

Essential Tools To Establish A Comprehensive Drought Management Plan: Konya Closed Basin as a Case Study

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Abstract

Drought is a vital phenomenon in semi-arid regions; particularly in endorheic (closed) basins where water resources are scarce to meet demands. Konya Closed Basin is one of the most susceptible basins to drought in Turkey. The basin has suffered and endured many severe droughts throughout the history: Thousands of people died and migrated as consequence drought hazards in 1874, 1928 and 1933. Almost one-third of last 60-years and almost half of the last decade were dry-years and droughts have been experienced at various severity levels. With respect to frequently occurring droughts in the basin, Ministry of Forestry and Water Affairs of Turkish Republic commissioned Drought Management Plan (DMP) for the Konya Closed Basin. The objective of the plan is to estimate prospective drought risks, determine measures to be taken before-, during- and after-drought hazards and resolve drought-caused problems in the basin. Furthermore, how and what extent will municipal water, agricultural irrigation and aquatic ecosystem be impacted by changes in surface and ground water potential during expected drought hazards and determine necessary preventive actions to reduce water scarcity. This article is aimed to share experiences achieved during the preparation of the plan and present primary results and discuss essential tools to establish a comprehensive drought management plan.

Keywords

Drought, Water Scarcity, Climate Change, Regional Climate Modeling, Mitigation, Vulnerability, Hydrologic Modelling, Endorheic (Closed) Basin

1. Introduction

Drought is a gradually occurring phenomenon which threatens life quality, production sources and nature of considerably large areas. It usually develops as a consequence of deficient precipitation or excessive evapotranspiration depending upon high temperature over an extended period of time. Prolonged meteorological drought conditions may trigger hydrological droughts by means of depletion of surface waters, shrinking water bodies and decreasing groundwater table. If drought conditions persist, soil moisture depletes and crops are not able to uptake required water for transpiration; thus crops fail to grow properly as a consequence of agricultural drought.

Droughts should be regularly monitored and assessed to detect the onset, duration, severity and impact of drought hazards. Respectively, various drought indicators and indices have been developed as functions of hydro-meteorological parameters –such as precipitation, temperature and evapotranspiration– by researchers depending upon their professional perceptions and area of interests: Standard Precipitation (SPI), Percent of Normal Precipitation (PNI) and Palmer indices (PDSI, PHDI and ZIND) are notable examples of universally referred indices to assess drought hazards.

Deterministic and statistical approaches preferably apply to streamflow records to magnify hydrological drought characteristics of watersheds. Deterministic approaches –such as precipitation-runoff models– present water budget and full-scale hydrological behavior of the watershed. Further statistical approaches –such as flow-duration, flow-frequency and recession curve analyses– extract valuable and multifaceted information about low flow and subsurface flow characteristics of surface waters.

Remote sensing techniques have been used in drought studies for almost three decades. Normalized Difference Vegetation Index (NDVI), Vegetation-Temperature Condition Indices (VTCI or VCI and TCI) and Land Surface Temperature (LST) data derived using either The National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR) or The National Aeronautics and Space Administration's (NASA) Moderate-resolution Imaging Spectroradiometer (MODIS) satellite images have been widely accepted and applied by the international authorities for drought and vegetation monitoring. Integrated analysis of NDVI and VTCI indices along with traditional indices such as the SPI and the PDSI expose prosperous information about agricultural drought such as spatial and temporal characteristics, duration and severity of droughts (Owrangi, et al. 2011).

Seasonal and annual mean temperatures have been increased –particularly in northern hemisphere– in the last three decades (IPCC, 2013). Moreover, accumulation in global surface temperature is estimated to continue to increase more than 2°C by 2100 (IPCC, 2013). These accumulations are prone to changes not only in air temperature, but also precipitation. Total precipitation is estimated to decrease in the Mediterranean, South Africa and Western Asia regions (IPCC, 2013). Furthermore, precipitation frequency is expected to change as well and more frequent droughts and floods are anticipated to occur (IPCC, 2013). Therefore, drought analyses should be supplemented by climate change studies, and potential impacts of climate changes on variety of sectors and hydrograph for major rivers in the region should be assessed.

Future climate change projections are performed by climate modeling. Increasing power of computers supports developing complex, three dimensional and high-resolution general circulation models (GCM) that simulate global dynamics of climate systems and interactions between atmosphere, ocean, sea-ice and land-surface components. Main inputs of GCMs are: incoming solar radiation, geomorphology of earth surface, land cover and greenhouse gas emissions in the atmosphere. Future predictions of greenhouse gas emissions are associated with demographic change, socioeconomic and technological development, and reported by the Intergovernmental Panel on Climate Change (IPCC). Regional Climate Models (RCM) are essentially used to downscale GCM outputs to a limited area; consequently local characteristics such as complex topographical features, heterogeneous land-surface cover are simulated at higher spatial resolution. RCM simulations provide valuable insight into drought studies. These outputs can be used to project future streamflow and water potential using deterministic hydrologic models, future low flow behavior of surface waters using statistical hydrologic approaches, and future drought conditions using meteorological, hydrological and agricultural indices.

Drought studies supplemented with remote sensing and climate change studies yield millions of data even for a small-sized basin; therefore it is not feasible to analyze or assess droughts using traditional methods. International institutions working on drought studies have been developed software, modules for well-known engineering programming languages (e.g. Matlab and R) and web applications to compute and access drought hazards. A planning toolbox (or a decision support system) associated with a geographical database is required to compile all available datasets –such as meteorological, hydrological, agricultural, administrative, economic and social– and monitor, forecast and assess historical and prospective drought risks using this toolbox.

Information related to historical drought hazards is vital to assess severity-duration-impact relationship and establish vulnerability of region to drought hazards. However, impacts of historical droughts –particularly mild and moderate droughts– are usually not well-reported or quantitatively assessed. Furthermore quantitatively assessed droughts in different times or regions usually do not have a datum to compare and contrast historical drought hazards. Therefore drought impact data needed to be generated by applying statistical and scientific methods to long-term continuous records and crosscheck generated drought data with surveys.

Vulnerability assessment is a beneficial tool that integrates impact analysis with mitigation measures and helps to develop a management methodology. This novel approach focuses on drought developing mechanisms instead of drought impacts. This assessment can be performed for various sectors (e.g. municipal water, agriculture, ecosystem, etc.) and/or sources (e.g. groundwater). Multifaceted assessment of sectors/sources is required to determine threads of drought to sectors, sensitivity of sectors to drought, adaptive capacities of sector for drought-caused environment. Vulnerability assessment is first stage of three stage drought mitigation measures; which is followed by mitigation planning and mitigation implementations.

The main purpose of this study is to display the historical and future drought characteristics in the Konya Closed Basin and present methods used to analyze drought hazards and impacts in order to establish a comprehensive drought management plan. For this purpose, well-accepted drought indices are used to compute historical droughts. Impacts of droughts to production sources are assessed. Future climate changes are estimated by regional climate modeling. The RCM outputs are used to predict future drought conditions, changes in hydrological regime and future water potential. Finally, a planning toolbox is developed to compile all available data and computations to monitor, forecast and assess prospective drought risks and create an environment for a multifaceted vulnerability assessment.

2. Study Area

Konya Closed Basin is almost 50 000 km², located in the Central Anatolian Plateau (Figure 1). The elevation of the plateau is mostly 1 000 m and above. The southern border of the basin is surrounded by Central Taurus Mountains which partly reaches 2 500-3 000 m altitude. Central Taurus Mountains prevent rainfall passing from Mediterranean Sea to the basin; therefore dominant climate is classified as semi-arid to arid. However, various climates possess at the basin due to its large area: The southern areas have Mediterranean climate; central and

northern areas have semi-arid and sub-humid continental climate; Konya and particularly Karapınar district have continental and exact semi-arid climate. Annual mean precipitation is 374 mm, however records range between 275 mm (in the eastern part of the basin) and 755 mm (in the western part of the basin). Monthly mean evaporation ranges between 200 mm and 300 mm throughout the summer, and annual mean evaporation is higher than 1250 mm.

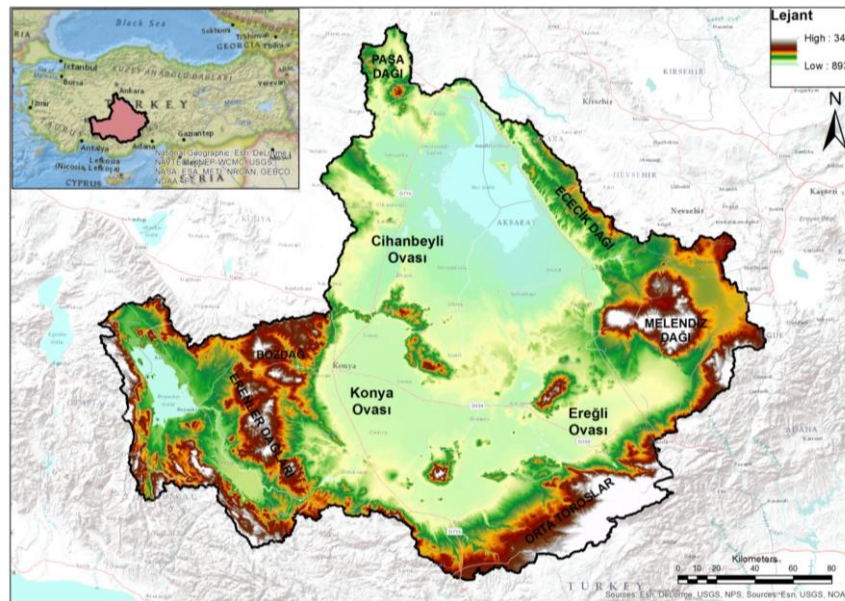


Figure 1 – Map of the Konya Closed Basin

The basin has 2 500 hm³/year surface, 2 000 hm³/year subsurface and 4 500 hm³/year total water potential. While the basin has only 2% of Turkey’s surface water potential, it houses 17% of subsurface water potential; thus, Konya Basin has the lowest surface water, but the highest subsurface water potential all across Turkey.

The basin has 2.5 million ha of arable lands and agriculture is the most important practice in the basin. Socioeconomic development is predominantly relied on irrigated agriculture. Irrigation facilities have been operated since 1914 and more than 600 000 ha lands are irrigated with surface and groundwater irrigation facilities. Agriculture sector is the major water consumer. Approximately 3 billion m³ water is allocated for irrigation. Extending irrigated land area is always primary subject in the basin; however, available water resources are not adequate. Therefore, an inter-basin water transfer project (The Mavi Tunnel) has already been constructed to supply additional 414 million m³ water to the basin, and other water transfer projects have been drafted to develop water resources of the basin.

The basin has experienced serious droughts throughout the history. Drought records date back to mid-19th century. Droughts have experienced in 1844, 1845, 1854, 1874, 1887, 1917, 1918, 1928, 1933, 1935, 1939, 1942 and 1945 caused thousands of people suffer with low crop yield, hunger, malnutrition and water scarcity. Moreover, thousands of people died and migrated as consequence droughts occurred in 1874, 1928 and 1933. Almost one-third of last 60-year and almost half of the last decade were dry-years. Severe droughts have experienced between 1973-1974, 1984-1985, 2000, 2004-2009 and 2013 periods.

3. Methodology

3.1. Trend Analysis

Trend analysis is a widely applied method to assess changes in hydro-meteorological indicators throughout the record period. Innovative trend analysis is used in this study (Şen, 2011). Observations in the first half of the record period is normalized, ranked in ascending order and plotted against second half of the record period. A 45-degree (reference) line starting from the origin of the plot is drawn to indicate and assess the trend. If plotted points fall below the reference line it represents decrease in trend and vice versa.

3.2. Drought Indices and Basin-Specific Threshold Values

Well-accepted meteorological, hydrological and agricultural drought indices by national and international authorities are evaluated in this study. Preliminary analyses demonstrated that Percent of Normal Precipitation Index (PNPI), Standard Precipitation Index (SPI), and Palmer indices (PDSI, PHDI and ZIND) successfully characterize historical drought hazards experienced in the basin. Besides, Aridity Index (AI) is used to define the annual climatic condition changes in the basin. Basin-specific threshold values of these indices are determined to

indicate drought severity categories (mild, moderate, severe and extreme or exceptional) in the basin. Historical drought hazards are calculated using meteorological records and prospective drought hazards are forecasted using Regional Climate Modeling projections.

3.2.1. Aridity Index (AI)

Aridity Index is defined as the ratio of annual potential evaporation to annual average precipitation (UNEP, 1992). United Nations Convention to Combat Desertification (UNCCD) classified arid, semi-arid and dry-subhumid areas as areas based on AI index (Table 1).

Table 1 – Aridity classification system

<i>Class</i>	<i>AI</i>	<i>Class</i>	<i>AI</i>
Hyperarid	< 0.05	Moist subhumid	0.65-0.80
Arid	0.05-0.20	Subhumid	0.80-1.00
Semi-arid	0.20-0.50	Humid and very humid	1.00-2.00
Dry subhumid	0.50-0.65	Extremely humid	>2.00

3.2.2. Percent of Normal Precipitation Index (PNPI)

Percent of Normal Precipitation Index is calculated by dividing the actual precipitation by long-term mean precipitation and multiplying by 100. This index can be calculated for monthly, seasonal and annual time scales. Threshold values are given in Table 2.

3.2.3. Standard Precipitation Index (SPI)

Standard Precipitation Index (SPI) calculates precipitation deficiency for multiple time scales (McKee, et al. 1993). Historical precipitation data is fitted to a two-parameter gamma distribution. Parameters (shape and scales) of the distribution are estimated using maximum likelihood approach. Cumulative distribution function is then transformed into a standard normal random variable Z with mean of 0 and standard deviation of 1. Standardized Z -scores indicate SPI values (Table 2).

3.2.4. Palmer Indices (PDSI, PHDI and ZIND)

Palmer indices are developed on the basis of water balance equation (Palmer, 1965). Historical precipitation and temperature data and available soil water content are used in computation.

Table 2 – Konya Closed Basin-specific Threshold Values of Drought Indices

Class Definition	PDSI	SPI	PNPI
Extremely wet	>4.00	>2	> %210
Very wet	3.00 - 3.99	1.5 – 1.99	%175 - %210
Moderately wet	2.00 - 2.99	1 – 1.49	%150 - %175
Slight wet	1.00 - 1.99	0.5 – 0.99	%120 - %150
Normal	0.99 – -0.99	-0.499 – 0.499	%80 - %120
Mild drought	-1.00 – -1.99	-0.5 – -0.99	%80 - %50
Moderate drought	-2.00 – -2.99	-1 – -1.49	%50 - %25
Severe drought	-3.00 – -3.99	-1.5 – -1.99	%25 - %5
Exceptional drought	-4.00<	-2<	< %5

The Palmer Drought Severity Index (PDSI) and the Palmer Hydrological Drought Index (PHDI) measures the duration and intensity of long-term droughts. With this respect, antecedent precipitation, moisture supply and moisture demand are taken into consideration in computation. The PHDI focuses to assess hydrological effects and it responds more slowly to changes in soil moisture conditions compared to the PDSI. The Palmer Z-Index (ZIND) measures short-term droughts. The ZIND quickly responds changes in soil moisture and it is a powerful index to display agricultural droughts. Threshold values are given in Table 2.

3.3. Regional Climate Modeling

Climate modeling simulations and projections are performed using the Regional Climate Model version 4.3.5 (RegCM4.3.5) on the basis of new regional concentration pathway scenarios RCP 4.5 and RCP 8.5 described in the AR5 of Working Group of I and II of the IPCC.

The global outputs of HadGEM2-ES (Hadley Global Environment Model 2 – Earth System) of UK Met Office Hadley Centre, MPI-ESM-MR (Max Planck Institute – Earth System Model – Mixed Resolution), GFDL-ESM2M (Geophysical Fluid Dynamics Laboratory – Earth System Model) of NOAA are dynamically downscaled for the study area. The RegCM is run at 10 km resolution. The best model parameters representing the study area are determined following to examination of regional climate model performance for 1980 – 2005 reference period using CRU datasets developed by the Climatic Research Unit at the University of East Anglia and ERA-Interim datasets developed by European Centre for Medium-Range Weather Forecast (ECMWF).

The regional climate model outputs often have systematic biases. These biases are mostly reported for precipitation outputs; however, air temperature outputs may also have biases. Therefore, utilization of regional climate model in hydrologic models without bias correction may cause remarkable errors (Olsson, Yang and Bosshard, 2013). In order to eliminate biases, downscaled outputs are subjected to bias-correction using delta-change approach (Lenderink, Buishand and van Deursen, 2007). This approach considers difference between regional climate outputs and observation records for a reference period, and calculates factors of alternation, then biases in regional climate outputs eliminated by either addition or multiplication of calculated factors.

3.4. Planning Toolbox

A software is developed to compute analyses and assess drought hazards. Meteorological, hydrological and hydrogeological observation data and regional climate modeling outputs are hardcoded in the software. The software has a few modules. These modules are Regional Climate Modeling, Drought Indices, Hydrology and Vulnerability Assessment.

The Regional Climate Modeling module houses more than a number of 100 million data resulted from modeling studies. This module helps user to visualize and assess (compare-contrast) changes in the climate from the onset of observation records till end of climate projections for various hydro-meteorological outputs (temperature, precipitation, evapotranspiration, soil moisture, etc.) on the basis of user-defined models (either SRES or RCP outputs of HadGEM2, MPI and GFDL), analyze period, time-scale (monthly, seasonal, annual, etc.) and calculation method (averages, minimum values, maximum values, percent of difference). The module display results on a time series graph for station-based analysis or on a map for basin-wise analysis.

The Drought Index module does drought analyzes using AI, PNI, SPI (for ten different time scales) and Palmer indices using either solely observation data or observation data following with a climate modeling simulation outputs. The analyses can be either performed for an observation station or basin-wise. The critical drought periods and cumulative severities, major drought hazards in descending order, risk and return periods of drought hazards, the risk histogram, time series graph of annual, seasonal and monthly values of indices can be viewed, calculated and exported to an MS Excel workbook. Moreover, maps can be created exported either as geographic tagged image file for GIS applications or plotted as a standard image or portable document.

The Hydrology module does hydrological analyses and estimates future changes of river flows using rainfall-runoff models and climate modeling outputs. Besides it computes subsurface and low flow characteristics on the basis of flow-duration, flow-frequency and recession curve analyses using regionalization methods.

The Vulnerability Assessment module is basically developed to assess drought hazards using remote sensing tools. The module extracts valuable drought-related information (e.g. NDVI, VCTI) from satellites, combines with drought and hydrologic indices and correlates them to establish drought developing mechanism in the area of interest.

4. Results

4.1. Trends in Hydro-meteorological Indicators

Trend analyses are performed for historical precipitation and temperature data recorded at 20 meteorological observation stations located in and around the outer periphery of the basin (Figure 2). It is calculated that annual precipitation rates decreased about 5-10% in the region. Moreover, trend analyses performed using monthly precipitation rates expressed that frequency of light precipitation remained constant, but high and moderate precipitation frequencies were found to decrease in the basin.

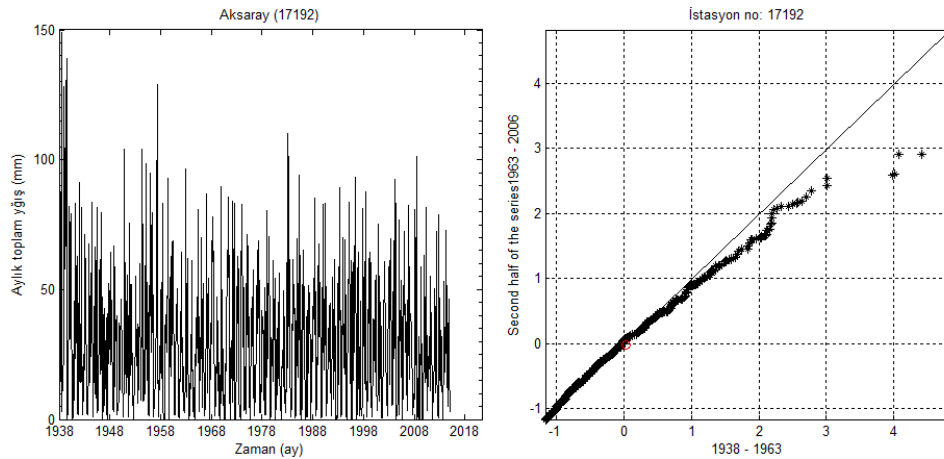


Figure 2 – Precipitation trend at the Aksaray Meteorological Observation Station

4.2. Droughts in the Basin

Konya Closed Basin has been overwhelmed by droughts at various severity levels once in every 2½ to 3 years. Mild and moderate droughts are computed most frequent and recurred once in every 5½ to 7 and 9 to 10 years, respectively. The frequency of severe and extreme (exceptional) drought hazards was spatially distinguishable as a consequence of climatic conditions in the Lake Beysehir subbasin (west rim) and the central basin. Severe drought conditions are computed to appear once in every 10 to 20 years in the central basin, while it was once in every 20 to 25 years in the Lake Beysehir subbasin. Likewise, extreme drought conditions are computed to emerge once in every 20 to 30 years in the central basin and once in every 60 to 90 years in the Lake Beysehir subbasin.

The basin has experienced three major drought hazards in the last four decades. The longest and most severe drought was experienced between 1973 and 1974. Severe drought conditions sustained all over the basin as long as two years and the cumulative PDSI and PHDI values as low as -100 and -140, respectively (Figure 3). The 9-month SPI index values were also in agreement with Palmer indices. Severe drought conditions widely dominated the basin and exceptional drought conditions exacerbated at Nigde, Ilgin and Kulu observation stations. Supplementarily, annual PNPI index values were also below 60% in most of the stations in 1973. Seasonal PNPI values are computed as low as 10% at central and northern stations in fall of 1973. Likewise, AI values were calculated as low as 0.30 in most of the stations except Lake Beysehir Sub basin.

Temporarily moderate to severe drought hazards were existed in 1984-85 and in 1989 for half-year-long, respectively. Both the PDSI and the 6-month SPI indices agreed that drought has appeared, but in distinctive patterns in 1984-85. While the PDSI portrayed a wide-spread drought in the central and western basin, but also partly in the northern basin; the 6-month SPI more concentrated drought hazard in the northern basin. Severe drought conditions were only emerged in the southeast basin in the 1989 drought, and rest of the basin was dominated under moderate drought conditions.

Droughts were more frequent and severe in 2000s. The onset of 2000s droughts was in late 2000 and it persisted for a year. The 2000-01 drought was originated in the northeastern basin and lately dominated all northern region of the basin according to development of 3-, 6-, 9- and 12-month SPI values. The drought developed gradually since early fall of 2000. The PNPI computations affirmed that unconsecutive wet or slightly dry months amongst extremely dry months in the drought period remediated drought conditions. Therefore the 2000-01 drought hazard could not be portrayed using singular SPI index. However, the spatial drought pattern in the basin computed using the 12-month SPI was in agreement with the PDSI.

Either nested or sequential drought hazards were observed between 2004 and 2009. The sc-PDSI and sc-PHDI analyses portrayed 4-year long drought persisted in the basin. However, other indices did not agree with self-calibrated palmer indices. The 6-, 9- and 12-month SPI, PDSI and PHDI values agreed that a 4-month temporary drought was affected the basin in early 2005. Successively hydrologic droughts were identified 7-month and 8-month periods in mid-2007 and from March 2008 to December 2008.

Lately, severe drought conditions recurred in 2013. The 6- and 9-month SPI values characterized 4-month long droughts dominantly in the fall season. The PDSI and PHDI exhibited a more severe and prolonged drought from April 2013 to December 2013.

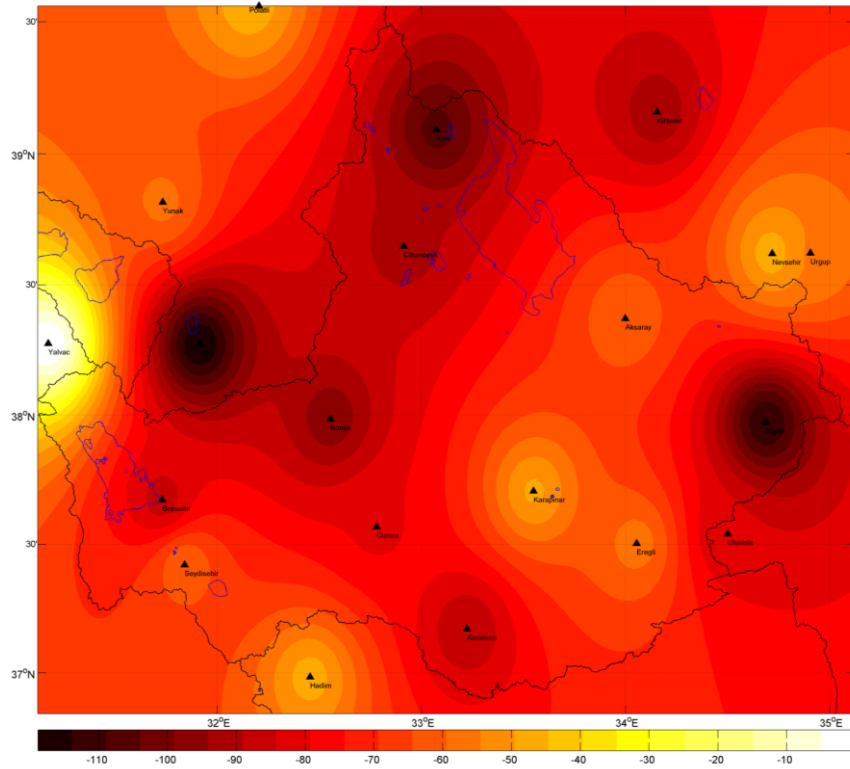


Figure 3 – The spatial distribution of cumulative PDSI value in the 1973-74 drought

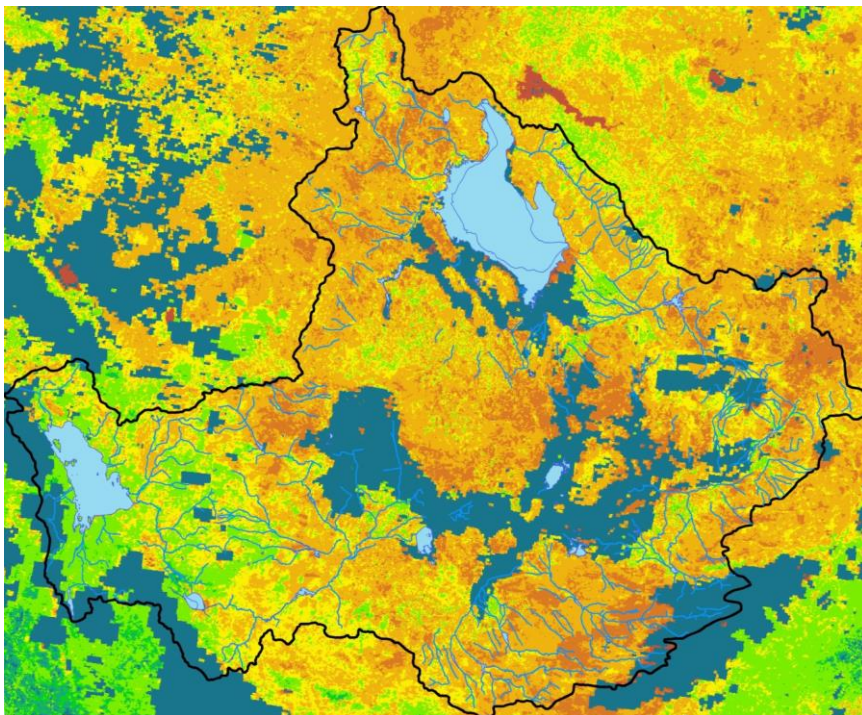


Figure 4 – The NDVI computed using the MODIS data acquired on March 22nd, 2008

Droughts computed using traditional indices (PDSI, SPI, etc.) were also validated using remote sensing products (NDVI). The NDVI values computed between 2000 and 2013 period using MODIS satellite images successfully portrayed the spatial distribution of droughts and mostly in agreement with traditional indices, particularly in unirrigated areas (Figure 4). The NDVI is capable of detecting irrigated areas; therefore it reflects the augmentation of irrigation in agricultural drought conditions.

4.3. Impact Assessment of Historical Drought Hazards

Historical droughts are assessed using agricultural production and groundwater level records. National and regional (for Konya, Niğde, Aksaray and Karaman provinces) crop yield data for wheat, barley, rye, oats, legumes and chickpeas production are obtained from the Turkish Statistical Institute (TURKSTAT). Change in regional wheat crop yield data is given in Figure 5. Groundwater level records for a number of 26 stations in the basin are obtained from the State Hydraulic Works (DSI). Changes in groundwater levels in the central and northern basin are given in Figure 6.

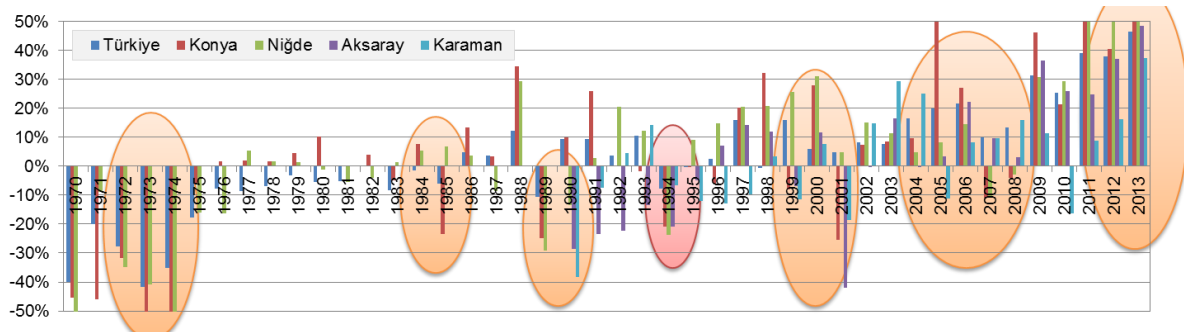


Figure 5 – Change in regional wheat crop yield between 1970 and 2013

The wheat crop yield was devastatingly impacted during the 1973-1974 drought hazard. The groundwater irrigation was not widely applied in the basin during the early 1970s, however the records portrayed that there was about 5 m decrease in groundwater level during the drought.

Except southeastern region of the basin (Niğde), the 1985 drought impacted the crop yield. Likewise, a remarkable decrease in groundwater level was observed. While the crop yield decreased in Konya and Niğde provinces in 1989, there was increase in crop yield in Konya, but decrease in Niğde, Aksaray and Karaman provinces in 1990. There was no remarkable groundwater level change during the 1989-1990 drought.

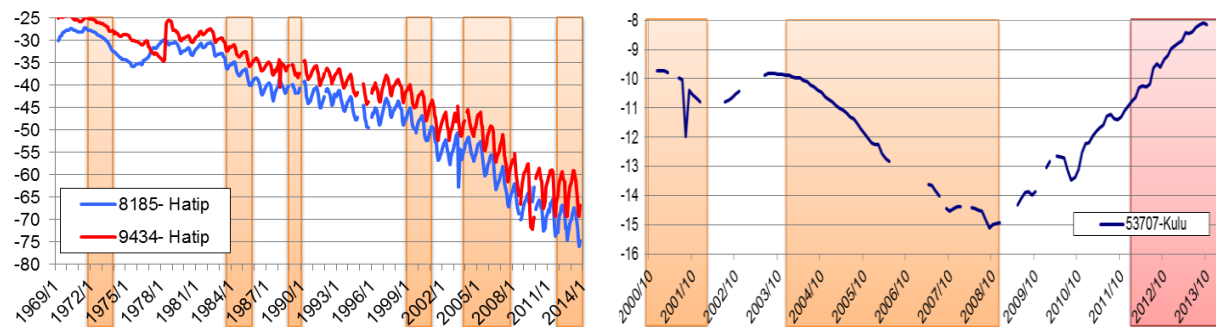


Figure 6 – Changes in groundwater levels in the central (on the left hand) and northern basin (on the right)

There was a very significant crop yield loss in 1994. Palmer indices did not exhibit a drought in 1994. However, the 12-month SPI interpreted a drought during the 1994 summer; moreover the 3-month SPI agreed that there were temporary droughts for short period of time (less than 3 months) in the 1993 fall and the 1994 summer. There was no remarkable groundwater level change in 1994.

The 2000-01 drought overwhelmed the basin. The crop yield and groundwater levels excessively dropped. The PHDI exhibited a prolonged hydrological drought between 2004 and 2009 while the PDSI and the SPI did not depict such long drought period. Respectively, groundwater levels were gradually decreased from late 2003 till early 2009. Moreover, the SPI calculations portrayed crop yield decrease in the 2007-2008 period very well.

Irrigated agriculture has been progressively applied in the basin since early 2000. Consequently, the crop yields increase and groundwater levels decrease more significantly. The crop yield in 2013 was surprisingly around 40% more than the long-term average of the basin although the drought was very destructive in 2013.

4.4. Climate Change Predictions

The HadGEM2-ES, the MPI-ESM-MR and the GFDL-ESM2M global climate model outputs are run under the RCP 4.5 and the RCP 8.5 using the RegCM 4.3.5. Monthly mean total precipitation, surface temperature, total

evapotranspiration, soil moisture, runoff flux and snow melt projections are simulated in scope of this project. Among the named GCMs above, the HadGEM2-ES outputs reflected the climatology of the basin considering the reference period (1980-2005) better than the two other GCMs. Therefore only the HadGEM2-ES outputs are interpreted in this paper.

4.4.1. Changes in Monthly Mean Surface Temperature

RCP 4.5 results showed that most of the months are expected to be warmer about 1.5 to 3°C (Figure 7). Estimated temperature increment is found to be maximal in the months of July and August. Julys and Augusts will be 1.5-2°C and 1.5-3°C warmer, respectively. Estimated temperature increments from Octobers to Decembers are computed as 0.5-1.5°C.

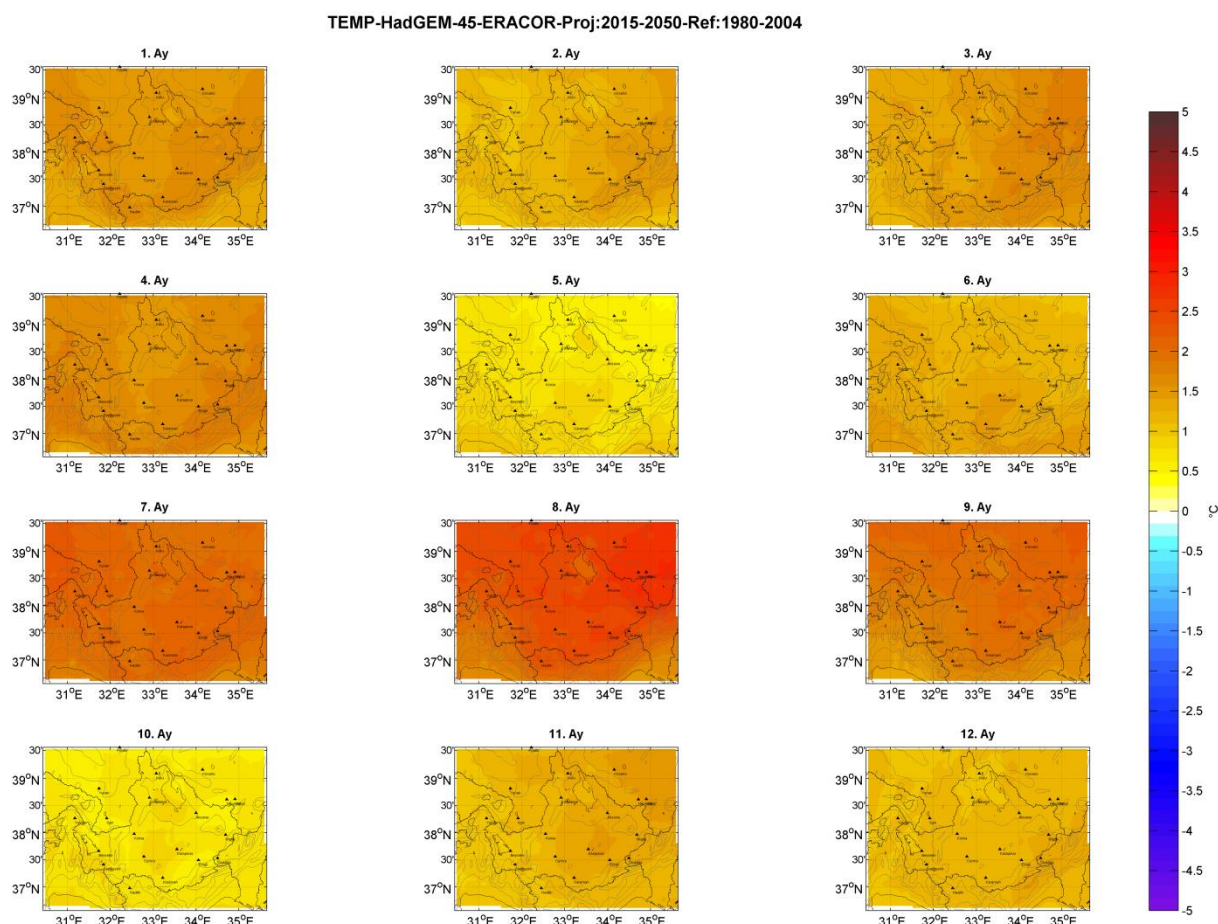


Figure 7 – Monthly mean temperature changes estimated for the 2015-2050 period using the RCP4.5 scenario of the HadGEM2-ES

RCP 8.5 results provided that the expected temperature increase is computed stronger than RCP 4.5 throughout the 2015-2050 period. Minimal temperature increment is computed to be occurring in Decembers. Under RCP 8.5, 2015-2050 period will be warmer about 1.5 to 3.5°C, excluding Decembers. Maximum temperature increase is estimated to occur in Julys about 2.5-3°C. Temperature increment in Aprils is computed less in RCP 8.5 than RCP 4.5.

4.4.2. Changes in Monthly Total Precipitation

According to 2015-2050 projections of regional climate modeling under the RCP 4.5, precipitation is computed to decrease in the months of January, February, March, April, July, August and December. Precipitation is estimated to increase in the western, northern and southern regions of the basin (Figure 8).

Precipitation is estimated to decrease about 50% near the Lake Tuz and central plains of the basin in Januarys. Likewise, February precipitations are estimated to decrease 25-50% in the basin, except central and northern plains. Central basin will have less precipitation about 25-50% in Marchs. Northern basin will receive about 25-50% more precipitation, but southern basin will receive 25-50% less precipitation in Aprils. Precipitation is expected to increase 15-75% in the basin, except central and eastern plains where precipitation is anticipated to

decrease less than 25%. Julys are estimated to be the driest months. Northeast and northwest basin is expected to have more precipitation about 15-65%, but have less precipitation about 15-75% in Septembers. Octobers are anticipated to be the wettest months, where precipitation is expected to increase about 25-150%. Novembers will be wetter about 15-75% in the basin, particularly near northern basin. Decembers are anticipated to receive less precipitation as low as 50% near southwestern and southeastern regions of the basin.

Major difference between the RCP 4.5 and the RCP 8.5 simulations is the precipitation regime in the month of February, May and June. Februarys and Mays are expected to be dominantly drier in RCP 8.5 scenario than the RCP 4.5 scenario. Dry region in June is expected to shrink and precipitation is anticipated to increase about 25%. Precipitation will be 50-100% less in Septembers. Octobers will be the wettest month according to RCP 8.5 scenario as well.

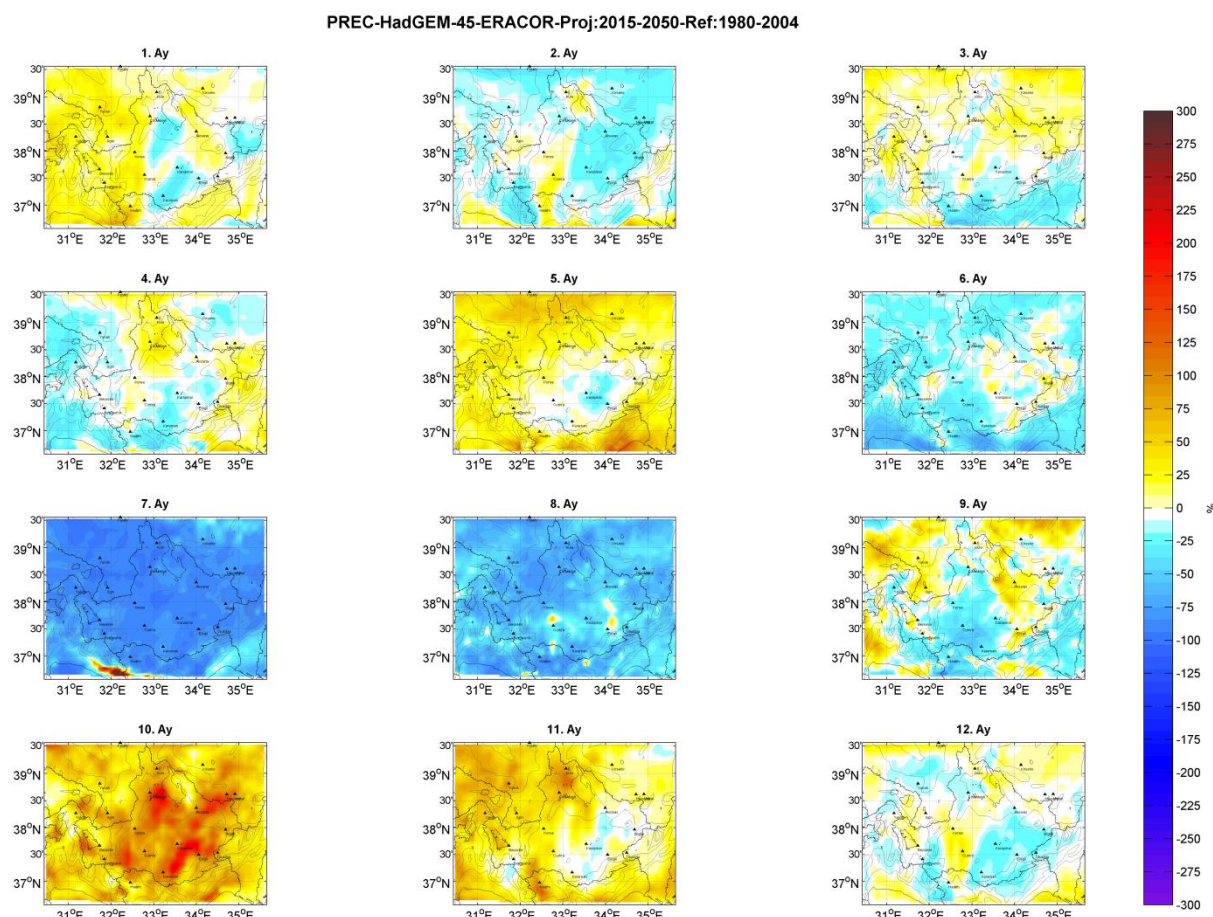


Figure 8 – Monthly total precipitation changes estimated for the 2015-2050 period using the RCP4.5 scenario of the HadGEM2-ES

4.5. Prospective Droughts in the Basin

Prospective drought hazards are forecasted for the 2015-50 period using high-resolution RCM simulations of HadGEM2-ES model. Simulations established that three major droughts would emerge in the next 35 years.

The 2024-25 drought will persist for 9 months. The basin will be extensively under stress of severe to extreme drought conditions. The will exhibit destructive drought impacts in central plains during winter and spring seasons of 2025.

Nested and sequential drought hazard is anticipated between 2035 and 2040. Not only original and self-calibrated palmer indices, but also the SPI indices for various time scales (6-, 9-, 12-, 18- and 24-month) portrayed similar temporal and spatial distribution all over the basin. The drought will develop from late-2035 to 2037, and begin exhibiting destructive impacts from 2037 to 2040. Extreme drought conditions will persist for two years and followed by a severe drought for a year.

The last drought of mid-century is expected between 2047 and 2049. The drought will develop from mid-2047 to late-2048, and affect from late-2048 to 2049. Mild to moderate drought conditions will persist for less than two years.

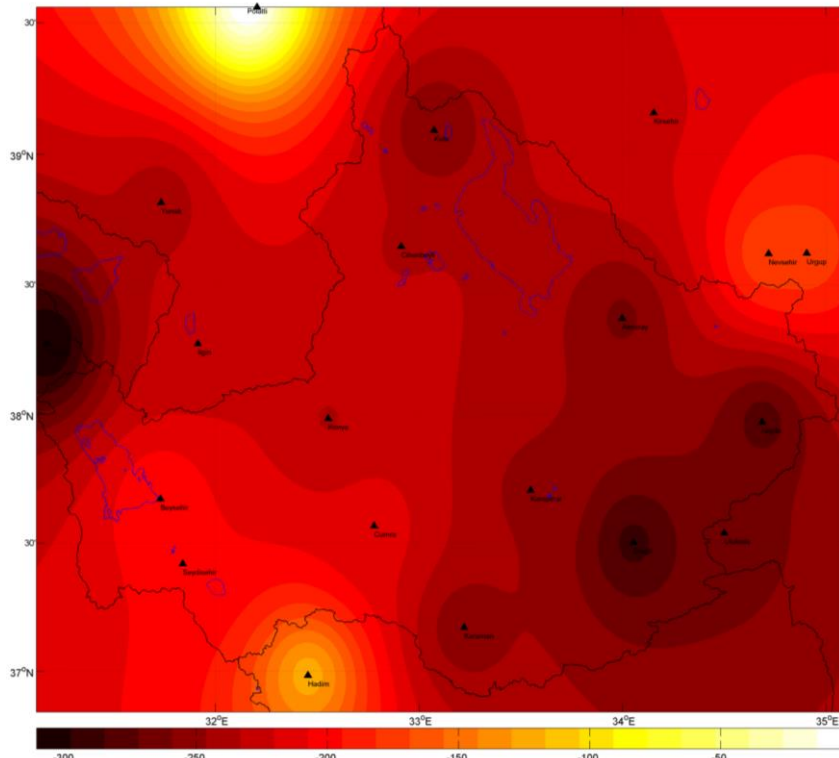


Figure 9 – The spatial distribution of cumulative PDSI value for the expected 2037-40 drought

5. Discussion

Drought is a multifaceted hazard that should be assessed not only technical, but also social, administrative and political perspectives. Drought vulnerability assessment approach incorporates meteorological, agricultural, hydrological, geographical, geological and hydrogeological information along with temporal and spatial characteristics, severity, frequency and impacts of drought hazards; however produces a singular vulnerability score –usually ranging between 1 and 4– that indicates susceptibility of either sectors (e.g. municipal water, agriculture, ecosystem, energy, etc.) or sources (e.g. groundwater) to drought hazards. Besides future drought impacts to sectors and sources may be simulated using vulnerability assessment whether information related to future climate conditions and water potential exists. Vulnerability assessment is a beneficial tool for administrators and policy makers not only understanding the drought-developing mechanisms but also constituting drought management procedures.

Drought mitigation, preparedness and action plans are established in consonance with the lessons-learned from previous drought hazards and forecasted future drought conditions. These plans included measures for drought mitigation and prevention of the impacts of water scarcity on production resources and socio-economical life such as: (i) operation advices of existing water systems under various drought severity conditions; (ii) policies for efficient use of limited water resources considering existing agricultural policies and practices; (iii) suggestions for conservation and prevention of illegal use and overdrafting groundwater resources; (iv) actions for raising consumer awareness; (v) water pricing policies under various drought severity conditions; (vi) enforcement and inspection of foreseen actions by pertinent institutions.

Drought management plan is a complementary and final document. This document essentially includes a conceptual management organization to take actions, make enforcement and inspect foreseen actions. Besides, the plan includes key findings of aforementioned analyses and assessments that guide decision-makers during strategy development and implementation process.

Drought geodatabase associates management plan by storing and querying drought-relevant information. The database can be either a web application or a software. Besides the database can be improved with dynamic computation tools and ease the job of policy makers.

6. Conclusion

More frequent droughts and floods are anticipated in following decades as a consequence of global warming and climate change. Therefore institutions and organizations commissioned to act for the prevention of extreme hydrological hazards should develop strategies and management plans. Most of the countries have national strategy document or guideline for drought mitigation; however, there are very few plans exist for regional or basin-wise drought management.

Konya Closed Basin is one of the most susceptible basins to drought in Turkey. Almost one-third of last 60-years and almost half of the last decade were dry-years and droughts have been overwhelmed at various severity levels. A drought management plan has been commissioned to determine measures to be taken before-, during- and after-drought hazards and resolve drought-caused problems in the basin.

In this paper, essential tools to establish a comprehensive drought management plan is discussed and illustrated considering the Konya Closed Basin. With this respect, historical and future drought characteristics in the basin are analyzed and methods used to analyze drought hazards are presented.

References

- IPCC. 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Lenderink, G., A. Buishand, and W. van Deursen. 2007. "Estimates of future discharges of the river Rhine using two scenario methodologies: direct versus delta approach." *Hydrol Earth Syst Sci*.
- McKee, T.B., N.J. Doesken, and J. Kleist. 1993. "The relationship of drought frequency and duration to time scales." *8th Conference on Applied Climatology*. Anaheim, CA, USA. 179–184.
- Olsson, J., W. Yang, and T. Bosshard. 2013. "Climate model precipitation in hydrological impact studies: limitations and possibilities." *Journal of Water Management and Research* 69: 221-230.
- Owrangi, M. A., J. Adamowski, M. Rahnamaei, A. Mohammadzadeh, and R. A. Sharifan. 2011. "Drought Monitoring Methodology Based on AVHRR Images and SPOT Vegetation Maps." *Journal of Water Resource and Protection* 3: 325-334.
- Palmer, W.C. 1965. *Meteorological drought*. Washington, D.C.: U.S. Department of Commerce Weather Bureau.
- Şen, Zekâi. 2011. "Innovative trend analysis methodology." *Journal of Hydrologic Engineering* 17 (9): 1042-1046.
- UNEP. 1992. *World Atlas of Desertification*. London: Edward Arnold.