ICONARP
International Journal of Architecture and Planning
Received: 24.06.2023 Accepted: 03.01.2024
Volume 12, Issue 1/ Published: 30.06.2024
Research Article *DOI: 10.15320/ICONARP.2024.290 E- ISSN:2147-9380*
ICONARP

Determination of Drinking Water Basin Protection Zones: Case of Beyşehir Basin, Türkiye

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Abstract

Global climate change, one of the most important problems of today, and human activities have negative effects on the sustainability of natural resources. It has become necessary to establish planning and management mechanisms for the sustainable use of drinking water basins within the protection-use balance. Beyşehir Basin, Türkiye was chosen as the study area. The aim of this study is to present a new model approach for the use of Analytical Hierarchy Process and Geographic Information Systems, based on the unique topographic, hydrological, and environmental characteristics of the basin, in the determination of the drinking water basin protection zones. Thirteen criteria, which affect the reaching of the pollutants to the water surface and reflect the topographic, hydrological, and environmental characteristics of the basin, were used in the determination of the protection zones. As a result of the study, it was determined that 2.83% of the basin is in the absolute protection zone, 44.97% in the short-range protection zone, 35.93% in the medium-range protection zone and 16.26% in the long-range protection zone. In the last stage, the conservation areas determined by the current legal regulations for the basin and the protection zones determined by the model approach were spatially and areally compared. According to the results of the comparison, it was determined with the proposed protection model that the absolute protection, the short-range protection, and the medium-range protection zones increased areally, and the spatial distributions of these protection zones were shaped according to the structure of the basin.

Keywords:
AHP, Drinking water basin, GIS, Protection zones, Sustainable watershed management

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To cite this article: Akdeniz, H.B., Levend, S., & İnam, Ş. (2024). Determination of Drinking Water Basin Protection Zones: Case of Beyşehir Basin, Türkiye. *ICONARP International Journal of Architecture and Planning,* 12 (1), 417-443. DOI: 10.15320/ICONARP.2024.290

INTRODUCTION

The main reason why Earth is called the blue planet is that more than 70% of its surface is made up of water. Although this rate seems high, only 3% of the total water in the world is fresh water and freshwater resources are not evenly distributed throughout the world (EEA, 2018). In addition, although water is the most basic source of life for all living things, the water source suitable for use in the world is less than 1% of all water resources (Muluk et al., 2013). This shows that water is a scarce natural resource.

In addition, climatic changes and social developments after the Industrial Revolution adversely affected the quantity and quality of water resources. Phenomena such as rapid increase in world population, excessive use of fossil fuels, urbanization, industrialization, and agricultural activities, which are also the main causes of climate change and water scarcity arising from global warming, lead to pressure and destruction on all natural resources, especially water resources (Cicek et al., 2015; WHO, 2022).

Today, the demand for water is increasing day by day. According to the United Nations International Children's Emergency Fund (UNICEF) and World Health Organization (WHO) data, 1 out of every 3 people experience water shortages because they cannot access adequate and healthy drinking water (UNICEF & WHO, 2019). The fact that people cannot reach a safe drinking water source shows that they must use and consume drinking water containing high levels of microbial microorganisms and chemicals. It is predicted that approximately half of the world's population will live in water-stressed basins by 2050 (Uyduranoglu Oktem & Aksoy, 2014).

The annual amount of usable water per capita in Türkiye is approximately 1350 m^3. Considering that this amount is 10,000 m^3 in water-rich countries, it shows that Türkiye is a country experiencing water scarcity. In Türkiye, which has a semi-arid character in terms of water, pressure has increased in water resources in terms of quantity and quality with the effect of population growth and climate change (TOB, 2018). By 2030, the population of Türkiye is expected to be 100 million and the need for water is expected to increase day by day (Kunt et al., 2020). By 2045, it is estimated that the amount of water needed in Türkiye will be three times the current water consumption (TOB, 2018). In addition, the pollutants formed in the basins because of urban, industrial, and agricultural activities cause deterioration of surface and even underground water quality. However, the absence of a water law in Türkiye that addresses and regulates all aspects of water and the fact that many institutions and organizations have authority in the management of water resources cause conflicts between institutions and laws in the process of protecting and using water resources. In this context, Türkiye will become a country experiencing water stress unless measures are taken for the protection and sustainable use of water resources (Ozturk

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et al., 2016). In this context, it is of great importance for sustainable Türkiye to evaluate the potential of water resources, protect their quality, prevent pollution, and use them efficiently in a very purposeful way.

In line with this awareness and the principles of the Water Framework Directive adopted in the process of orientation with the European Union (EU), some arrangements have been made both at the institutional level and in the legal legislation for the protection of drinking water basins in Türkiye (Cicek et al., 2015). The most important regulation made for the protection, improvement and sustainability of drinking water basins are undoubtedly the Regulation on the Protection of Drinking-Utility Water Basins and the Declaration of the Procedures and Principles for the Preparation of the Drinking-Utility Water Basin Protection Plan based on this regulation. These legal regulations necessitate the preparation of protection plans and the determination of special provisions for each drinking water basin with a scientific study, considering the characteristics of drinking water basins. However, although the legal regulations emphasize that a mathematical model should be used in the determination of the watershed protection zones, it is seen in the planning studies that the characteristics of the basins are not considered sufficiently, and the watershed protection zones are created by determining the distances to create bird flight buffer zones. This approach, in which natural thresholds are not adequately considered, is not sufficient to guide policies for the protection, improvement and sustainability of drinking water basins (Kuru & Tezer, 2020).

Geographic Information System (GIS) is a decision support system designed for the collection, storage, processing, analysis, and display of large volumes of data from various sources. By using GIS, the determination watershed protection zone can be analysed much more quickly, comprehensively, cost-effectively, with higher accuracy and systematically. Multi-Criteria Decision Making (MCDM) methods provide convenience to decision makers in designing and solving complex problems with many criteria or evaluating possible alternative ways (Feizizadeh et al., 2014). Spatial MCDM methods, on the other hand, were developed based on combining spatial analyses in GIS with MCDM methods. Today, many MCDM methods such as Analytical Hierarchy Process (AHP), Analytic Network Process (ANP), Inner Product of Vector, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) are successfully applied in a wide variety of GIS applications (Afzali et al., 2014; Beskese et al., 2015; Sisman et al., 2021, Akdeniz et al., 2023). The AHP is a method of "measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales" (Saaty, 2008). AHP, provides a framework for selecting a preferred alternative from among a set of potential solutions to a problem, therefore leads to more sustainable watershed planning and management decisions (Yavuz & Beycan, 2013). It has been one of the most widely used MCDM tools (Vaidya & Kumar, 2006).

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The aim of the study is to present a model for the use of GIS technologies and AHP method, which is one of the multi-criteria decision-making methods based on the unique topographic, hydrological, and environmental characteristics of the basin, in determining the protection zones, which is the main determinant in the planning of drinking water basins in line with the principle of protection and use. Thus, an objective method of determining drinking water basin protection zones has been defined for the limitation of activities that will affect the quality and quantity of drinking water. Within the scope of the study, the Beyşehir basin was determined as the study area. The main reason for choosing the Beyşehir basin as the study area is that Beyşehir Lake, which is the largest freshwater source in Türkiye, is located within the borders of the basin and it is predicted that the basin will experience significant water scarcity soon (OSIB, 2016).

This study makes a unique contribution to the literature, as it considers the determination of the basin's unique topographical, hydrological, and environmental characteristics with GIS and MCDM method instead of determining the protection zones based on distance in drinking water basins. In addition, it will be an important base for the determination of more sustainable policies at the basin scale.

WATERSHED PROTECTION IN TURKIYE

Although the basin planning approach is a multidimensional concept in socio-cultural, economic, and ecological sense, the essence of basin planning studies includes determination of policies for the protection of water resources, which are of vital importance for humans and all other living things. For this reason, many countries use different methods for the protection of drinking water resources in their studies on basin planning and management. The most widely used method is the creation of protection zones for the protection of water resources. While conservation precautions are being increased in the areas nearer to the lake or the water resource, the conservation precautions are diminished in the further areas (Ozdemir & Ozkan, 2007). Protection zones are determined by considering the characteristics of the basins during the basin planning process. Then, policies are determined on how to carry out urban, industrial, and agricultural activities that affect the quality or quantity of water resources according to the nature of each protection zone. Determination of the protection zones for drinking water resources is a powerful protection method for restricting the activities or pollutants that cause the quality of surface and even groundwater to deteriorate (Ozdemir, 2021).

EU countries have different protection legislation to prevent activities that threaten drinking water resources, and different methodologies for determining protection zones (Ozdemir, 2021). Due to the gradual decrease in the amount of usable water caused by increasing demand, pollution, and drought in Türkiye (TOB, 2018), legal arrangements have been made to determine the protection zones of

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water basins in line with the Water Framework Directive accepted by the EU. Undoubtedly, the main regulation among these regulations is the Regulation on the Protection of Drinking-Utility Water Basins, published by the Ministry of Agriculture and Forestry, which obliges the preparation of watershed-scale protection plans and the determination of special provisions for the protection, improvement, and sustainability of water resources (Date: 28.10.2017; No. :30224). The main purpose of the said regulation is *"...to regulate the procedures and principles regarding the protection and improvement of the quality and quantity of all surface and groundwater resources from which drinking water is provided or planned to be provided."*

The regulation requires the preparation of drinking water basin protection plans, in which special provisions are defined for each basin, with a participatory approach, considering the unique characteristics they have, integrated with the basin management plan. The regulation also determines the principles for the determination of protection zones for the protection of drinking water resources. In this context, the zone with a width of 300 meters in horizontal bird flight starting from the highest water level of the drinking water source is defined as the absolute protection zone. The permitted activities for the absolute protection zone are limited. The regulation defines an area of 700 meters starting from the absolute protection border towards the outer border of the basin as a short-range protection zone, the area of 1000 meters from the short-range protection zone to the outer border of the basin as a medium-range protection zone and the area from the medium-range protection zone to the outer border of the basin as a long-range protection zone. Beyşehir Basin Special Provisions have been prepared by the General Directorate of Water Management, based on the Environmental Law No. 2872 and the Regulation on Water Pollution Control No. 25687, to protect the existing water quality and quantity of Beyşehir Lake and its Basin, from which drinking water is supplied, and to ensure its sustainable use. These special provisions regulate the legal and technical principles regarding the activities in the basin. While the regulation restricts the activities in protection zones close to the water surface more severely, it stretches the activities in the protection zones away from the water surface towards the periphery of the basin.

The Ministry of Agriculture and Forestry has published the declaration on the Procedures and Principles for the Preparation of the Drinking-Utility Water Basin Protection Plan (Date: 20.02.2019; Number: 30692) in line with the Regulation on the Protection of Drinking-Utility Water Basins. In order to ensure the sustainability of drinking water, the declaration regulates the procedures and principles for the activities regarding the determination of the protection zones and principles in the drinking water basin, considering the characteristics of the water basins. In the second paragraph of Article 8 of the declaration, how protection zones in water basins will be determined is explained as follows: *"Protection zones are determined by considering the environmental* *pressures and effects in the basin, and the physical, geological, hydrological, ecological and socio-economic conditions of the basin."*

The declaration also emphasizes the need to determine the protection principles (special provisions) regarding what kind of activities can or cannot be done in the protection zones determined for the basins, with the drinking water basin protection plans. However, there is no explanation in the declaration on how the physical, geological, hydrological, ecological, and socio-economic characteristics of the basin will be handled or what method will be used in the process of determining protection zones. This causes deficiencies and differences in the applications for the determination of protection zones.

MATERIALS AND METHODS

Study Area

Beyşehir Basin is one of the nine sub-basins of Konya Closed Basin, which is the largest closed basin in Türkiye. The basin is located within the provincial borders of Konya, Isparta and Antalya and has a size of 473,690.27 hectares (Figure 1). The study area is located between 38° 12' 00'' – 37° 15' 00'' north latitudes and 32° 9' 00'' – 31° 7' 00'' east longitudes. According to the census data of 2021, the total population of the settlements within the borders of the basin is 126,180. Beyşehir Lake, Türkiye's largest freshwater lake, is located within the borders of the basin. Beyşehir Lake, with an area of approximately 67,251.59 hectares, is one of the most important water resources that meet the drinking water needs of the region. Today, Beyşehir Lake and its immediate surroundings are under protection as both a natural protection area and a drinking water basin.

The elevation of the Beyşehir Basin is between 1118 and 2985 m (Figure 1). The basin is surrounded by mountains, except for the plains in the east and north of the lake. In terms of climate characteristics, the basin shows transitional characteristics between Mediterranean and Continental climates. While the annual average precipitation is between 480 and 550 mm in the north of Beyşehir Basin, it is 650-750 mm in the south. There are many seasonal and continuous river networks in the Beyşehir Basin. The basin is fed by surface flow of 26 brooks/streams, 45 underground and aboveground springs and precipitation.

Study Desing

In this study, it is emphasized that the protection zones should be determined by using the topographic, hydrological, and environmental criteria specific to the basin to produce an alternative to the approach of determining the protection zones based on bird flight distances defined in the Regulation on the Protection of Drinking-Utility Water Basins. In this context, "height, slope, erosion, geology, distance to riverbeds, distance to water surface, rainfall, drainage density, vegetation, land capability classes, distance to solid waste landfills and distance to mining sites" criteria of the study area were used. Compliance degrees and scores

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of the criteria were evaluated under the main theme of "the pollutants reaching the water surface" and were determined based on literature research and expert opinions.

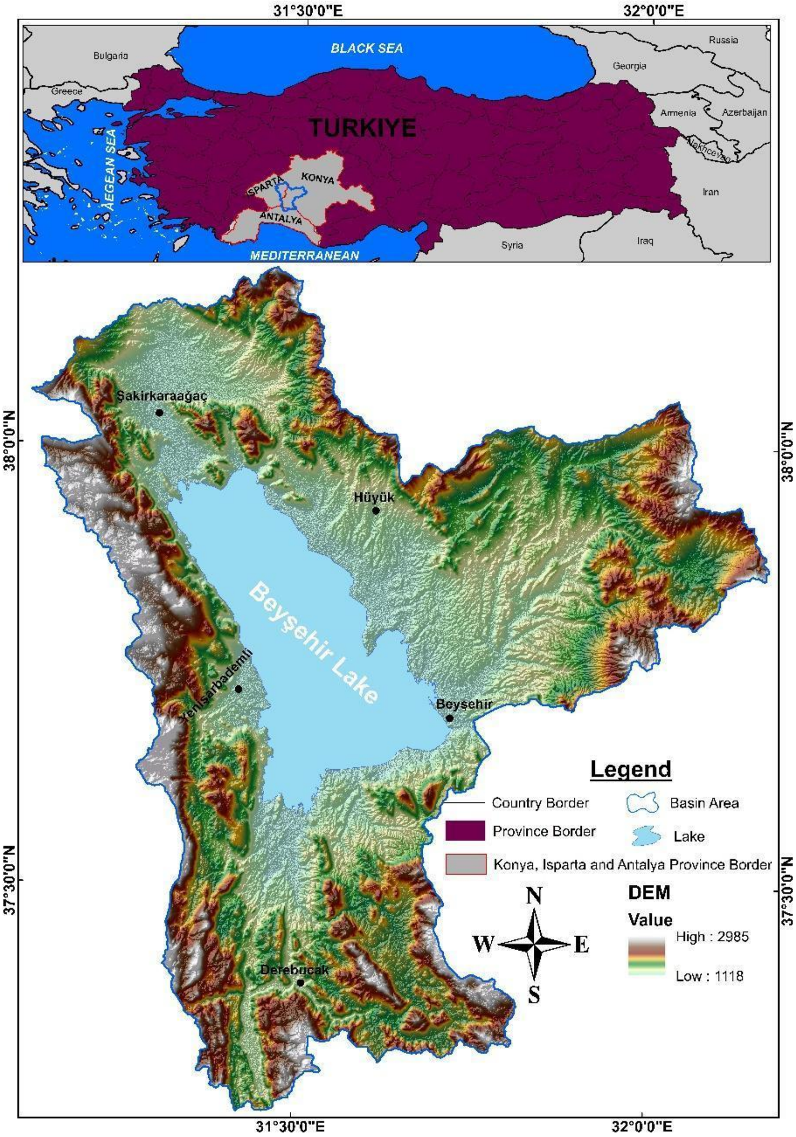

Figure 1. Location of Beyşehir Basin

Which criterion has higher or lower importance in determining the drinking water basin protection zones was determined by the AHP method, which is one of the MCDM methods. The criteria maps and the weights determined by the AHP method were overlapped using the "weighted overlay" analysis, and the protection zones of the Beyşehir drinking water basin were determined. At the last stage of the study, the approach to determination of protection zones based on distance defined in the legal legislation and the results of the model approach used in the study were compared on a spatial and areal basis and suggestions were developed for the sustainable use of the basin. The workflow of the study is shown in Figure 2.

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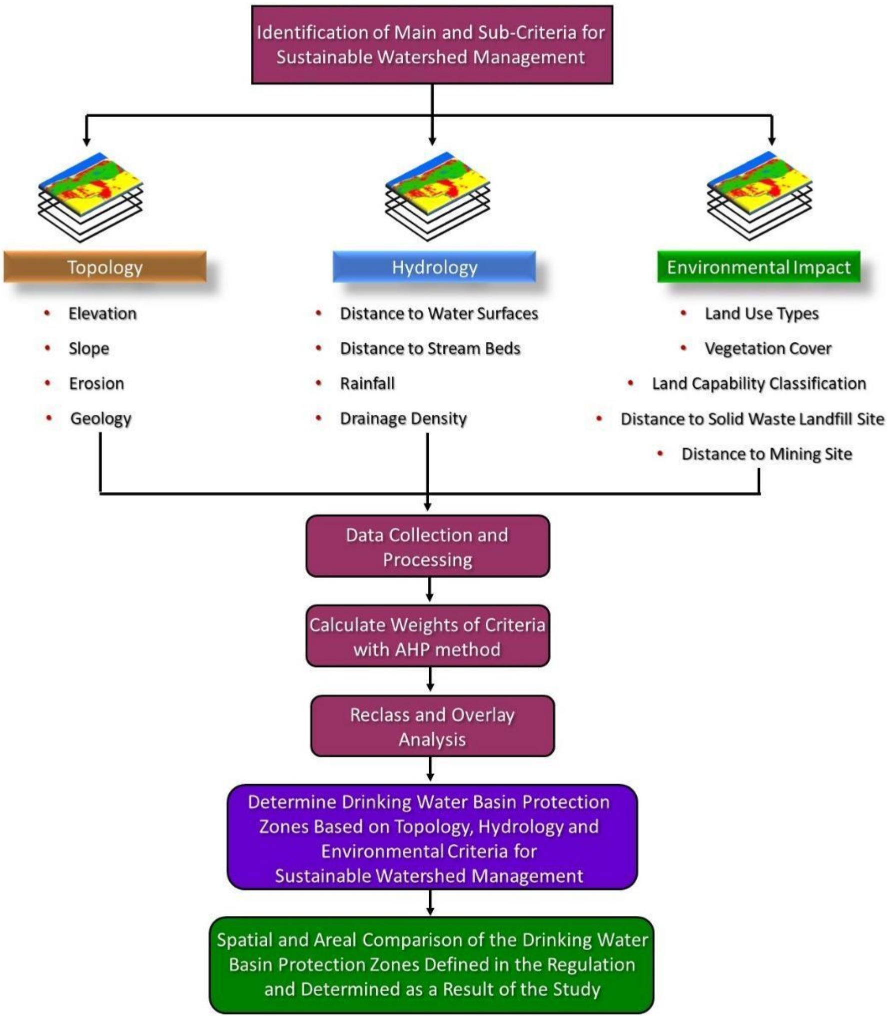

Figure 2. Workflow of GIS based AHP model for determination of drinking water basin

Identification of Criteria

One of the most important steps in the determination of the watershed protection zones is to determine the criteria that can directly or indirectly affect the pollutants reaching the water surface. In the legal regulations regarding the protection of drinking water basins in Türkiye, the protection zones are determined by considering the distance of the pollutants to the water surface. However, the data on distance to the water surface alone is insufficient to explain the possibility of the negative effects of the pollutants reaching the water surface. For this reason, multiple criteria should be considered, not a single criterion, in the determination of the protection zones for the drinking water basin. In this study, protection zones were determined by using topographic, hydrological, and environmental criteria specific to the basin. In the study, the evaluation criteria characterizing the drinking water basin protection zones were determined by considering the studies in the literature (Kuru & Tezer, 2020; Ozdemir, 2021; Deh et al., 2017; Erdogan & Karagüzel, 2016; Eba et al., 2013; Ake et al., 2020), the characteristics of the basin and the opinions of experts on the subject. The criteria were grouped under three main criteria as "topology, hydrology and environmental impact" (Table 1). Thirteen sub-criteria were determined

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under the main criteria. Elevation, slope, erosion, and geology sub-criteria were grouped under the main criterion of "topology". Distance to stream beds, distance to water surface, rainfall and drainage density sub-criteria were grouped under the main criterion of "hydrology" and vegetation cover, land use types, land capability classification, distance to solid waste landfill site and distance to mining sites sub-criteria were grouped under the main criteria of "environmental impact". In the study, the lake area was determined as an "absolute protection zone" in all criteria to protect the water quality and quantity of Beyşehir Lake and to ensure its sustainable use. Therefore, the Beyşehir Lake area was not included in the area calculations.

The data used in the study was obtained from a wide variety of data sources. A land use map was obtained from the CORINE 2018 data produced in line with the land cover classification determined by the European Environment Agency. Digital Elevation Model (DEM) was obtained from Shuttle Radar Topography Mission (SRTM) data. Slope maps of the study area were produced using DEM data. The geological structure of the study area was created by digitizing the 1:100000 scale geological maps obtained from the 2nd Regional Directorate of Mineral Research and Exploration (Konya). Stream beds and water surfaces were digitized using 1:25000 scale topographic maps and OpenStreetMap (OSM) data. Drainage density was calculated using stream beds and basin area data. Inverse Distance Weighted (IDW) method was applied to the rainfall data between the years 2011-2020 taken from the meteorological stations in the study area and the average rainfall map was produced for the Beyşehir basin. Erosion, vegetation cover, land capability classes, solid waste landfill site and mining site data were obtained from Konya Metropolitan Municipality. All data were converted to Universal Transverse Mercator (UTM), Zone 36 N projection system. ArcGIS software was used for data collection, storage, processing, spatial analysis, and mapping.

In the study, the protection zone classifications of the criteria were created according to the classification of protection zones (absolute protection zone, short-range protection zone, medium-range protection zone, long-range protection zone) defined in the Regulation on the Protection of Drinking-Utility Water Basins in Türkiye. Absolute protection zone was rated as 4, short range protection zone was rated as 3, medium range protection zone was rated as 2, and long-range protection zone was rated as 1. The protection zone rates and scores of the criteria were determined by literature research and the Beyşehir basin was arranged to adapt to the environmental conditions based on expert opinions. All criteria were graded and scored by considering the "The degree of effect of surface water on mobility and the state of transmitting the negative effects of pollutants to the drinking water surface" (Kuru & Tezer, 2020). The protection zone rates and scores of the criteria are shown in Table 1.

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Table 1. Protection zone rating and scores of drinking water basin criteria.

Main Criteria	Sub-Criteria	Unit	Protection zone rating and score			
			Absolute protection zone (4)	Short Range Protection zone (3)	Medium Range Protection zone (2)	Long Range Protection zone (1)
Topology	Slope	%	>15	10-15	5-10	<5
	Elevation	m	2500<	>2000-2500	>1500-2000	1000-1500
	Erosion	-	Very severe	Severe	Moderate	Mild or none
	Geology	-	Marble	Schist, Volcanic Rocks	Clastic and Carbonate Rocks, Limestone	Alluvion
Hydrology	Distance to Stream Beds	m	<1000	>1000-2000	>2000-3000	>3000
	Distance to Water Surfaces	m	0-300	>300-1000	>1000-2000	>2000
	Rainfall	mm	>675	>600-675	>525-600	>450-525
	Drainage Density	Km/Km²	>3	>2-3>	>1-2	<1
Environmental Impact	Land Use Type	-	Wetlands and Water bodies	Agricultural areas	Forest and seminatural	Artificial surface
	Vegetation Cover	-	Steppe, Shrubbery, Reeds,	Pasture, Meadow	Maquis shrubland	Broad-leaved tree, Pinales
	Land capability classification	-	6th Class, 7th class, 8th class	4th class, 5th class	3rd class,	1st class, 2nd class
	Distance to Solid Waste Landfill Site	m	0-500	>500-1000	>1000-2000	>2000
	Distance to Mining Site	m	0-500	>500-1000	>1000-2000	>2000

Topology

Land-use contains potential sources of water reservoirs pollution (Deh et al., 2017). It also plays an important role in the rainwater runoff, retention of suspended solids and pollutants absorption (Douay & Lardieg, 2010). In this study, land use was examined in five classes (agricultural, artificial, forest and seminatural, wetlands and water bodies). Wetlands and water bodies are classified as absolute protection zones since they are the type of land use where drinking water is provided. Agricultural fertilizers and pesticides are used in agricultural production, so agricultural lands carry a high risk of water reservoir pollution. For this reason, agricultural areas are classified as short-range protection zones. Since forest areas have high water holding capacity due to their natural structure, they reduce the severity of erosion and prevent the leakage of pollutants to the water surface.

Slope is one of the most important criteria for determining protection zones, as it shows whether pollutants can flow or leak from the surface (Aller et al., 1987). As the degree of slope increases, the water holding capacity of the soil decreases, and the flow rate and amount of erosion and surface water increases (Ozdemir, 2020). Therefore, the potential for contamination of surface waters increases. In the study, the areas with high slope degree (>15%) were classified as absolute protection zones, while the areas with low slope degree (<5%) were classified as long-range protection zones.

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Similarly, elevation is as important as slope since it affects the rate and amount of surface water flow. Pollutants are more likely to reach surface waters in regions with high elevations (Kuru & Tezer, 2020). In the study, the areas with an elevation of 1000-1500 m were determined as absolute protection zones.

Soils formed on slopped topography and containing less vegetative cover are eroded and transported in accordance with the severity of the factors. Erosion is exacerbated by the removal of vegetation, heavy rains, overgrazing and incorrect land use decisions. The erosion degree of the study area (very severe, severe, moderate, mild or none) was determined based on the classification of the Ministry of Agriculture and Forestry. Very severe erosion refers to areas where all the topsoil and more than 25% of the subsoil has been eroded, while mild or no erosion refers to areas where less than 25% of the topsoil has been eroded. Erosion soils carry their pollutants to surface waters, which causes the contamination of surface water with organic waste, heavy metals and chemicals, and damage to drinking water ecosystems. Therefore, in the study, areas with very severe erosion degree are classified as absolute protection zone, and areas with mild or no erosion degree are classified as long-range protection zones.

The geological structure of the land is another important topographic criterion that is effective for the pollutants to reach the water surface. Geological structures such as alluvium, sandstone, limestone, pebble, mudstone, etc. with high permeability absorb surface water and reduce the access of pollutants to the water surface, while geological structures such as marble, schist, gneiss cannot absorb surface water due to their low permeability level and increase the mobility of water containing pollutants (Kuru & Tezer, 2020). In the study, areas with marble geological structure were classified as absolute protection zones, and areas with alluvial geological structure were classified as long-range protection zones.

Hydrology

Watershed lines and stream beds, where the surface water flow rate and flow amount are relatively high, make it easier for pollutants to reach the drinking water surface (Kuru & Tezer, 2020). Therefore, these areas and buffer zones need to be cleared of pollutants. In the study, areas less than 1000 meters away from stream beds were determined as absolute protection zones.

In order to protect the water quality and quantity of the drinking water surface and to ensure its sustainable use, it is necessary to determine the protection distances that will prevent the pollutants from reaching the water surface. These distances were determined in the Regulation on the Protection of Drinking-Utility Water Basins in Türkiye. In the study, the distance to the water surface criterion was classified using the protection distances in the legal legislation.

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Rainfall is a key parameter in the process of assessing vulnerability to pollution of surface water (Eba et al., 2013). The duration and the amount of rainfall determine the onset of runoff when the soil has reached the maximum infiltration capacity (Codvelle et al., 2001). Rainfall makes it easier for pollutants to reach the water surface. As the amount of rainfall increases, the probability of transporting pollutants to the water surface also increases. In the study, areas with an annual average rainfall of more than 675 mm were classified as absolute protection zones.

Drainage density is the average river length per km2, which shows the degree of fragmentation of the basin by the rivers. Pollution of water resources is also linked to the hydrographic network density/drainage density underlying these resources (Codvelle et al., 2001). In areas where the drainage density and slope are high, the flow rate and amount of water is high, and its infiltration is low (Demiroglu & Dowd, 2014). Therefore, areas with high drainage density were classified as absolute protection zones.

Environmental impact

Vegetation is one of the other important criteria affecting the movement of surface water and the access of pollutant sources to the drinking water surface. While the amount of erosion increases in areas with insufficient vegetation, surface water and the pollutants carried by surface water can reach longer distances (Kuru & Tezer, 2020). In forested areas with dense vegetation, erosion severity is low and water holding capacity is high. Therefore, in the study, areas with broad-leaved and coniferous vegetation were classified as long-range protection zones, while areas with steppe, shrubbery, and reeds were classified as absolute protection zones.

Another important criterion in the contamination process of surface waters is soil. Because soil plays an important role in the transfer of pollutants from the soil surface to the water surface due to its natural structure (Macary et al., 2007). Pollution transport is graded as fast or slow according to whether the soil medium is fine-grained or coarse-grained (Ozdemir, 2020). If the soil medium is fine-grained such as silt or clay, the soil permeability is lower and the transport of pollutants to the water surface is reduced (Erdogan & Karaguzel, 2016). In the study, the soil criterion was examined by considering the "land capability classes" defined in the legal legislation in Türkiye. Land capability classes are determined by considering the characteristics of the soil and the land, such as soil structure of the land, soil depth, degree of erosion, ground water, stoniness, salinity, and alkalinity. Land use capability consist of eight classes (I, II, …, VIII). Classes I and II are lands with low degree of slope, water and wind erosion, high water holding capacity and less permeable soil. On the contrary, Classes VII and VIII, are lands with a high degree of slope, severe water and wind erosion, coarse-grained soil

DOI: 10.15320/ICONARP.2024.290

structure and high permeability. In the study, classes I and II were classified as “absolute protection zones”.

Solid waste landfill sites are important resources of surface water and groundwater contamination due to the leakage of leach- ate, a complex mixture of pollutants having high chemical oxygen demand, high ammonium nitrogen content and lasting toxicological characteristics (Han et al., 2016; Li et al., 2014). Waste placed in landfill sites or open dumps are subjected to either surface water and groundwater underflow or infiltration from precipitation (Mor et al., 2006). Many studies have indicated that the major surface water and groundwater pollutants from solid waste landfills include chloride (Cl^-), sodium (Na^+), ammonium (NH_4^+), total dissolved solids (TDS), organic matter such as chemical oxygen demand (COD), heavy metals and phosphate (Akinbile, 2012; Smahi et al., 2013). Therefore, in the study, the areas 500 meters away from the solid waste landfills were classified as “absolute protection zones”.

Mining poses a great risk for people accessing clean drinking water (Khan et al., 2013). Mining driven by human demand for minerals and metals is a major contributor to the current observed environmental pollution. Both heavy metals and metalloids are contaminants in areas of mining and smelting, posing a very serious and significant threat to the microfauna in watershed and for the hydrological cycle (Gu, 2018). Therefore, in the study, the areas 500 meters away from the mining sites were classified as “absolute protection zones”.

The Analytic Hierarchy Process (AHP): A Multiple Criteria Decision-Making Method

AHP is a multi-criteria decision-making method based on the binary comparison of criteria, rather than evaluating all criteria together, in problems involving multiple criteria and alternatives. Pairwise comparison provides the comparison of the criteria used in decision analysis and determines the value for each of these criteria (Vaidya & Kumar, 2006). When making pairwise comparisons, searching for the answer to the question “How important is criterion A compared to criterion B?” forms the basis of the method. The advantages of using the AHP method among other multi-criteria decision making methods in the literature are explained as follows; (I) all types of information related to problems can be included in the discussion process; (ii) judgment is structured in such a way that all the information are considered; (iii) the rules of discussions are based on knowledge, skill and experience of the expert; (iv) the weights for each relevant factor are obtained automatically by normalized principal eigen vector calculation of the decision matrix; and (v) inconsistencies in the decision process can be detected and corrected (Thanh ve De Smedt, 2012; Kayastha et al., 2013). However, the biggest disadvantage of this method is that the rating values given differ among experts and can be evaluated by experts who do not have sufficient knowledge about the subject.

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Pairwise comparisons are made using the scale developed by Saaty (1977). The pairwise comparison of criteria is made using a scale from 1 to 9 if there is a direct relationship between the criteria, and from ½ to 1/9 if there is an inverse relationship between the criteria. The value of 1 in the scale means that one criterion has equal importance compared to the other criterion, and the value of 9 means that one criterion is more important than the other criterion.

Pairwise comparison matrices are formed because of pairwise comparisons between criteria. In this study, pairwise comparison matrices were created for the main criteria [3x3], for the topology sub-criterion [4x4], for the hydrology sub-criterion [4x4] and for the environmental impact sub-criterion [5x5]. Mathematical calculations are made for the row and column elements in the pairwise comparison matrices and the weight of each criterion is determined (Cay and Uyan, 2013). The "consistency ratio (CR)" should be calculated to evaluate whether the experts' decisions are consistent in pairwise comparisons. CR reveals the random probability of the values obtained in a pairwise comparison matrix (Yılmaz, 1999). If CR ≤ 0.10, the pairwise comparison matrix is consistent, and the weights produced can be used. If CR ≥ 0.10, the pairwise comparison matrix is inconsistent and needs to be rearranged (Saaty, 1990). The process steps of the AHP method are explained in more detail in Figure 3.

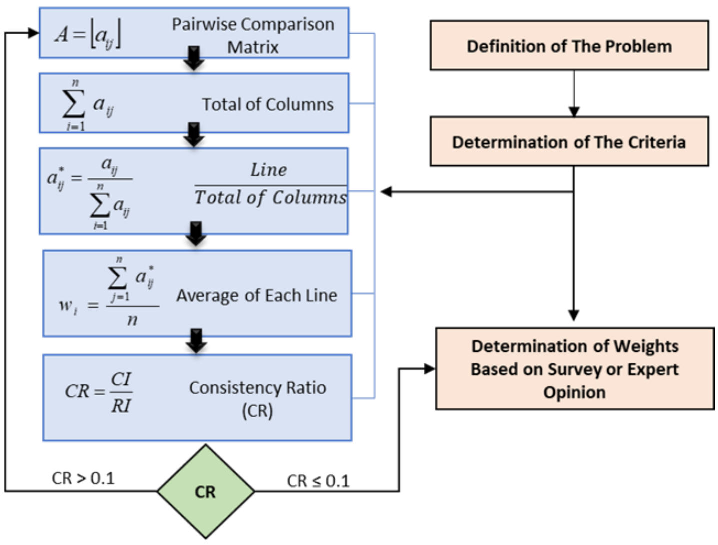

Figure 3. AHP process flow diagram (Sisman and Aydinoglu, 2020)

In this study, which aims to determine the protection zones of drinking water basin, the pairwise comparison matrices of the main and sub-criteria were formed by taking the geometric average of the opinions of 15 academicians who are experts in their fields. 8 of the experts are academicians in the department of city and regional planning and 7 of them are academicians in the department of geomatics engineering. The internal control of the pairwise comparison matrices created by the decision makers was checked by calculating the consistency ratio. The

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"Expert Choice" program was used to calculate the main and sub-criteria weights.

RESULTS

The spatial data for the protection zones of the Beyşehir drinking water basin were prepared and made ready for analysis. The main and sub-criteria weights calculated by the AHP method are given in Table 2. When Table 2 is examined, it is seen that the criterion with the highest importance in the main criterion comparison is "Hydrology (0.594)". The weight of the main criterion "Environmental Impact" was calculated as 0.249, and the weight of the main criterion "Topology" was calculated as 0.157. The consistency ratio of the pairwise comparison matrix created for the main criteria was calculated as 0.06.

When the sub-criteria weights of the "Hydrology" criterion are examined, while the most important sub-criterion is "distance to water surfaces (0.408)", the least important criterion is "rainfall (0.102)" (Table 2). The weights of the "Distance to stream beds" and "drainage density" sub-criteria were calculated as 0.38 and 0.11. The consistency ratio of the pairwise comparison matrix created for these sub-criteria was calculated as 0.01.

When the sub-criteria weights of the "Environmental Impact" main criterion are examined, it is observed that the most important sub-criterion is "land capability classes (0.312)", the least important criteria are "distance to solid waste landfill site (0.141)" and "distance to mining site (0.141)" (Table 2). The weights of the "vegetation cover" and "land use type" sub-criteria were calculated as 0.251 and 0.155. The consistency ratio of the pairwise comparison matrix created for these sub-criteria was calculated as 0.02.

When the sub-criteria weights of the "topology" main criterion are examined, it is seen that "geology (0.383)" has the highest degree of importance compared to the other sub-criteria (Table 2). This criterion is followed by "erosion (0.342), slope (0.168) and elevation (0.107)" sub-criteria, respectively. The consistency ratio of the pairwise comparison matrix created for these sub-criteria was calculated as 0.02.

In pairwise comparison of AHP criteria and sub-criteria, the aim is to measure whether experts behave consistently. Saaty (1990) accepts that the comparisons are consistent if the consistency ratio is less than 0.10. In the study, it was determined that the consistency ratios calculated for the main and sub-criteria ranged from 0.01 to 0.06. This result shows that the pairwise comparisons and matrices made by the experts are consistent.

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Table 2. Main and sub-criteria weights and consistency ratio.

Main Criteria	Weight	Sub-Criteria	Weight	Consistency Ratio
Topology	0.157	Slope	0.168	0.02
		Elevation	0.107	
		Erosion	0.342	
		Geology	0.383	
Hydrology	0.594	Distance to stream beds	0.380	0.01
		Distance to water surfaces	0.408	
		Rainfall	0.102	
		Drainage density	0.110	
Environmental Impact	0.249	Land use type	0.155	0.02
		Vegetation cover	0.251	
		Land capability classes	0.312	
		Distance to solid waste landfill site	0.141	
		Distance to mining site	0.141	

The protection zones map of each sub-criterion used in the determination of the drinking water basin protection zones is given in Figure. 4. The area amounts (ha) and ratios (%) belonging to the protection zones of each criterion are given in Table 3. When the sub-criteria evaluated under the topology main criterion were examined, it was determined that 4.88% of the study area was determined as absolute protection zone by slope, 4.88% by height, 45.11% by erosion and 0.39% by geology (Table 3). When the sub-criteria evaluated under the main criterion of Hydrology were examined, it was seen that 33.08% of the study area was determined as absolute protection zone by distance to stream, 1.66% by distance to water surfaces, 23.74% by rainfall and 0.00% by drainage density (Table 3). According to the sub-criteria of land use type, vegetation cover, land capability classes, distance to solid waste landfill site and distance to mining site, which were evaluated under the main environmental impact criteria, 1.36%, 53.04%, 69.11%, 0.08% and 21.75% of the study area were determined as the absolute protection zones, respectively.

When Figure 4 was examined, it was determined that the vicinity of Beyşehir Lake and the areas with high elevations are generally within the absolute protection zone boundaries in all sub-criteria protection zones map.

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Table 3. Drinking water protection zones area according to sub-criteria analyses and their ratio.

Criteria	Absolute protection zone		Short range protection zone		Medium range protection zone		Long range protection zone	
	Ha	%	Ha	%	Ha	%	Ha	%
Slope	19854.18	4.88	46614.15	11.47	105693.85	26.01	234276.60	57.64
Elevation	19853.48	4.88	46614.68	11.47	105694.39	26.01	234276.23	57.64
Erosion	183357.70	45.11	94919.94	23.35	81601.53	20.08	46559.61	11.46
Geology	1567.01	0.39	55580.07	13.67	282444.48	69.49	66847.22	16.45
Distance to stream beds	134457.07	33.08	100511.22	24.73	74390.59	18.30	97079.90	23.89
Distance to water surfaces	6745.31	1.66	16093.99	3.96	27527.64	6.77	356071.84	87.61
Rainfall	96491.89	23.74	64798.96	15.94	177462.47	43.66	67685.46	16.66
Drainage Density	0.00	0.00	0.00	0.00	0.00	0.00	406438.78	100.00
Land use type	5516.85	1.36	144887.68	35.64	250484.77	61.63	5549.48	1.37
Vegetation cover	215562.45	53.04	28560.1	7.02	5494.57	1.35	156821.66	38.59
Land capability classes	280884.23	69.11	34612.54	8.51	31701.37	7.80	59240.64	14.58
Distance to solid waste landfill site	313.55	0.08	942.40	0.23	3769.74	0.93	401413.09	98.76
Distance to mining site	88397.88	21.75	30449.67	7.49	54953.24	13.52	232637.99	57.24

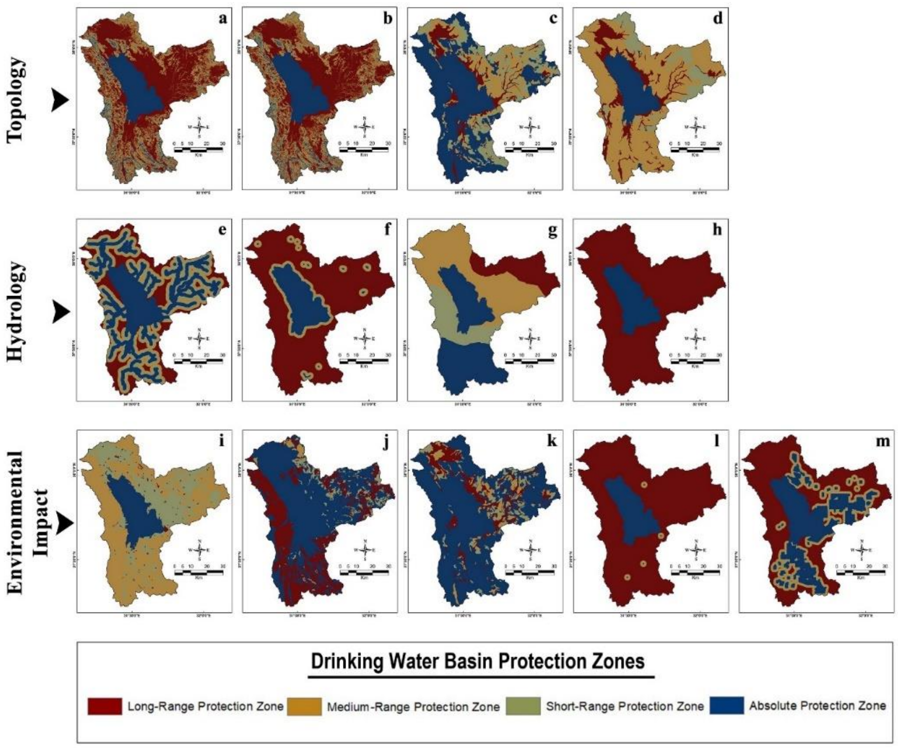

Figure 4. Protection zone maps of sub-criteria [(a) slope, (b) elevation, (c) erosion, (d) geology, (e) distance to stream beds, (f) distance to water surfaces, (g) rainfall, (h) drainage density, (ı) land use type, (j) vegetation cover, (k) land capability classes, (l) distance to solid waste landfill site, (m) distance to mining site].

The protection zones map of the main criteria in determining the drinking water protection zones of the Beyşehir basin is shown in Figure 5. When the protection zone ratios of the study area were evaluated according to the main criteria, 2.07% was determined as absolute protection zone by topology main criterion, 0.89% by hydrology main criterion and 7.43% by environmental impact main criterion (Table 4).

Table 4. Drinking water protection zones area of the main criteria and their ratio to the total area.

Criteria	Absolute protection zone		Short range protection zone		Medium range protection zone		Long range protection zone	
	Ha	%	Ha	%	Ha	%	Ha	%
Topology	8416.67	2.07	138330.41	34.04	141732.68	34.87	117959.02	29.02
Hydrology	3609.90	0.89	20183.41	4.97	222655.5	54.78	159989.97	39.36
Environmental Impact	30212.53	7.43	171379.15	42.17	200137.57	49.24	4709.53	1.16

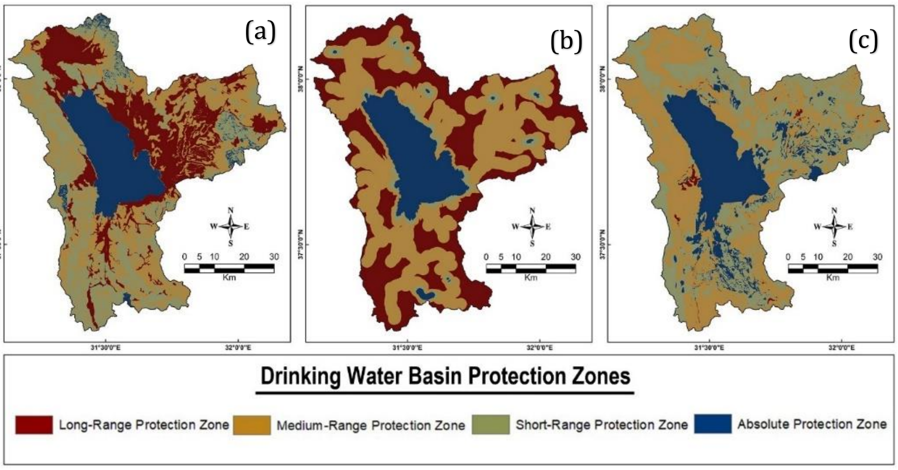

Figure 5. Protection zones maps of main criteria (Topology (a), Hydrology (b) and Environmental impact (c)).

According to the approach of determining the protection zones based on the distance specified in the regulation on the protection of drinking water basins, 0.13%, 0.97%, 1.60% and 97.30% of the Beyşehir basin are within the boundaries of absolute protection zone, short-range protection zone, medium-range protection zone and long-range protection zone, respectively. As a result of the proposed model application, it was determined that 2.83%, 44.97%, 35.93% and 16.26% of the basin are within the boundaries of the absolute protection zone, short-range protection zone, medium-range protection zone and long-range protection zone, respectively (Table 5).

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Table 5. Comparison of the areal and proportional amount of the Protection zones Based on the Distance Specified in the Regulation on the Protection of Drinking Water Basins and the protection zones produced by the model.

Protection zones	Regulation		Model	
	Ha	%	Ha	%
Absolute Protection zone	547.66	0.13	11487.01	2.83
Short-range Protection zone	3921.22	0.97	182784.47	44.97
Medium-range Protection zone	6514.97	1.60	146044.33	35.93
Long-range Protection zone	395454.93	97.30	66122.97	16.26
Total Area of the Basin	406438.78		406438.78	

The maps of the distance-based protection zones specified in the regulation on the protection of drinking water basins of the Beyşehir basin and the protection zones determined because of the proposed model are shown in Figure 6.

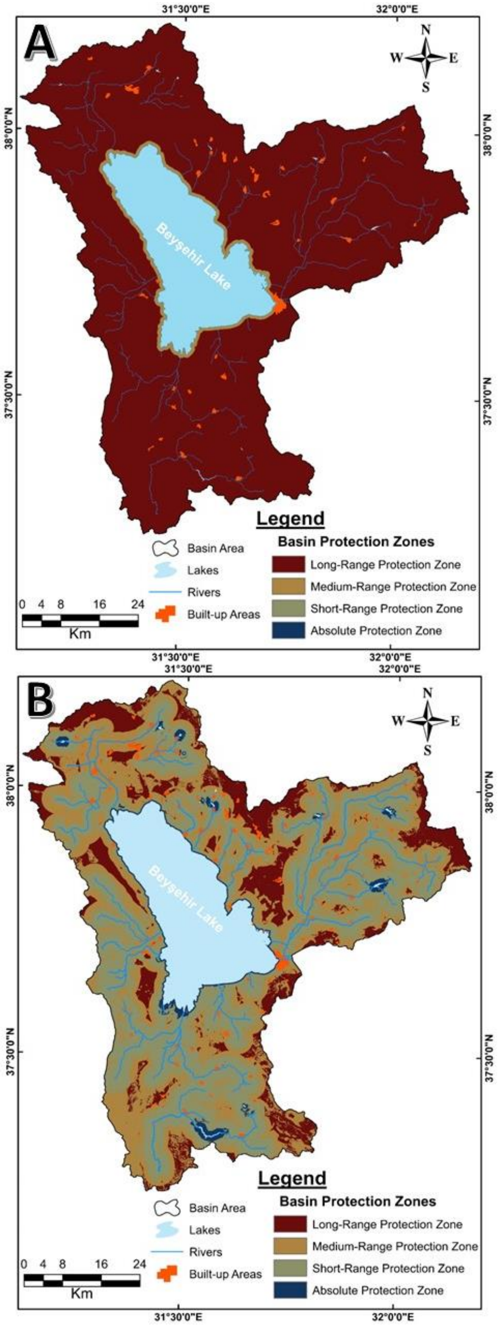

Figure 6. The boundary maps of distance-based protection zones specified in the regulation (A) and the protection zones determined because of the proposed model (B).

DISCUSSION

Different methodological approaches are used by the EU member and candidate countries to define the drinking water protection zones. While some countries adopt the distance-based protection zone approach, many countries determine the protection zones according to the characteristics of the basin. Depending on the amount of data available, simple, or complex calculations, methods or modelling approaches have been applied to determine the boundaries of protection zones (Ozdemir, 2021). For example, the drinking water basin protection zones in the Tuscany Region of Italy have been determined using an approach considering the geological, hydrogeological, hydrodynamic and hydrogeochemical characteristics of the basin (Menichini et al., 2015). In

DOI: 10.15320/ICONARP.2024.290

Germany, watershed protection zones have been determined using an integrated approach with modelling studies, considering the geological, hydrogeological, and hydrological characteristics of the basin (Hölting & Coldewey, 2019). However, in Türkiye, the protection zones of drinking water basins are determined by the distance-based protection zone approach included in the legal legislation. The most important aim of this study is to protect the existing water quality and quantity of the Beyşehir basin, which contains Türkiye's largest freshwater lake, and to ensure its sustainable use. For this purpose, Beyşehir drinking water basin protection zones were determined with a new approach that considers the topographical, hydrological, and environmental characteristics of the basin and uses the AHP method and GIS technologies.

The AHP method is a multi-criteria decision-making method that allows evaluation of multiple criteria together and is frequently used in the literature. However, the subjectivity of weights and scores assigned to criteria in AHP method is a limiting factor (Anoh et al., 2012; Deh et al., 2017). The values attributed to criteria have often tended to overestimate or underestimate the degree of vulnerability in the watershed. In the study, the opinions of 15 expert academicians who are experienced and knowledgeable in their field were taken to correct or minimize this subjectivity in assigning weights and points to the criteria in the evaluation of the sensitivity of the water source to pollution. The accuracy of the study results could not be compared since there was no different approach for the determination of Beyşehir basin protection zones. Despite these limitations in the method, the results of the study were examined by the experts and the reliability of the produced drinking water basin protection zones map was confirmed.

When the results of the distance-based protection zones approach specified in the regulation and the model/approach developed in this study were compared, it was seen the "absolute protection zone" specified in the regulation increased by 2.70% spatially (Table 5). While the "absolute protection zone" was limited only to the water surface of Beyşehir Lake in the regulation, both Beyşehir lake and all dam lakes in the basin showed expansion around the water surfaces in the model (Figure. 6). Similarly, in the model, there was a significant increase (44%) in "short-range protection zones". The "short-range protection zone" expanded not only around the Beyşehir lake, but also around the river and its branches in a large part of the basin. It is seen that the watershed protection zones are shaped according to the specific morphological structure of the basin (Figure. 6). The study findings confirm the study of Kuru and Tezer (2020), which uses a similar approach for the determination of a protection zone in a different drinking water basin. Kuru and Tezer (2020), in their study on the determination of watershed protection zones in Türkiye, found that the amount of "absolute and short-range protection zones" increased spatially and the protection zones of the basin expanded according to the regulation.

The model proposed by the study has shown that it is not appropriate to determine the protection distances with an approach that only considers the water surface. For the protection and sustainable use of the ecological structure of the basin, the model reveals the necessity of expanding the protection zones along the riverbeds carrying water to the basin, based on the topographic structure of the basin and other environmental criteria mentioned above. In order for this new model to be implemented in drinking water basins, protection principles should be determined by experts and decision makers and should be based on legal regulations.

The WFD (2000/60/EC) emphasized that the stakeholders in the basin have an important role in protecting the quality and quantity of water during integrated drinking water basin management. Stakeholders include local citizens, farmers, public authorities, private sector representatives. In order to make the basins sustainable, it is not sufficient only to determine the boundaries of the basin-specific protection zones and to implement the policies. It is also necessary to work in coordination with stakeholders. Therefore, after the protection zone boundaries and policies for each basin are determined, informative meetings should be held with stakeholders, training should be provided, and works should be carried out together in order to decide on the best watershed management plans to meet the socio-economic and environmental demands of the basin. Thus, more effective sustainable water management will be ensured for drinking water basins by reducing the use of polluting resources, both with the protection zone boundaries determined according to the topographical, hydrological, and environmental characteristics of the basin and legal regulations and with conscious stakeholders.

CONCLUSIONS AND RECOMMENDATIONS

In Türkiye, legal regulations for the protection of water quality and quantity of drinking water basins are insufficient. The main reason for this is that the regulations do not consider the characteristics of the basin and the boundaries of the protection zones are determined based on distance. In this framework, it is necessary to determine the protection zones and restrictions by considering the characteristics of each basin in terms of ensuring the balance of protection and use of drinking water basins and their sustainability.

This study aims to fill the above-mentioned gap. The study proposes a model based on AHP and GIS, in which topographic, hydrological, and environmental characteristics are considered in the determination of protection zones. The model aims to prioritize the criteria related to the basin in a systematic way with the AHP method and to obtain fast and reliable results by using the spatial analysis capability of GIS. In this framework, using the proposed model, it was determined that the protection zones produced for the Beyşehir basin (Konya-Türkiye), which is the sample area of the study, are more inclusive than the

DOI: 10.15320/ICONARP.2024.290

determined protection zones. When the protection zones produced by the proposed model were compared with the protection zones determined by the current legal regulations, it was determined that the area amounts of absolute protection zone, short-range protection zone and medium-range protection zone increased, and their spatial distribution was shaped according to the original morphological structure of the basin.

While the study makes a clear contribution to the literature on the protection of water basins, it also has some limitations. The study only focuses on surface water quantity and quality. For this reason, no investigation was made on the quality and quantity of groundwater within the scope of the study. In addition, the hydrogeological and hydrogeochemical characteristics of the basin were not included in the study due to data limitations. The above-mentioned deficiencies should be considered in future studies on this subject.

It is expected that the results of this study will guide the managers and authorities in the use, protection, management, sustainability of water resources and in making land use decisions in Beyşehir drinking water basin. The legal regulations in Türkiye need to be reconsidered to apply this new model, which evaluates the basin-specific features together in the determination of protection zones. In addition, the participation of all stakeholders who will be affected by the decision in the planning and implementation of drinking water basins will contribute to the sustainable water management of the basin.

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DOI: 10.15320/ICONARP.2024.290

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