesine bağlıdır. İklim değişikliğinin bu bölgelerdeki su kaynakları üzerindeki etkileri bazı projeksiyon tabanlı çalışmalarla araştırılmıştır. Örneğin, Fırat Havzasının yüzde 50'sini oluşturan Yukarı Fırat Havzasında Su Yönetimi Genel Müdürlüğü'nce yürütülmüş olan İklim Değişikliğinin Kar Erimelerine Etkisinin Belirlenmesi Projesine göre, havzada öngörülenin üzerinde sıcaklık arttıkça kar erimesi daha erken gerçekleşmekte ve sıcak aylarda yüzey akışı azalmaktadır. Diğer bir kar yağışlı bölge olan Yukarı Kızılırmak Havzasında, sıcak aylarda artan sıcaklıkla birlikte yüzey akışı azalmaktadır. Bu çalışmalar, projeksiyon tabanlı çalışmalar olduklarından, son 21 yılda kar erimesinin akışa katkısının değişimi konusunda Türkiye genelinde gözleme dayalı bir çalışmaya ihtiyaç duyulmuştur. Kar erimesinin akış üzerindeki etkisi, kar yağışının toplam yağışa oranı, kar yağışlarının toplam akışa oranı ve derece-gün yaklaşımları gibi çeşitli yöntemlerle analiz edilmiş ve bu yöntemler kullanılarak yapılan çalışmalarda Kar-su eşdeğerinin (KSE) yüzeysel akış oluşumuna katkısında önemli düşüşlerin olduğu görülmüştür.

Bu çalışmada, NASA'nın son 21 yıldan günümüze değin küresel olarak paylaştığı ve uzaktan algılama ve diğer verilerin girdi olarak kullanıldığı Küresel Hidrolojik Model (GLDAS v2.1) çıktıları kullanılarak Türkiye'deki kar baskın bölgeler belirlenmiş ve bu bölgelerde karın yüzey akışına katkısındaki değişim, 11 yıllık iki dönem halinde karşılaştırılmıştır. Bu amaçla, 2000-2010 ve 2011-2021 periyotları için Kar Erimesinin Yüzey Akışına Oranı (Rsr) değerleri hesaplanmış ve bu dönemlere ait Rsr değerlerinin ortalamaları Türkiye üzerinde mekânsal olarak temsil edilmiştir. Daha sonra Rsr değerlerinin her iki dönemdeki değişimleri de gösterilmiş ve analiz edilmiştir.

Genel olarak, hesaplanan Rsr değerlerine göre, Fırat-Dicle, Aras, Çoruh, Doğu Karadeniz Bölgesi, Sivas ili çevresinde Kızılırmak havzasının membası ile Yeşilırmak, Doğu ve Batı Karadeniz Havzalarının güney kısımları, yüzey akışının yoğun olarak kar yağışıyla beslendiği bölgelerdir (Rsr >0.50). Buna karşılık, Türkiye'nin batısı, İç Anadolu bölgesinin batısı, Ege ve Akdeniz kar yağışlı bölgelerin dışındadır (Rsr<0.50). Rsr değerleri 0,50'den düşük ise karın akış üzerindeki etkisi ihmal edilebilir düzeyde demek olduğundan bu çalışmada değerlendirilme dışında tutulmuştur.

Rsr değerleri hemen hemen tüm kar yağışlı bölgelerde azalmaktadır. Kar yağışlı bölgelerden Yukarı Fırat, Van Gölü, Yukarı Kızılırmak, Doğu Karadeniz, Seyhan'ın kuzeyi ve Dicle havzalarının doğu kesimlerinde son 11 yıllık (2011-2021) dönemde Rsr değerleri ilk 11 yıllık (2000-2010) döneme göre azalmıştır. Özellikle Yukarı Fırat ve Van Gölü Havzalarında son 11 yılda Rsr değerlerinde yüzde 50'ye varan düşüş, diğer bölgelere nazaran dikkat çekicidir. Benzer şekilde, 2011-2021 döneminde kar yağışlı bölgelerin çoğunda 2000-2011 dönemine göre KSE'de kayda değer bir azalma olmuştur. Palandöken Dağları'nın batı ve güney kesimleri, Mercan, Tecer ve Tahtalı Dağları gibi bölgelerde KSE, ilk 11 yıllık döneme göre son 11 yılda dikkate değer şekilde azalmıştır. Bu bölgelerde Rsr değerleri daha çok KSE'deki azalışlara bağlı olarak düşüş göstermektedir.

Bir başka vurgulanması gereken nokta olarak, bölgenin karla kaplı olup olmamasına bakılmaksızın, Türkiye'nin çoğunda son 11 yıllık dönemde yüzeysel akış oranlarının azaldığının gözlenmesi ifade edilebilir. Özellikle Orta Karadeniz kıyısının batı yakasında, Çoruh, Doğu Karadeniz, Yeşilırmak ve Batı Karadeniz havzalarında akıştaki azalma diğer bölgelere göre dikkatle izlenmeyi gerektirmektedir. Bu bölgelerdeki akıştaki azalmalar, toplam yağıştaki azalmaların yanı sıra kar suyu eşdeğerindeki azalmalarla da ilgilidir. İç Anadolu, Ege ve Akdeniz Bölgeleri gibi dağlık bölgelerin az olduğu ve karın hâkim olmadığı diğer havzalarda ise yağışların azalması veya buharlaşmanın artmasından kaynaklanmaktadır.

5. Birleşik Model Karşılaştırma Projesi (CMIP5) ve Su Yönetimi Genel Müdürlüğünün yürütmüş olduğu "Su Kaynaklarında İklim Değişikliğine Uyum" projesinin iklim projeksiyonları ile uyumlu olan mevcut çalışmanın sonuçlarına göre, içme suyu için kar yağışına yüksek oranda bağımlı olan Türkiye'nin kar yağışlı bölgelerinde su mevcudiyeti iklim değişikliğinden olumsuz etkilenmeye başlamıştır. Son 11 yılda Rsr değerlerindeki düşüşün, son yıllarda neredeyse rekor sıcaklıkların yaşandığı Türkiye'de gelecekte daha da hızlanması beklenebilir. Fırat, Dicle, Doğu Karadeniz, Yeşilırmak ve Kızılırmak Havzalarının karla kaplı bölgelerinin yüksek enerji üretimli bölgeler olduğu düşünüldüğünde, su yeterince mevcut olmadığında enerji üretimi sorunlarının çok uzak olmayan bir gelecekte tecrübe edileceği aşikardır.

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