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A study on assessing the urban growth, population, and water resources of Bodrum Peninsula, Turkey

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Abstract In recent years, it has been difficult to establish a supply-demand balance between urban growth, increasing population, and existing water resources in many countries. In this study, the Bodrum Peninsula, which is an important tourism center for Turkey, was examined in terms of the relationship between the urban growth of the peninsula, population projections, the need for drinking and potable water, and the availability of the existing water resources. Using the Geographic Information System, it has been determined that the urban growth of the peninsula increased by 11.36% between 1985 and 2010. Urban growth is mostly concentrated in the coastal areas where 2 houses are densely built. The population is expected to increase approximately six times between 2010 and 2060. The amount of drinking and potable water required according to the population projection is 12.38, 26.50, 69.12, and 109.50 hm^3/year for 2010, 2030, 2050, and 2060 respectively. The existing water resources of the peninsula will be able to meet the requirements until 2030. In order to meet the water needs of the peninsula until 2055, the Bozalan and Gökçeler dams located nearby as well as the Namnam dam located at mid-range to the peninsular should be built. It is not possible to meet the water needs of the peninsula in 2060 with just the near and medium distance water resources. However, by supplying water from the Akköprü dam located at a further distance, it is possible that 2060 water needs can be met.

Keywords Urban growth · Population · Water requirements · Water resources · Bodrum Peninsula · Turkey

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Introduction

Providing urban water security is an essential requirement for many countries. There is no clearly defined and widely approved definition of urban water security. Urban water security is a multi-faceted concept and is associated with urban metabolism, ecological security, integrated urban water management, water-energy-food safety net, risk management, flexible and adaptable water concept, and cities sensitive to water (Maheshwari et al. 2016; Aboelnga et al. 2018). Urbanization is one of the most important trends of the twenty-first century that affect global economic development, energy consumption, natural resource use, and human welfare (Brown et al. 2009; Elmqvist et al. 2013; Fitzhugh and Richter 2004; Jenerette and Larsen 2006; Lederbogen et al. 2011; McDonald et al. 2011, 2013).

Today, 4.2 billion people, who make up 55% of the world's population, live in urban areas. With the addition of 2.5 billion people to urban areas, which is approximately 90% of the increase in Asia and Africa, this rate is expected to increase to 68% by 2050 (UN DESA 2018).

People living in new cities will need water. However, little is known about where surprisingly growing cities will provide their water or what this infrastructure means in the global hydrological cycle (McDonald et al. 2011; Padowski and Jawitz 2013). The total increase in municipal water demands causes the search for new, sufficient, and clean water resources that lead to the formation of highly complex urban infrastructure systems of cities (Alcott et al. 2013; Brown et al. 2009; Chau 1993). Urbanization acts together with urban water security and economic growth. However, in order for growth to be sustainable, the impact of rapid urbanization on urban water security should be at the center of national and regional development (Aboelnga et al. 2018; Scanlon et al. 2017). According to the Global Risks Report, the water resources of many cities face an increasing risk of reduction and exhaustion (UN 2019). Water supply crises, which are ranked as the first of the biggest global threats in terms of probability and impact, focus on quantity and quality issues of freshwater resources (Kala et al. 2007). Typical water supply design in urban systems is based on providing continuous, safe, and clean drinking water (Charalambous and Laspidou 2017). Today, increasing urbanization, population, and climate change are putting great pressure on water supply (LeChevallier et al. 2003). Clean water is an indispensable element for people's living and well-being (Specter 2006; Keenan 2008).

One of the biggest challenges that increase water stress in developing countries is rapid urbanization (POST 2002). The increase in the number of people living in urban areas is associated with increased water demand as well as the difficulty of many people in having access to adequate clean water and sanitation. The difficulties encountered have contributed to the continuous development of urban water areas. The biggest challenges are population growth, migration, and climate change (Vörösmarty et al. 2000; Alcamo et al. 2007). Increasing population, urbanization, environmental pollution, deforestation, intensive agriculture, water scarcity, urban flood, aging infrastructure, and many other problems have been caused all over the world (Grimm et al. 2008; Sharma et al. 2010). Estimates of the future urban population of the world show Asian and African countries as high urban concentration areas (Jiang et al. 2008).

In this study, the Bodrum Peninsula, which is an important tourism center for Turkey, was examined in terms of the relationship between the urban growth of the peninsula, population projection, the need for drinking and potable water, and the availability of the existing water resources.

Study area

The Bodrum Peninsula is an important tourist region located on the southwestern tip of Turkey. The peninsula is located between 37° 2′ 18″ North latitude, 27° 25′ 45″ East longitude. There is Güllük Gulf on the north of the peninsula, Gökova Gulf on the south, and the Aegean Sea on the west. The peninsula has a basin area of 680 km^2 and a coastline of 174 km. The region is under the influence of the Mediterranean climate. It has hot and dry summers, wet and rainy winters. The average annual precipitation is 681.9 mm, and the average temperature is 21.35 °C. The peninsula consists of Bodrum Center and 55 neighborhoods. The geological structure consists of paleolithic schists and limestone. Surface waters, spring waters, and groundwater are not sufficient in the parts of the peninsula near the sea. Groundwater and spring waters are more in the inland areas (Bakış 2001; MM 1996; 1998). The general concern in the Mediterranean region is the availability of water and anticipation of increased water deficiencies as a result of climate change (Hein et al. 2009; Iglesias et al. 2007; Scott and Becken 2010). There are no streams with regular flows in the Bodrum Peninsula. Therefore, it is not possible to build a dam within the borders of the peninsula (DSI 2009). The location of the Bodrum Peninsula, which is analyzed as a study area, is given in Fig. 1.

Data and method

Water resources data

Water resources in the peninsula of Bodrum are very extremely limited. The intense population movement to the coastal regions of the peninsula increases the demand for water resources in the summer months. Water

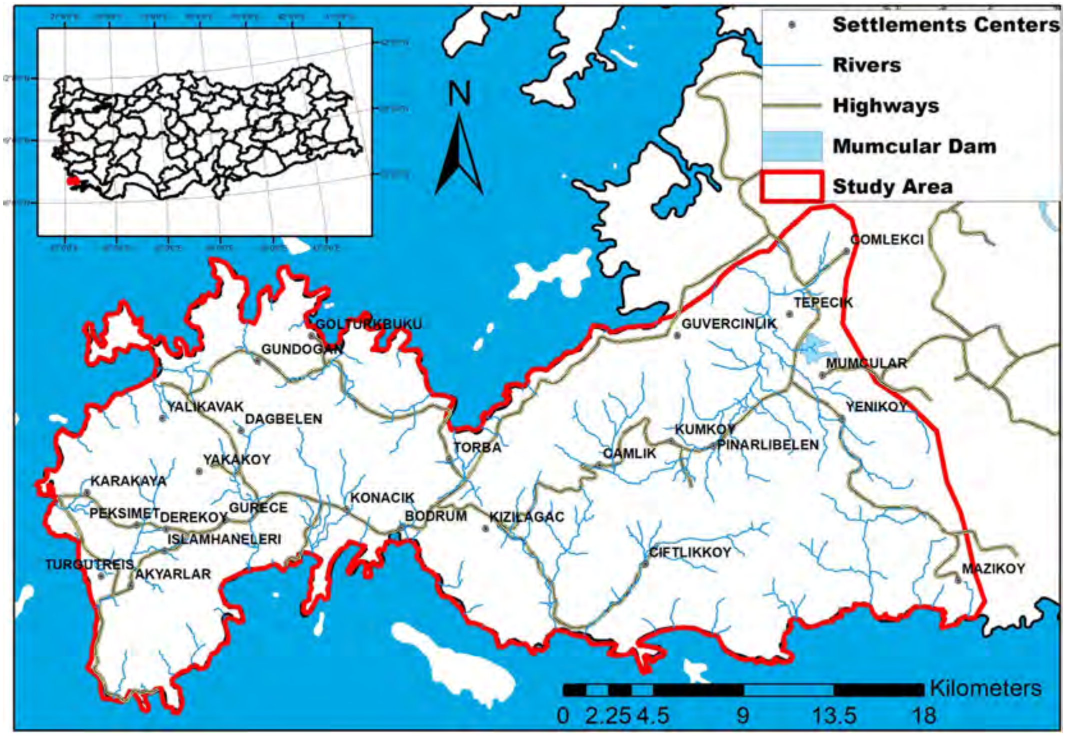


Fig. 1 Location of the Bodrum Peninsula in Turkey

resources of the Bodrum Peninsula have been procured from five important water sources since 2011 (Table 1) (DSI 2010). Depending on the future population of the peninsula, the daily water consumption per person is 170–260 L day^{-1} person^{-1}, and the network loss-leakage values are in the range of 18–27%. The drinking water consumed per capita in Turkey in the 2000s is taken as an average amount of 260 L day^{-1} person^{-1} (DSI 2009). Domestic water use standards in any society vary depending on climate conditions, lifestyle, culture and tradition, technology, and economy.

Table 1 Bodrum Peninsula water resources (DSI 2010)

Water resources	Capacity (hm^3/year)
Peninsula GW	5.00
Mumcular Dam	5.00
Karaova GW	2.80
Geyik Dam	5.00
Çamköy GW	4.72
Total	22.52

GW groundwater well, *hm*^{3} million cubic meters

Population data

In order to reveal the relationship between urbanization and population growth in the region, population data for the years 2007–2019 for the Bodrum Peninsula have been taken from the database of the Statistical Institute of Turkey (TSI) (TUIK 2020). The annual population growth rate in the region was calculated as 4.94%. Population projections up to the year 2060, for the Bodrum Peninsula in Turkey for 5-year period, are calculated according to Compound Interest formula which expresses exponential growth method (Bartlett 1993; Anonymous 2002). The calculated population in this method is the permanent or winter population of the peninsula. The equation used in this method is given below.

$$P_{\text{future}} = P_{\text{past}}(1+i)^N$$

where P_{future} = future population, P_{past} = past population, i = annual population growth rate, and N = projection years.

The population of the peninsula reaches far above the winter population in summer. Second residences used for tourism purposes and tourism population should be known in order to determine the summer population. Although the summer population is more important in terms of water demands, official records and demographic data about the winter population are accessed from TUIK records. There is no recorded data to refer to the summer population and the 2nd residence for tourism purposes. First of all, knowing the 2nd residential population in the period between May and September is of great importance for projects to be prepared to meet water demands. In the study, the 2nd resident population was determined by the areas shown in the existing development plans and the interviews with the Municipality.

Data collection for satellite images

In the study, some sophisticated and much data was needed to examine the impact of urbanization and population change on water resources. To analyze the relationship between different land uses and water demand, for 2nd residency as well as for different types of housing and permanent accommodation, average estimates and water consumption data for each municipality have been used (Rico-Amoros et al. 2009). The most important data source for determining the change in urbanization is satellite images. Today, it is quite easy to access satellite images for free. In the study, 8 satellite images of 1985, 1990, 1995, 2000, 2005, 2010, 2015, and 2020 were used to examine the change in urbanization. Satellite images are taken from Google Earth satellite images. Google Earth is a web-based software (Google Earth 2020) that can provide free global satellite images. Google Earth can be very useful for urban planners working on the land-use change by providing satellite images taken in different time periods. In addition, Google Earth ensures low margin of error in studies by providing high-quality spatial resolution (Malarvizhi et al. 2016). Satellite images and features used in the study are given in Table 2.

Satellite images provided for the Bodrum Peninsula are geo-referenced (Universal Transverse Mercator (UTM) Projection European Datum 35N Zone) according to their coordinates in the Geographic Information Systems (GIS) software, ArcGIS 10.4.1; and the working area limits have been defined. Satellite images are prepared for the study of the increase in urbanization according to the method described in the "Method" section.

Table 2 Satellite images used in the study

Satellite images type	Date (yyyy)	Spatial resolution (m)	Cloud cover (%)
Google Satellite Imagine	1985	10	0
	1990		
	1995		
	2000		
	2005		
	2010		
	2015		
	2020		

Method

Satellite images need to be classified and interpreted to examine the change in urbanization. Depending on the different feature types, natural spectral reflection, and emission characteristics, satellite combinations with different numerical values are created (Musaoğlu 1999). By making use of this difference, objects on the earth having the same spectral properties can be grouped. Classification is a decision-making process used in many disciplines. The purpose of the image classification process is to automatically assign and place all the pixels in an image in the classes or themes they correspond to in the field (Tunay and Ateşoğlu 2004). There are 3 main image classification techniques in remote sensing: Unsupervised, Supervised, and Object-based. Unsupervised and supervised image classification methods are the most used methods (Zhang et al. 2019; Oyekola and Adewuyi 2018; Abburu and Golla 2015). It is based on the automatic clustering with the help of algorithms without user intervention in the uncontrolled classification method. This method is mostly used when the data in the satellite image cannot be identified. However, since the pixel data in satellite images can be identified in this study, the supervised classification method was used.

Supervised classification method

In this method, using the sufficient number of sample regions (test areas) that define the earth properties in the study area, feature files with defined spectral properties are created for each object to be classified. By applying these files to the image data, each image element (pixels) is assigned to the class in which it is most similar to the calculated probability values. In the study, the satellite images were examined, and the classification of the pixels was made using the maximum likelihood method. This method is one of the most frequently used methods in many studies (Ahmad and Quegan 2012; Shivakumar and Rajashekararadhya 2018; Norovsuren et al. 2019; Hagner and Reese 2007; Medina and Atehortúa 2019). This method is based on the principle of defining equivalent probability curves for classes and assigning the pixels to be classified to the class with the highest probability of membership. In the study, classification was made for 3 land classes (Table 3). While creating 3 land classes in the study area, observations made in the field were taken into account. According to these observations, it was determined that the 3 land classes which dominate in the study area are Forest, Bare Land, and Residential Area.

In this study, the Maximum Likelihood Classification tool module was used by using ArcGIS 10.4.1 software. According to the classes given in Table 3, a controlled classification was made for each satellite image between 1985 and 2020. After determining the forest, bare lands, and residential areas, how much space they occupied was determined by calculating their areas, and then their increases and decreases by years were calculated. The change of the Bodrum Peninsula, in terms of urbanization between 1985 and 2020, has been revealed. The flow chart of the method applied in the study is given in Fig. 2.

Results and discussion

Urbanization is a process that can be managed with appropriate planning for development but cannot be stopped. Planning in urban management is possible by detecting the growth of urbanization. Satellite images are the main sources in the process of identifying and mapping this growth (Ngie et al. 2013). In this study, the images obtained from satellite images are controlled and classified, and the study area is evaluated under 3 main land use classes (Forest, Bare Land, Residential). Bare lands also include agricultural lands. The change in land use, for 5-year periods between 1985 and 2020, shows that urbanization in the region has increased rapidly. According to the controlled classification in the study, land use maps in 1985–2020 are given in Fig. 3.

Table 3 Land types used in land classification

Classification scheme	Description
Forest	Deciduous, evergreen forests, shrubs, and mixed forests
Bare land	No vegetation, lichens/moss
Residential area	Rural houses, urban buildings

According to Fig. 3, the residential areas shown in red have increased regularly from 1985 to 2020. It was observed that the bare lands indicated by yellow have been replaced by the settlements. Due to the increasing population and tourism potential of the peninsula, it is seen that the settlements replace bare lands. Forest lands decreased at a relatively lower rate than bare land. Since it is known that the pixel size of the raster maps given in Fig. 3 is 10 × 10 m in dimensions, it is possible to examine the land changes regionally in the years studied. The graphs given in Fig. 4 show the areal change of land change between 1985 and 2020.

According to Fig. 4, the forest areas in the peninsula decreased by 5.75% and covered an area of 15,665.58 ha in 2020. It was observed that the bare lands decreased by 5.61% within the 35-year period covered, covering an area of 39,937.77 ha in 2020. Unlike forests and bare lands, an increase has been observed in the peninsula's residential areas. The residential areas covering only 2.35% of the peninsula with an area of 1510.94 ha in 1985 have become 8830.88 ha by 2020 covering 13.71% of the peninsula. This situation reveals that urbanization increased by 11.36% in the years studied.

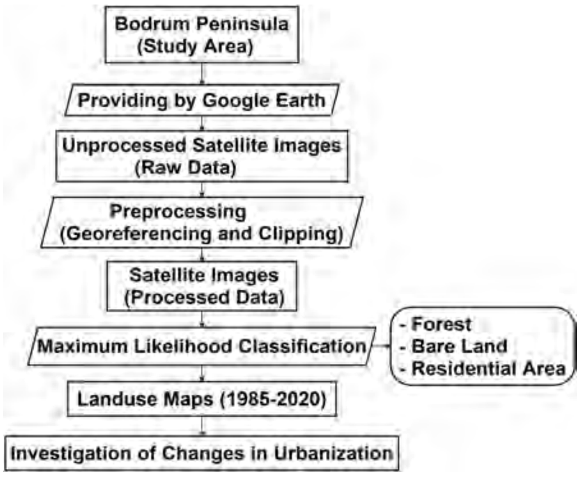


Fig. 2 Flow chart of the method applied in the study

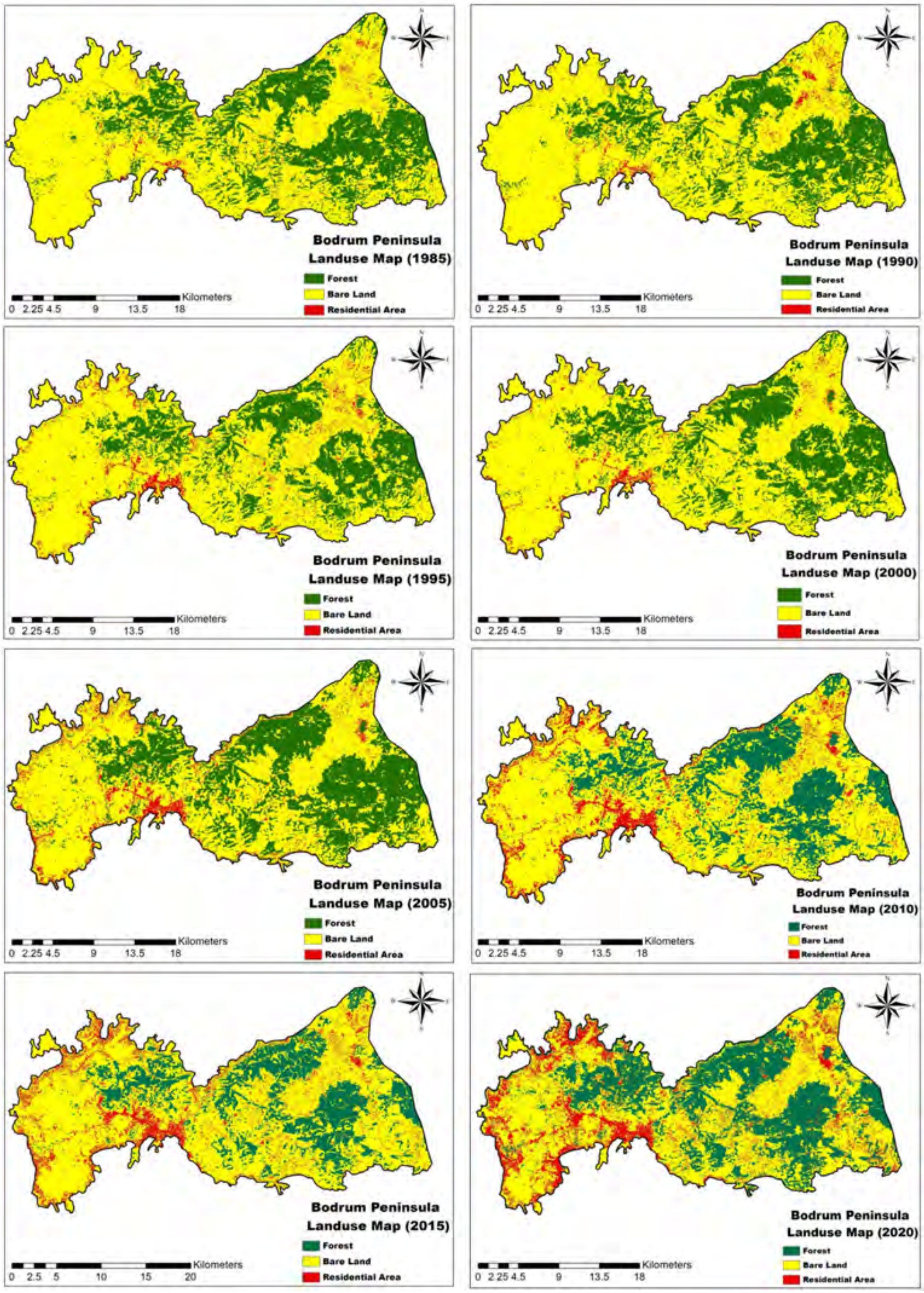


Fig. 3 Change of land use status by years

Relationships with urbanization, population, and water resources

Population projections for the Bodrum Peninsula show the total population including the winter and the 2nd residential population. Population projections for the years examined are given in Fig. 5. The expected total population of the peninsula for 2030, 2040, 2050, and 2060 is 518,912, 755,523, 1,115,067, and 1,675,148, respectively. The population for 2nd residency in the

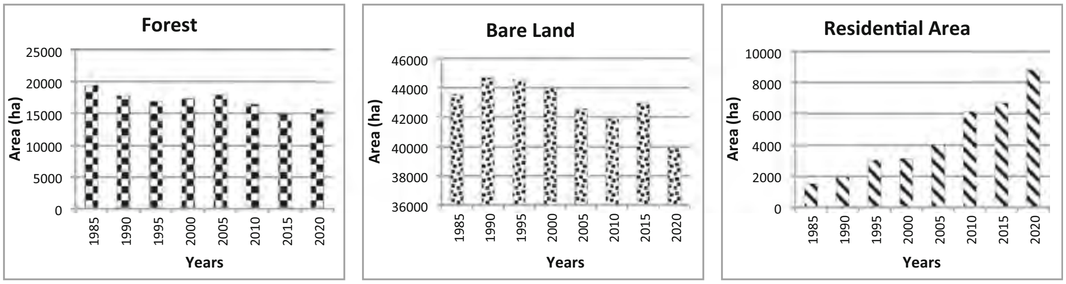
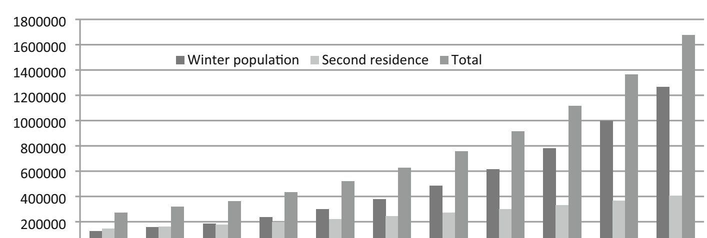


Fig. 4 Changes in land use

years examined is approximately half of the total population. Since the Bodrum Peninsula activity is mainly tourism, many people prefer this region in order to own a second residence. When seasonal population mobility is analyzed, it is seen that the 2nd residency and winter population are developing in parallel. In the peninsula, the residential areas with the highest housing capacity are the regions close to the shore. In the analyzed years, the winter population increased by 10.1 times, and the 2. residency population increased by 2.80, while the total population increased by 6.15 times. European Environment Agency (2000) reports that approximately 335,000 2nd residences have been built in the coastal regions of France in the last 20 years and these structures cover more than 22 million m^2. EC (2000) argues that the winter population in Rimini, Italy, is 130,000, the summer population is 260,000, and the average density in winter is 4000 people km$^{2-1}$ and 9000 people km$^{2-1}$ in July and August respectively.

With the examination of the change in land use, an increase in urbanization emerged; and the increase in the population was revealed through population projections. In Fig. 6, the relationship between population and urbanization was revealed in the Bodrum Peninsula between 1985 and 2060. When an evaluation was made by considering only the winter population of the peninsula, it was observed that the settlement area corresponding to 124,820 people for 2010 was 6121.15 ha. From here, it was calculated that the residential area per capita in 2010 was 490,398 m^2. In the projection of the winter population, the expected population in 2060 is 1,266,776 and the expected residential area is 66,419.78 ha. In this case, the residential area per capita in 2060 is 524,321 m^2. It is known that there are many people who do not officially reside in the peninsula, but own a second residence for tourism purposes. Therefore, it would be more meaningful to evaluate the winter population and the second housing population together. When the winter population and the 2nd residential population are evaluated together, it was observed that the residential area per capita in 2010 fell from 490,398 to 224,929 m^2. According to the population projection of 2060, it was calculated that the residential area per capita is 396,500 m^2. Calculations show that the rate of increase in residential areas is higher than the rate of population growth. The reason for the rapid urbanization in the Bodrum Peninsula is that it is an important tourism region. Considering that the number of tourists coming to the peninsula continues to increase year by year, it is important to build many touristic facilities in the region in terms of urbanization. These facilities have an important place in meeting the tourism population,



	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
Winter population	124820	155815	184102	234294	298172	379466	482924	614588	782148	995392	1266775
Second residence	145307	160641	177801	197069	218710	243073	270559	298576	330869	366656	406313
Total	272137	318471	363923	433388	518912	624574	755523	915209	1115067	1364103	1675148

Fig. 5 Winter, second residence, and total population of Bodrum Peninsula between 2010 and 2060

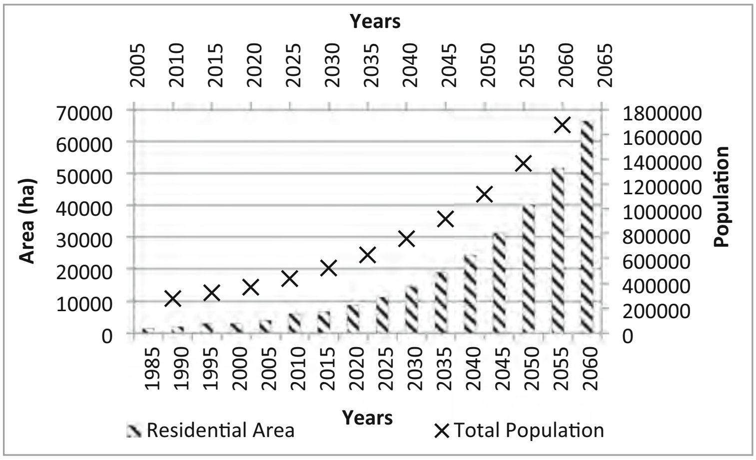


Fig. 6 The relationship between the total population and urbanization of the Bodrum Peninsula between 1985 and 2060

especially in the summer, except for the winter population and the 2nd residential population. The fact that urbanization is higher than the total population is related to the increase in the number of these tourist facilities (hotels, motels, hostels). In their study, Burak et al. (2004) revealed that the increase in urbanization in the coastal areas of the Mediterranean and Aegean regions is developing faster than the population. This situation shows that tourism enterprises are important in urbanization.

Due to the extreme temperature and relative humidity in the region during summer months, water consumption is excessively increasing. In addition, the limited availability of freshwater causes competition for water in agriculture, industry, and urban use. Taking into consideration the population calculated for the peninsula, daily peak water requirement, flow rate, peak factor, and future expected water needs are given in Table 4. The amount of net water needed per capita in the Bodrum Peninsula between 2010 and 2060 is 170–260 L day^{-1} person. There is no fixed data to estimate the amount of water required to maintain an acceptable minimum living standard for countries (Zhang 2005; WHO 2003). According to the World Health Organization (2008, 2009) and National Water Policy (2004), the average amount of water needed per person to maintain a healthy life in the city center is 120 L day^{-1} person^{-1}. The average water consumption per person in New Zealand is 180, 270 in Australia, 150 in England and Wales, and 230 L day^{-1} person^{-1} in China (Lu 2007). In the European Union, the water needs per person in Denmark was 128 L day^{-1} person^{-1} in 1998 and now

Table 4 Annual total water needs of Bodrum Peninsula

Year	Net water need (L/day/person)	Scheme loss (%)	Brut water need (L/day/person)	Peak water need		Peak factor (−)	Total water need (hm^3/year)
				m^3/day	L/s		
2010	170	27	233	63,407	734	1.87	12.38
2015	180	25	240	76,433	885	1.86	15.00
2020	185	24	243	88,433	1024	1.85	17.45
2025	200	23	260	112,681	1304	1.84	22.35
2030	200	22	256	132,842	1538	1.83	26.50
2035	220	20	275	171,758	1988	1.82	34.45
2040	230	20	288	217,591	2518	1.81	43.88
2045	245	18	298	272,733	3157	1.80	55.30
2050	250	18	304	338,981	3923	1.79	69.12
2055	250	18	304	414,687	4800	1.78	85.03
2060	260	18	317	531,022	6146	1.77	109.50

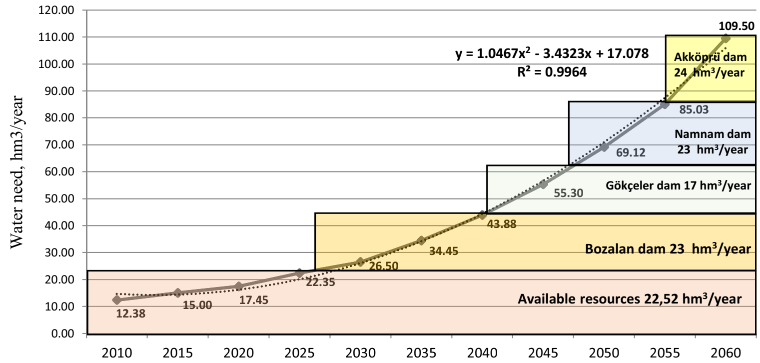


Fig. 7 Water need and resource adequacy status

it is 138 L/day/person today (EEA 2014). Gascon et al. (2010) found that the average water requirement in the city of Barcelona in Barcelona is 334 L day^{-1} $person^{-1}$. Average water use per person is 47 in Africa, 95 in Asia, and 578 L day^{-1} $person^{-1}$ in the USA (UNFPA 2002). In the coastal regions of Spain, the amount of water used per person can increase to 440 L day^{-1} $person^{-1}$ due to the use of more water in the 2nd residencies for tourism purposes (Lehmann 2009; UNEP 2002). Daily peak water requirement of the peninsula ranges from 63,407 m^3 day^{-1} (734 L s^{-1}) to 531,022 m^3 day^{-1} (6146 L s^{-1}). In this process, while the total population increased by 6.15 times, the total water demand has increased by 8.84 times. Estimating supply and demand is fundamental to the sustainability of the water system. In their study, Cosgrove and Rijsberman (2000) found that the demand for water has increased significantly in the twentieth century, and the population of the world has increased three times, while domestic water use has increased six times. The amount of water needed in the future of the peninsula according to the population projection is 12.38, 26.50, 69.12, and 109.50 hm^3 $year^{-1}$ for 2010, 2030, 2050, and 2060 respectively. The total water supply of the peninsula is 22.52 hm^3 $year^{-1}$, and this will be sufficient until 2030. For this reason, it is not possible to meet the water supply needs until 2060 with the existing water resources of the peninsula.

Figure 7 shows the water requirements, the status of existing water resources, and the water resources that need to be developed in the future. To meet the water resources needed in the future, it is necessary to develop water sources close to the peninsula as well as in the medium distances. For this reason, the Bozalan dam (23 hm^3 $year^{-1}$) for storing nearby water resources should go into operation by 2030, Gökçeler dam (17 hm^3 $year^{-1}$) by the year 2040, and the medium distance Namnam dam (23 hm^3 $year^{-1}$) should be built

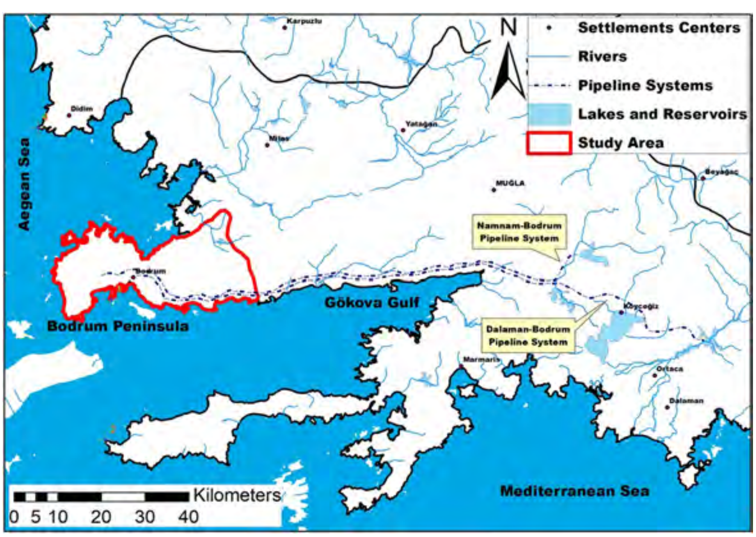


Fig. 8 Water resources need to be developed and available in Bodrum Peninsula

and put into operation by 2050. It is possible to meet the requirements until the end of 2055 with the water sources close to the peninsula and in the medium distances. However, the water requirements of 2060 will not be met from the water sources located at close and medium distances. For this reason, the water needs of 2060 can be met by providing water from the remote Akköprü dam. Figure 8 shows the water resources available and those that need to be improved according to the years examined for the peninsula.

Conclusion

The relationship between urban growth and water supply is both interrelated and affects each other. Urbanization, on the one hand, affects water resources through an increasing population, economic development, water resource consumption, and regional expansion; on the other hand, water resources, with urban growth in the direction of industrial zones, population migration, and water resources constraints limit the political intervention to develop water resources and the fight to get funds allocated to develop water resources. This study has examined the relationship between the urban development of the Bodrum Peninsula, which is one of Turkey's most important tourism centers, with population projections, water needs, available water resources, and water resources that need to be developed. According to the total population projection, the residential area per capita increased by 224,925 m^2 in 2010 and by 56.7% in 2060, reaching 396,500 m^2. In the years studied, the urbanization of the peninsula has increased by 11.36%. The rate of increase in the residential areas of the peninsula is higher than the rate of the population growth. Existing water resources of the peninsula will be able to meet the needs by 2030. In order to meet the peninsula's water needs in the future, it is necessary to transfer additional water from the near and medium distance water sources. In order to meet the water needs of the Bodrum Peninsula until 2060, water should be transferred from the Bozalan and Gökçeler dams, which are close to the peninsula, and the Namnam dam, which is in the medium distance. However, water should be transferred from the remote Akköprü dam to the peninsula for the needs of 2060. The scope of urban water infrastructure is quite wide. For urban water requirements, approximately half of the global land surfaces are drawn, and water is transported to a total distance of 27–35 km. Urban water management of the peninsula should be evaluated in a unified manner. Integrated urban water management plans should be prepared in order to sustain the economic and vital activities of the whole peninsula. Increasing population and increasing residential construction areas cause a decrease in surface areas that will allow the storage of water resources, as well as the change of surface flow conditions and urban hydrology. This situation adversely affects the location selection of water storage structures that need to be built in order to provide water from a close distance to the peninsula.

In order to prevent losses and leakages in existing water transmission and distribution networks, it is necessary to maintain and renew pipelines, to establish incentive mechanisms and new technologies that direct water users to save water, to accurately measure the amount of water used, and to keep records regularly.

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