GEOMED 2016
4th International Geography Symposium

May 23 - 26, 2016 - Kemer, Antalya, TURKEY

BOOK OF PROCEEDINGS

Editors

Recep EFE, İsa CÜREBAL, László LÉVAI

ISBN 978-605-66576-1-0

Climatic Assessment of Sustainable Water Management in Melen River Basin (NW Turkey)

Hüseyin TUROĞLU[1]

Abstract

The Melen Project is a large investment by Istanbul Municipality to meet the water requirements of Istanbul until the year 2071. This project will transform the Melen River Basin into Istanbul's most important water source. The question is whether the Melen River can actually meet the water needs of Istanbul until 2071. The streamflow characteristics of the Melen River are the fundamental factor that will determine the sustainability of water supply and success of the project.

As streamflow is sensitive to changes in precipitation and temperature, changes in climate have the potential to change the long-term outlook for the project. In this study, climatic data for the last 52 years and streamflow data of the last 18 years were correlated to create a streamflow forecast model for the years to come. Regression analysis was performed on daily temperature and precipitation data observed at Düzce Meteorological Station between 1963-2014. Potential evapotranspiration changes were derived from the same data. Streamflow data observed on the downstream section of the Melen River between 1997 and 2014 were used to predict future trends of streamflow.

Climatic analysis results show an increase in temperature, reduction in precipitation, increase in potential evapotranspiration and decrease in the streamflow of Melen River. Overall, the trends of climate change and its variability will cause a reduction in water potential and streamflow. As a result, the Melen River will be far from meeting the water needs of the Istanbul in the long run, indicating a significant risk to the Melen project.

Key Words: Climate Change, Potential Evapotranspiration, Streamflow, Melen River Basin.

INTRODUCTION

An increase in the water needs of cities is primarily due to increase in population. Population growth leads to increased pressure on water consumption and water resources. Climate change is one of the basic factors, in addition to demographic, socio-economic and technological factors, playing a role in the increasingly unfavourable impact on water resources and also causing an increase in water demand (IPCC 2008; IPCC 2014). Istanbul is one of the most populated cities in the world. According to the TurkStat (2016) data, Istanbul's population was 14,657,434 at the end of 2015. The population density was 2,759 / km^2 and the average population growth rate was 1.94% during 2007-2015. Considering the population growth rate of Istanbul, the need for water is expected to continue to increase. Various projects have been developed to satisfy the future water needs of Istanbul. The "Melen Project" is the most ambitious of these projects. According to the authorities, the Melen Project is an investment that will meet the water needs of Istanbul until the year 2071 (GDSHW 2012; Saatci 2013; Eroğlu 2014; GDSHW 2014). The Melen Project consists of

[1] *Istanbul University/Prof. Dr., turogluh@istanbul.edu.tr*

the Melen Dam, Melen regulator, a drinking water treatment plant and a 189 km pipeline, based on the principle of transporting the Melen River water to Istanbul metropolis (GDSHW 2012; IWSA 2016) (Fig. 1).

This study aimed to investigate whether the streamflow of Melen River is adequate to meet the water needs of Istanbul until 2071 or not. Streamflow characteristics of Melen River are a key factor in determining the sustainability of the water supply to Istanbul from the Melen River Basin. The streamflow of a river shows its sensitivity to changes in precipitation and temperature over the river basin. Therefore, the statistical trends of precipitation, temperature and streamflow data, and also the relationship between precipitation, temperature and streamflow, were all analyzed. The results of the trend analysis are related to the population and water consumption data of Istanbul throughout 2005-2015. The findings evaluated the water potential of Melen River in the future.

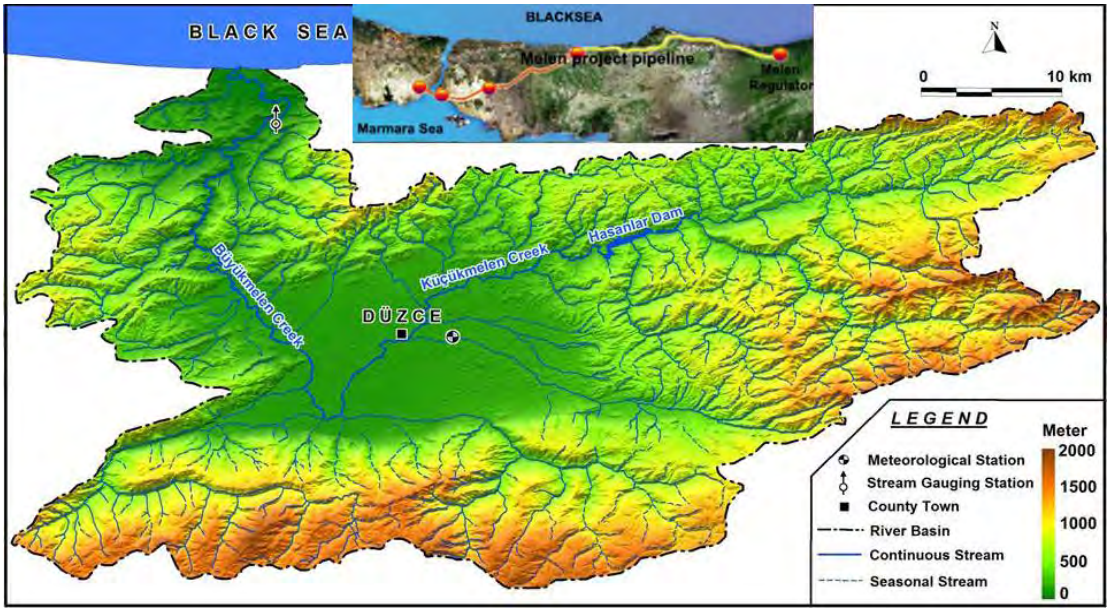


Figure 1. *Melen River Basin and Melen Project pipeline.*

DATA AND METHODS

Daily temperature and precipitation time series observed at Düzce Meteorology Station (Latitude: 40°50' N, Longitude: 31°09' E, Altitude: 149 m) in the years 1963-2014 were used for climatic analysis. Monthly and annual temperature and precipitation data were produced from the daily time series data.

Daily streamflow statistics observed in the Stream Gauging Station at Uğurlu Köy-Akçakoca in Düzce province (Latitude: 41° 1' 51" N, Longitude: 30° 59' 54" E, Altitude: 10 m) in 1997-2014 were used to identify the change in streamflow properties of Melen River.

Annual Water Surplus, Water Deficiency, and Potential Evapotranspiration values were calculated using "Thornthwaite Water Balance" analysis (Thornthwaite 1948).

Excel template MAKESENS (Mann-Kendall test and Sen's slope estimator) (MAKESENS, 2002; Timo et al. 2002) was used for the trend analysis in this study. MAKESENS trend analysis was applied to the climatic data as well as the streamflow.

Linear regression analysis was performed on Istanbul's population and water consumption trend predictions. The annual amount of water supplied to the city of Istanbul (IWSA 2016) and its annual population statistics (TurkStat 2016) were used in this analysis for the period 2005-2015.

CLIMATIC AND HYDROGRAPHIC TREND ANALYSES

Annual mean Temperature (T), annual Precipitation (P) and annual Potential Evapotranspiration (PET) are significant climatic factors for calculating streamflow (Rao 1993; Yang et al. 2012; Palmer et al. 2014; Wanga et al. 2016). To predict the possible effects of change in climate over the Melen River Basin, the trends of long-term climatic elements were determined using the MAKESENS (Mann-Kendall test for trends and Sen's slope estimates) application. The MAKESENS-excel application was preferred for estimating trends in the time series of annual values of precipitation and temperature observed in the Melen River Basin and the annual Potential Evapotranspiration, Water Deficiency, and Water Surplus values calculated by the Thornthwaite (1948) method.

The Mann-Kendall test for trend and Sen's slope estimates (MAKESENS) template produced in excel 97 environments is a statistical analysis tool to control and predict trends in the time series of annual values (MAKESENS, 2002; Salmi et al. 2002). MAKESENS gives two different types of statistical results; a monotonic increasing or decreasing trend and the slope of a linear trend. The monotonic increasing or decreasing trend is calculated by the nonparametric Mann-Kendall test and the slope of a linear trend is estimated with the nonparametric Sen's method (Gilbert 1987; Salmi et al. 2002) (Table 1).

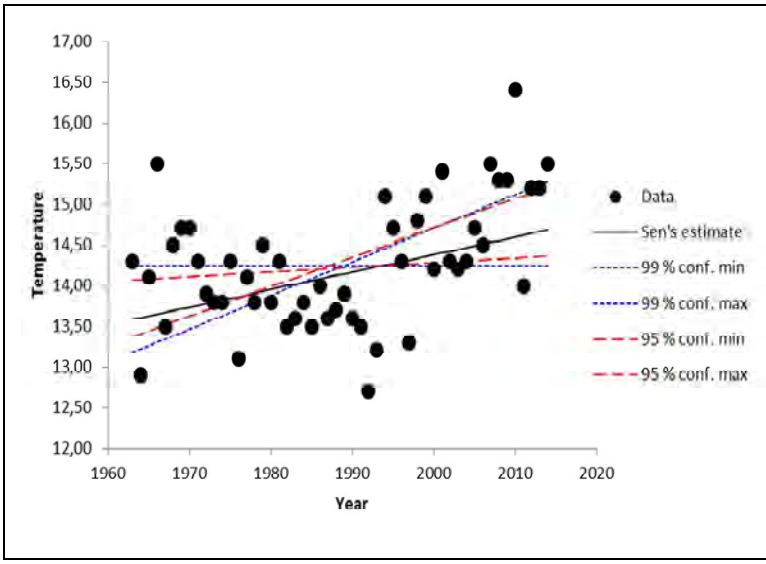
Table 1. *MAKESENS trend analysis results (Test Z indicates whether there is a trend or not. Significance levels α: 0.1, 0.05, 0.01 and 0.001.)*

	Fig.	Time (years)	MAKESENS Trend features		
			Test Z	Level of Significance	Meaning
Temperature	2	52	2.72	** (0.01)	Increase
Precipitation	3	52	-1.85	+ (0.1)	Decrease
Potential Evapotranspiration	4	52	2.68	** (0.01)	Increase
Water Deficiency	5	52	2.09	* (0.05)	Increase
Water Surplus	6	52	-1.82	+ (0.1)	Decrease
Streamflow of Melen River	7	17	-2.27	* (0.05)	Decrease

RESULTS AND DISCUSSION

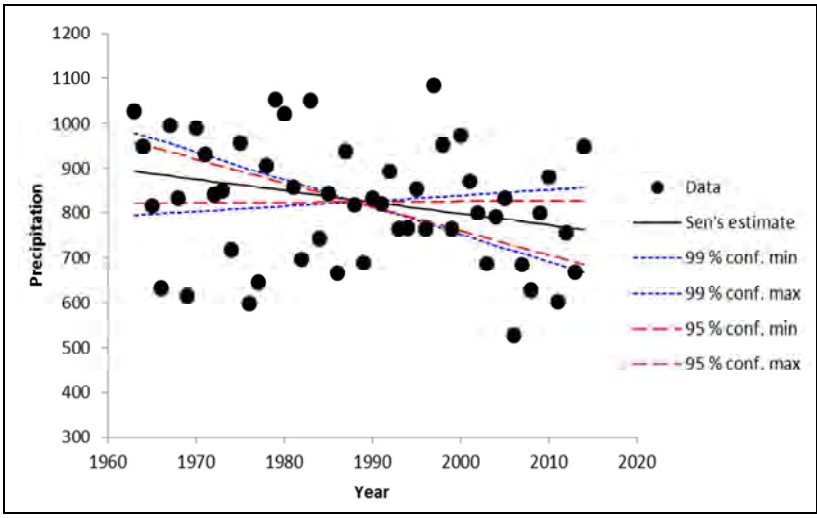
When the 52-year observations are taken into consideration, it is clearly understood from the results of MAKESENS trend analysis that the temperatures over Melen River Basin will rise significantly (Test Z: 2.72) (Fig. 2) (Table 1). Although there are other influential factors, the increase in temperature causes the PET value to climb (Test Z: 2.68). The similarities in rise between temperature and PET values are striking (Fig. 3 and 4) (Table 1). MAKESENS analysis results show a decreasing trend of annual precipitation values for the period 1963-2014 (Test Z: -1.85). According to MAKESENS classification, the importance level of the reduction in annual precipitation is calculated as a level to be taken seriously (Fig. 3) (Table 1).

Potential Evapotranspiration, Water Deficiency and Water Surplus values play an important role in surface flow. Firstly, the Annual Potential Evapotranspiration, Annual Water Deficiency and Annual Water Surplus values were calculated separately using Thornthwaite water balance analysis. Secondly, the relationship between these climatic parameters and the streamflow in the Melen River Basin was checked by MAKESENS trend analysis. From this, an increase in Annual Potential Evapotranspiration (Fig. 3) and Annual Water Deficiency (Fig. 5), and decrease in Annual Water Surplus (Fig. 6), can be readily understood (Table 1). The increase in PET, which encourages surface water loss, is a climatic development. The increase in Annual Water Deficiency and decrease in Annual Water Surplus are climatic indicators confirming a decreased streamflow in the Melen River Basin.



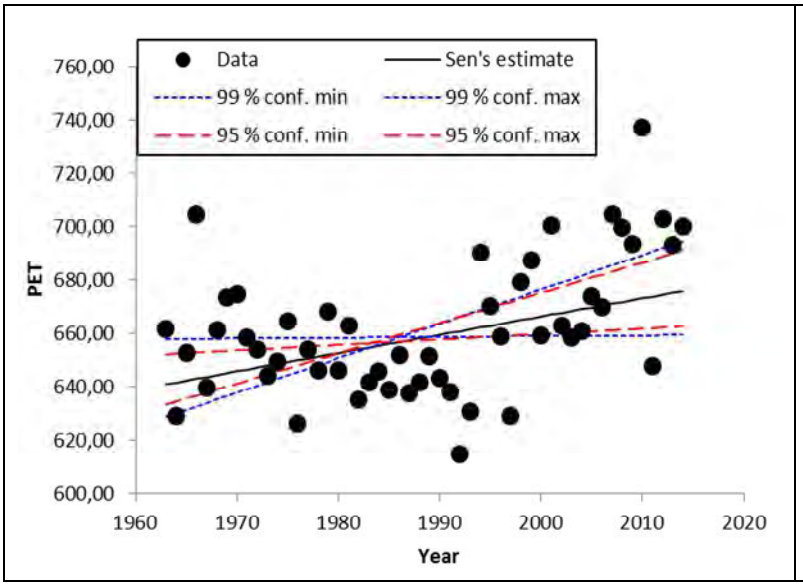
TsNumber	1
Name	Temperature
Years	1963 - 2014
n	52
Test S	
Test Z	2,72
Signific.	**
Q	2,14E-02
Qmin99	0,00E+00
Qmax99	4,14E-02
Qmin95	5,74E-03
Qmax95	3,61E-02
B	1,36E+01
Bmin99	1,43E+01
Bmax99	1,32E+01
Bmin95	1,41E+01
Bmax95	1,34E+01

Figure 2. *Numerical and visual time series trend of annual mean Temperature.*



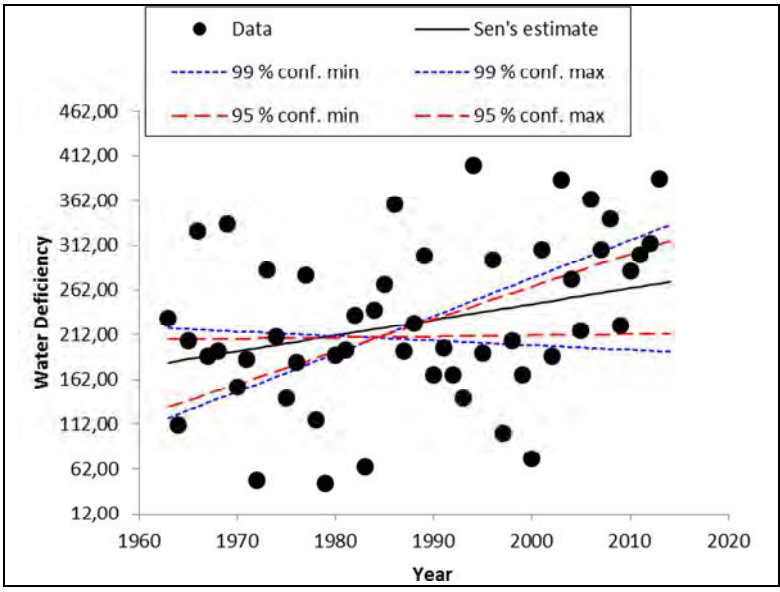
TsNumber	2
Name	Precipitation
Years	1963 - 2014
n	52
Test S	
Test Z	-1,85
Signific.	+
Q	-2,58E+00
Qmin99	-6,12E+00
Qmax99	1,20E+00
Qmin95	-5,36E+00
Qmax95	1,28E-01
B	8,94E+02
Bmin99	9,79E+02
Bmax99	7,95E+02
Bmin95	9,58E+02
Bmax95	8,22E+02

Figure 3. *Numerical and visual time series trend of Precipitation annual values.*



TsNumber	3
Name	PET
Years	1963-2014
n	52
Test S	
Test Z	2,68
Signific.	**
Q	6,85E-01
Qmin99	2,90E-02
Qmax99	1,29E+00
Qmin95	2,05E-01
Qmax95	1,13E+00
B	6,41E+02
Bmin99	6,58E+02
Bmax99	6,29E+02
Bmin95	6,52E+02
Bmax95	6,33E+02

Figure 4. *Numerical and visual trend of average annual Potential Evapotranspiration.*



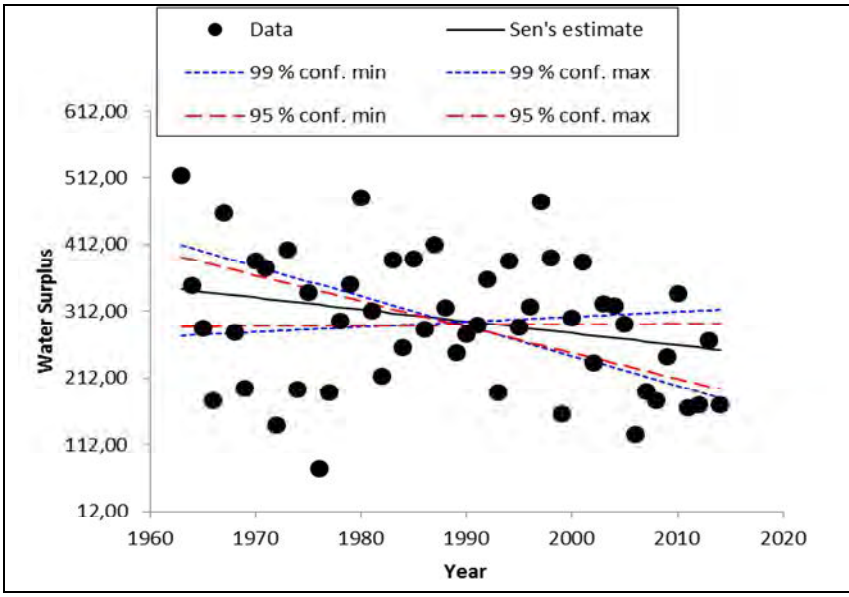
TsNumber	4
Name	Water Deficiency
Years	1963 - 2014
n	52
Test S	
Test Z	2,09
Signific.	*
Q	1,76E+00
Qmin99	-5,12E-01
Qmax99	4,23E+00
Qmin95	1,25E-01
Qmax95	3,64E+00
B	1,81E+02
Bmin99	2,19E+02
Bmax99	1,19E+02
Bmin95	2,06E+02
Bmax95	1,31E+02

Figure 5. *Numerical and visual trend of annual Water Deficiency.*

Over the last 17 years, a significant reduction occurred in the streamflow characteristics of Melen River (Fig. 7) (Table 1). The decrease in streamflow is understood to originate from temperature changes in an increasing trend, and precipitation changes in a lower decreasing trend. In other words, the streamflow of Melen River is more sensitive to precipitation than temperature (Fig. 2 and 3) (Table 1).

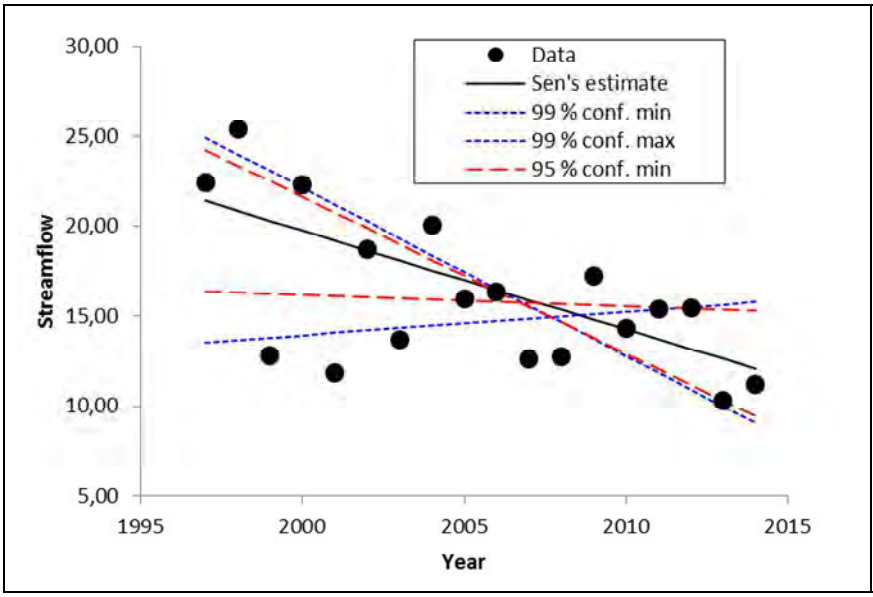
According to the Intergovernmental Panel on Climate Change (IPCC) and Special Report on Emissions Scenarios (SRES) reports on climate change scenarios, global temperatures have increased markedly in the last 30 years (IPCC 2008; IPCC 2013; IPCC

2014). Temperatures will continue to rise on a global scale and precipitation will continue to change regionally, as stated in the same reports.



TsNumber	5
Name	Water Surplus
Years	1963 - 2014
n	52
Test S	
Test Z	-1,82
Signific.	+
Q	-1,78E+00
Qmin99	-4,47E+00
Qmax99	7,61E-01
Qmin95	-3,88E+00
Qmax95	7,33E-02
B	3,45E+02
Bmin99	4,10E+02
Bmax99	2,75E+02
Bmin95	3,93E+02
Bmax95	2,89E+02

Figure 6. *Numerical and visual trend of annual Water Surplus.*



TsNumber	6
Name	Streamflow
Years	1997 - 2014
n	18
Test S	
Test Z	-2,27
Signific.	*
Q	-5,49E-01
Qmin99	-9,34E-01
Qmax99	1,32E-01
Qmin95	-8,70E-01
Qmax95	-6,24E-02
B	4,01E+01
Bmin99	5,67E+01
Bmax99	9,02E+00
Bmin95	5,38E+01
Bmax95	1,85E+01

Figure 7. *Numerical and visual trend in average annual Streamflow of Melen River.*

Temperatures will be approximately 2.5-3°C higher than today on average in the north of Turkey within the next century. Rainfall over Turkey in the next century (100 years) is expected to decline according to the current annual average. A decrease of 5% in average annual precipitation may occur up to 2030. This rate of decrease in average annual precipitation is expected to rise to about 10% by around 2050 (CCP 2016). An increase in

PET over the Black Sea will continue. Because of the high evapotranspiration rate, a decrease in surface runoff should be expected (Kitoh 2014). The climate of the Black Sea region in terms of temperature will return to a Mediterranean climate. The boundaries of the Mediterranean climate will shift further north. Istanbul's climate will become similar to the Mediterranean (Türkeş 2003; Şen et al. 2013). Due to rising temperatures, the number of hot days throughout the year will increase (Turp et al. 2013). These changes in climate will cause a reduction in water resources (Şen et al. 2013; Turoğlu 2013, 2014).

There is a direct and indirect relationship between water consumption and population. Population growth is the main reason for an increase in water consumption (WWF 2011). Due to much greater need for water, populated cities create huge pressure on water resources. Istanbul's population has been increasing rapidly (Fig. 8). The relationship between Istanbul's annual population growth rate and annual amount of water supplied to the city was verified by the results of linear regression analysis. The numerical results of the regression analysis are given as linear regression equations and in R-squared coefficient format. R-squared is the percentage of the variable variation and a value between 0 and 100%. R-squared values clearly show the increase in population growth and water consumption (Fig. 8). Furthermore, the increasing trends are confirmed by the regression equation (Fig. 8).

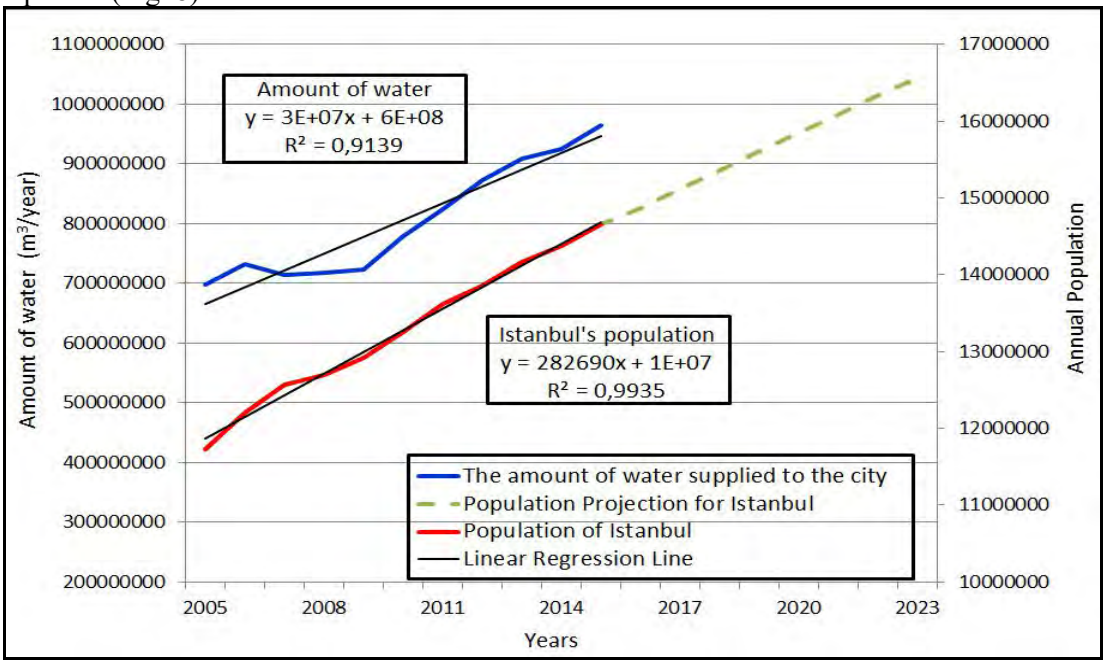


Figure 8. Actual projected population figures and annual amount of water supplied to Istanbul (Data from IWSA 2016 and TurkStat 2016).

CONCLUSION

MAKESENS trend analysis results based on climatic observation during the years 1963-2014 show a rise in annual average temperatures and decline in annual precipitations over the Melen River Basin. This is the most important reason for the increase in average annual Potential Evapotranspiration and Annual Water Deficiency values and decrease in the Annual Water Surplus value for the Melen River Basin.

Results of climatic trends analysis indicate a reduction in the streamflow of Melen River. MAKESENS Trend analysis based on Melen River streamflow statistics from 1997 to 2014 also quantitatively reveals the downward trend of the streamflow of Melen River.

For the next 30 and 50 years, it should be considered a high probability that the temperature and precipitation over Melen River Basin will preserve their character. In this case, the surface water potential may be negatively affected. These developments may cause a significant reduction in the streamflow of Melen River; an interaction that should be taken into account.

On the other hand, the upward trend of Istanbul's population shows that people will require more water in the future. This is a reality; relational trends in population growth and the amount of water supplied to Istanbul city is clearly seen in the results of linear regression analysis. Istanbul will obviously need much more water in the future.

These results leave open to discussion the sustainability of water management plans and projects for the Melen River Basin. The approaches and assessments should be re-examined within an integrated perspective looking at the issue of whether the Melen River water is adequate to meet the needs of Istanbul until the year 2071 and ensure that Istanbul will not suffer from water shortages.

REFERENCES

CCP (2016). ClimateChangePost, Climate change Turkey. http://www.climatechangepost.com/turkey/climate-change/ (Accessed April 30, 2016).

Eroğlu, V. (2014). İstanbul'da su sıkıntısı olmayacak. http://www.hurriyet.com.tr/bakan-eroglu-istanbulda-su-sikintisi-olmayacak-26852263 (Accessed April 30, 2016).

GDSHW (2012). Melen'de Sona Geliniyor. The General Directorate of State Hydraulic Works, http://web.archive.org/web/20150524145817/http:/www.dsi.gov.tr:80/haberler/2012/04/10/melendesonageliniyor (Accessed April 30, 2016).

GDSHW (2014). Melen Barajı ile İstanbul'un Suyu Garanti Altında. The General Directorate of State Hydraulic Works, http://www.dsi.gov.tr/haberler/2014/03/06/melenbarajiilesugarantialtinda (Accessed April 30, 2016).

Gilbert, R. O. (1987). Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold, New York. http://www.osti.gov/scitech/servlets/purl/7037501/

Grijsen, J. G., Brown, C., Tarhule, A., Ghile, Y. B., Taner, Ü., Talbi-Jordan, A., Doffou, H. N., Guero, A., Dessouassi, R. Y., Kone, S., Coulibaly, B., Harshadeep, N. (2013). Climate Risk Assessment for Water Resources Development in the Niger River Basin Part I: Context and Climate Projections, In "Climate Variability - Regional and Thematic Patterns", (Edited by Aondover Tarhule), ISBN 978-953-51-1187-0, http://dx.doi.org/10.5772/56707.

IPCC (2008). Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, Eds. Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof. IPCC Secretariat, Geneva, ISBN: 978-92-9169-123-4.

IPCC (2013). Summary for Policymakers (SPM), In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi: 10.1017/CBO9781107415324.

IPCC (2014). Climate Change 2014, Synthesis Report Summary for Policymakers, https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf (Accessed April 30, 2016).

IWSA (2016). Strategic Plan (2016-2020). Istanbul Water & Sewerage Administration (IWSA). http://www.iski.gov.tr/web/tr-TR/kurumsal/stratejik-plan-ve-programlar (Accessed April 30, 2016).

Kitoh, A. (2014.) Future Climate Projections around Turkey by Global Climate Models. http://cirrus.ucsd.edu/~pierce/mideast_refs/future_climate_change_turkey_Kitoh.pdf (Accessed July 8, 2015).

MAKESENS (2002). Mann-Kendall Test and Sen's Slope Estimates for the Trend of Annual Data, Version 1.0 Freeware, Copyright Finnish Meteorological Institute, http://taurus.gg.bg.ut.ee/jaagus/MAKESENS_Temperatuur.xls (Accessed April 30, 2016).

MGM (2015). Düzce Meteoroloji İstasyonu (17072) (40,8437 K – 31,1488 D, h: 146 m) 1963-2014 tarihleri sıcaklık ve yağış rasatları. T.C. Orman ve Su İşleri Bakanlığı, Meteoroloji Genel Müdürlüğü, Ankara.

Palmer, R. N., Clancy, E., VanRheenen, N. T., Wiley, M. W. (2004). The Impacts of Climate Change on The Tualatin River Basin Water Supply, Department of Civil and Environmental Engineering, University of Washington, Seattle. https://cig.uw.edu/publications/the-impacts-of-climate-change-on-the-tualatin-river-basin-water-supply-an-investigation-into-projected-hydrologic-and-management-impacts/ (Accessed April 30, 2016).

Rao, P. G., (1993). Climatic changes and trends over a major river basin in India. Climate Research Climate Research, Vol. 2, 215-223.

Saatci, A. M. (2013). Solving Water Problems of a Metropolis. Journal Water Resources Protection, 5, 7-10. http://www.scirp.org/journal/PaperInformation.aspx?PaperID=30569#.VD4XrvmsWSo (Accessed July 8, 2015).

Salmi, T., Määttä, A., Anttila, P., Ruoho-Airola, T., Amnell, T. (2002). Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates-the excel template application MAKESENS, Publications on air quality, Report code FMI-AQ-31, No: 31, p 35, Finnish Meteorological Institute, Helsinki.

Şen, Ö. L., Bozkurt, D., Göktürk, O. M., Dündar, B., Altürk, B. (2013). Türkiye'de İklim Değişikliği ve Olası Etkileri. http://ipc.sabanciuniv.edu/en/wp-content/uploads/2012/10/Bildiri_Omer_L_Sen_vd_2013.pdf (Accessed July 8, 2015).

Thornthwaite, C. W. (1948). An Approach toward a Rational Classification of Climate. Geographical Review, 38(1): 55-94. https://www.unc.edu/courses/2007fall/geog/801/001/www/ET/Thornthwaite48-GeogrRev.pdf

TurkStat (2016). Turkish Statistical Institute (TurkStat), Population and Demography, Population Statistics, http://www.tuik.gov.tr/UstMenu.do?metod=temelist. (Accessed April 30, 2016)

Turoğlu, H. (2013). Possible Effects of Climate Change on Water Management in Istanbul. (Ed. S. Atabay), In Global Climate Change, 82-92.

Turoğlu, H. (2014). Detection of Changes on Temperature and Precipitation Features in Istanbul (Turkey). Atmospheric and Climate Science, 4, 549-562.

Turp, M. T., Ozturk, T., Türkes, M., Kurnaz, M. L. (2014). Investigation of projected changes for near future air temperature and precipitation climatology of Turkey and surrounding regions by using REGCM4.3.5. In: Medclivar 2014 Conference, pp. xx-xx.

Türkeş¸ M. (2003). Spatial and temporal variations in precipitation and aridity index series of Turkey. In H. J. Bolle (Ed.) Mediterranean Climate – Variability and Trends. Regional Climate Studies, 181–213.

Wanga, L., Hai-Long, L., An-Ming, B., Xiang-Liang, P., Xi, C. (2016). Estimating the sensitivity of runoff to climate change in an alpine-valley watershed of Xinjiang, China, Hydrological Sciences Journal, DOI:10.1080/02626667.2014.964718, 1-21.

WWF (2011). Big Cities. Big Water. Big Challenges. Water in an Urbanizing World, Pages 81. http://www.wwf.se/source.php/1390895/Big%20Cities_Big%20Water_Big%20Challenges_2011.pdf

Yang, Z. F., Yan, Y., Liu, Q. (2012). The relationship of streamflow-Precipitation-Temperature in the Yellow River Basin of China during 1961-2000, Procedia Environmental Sciences, vol. 13, 2336-2345.