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DROUGHT HAZARD AND WATER SHORTAGES IN ISTANBUL, TURKEY

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ABSTRACT

Data from 1960 to 2014 reveal significant changes in the climatic characteristics of Istanbul. Rising temperatures and changes in precipitation, along with population growth, rapid urbanization and the impact of industrial activities, have led to water scarcity in Istanbul. The purpose of this study was to analyze the drought hazard and problem of water scarcity in Istanbul using measurements compiled over 55 years. Daily precipitation and temperature data sets observed at Florya Meteorological Station were used for the drought analyses. Statistical analysis of Istanbul's population is based on data from the Turkish Statistical Institute. Analysis results show that Water surplus, Storage change, Water deficiency and also Potential Evapotranspiration values in Istanbul are key evidences of a negative change in the water balance of Istanbul. It has been understood that seasonal changes and decrease of precipitation and the increase in monthly and annual average temperature encourage the water shortage in Istanbul climate. Results of the analysis were evaluated and were discussed here in terms of both Istanbul's water needs and water management. The data show that the city is faced with drought hazard risk and increasing water scarcity.

Keywords: Drought hazard, Water scarcity, Istanbul, Population, Climate Change.

INTRODUCTION

Istanbul (N40°48'-N41°30' - E28°00'-E30°55') is one of the most important historical, cultural and economic cities not only in Turkey but also the world. According to data from The Turkish Statistical Institute (TSI), Istanbul had a population density of 2759 /km^2 people per square kilometer [1] and is among the cities with the world's highest population density. In the period 2009-2015, the amount of registered freshwater consumed steadily increased at rates ranging from 1.01 to 6.99% per year. This does not include fresh water used off the record drawn by pumps from wells and lakes. According to statistics, Istanbul's water needs increase every year. However, the amount of fresh water in reservoirs serving the city is decreasing each year [2], [3], [4]. In brief, Istanbul faces severe water problems.

Istanbul's water needs are supplied almost entirely from surface waters. Measurements indicate that the reserves of the city's water sources have steadily declined in recent years [2], [4]. This shows that Istanbul is on the verge of drought hazard and more pronounced water scarcity. The aim of this paper was to investigate these two issues. In this context, using various aridity measures and indices and analysis and statistics based on the climatic database, the changing water requirements of Istanbul were examined focusing on the cause of water scarcity and potential of drought hazard.

The data concerning the water needs of Istanbul, consumption per year, potential of dams and occupancy rates, and variations in the occupancy rate of the dams were obtained from the Istanbul Water and Sewage Administration (IWSA) [3], [4], [5]. Daily precipitation and temperature data sets observed at Florya Meteorological Station during the 55 years from 1960 to 2014 were used for the aridity index analyses and precipitation and temperature variation analyses. Different aridity measures and indices were calculated for comparison and verification. Population data were obtained from the Turkish Statistical Institute (TSI).

Population growth and Water consumption

Istanbul's population has increased rapidly in the last 60 years, surpassing 14.7 million today [1]. A total of 5.5% of Turkey's population was living in Istanbul in 1950. This ratio reached 10.4% in 1980, 14.8% in 2000, and 18.0% in 2009 [7]. According to data from 2016, the population of Istanbul (14,657,434) represented 18.61% of Turkey's population (78,741,053) [1], [6]. Despite a reduction in the population growth rate, projections indicate that the city's annual growth rate will continue to rise, ranging between 20-29 ‰ (Table 1) [1], [6], [7].

Table 1. Annual population growth rate and density of Istanbul for 2007-2015 [1], [6]. P: Population, R: Rate of change (‰).

	2007	2008	2009	2010	2011	2012	2013	2014	2015
P:	12573836	12697164	12915158	13255685	13624240	13854740	14160467	14377018	14675434
R:		9.8	17.2	26.4	27.8	16.9	22.1	15.3	19.5

Istanbul's daily water consumption was 1.9 million m^3 in 2003. In ten years, this increased to 2532736m^3/day in 2014 [4]. An increase in daily water consumption in Istanbul is inevitable; due to population growth, rapid urbanization, and an increase in industrial activity.

Water supply and reservoirs

Groundwater potential of Istanbul is low, and almost all (98%) of the water needs of Istanbul are supplied from surface water sources such as dams, lakes and rivers [4]. The occupancy rates as of 24 August 2014, and data on the maximum volume of dams and rivers providing fresh water to Istanbul, are given in Table 2. The occupancy rate of Istanbul's water resources at 24 August 2014 is remarkable. When the occupancy rate for August 2013 in the dams is compared with the occupancy rate for August 2014, serious differences emerge (Table 2) [8]. A decline in Istanbul's water resources is observed in the annual averages. For the 5 years between 2009 and 2013, a steady decrease was measured in the average annual volume of fresh water. During the first 8 months of 2014 (January to August), a significant reduction occurred in the volume of fresh water in dams (Table 3) [8].

Table 2. Average occupancy rate of Istanbul’s dams August 2013-August 2014 measured at end of each month [8].

	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
(%)	64.32	54.41	46.88	41.92	38.13	34.77	31.32	32.29	32.52	28.57	25.32	21.33	16.73

Table 3. Average annual occupancy rate of Istanbul’s dams 2009 to 2014 [8].

Year	2009	2010	2011	2012	2013	2014 (first 8 months)
Occupancy rate (%)	76.11	73.14	70.2	61.63	60.77	27.77

Changes in precipitation and temperature

Changes in the climatic characteristics of Turkey have been felt more prominently each year. Records clearly reveal the variations in precipitation and temperature characteristics [9], [10]. An increase in temperature and decrease in precipitation are expected to affect climatic conditions in large areas of the country. Despite unique differences, the temperature and precipitation characteristics of Istanbul are consistent with this general climatic trend [11], [12].

The maximum temperatures of the last century (20th) on a global scale were measured in 1998. According to meteorological records extending into the 21st century, 9 of the 10 warmest years occurred since the year 2000 [13]. These data identify the last 15-year time span as an important period in terms of global climate change. Considering 55-year climate data, changes in the temperature and precipitation features of Istanbul show compliance with the global climatic trend since 2000. According to, data covering the period 1960-2014 from Florya Meteorological Station, the 8 warmest years in Istanbul occurred since the year 2000 (Table 4). The years receiving minimum precipitation throughout 1960-2014 occurred in the first decade of the 21st century. According to Florya data for the past 55 years, the driest years were observed in three of the five years in 2006-2014 (Table 4). These climatic data are evidence that the last 15 years are an important period in terms of climate for Istanbul. Therefore, in order to demonstrate variations in temperature and precipitation, data were compared in the periods 1960-1984, 1985-1999 and 2000-2014 (Table 4).

Table 4. Amount and distribution of lowest precipitation and warmest years since 1960 in Istanbul (P: Precipitation) (Source: Florya Meteorology Station, Istanbul).

Years	Lowest mean precipitation	Warmest years	
	Annual (P<500mm)	Annual Mean Temperature (15.5 - 16.1 °C)	Annual Mean Maximum Temperature(19.5 - 20.7 °C)
1960-1984	null	null	1 year
1985-1999	2 years	null	1 year
2000-2014	3 years	8 years	8 years

Climatic features of precipitation

Climate change affects a variety of factors associated with drought. One of these factors is precipitation, and the other is temperature. Drought indicators not only show a decrease in the amount of annual precipitation, but also changes in the timing and distribution of precipitation throughout the year. There are important differences in the annual precipitation, timing and seasonal distribution of daily precipitation in the 55-year (1960-2014) and 15-year periods (2000-2014) over Istanbul (Table 5). In the 55-year period (1960-2014) and first period (1960-1984), the average annual amounts of precipitation closely approximate each other. However, in the most recent 15-year period (2000-2014), the average annual amount of precipitation is less than the other two periods (1960-1984 and 1985-1999) (Table 5) (Fig. 1, Fig. 2). A divergence in the seasonal distribution of precipitation during the year can be seen. When the average monthly amounts of precipitation for the 2000-2014 period is analyzed, it appears that the reduction rate in the “Wet Season” of the year (October-March) is more than the “Dry Season” of the year (April-September) (Table 5) (Fig. 2). A further contrast in the last 15 years is irregularities of average monthly precipitation during the warm period of the year (Fig. 2).

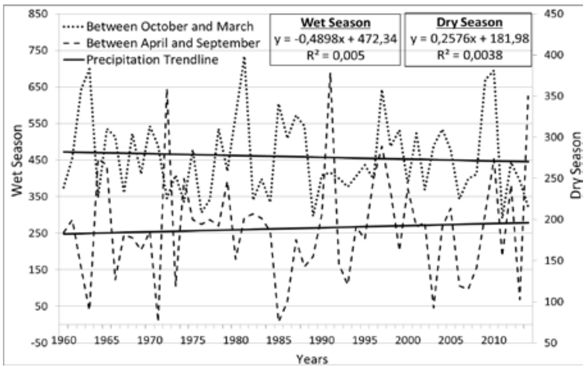

Figure 1: Precipitation variation trends over Istanbul in 1960-2014.

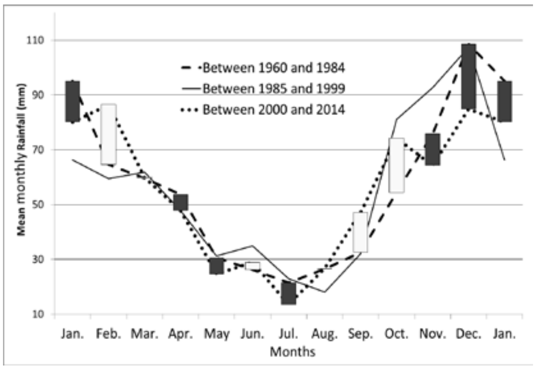

Figure 2: Changes in average monthly precipitation for three periods.

Table 5. Monthly and annual average rainfall (mm) in Istanbul between 1960 and 2014 (Source: Florya Meteorology Station, Istanbul).

Years	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1960-2014	83,1	69,1	60,3	50,4	29,1	29,3	19,7	24,2	36,4	67,1	77,3	101,7	647,7
1960-1984	95,0	64,6	59,6	53,6	30,6	26,3	21,5	26,4	32,6	54,4	75,8	108,5	647,7
1985-1999	66,2	59,4	61,8	47,8	31,2	34,9	23,0	18,0	32,0	81,1	92,7	107,4	652,0
2000-2014	80,1	86,4	59,9	47,8	24,6	28,9	13,5	26,6	47,2	74,2	64,3	84,9	638,4

The daily temperature observations for the 1960-2014 period is summarized in Table 6. If the monthly average temperatures for the 55-year period (1960-2014), and three periods (1960-1984, 1985-1999, 2000-2014) are compared, then it is understood that the monthly and annual average temperatures (Fig. 3) and the monthly and annual average maximum temperatures are rising, the warm period of the year is being extended, and monthly average temperatures are rising. Furthermore, the increases in temperature in January, February and March of the winter season are especially remarkable (Table 6) (Fig. 4). It is expected that increase temperature might intensify the evaporation process in Istanbul and close vicinity.

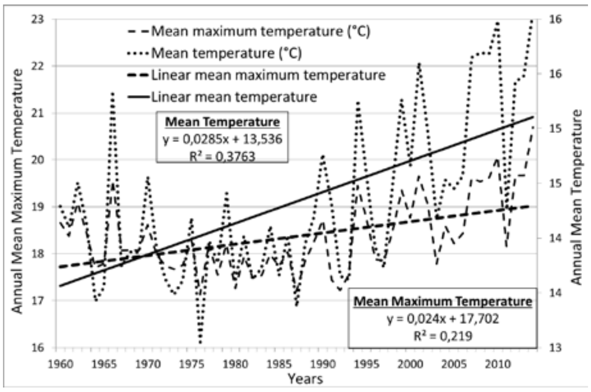

Figure3: Features of temperature variation trends over Istanbul in 1960-2014.

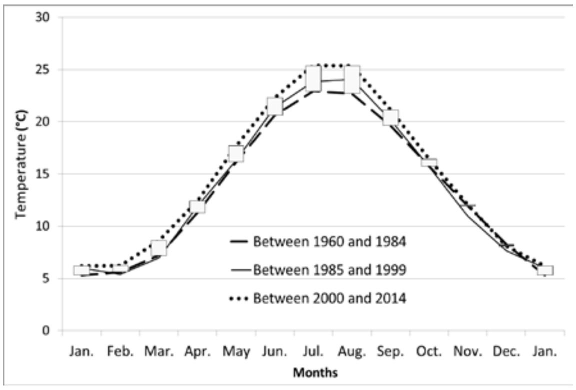

Figure 4: Changes in monthly average temperature for three periods.

Table 6. Monthly and annual average temperature (°C) in Istanbul for 1960-2014 (Source: Florya Meteorology Station, Istanbul).

Years	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1960-2014	5,7	5,7	7,5	11,8	16,6	21,3	23,8	23,8	20,3	15,9	11,7	8,0	14,3
1960-1984	5,3	5,6	7,2	11,3	16,1	20,6	22,9	22,7	19,6	15,7	11,9	8,2	14,3
1985-1999	6,0	5,4	7,0	11,9	16,3	21,4	23,8	24,1	20,2	15,7	10,9	7,6	14,0

2000-2014	6,2	6,2	8,6	12,4	17,7	22,3	25,4	25,3	21,1	16,4	12,0	8,1	15,1

Aridity index variations

The Aridity Index is a numerical indication of drought and drought severity in a particular region. In this study, two different methods, the aridity index and the annual water balances were used to calculate [14], [15]. The Aridity Index, which is calculated by using precipitation and temperature data, describes the balance between Precipitation (P) and Potential Evapotranspiration (PET) in that region. This is why both the Aridity Index and Water Deficiency values are important data for water management and planning. Therefore, analyses were carried out to determine Istanbul's aridity index and water shortage changes using the UNEP [15] annual aridity index (Table 7, 8, 9), and Thornthwaite's [14] annual water balances (Table 10), based on daily temperature and precipitation data recorded at Florya Meteorological Station from 1960 to 2014.

Table 7. The method used to calculate aridity index [15].

UNEP Annual aridity index	I_U=P/PET	I_U: Annual aridity index, P: Mean Annual Precipitation (mm), PET: Mean Annual Potential EvapoTranspiration (mm).

One commonly-used Aridity Index calculation method based on the "Annual Precipitation" and "Potential Evapotranspiration" Proportion (P/PET) method is the UNEP annual aridity index [14], [15].

The climate type of any region can be determined according to the UNEP annual aridity index value (Table 8). Temperature and precipitation data sets recorded at Florya (Istanbul) Station were used in our analyses. Results show a significant decrease in annual aridity index values over the last 15 years. The changing trend of the monthly aridity index value is remarkable in this regard (Table 9).

Table 8. UNEP Aridity classification [15].

Classification	Aridity index
Hyper-arid	AI < 0.05
Arid	0.05 <AI < 0.20
Semi-arid	0.20 < AI < 0.50
Dry sub-humid	0.50 < AI < 0.65
Humid	0.65 < AI

Table 9. Monthly UNEP (1992) aridity index values for 1960-2014.

Years	Mounths												Annual
	Jan,	Feb,	Mar,	Apr,	May	Jun,	Jul,	Aug,	Sep,	Oct,	Nov,	Dec,	
1960-2014	6,18	5,14	2,97	1,26	0,44	0,30	0,17	0,21	0,41	1,07	1,95	4,55	**0,93**
1960-1984	7,31	4,59	2,94	1,37	0,47	0,28	0,20	0,24	0,37	0,86	1,80	4,42	**0,95**
1985-1999	4,49	4,71	3,33	1,17	0,48	0,36	0,20	0,15	0,36	1,31	2,58	5,12	**0,94**
2000-2014	6,00	6,47	2,67	1,19	0,35	0,28	0,11	0,21	0,50	1,18	1,68	4,16	**0,88**

Analyses by Thornthwaite [14] based on the relationship between temperature-potential evapotranspiration and precipitation-potential evapotranspiration give impressive results on water balance assessment. This method was applied to the periods 1960-1984, 1985-1999 and 2000-2014 and is summarized in Table 10. In the last 15-year period (2000-2014), the change in the direction of the decrease in water balance in May and June, and also the increase in the water shortage in June to September, are clearly seen (Table 10). The increase in monthly and annual values of potential evapotranspiration can be accepted as a reliable indicator of drought in Istanbul.

Table 10. Thornthwaite annual water balances based on climatic data set from Florya Meteorology. Station (WS: Water Surplus, SC: Storage Change, WD: Water Deficiency, PE: Potential Evapotranspiration).

		Jan,	Feb,	Mar,	Apr,	May	Jun,	Jul,	Aug,	Sep,	Oct,	Nov,	Dec,	Annual (mm)
1960-1984	WS	100,0	100,0	100,0	100,0	48,9	0,0	0,0	0,0	0,0	0,0	41,2	100,0	-
	SC	0,0	0,0	0,0	0,0	-51,1	-48,9	0,0	0,0	0,0	0,0	41,2	58,8	-
	WD	0,0	0,0	0,0	0,0	0,0	42,7	117,1	101,8	57,9	6,1	0,0	0,0	325,74
	PE	13,0	14,1	20,3	39,1	65,4	93,6	109,2	107,8	87,1	63,1	42,1	24,5	679,10
1985-1999	WS	100,0	100,0	100,0	100,0	49,5	0,0	0,0	0,0	0,0	21,7	85,0	100,0	-
	SC	0,0	0,0	0,0	0,0	-50,5	-49,5	0,0	0,0	0,0	21,7	63,3	15,0	-
	WD	0,0	0,0	0,0	0,0	0,0	39,3	123,0	121,4	61,6	0,0	0,0	0,0	345,22
	PE	14,8	12,6	18,6	40,9	65,4	98,1	115,0	117,1	90,0	61,90	35,9	21,0	691,23
2000-2014	WS	100,0	100,0	100,0	100,0	36,0	0,0	0,0	0,0	0,0	13,9	46,9	100,0	-
	SC	0,0	0,0	0,0	0,0	-64,0	-36,0	0,0	0,0	0,0	13,9	33,0	53,1	-
	WD	0,0	0,0	0,0	0,0	0,0	64,1	146,5	122,3	50,3	0,0	0,0	0,0	383,15
	PE	13,4	13,4	22,5	40,2	70,9	102,4	126,0	125,2	93,8	62,8	38,2	20,4	728,90

Results

Impact of Aridity Index change on water supply

One of the indicators of the danger of water shortage in Istanbul is aridity index changes. Significant changes in temperature and precipitation characteristics have been taking place for the last 15 years (Table 4, 5, 6). Daily precipitation and temperature data, observed over 55 years, show that the average annual rainfall is decreasing, both the monthly maximum temperatures and monthly average temperatures are rising, and the warm period of the year is being prolonged (Fig. 1, 2, 3, 4). Decreases in aridity index values are further heightening the drought risk of Istanbul (Table 9, 10).

Future water demands

Another significant cause of water shortage is rapid population growth. Istanbul is not only one of world's most populated cities but also one of the fastest growing cities in the world (Table 1). This has had a direct effect on water consumption, causing the need for more water each year. More specifically, the density of population, rapid population growth, rapid and unplanned urbanization, artificially-created impermeable surfaces covering a large area, infrastructure deficiencies, uncontrolled industrial activity, and so forth directly and/or indirectly cause a rise in water consumption and water supply requirements. According to population projections, population growth will continue. As for the future, in spite of periodic reductions in the population growth rate of Istanbul, this will not change the fact that the overall population will continue to grow year by year, leading to heightened water demand.

Reservoir inflows and storage

The impact of the changes in temperature and precipitation over Istanbul will see a decrease in the amount of collected or accumulated water because the changing precipitation regime will trigger and create a change in surface runoff and flow characteristics. This change in the nature of surface runoff will negatively affect, and even prevent, the collection of water in Istanbul's dams. Dams that were almost dry during 2014 (Table 2, 3) are the natural result of the decrease in precipitation, increase in average temperature and maximum average temperature (Table 4, 5, 6) (Fig. 1, 2, 3, 4), and also increase in water consumption.

The rise of average air temperatures and maximum air temperatures and number of hot days in the year causes an increase in the severity of evaporation. Aggravation of evaporation has led by natural means to an increase in water losses. An important proportion of the fresh water stored in Istanbul's dams will suffer loss by natural processes during the hot season of the year. This will become a serious concern due to the rise in average and maximum temperatures with each passing year. Furthermore, results (Water surplus, Storage Change, Water Deficiency, Potential Evapotranspiration) (Table 10) obtained from the "Thornthwaite annual water balance analysis" clearly highlight the decrease in water potential of Istanbul's dams (Table 2, 3 and 9, 10).

CONCLUSION

The average monthly and annual temperature and the average monthly and annual maximum temperature have been significantly increasing in Istanbul since 2000. The number of hot days in the year has increased. In other words, the summer season is becoming longer than before. The Water surplus, Storage change, Water deficiency and also Potential Evapotranspiration values observed for the last 15 years are significant evidence of a negative change in the water balance of Istanbul. Precipitation observed over last 15 years shows a seasonal variation of precipitation, such as a decrease in November, December and January versus an increase in June, August, and September per year.

The results of calculation for the aridity index indicate that drought is increasing in Istanbul. Aridity Index analysis can be regarded as an indicator or evidence of water shortage hazard. According to the results of analysis in this study, droughts are expected to continue getting longer and more severe in the future in Istanbul.

An increasing need of fresh water for urban use is encouraged by changes in the climate elements and human geographic features of Istanbul. The increases in water demand arising from population growth, and water supply problems caused by climate change, represent a major problem for the city in the present and future. Analysis results and their general trends show that this problem will reach much more serious levels in the future.

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