Journal of Earth Sciences and Geotechnical Engineering, vol . 8, no. 3, 2018, 59-74
ISSN: 1792-9040 (print version), 1792-9660 (online)
Scienpress Ltd, 2018

The Future of the Tigris and Euphrates Water Resources in view of Climate Change

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Abstract

Climate Change which results from global warming is affecting the Tigris and Euphrates River basins in similar ways to all other parts of the Middle East and the East Mediterranean region. This contains also what is historically known as the "Fertile Crescent", which is threatened in the same way as the other parts and may disappear altogether. The climate change is manifested in increased temperatures, reduced precipitation in addition to erratic weather patterns and decreased annual stream flow of the two rivers. These phenomena have been markedly noticed during the last decades of the last century. Studies show that these changes are linked also to the variations of North Atlantic Pressure Oscillation (NAO) induced by Global Climate Change. Modeling studies on the future trends, in trying to define the magnitude of the changes to be anticipated, reveal clearly that these negative impacts are continuous in the future. But, the widely ranging projections and interpretations of different sources depict an uncertain future for the basin's climatic conditions and indicate the need for further modeling studies to reach more definitive conclusions. These studies show however, a drastic decline of the Euphrates and Tigris water resources at the end of this century by something like (30 to 70) %; as compared to their resources in the last three decades of the previous century. The wide variations in the projections emphasize the need of further future work on this matter. All in all, these studies should bring alarm to all responsible governments in the region to resort to long range planning by adopting rational policies in soils and water resources management to mitigate the adverse impacts that could hit human societies in these events.

Keywords: Climate Change, global warming, Fertile Crescent, North Atlantic Oscillation, Euphrates River, Tigris River.

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1 Introduction

The Tigris and Euphrates Rivers basins were the cradle of many ancient civilizations for thousands of years. Irrigated agriculture developed here, which had allowed the development of Sumerian, Acadian, Babylonian and other ancient cultures. This area was fertile and prosperous, and so it was described by the Greek historian Herodotus (484-425) B.C, who gave it the name (Mesopotamia); the land between the two rivers. At that time, these world earliest civilizations had already extensive network of canals and diversion dams and, a 70 km aqueduct was in place by 690B.C. (Krasny et al., 2006). Archaeologists believe that the high time in the development of the irrigation system occurred between about 500 A.D. at the climax of the Sassanid Period and the fall of Baghdad at the hands of Mongols in 1258 AD.; ending the Abbasid Caliphate. A network of irrigation canals permitted widespread cultivation that made the rivers basins into a regional granary (Metz, 1988). Successive invasions and negligence led to the deterioration and partial abandonment of the irrigation and drainage systems. Not until the twentieth century did Iraq make a concerted effort to restore the irrigation and drainage network and to control seasonal flooding (Metz, 1988). In 2006, about 25% of Iraq was irrigated by surface water (Krasny et al., 2006). About half of Iraq's total cultivated area is rain-fed in the northeastern plains and mountain valleys, where sufficient rain falls to sustain agriculture via surface and groundwater use. The remainder of the cultivated lands is in the valleys of the Euphrates and Tigris Rivers, which in Iraq receive scant rainfall and rely instead on irrigation water diverted from the two rivers.

2 The Euphrates and Tigris Rivers

Both the Euphrates and the Tigris rivers are fed by the melting of snowpack and rainfall in southeastern Turkey, north eastern Syria, northwestern Iran and northeast and east of Iraq. The rivers' discharges peak in March and in May, too late for winter crops and too early for summer crops. The flow of the rivers varies considerably every year, and destructive flooding is not uncommon, and conversely, years of low flow make irrigation and agriculture difficult. This regime requires an understanding of climatic and environmental conditions of the entire system, which extends from Turkey in the headwaters of both rivers, to Syria in the northwest, Saudi Arabia in the southwest, and Iran in the northeast and east. In this last part some of the Tigris River tributaries originate, and the Karkha and Karun Rivers flow and end in into Shatt Al-Arab contributing nowadays to its increased salinity and pollution. Figure (1) shows the catchment area of the Tigris and Euphrates Rivers and their tributaries in these countries; their sub-basins are shown in Figure (2). The majority of water that flows through the Tigris and Euphrates Rivers' basins originates outside the borders of Iraq. The southern Turkey sub-basin; known as South Eastern Anatolia Region, does not form the major sub-basin to the Tigris and Euphrates Rivers although it contributes the major share of their water resources. Therefore, an understanding of climate change impacts on the river's regime requires an understanding of the gross climatic and environmental conditions of the entire system; as already indicated and especially so with regard to South Eastern Anatolia Region.

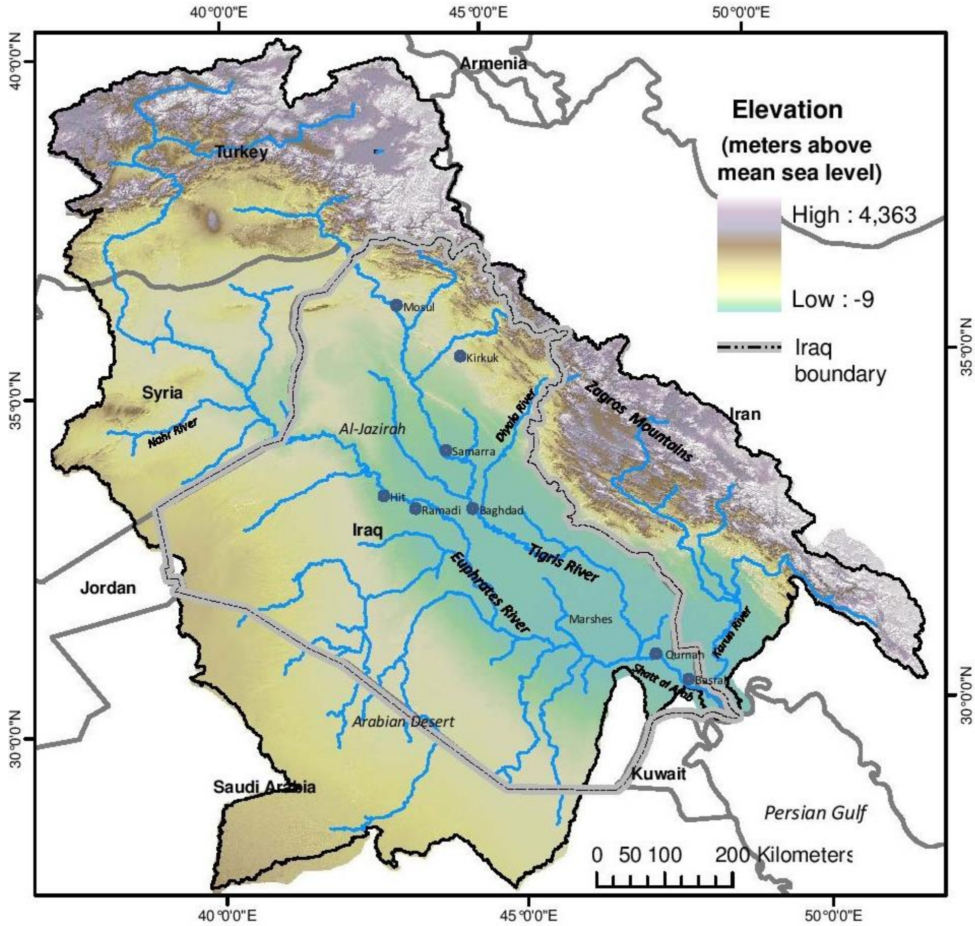

Figure 1: Tigris and Euphrates River catchment area (Flint et al., 2001).

Although much of the waterways flowing inside Turkey, Syria, and Iran are dammed at the present, an understanding of the natural, unimpaired water balance for the whole extent of the Tigris-Euphrates Rivers' Systems (TERS) serves to provide an understanding of the long-term impacts of climate change on this system. This understanding also provides recognition of recent changes throughout the system that may highlight locations, which are more or less sensitive to changes in climate and help to lay a foundation for long-term plans for water-resource management.

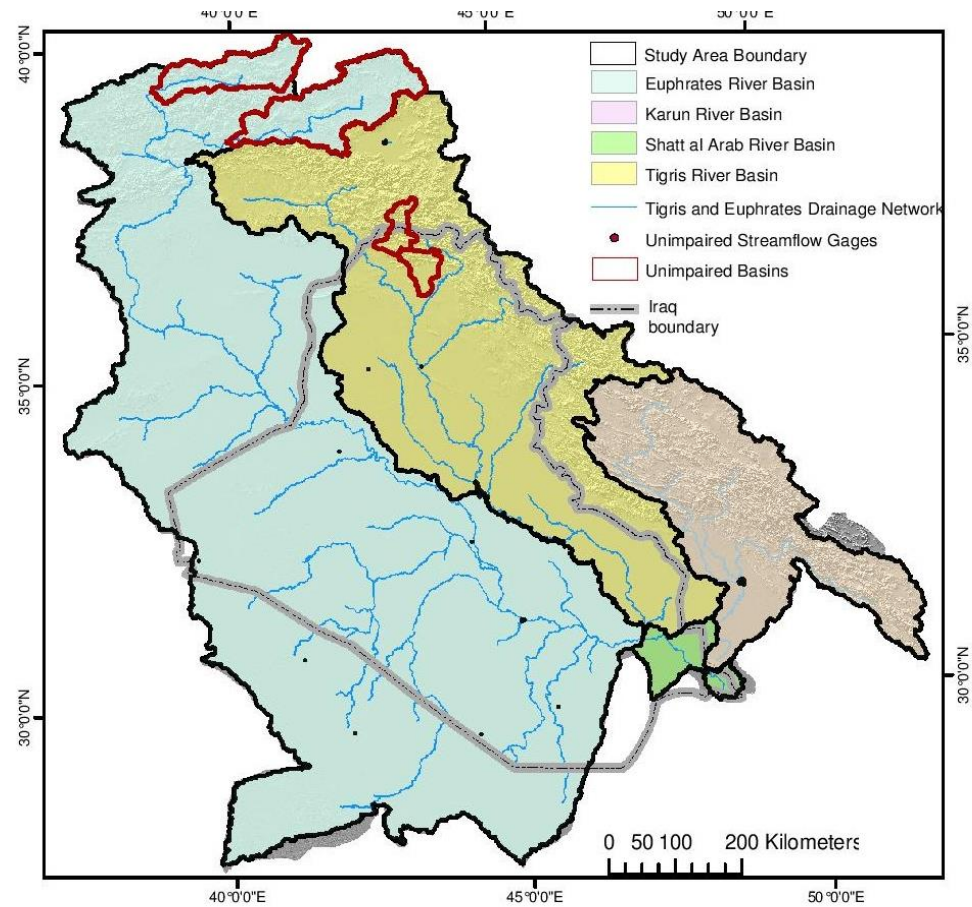

Figure 2: Tigris and Euphrates River Basin (Flint et al., 2001).

Climate change resulting from global warming has influenced all the weather driving elements within theTigris–Euphrates Rivers' basins including temperatures, atmospheric pressure variations, rainfall intensities and distribution, and has contributed to changes in annual stream flow volumes of the two rivers. A study into the causes of weather changes in the Euphrates –Tigris River basins must be traced to the wider changes occurring on the regional scale of which this basin is part of.

3 Climate Change Experienced on the Regional Scale

In all climatic changes and their consequences, those expected in the South Eastern Anatolia Region, which forms the southern part of Turkey and north east of Iran cannot be overlooked in any study on the impacts on the Euphrates and Tigris Rivers water resources. Table (1) gives the shares of these regions in the main hydrometric indicators of the Euphrates, and Table (2) gives those related to the Tigris River (Kibaroglu, 2014)

Table 1: Hydrometric Indicators of the Euphrates River indicating South Anatolia (Turkey) share.

Euphrates Basin area: 444,000 km^2; mean annual discharge 32 BCM		
Riparian position	**Basin area (percent of total) contribution to annual discharge**	**Main water uses of dams**
Turkey upstream	146,520 km^2 (33 percent) 28.922 BCM (90 percent)	Irrigation, hydropower, flood control
Syria downstream	84,360 km^2 (19 percent) 3.213 BCM (10.0 percent)	Irrigation, hydropower
Iraq downstream	204,240 km^2 (46 percent) 0.0 BCM (-)	Irrigation, hydropower, inhabitants of marshes

Table 2: Hydrometric Indicators of the Tigris River indicating South Anatolia (Turkey) share.

Tigris Basin area: 387,000 km^2; mean annual discharge 52 BCM		
Riparian position	**Basin area (percent of total) contribution to annual discharge**	**Main water uses of dams**
Turkey upstream	46. 512 km^2 (12 percent) 20.840 BCM (40 percent)	Irrigation, hydropower
Syria - border with Turkey / Iraq	776 km^2 (0.2 percent) --	
Iraq downstream	209.304 km^2 (54 percent) 26.571 BCM (51 percent)	Irrigation (diverts water through Tharthar Canal to Euphrates), hydropower
Iran **-** on Shatt Al-Arab	131.784 km^2 (34 percent) 4.689 BCM (9 percent)	Irrigation, hydropower

The geographical location of Turkey and its much-varied land forms topography divide it into many climatic sub-zones. The southeastern Anatolia region forms what is called the Eastern Mediterranean and the Middle East (EMME) sub-zone, which is adjacent to Syria and Iraq, and contributes heavily to their national water resources. The results of long-term analyses of meteorological database (1901-2006) along with regional climate change model projections for the 21st century (Special Report on Emission Scenario AIB) (Lelievld et al., 2012), suggest a continual gradual and strong warming of the area by about (1 – 3)º C in the near future (2010 – 2039) to (3 – 5)º C in the mid-century period (2040 – 2069), and (3.5 – 7)º C by the end of the century (2070 – 2099). According to the same scenario, but for the annual precipitation database of the same period (1901 – 2006), projections showed a sharp decline of annual precipitation of (5 – 25) % in (2040 – 2069) and (5 – 30) % in (2070 –2099) relative to the reference base period (1961 – 1990).

Another study employed a super-high-resolution atmospheric global climate model, to reproduce the precipitation and the stream-flow of the present day “Fertile Crescent” and projected the current trends in climate changes on the Middle East water resources till the end of the current century. The “Fertile Crescent” is the region, which historically includes Mesopotamia, the land in and around the Tigris and Euphrates Rivers and the eastern part of the Mediterranean Sea, as shown in the map in Figure (3). The modern- day countries with significant territory within the Fertile Crescent are Iraq, Syria, Lebanon, Cyprus, Jordan, Palestine, Egypt, as well as the southeastern fringe of Turkey and the western fringes of Iran. The results of the study showed severe reductions of the annual discharges of the rivers in the region. The Euphrates River annual flow; as one case, might suffer a reduction of, (29–73) %, as well as the stream flow of the Jordan River (Kitoh et al., 2008). In the wider picture of the Middle East, the study showed that, by the end of this century, the “Fertile Crescent” would lose its current shape and could disappear altogether.

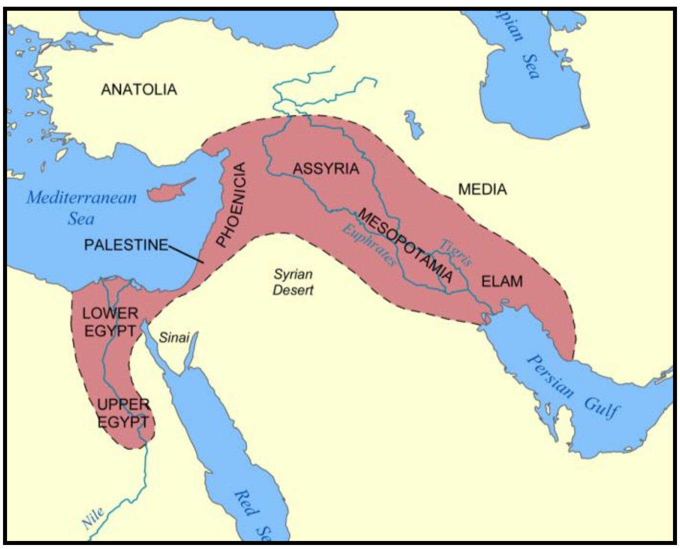

Figure 3: The Historic Map of the “Fertile Crescent” (Mark, 2009).

Another forecast has indicated that today’s 100-year drought could occur 10 times more frequently in the future over the large part of the northern Mediterranean, while in North Africa, today's 100-year drought will occur less frequently (Weiß et al., 2007). It is logical to expect that water resources, both, surface water and groundwater in the Middle East and EMME will be negatively affected as a direct consequence of the precipitation reduction and increased demand due to higher evapotranspiration and the growth of population.

Studies of changes occurring over this region have also revealed that these changes can be traced to and have resulted from the changes imposed on the North Atlantic Oscillation (NAO), which in turn falls under the impact of Global Climate Change and results from it. The North Atlantic Oscillation (NAO) is a weather phenomenon in the North Atlantic Ocean; of fluctuations in the difference of the atmospheric pressure at sea level (SLP) between the Icelandic Low and the Azores High. Through these fluctuations, it controls the strength and direction of westerly winds and location of storm tracks across the North Atlantic and surrounding regions. It is part of the Arctic oscillation and varies over time with no particular periodicity. The NAO was discovered and investigated through several studies in the late 19th and early 20th centuries (Hurell, 2001). Unlike the El Niño-Southern Oscillation phenomenon in the Pacific Ocean, the NAO is a largely atmospheric mode. It is one of the most important manifestations of climate fluctuations in the North Atlantic and surrounding humid climates. Modifications to these oscillations due to Global Climate Change naturally result in changing weather patterns over the regions where this mode prevails; including the East Mediterranean and the Middle East region (EMME) of which the Euphrates and Tigris Basin is one part.

The Euphrates and Tigris Basins form a major part of the Eastern Mediterranean and the Middle East region (EMME), and consequently this basin is subject to weather modifications as foreseen by the Intergovernmental Panel on Climate Change (IPCC) models. These models indicate that storms activity in the eastern Mediterranean is part of the NAO pattern and it will decline this century; if global warming continues on the present trends. Therefore, rainfall will decrease by (15 to 25) % over a large part of the land; encompassing parts of Turkey, Syria, northern Iraq and north-eastern Iran; including the strategically important headwaters of the Euphrates and Tigris Rivers.

Although the Euphrates and Tigris Basins occupy large part of southern Turkey, north and northeast of Syria, north and northeast of Iraq, and northwestern part of Iran, these parts do not contribute proportionate shares in the water resources of the basin, which is clearly shown in Table (1) and Table (2). Therefore, while this basin falls generally under the influence and impacts of Global Climate Change in the Middle East and North Africa (MENA), these impacts are modified to varying degrees by changes occurring to the NAO over these parts. This is a result of the large geographical extent of the basins, and due to changes in topography within them, which include mountain ranges, inland lakes, and even deserts (Hemming et al., 2010)

Recent work done by the University of New South Wales Climate Change Research Centre (Evans, 2009) suggests that the Climate Change projections on this region presents a significant challenge to the region's agricultural base, with longer dry seasons and changes in the timing of maximum precipitation .This paper quotes:

"The largest change, however, is a decrease in precipitation that occurs in an area covering the Eastern Mediterranean, Turkey, Syria, Northern Iraq, Northeastern Iran and the Caucasus caused by a decrease in storm track activity over the Eastern Mediterranean. Other changes likely to impact the region include a decrease of over 170,000 km² in viable rain-fed agriculture land by late-century, increases in the length of the dry season that reduces the length of time that the rangelands can be grazed, and changes in the timing of the maximum precipitation in Northern Iran that will impact the growing season, forcing changes in cropping strategy or even crop types".

The study; however, notes that projections based solely on the results of the global climate change modeling tend to obscure smaller-scale regional effects. Therefore, the results obtained by the same researcher; using the regional climate modeling; specific to the Middle East, suggest that despite declines in the storm activity. The moisture-bearing winds could be channeled inland more often and diverted by the Zagros Mountains bringing an increase of over 50 % in annual rainfall to some localities in the Euphrates and Tigris basins; and by that this research emphasizes that the topography of land in limited areas may modify the expected impacts of these climatic changes. These widely ranging projections and interpretations of different sources depict an uncertain future for the Tigris and Euphrates Rivers basin's climatic conditions and indicate the need for further modeling studies to reach more definitive conclusions.

It may be said; however, that the use of currently measured conditions and trends serve to lay a foundation for forecasting future changes in climate and hydrology, but it also requires at the same time to develop new models more adapted to the natural conditions of this region. Cullen et al. (2000) employed standard statistical techniques to analyze data available from the National Climate Data Center (NCDC), Global Climatic Perspective System (GCP), and stream flow records obtained from Turkey through the UNESCO for the period 1938-1972. The end of this record marks the initiation of the implementation of the Greater Anatolia Project (GAP) when the publication of Turkish hydrological data was stopped by the authorities. The other used data included a short record (1965 – 1972) of the Tigris River stream flow in Baghdad. The results of this study confirmed that the stream flow of the Tigris and Euphrates Rivers are associated with the North Atlantic Oscillation (NAO), which governs the path of the Atlantic mid-latitude storm track and precipitation in the Eastern Mediterranean. As the sea level pressure over the North Atlantic oscillates seasonally; A Sea Level Pursuer Index (NAOSLP) can be calculated as a simple difference between the normalized mean-variance at different locations, and it is used to indicate the signature of the NAO in these locations. This index was defined and developed by Walker et al. (1932) and Rogers (1984). Results of Cullen et al. (2000) study showed that the Euphrates and Tigris flow integrate regional precipitation variations over the headwater region in Turkey in the months from December to April (DFMA), which is clearly subjected to (NAOSLP); as shown in Figures (4 and 5). In Figure (4), a strong relationship was indicated between the monthly stream flows of the Euphrates River measured at Keban (35 year mean values) in Turkey and the monthly averages for the three lowest NAO years (1940, 1963, 1969), and monthly averages of the three highest years (1945, 1949, 1961). Similar relationship would also apply for the Tigris River due to the similar conditions. In Figure (5), a strong correlation is observed between the (NAOSLP), the Turkish winter temperature index, the Turkish winter precipitation index, and the Euphrates average stream flow for the winter months (DJFMA) over the years of record (1930 – 2000). Again similar correlation would appear for the Tigris River flow. These results support the proposition that; among other factors the variations of NAO as a result of the Global Climate Change has its bearing on the climate changes expected in the Euphrates and Tigris Basins, and; therefore, future studies on the impact of the global warming on the two river basins must not neglect the NAO variation's effects. In such future studies the exact geographical locations and specific topographical features within the basin should be considered also.

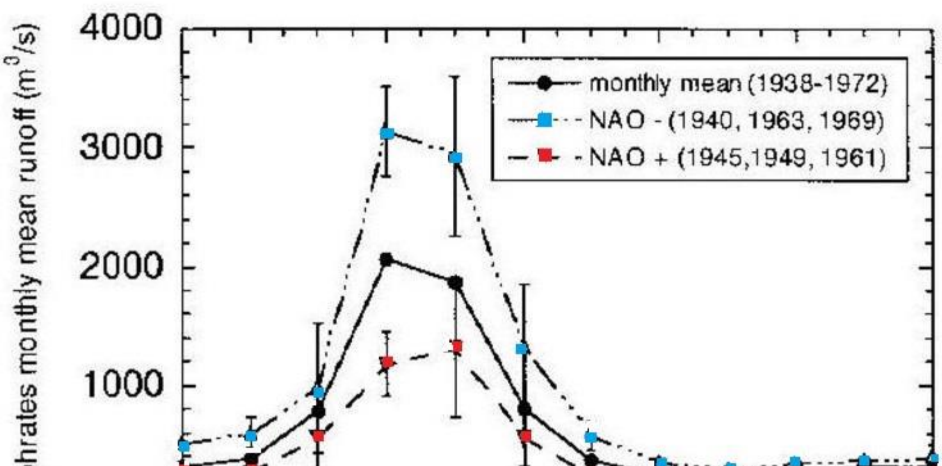

Figure 4: Monthly flow of the Euphrates River stream (solid line) measured at Keban, Turkey (35-year mean). Monthly averages for the three lowest NAO years (1940, 1963 and 1969; dashed line with filled circles, 2s S.D. shown), and monthly averages of the highest years (1945, 1949 and 1961; dashed line with triangles, 2s S.D. shown).

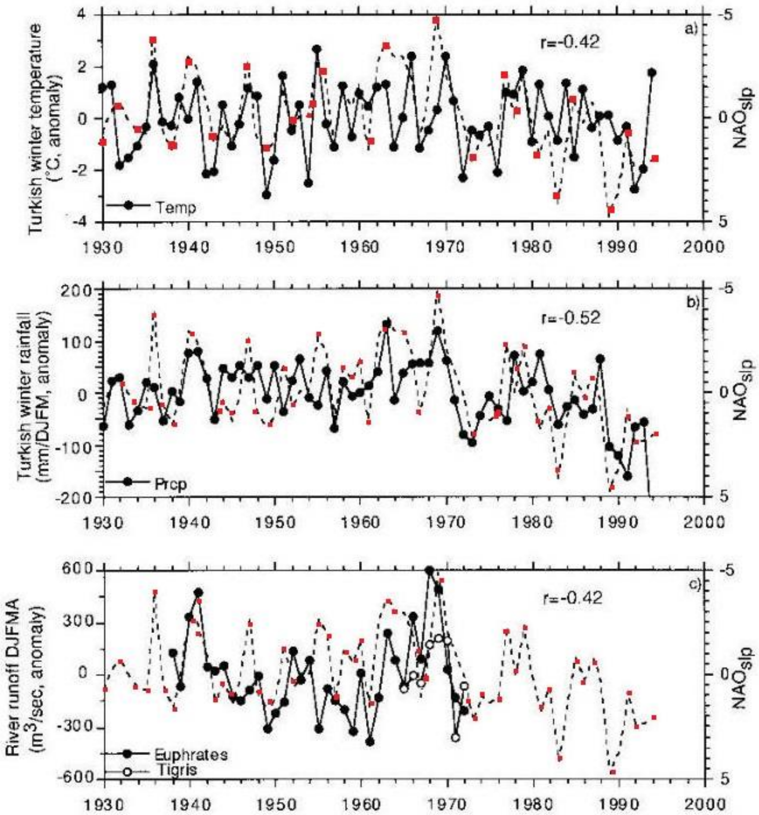

Figure 5: Correlation between the NAO_{SLP} index, (a) Turkish winter temperature index, (b) Turkish winter precipitation index and (c) DJFMA average stream flow of the Euphrates (filled circles) and the Tigris Rivers (open circles) (note: the NAOSLP index has been multiplied by _1.

4 Modeling studies for Present and Future Changes on the Euphrates and Tigris Basins due to Climate Change

Further modeling studies have been performed so far to determine the impacts of Climate Change on future water availability in the Tigris-Euphrates Rivers' Basins. According to a recent study (Voss et al. 2013), the Tigris-Euphrates Rivers' Basins experienced substantial water loss between January 2003 and December 2009, based on measurements of NASA's Gravity and Climate Experiment (GRSA's) Satellites. Chenoweth et al. (2011) investigated the likely future effects of the Climate Change on the water resources of the Eastern Mediterranean and Middle East regions using a high resolution climate model forced by lateral boundary conditions from the HadCM3 (abbreviation for a Hadley Model-version 3), which is coupled to Atmosphere-Ocean General Circulation Model (AOGCM), that was developed at the Hadley Centre in the United Kingdom and was one of the major models studied and formulated in the IPCC- Third

Assessment Report (IPCC, 2001 A). In this study, this model was driven by the (A1B) scenario formulated in the IPCC special report on emission scenarios (SERES) (IPCC, 2000 B); and it was found that the average annual Euphrates-Tigris Rivers' discharges may decline by 9.5% between 2040 and 2069, with the greatest decline (12%) in Turkey and only (4%) in Iraq. They also projected further decrease in the two rivers in the period 2070 – 2099; however, the decrease would be < 1%. Simulation was also performed on the Climate Change Impact over the Euphrates and Tigris basins in terms of the decrease of discharges of the two rivers. This was compared to a known reference base period in which these discharges were recorded. Bozkuri et al. (2015) applied both the hydrological model (HD) of the Max Plank Institute, which was developed by Hagemann et al. (1997 a) and Hagemann et al. (2001 b) to simulate discharge from the outputs of two chosen General Circulation Models GCMs (AIB) scenarios, and Regional Climate models for climate application (RCMs); as pioneered by Dickinson et al. (1989). For the reference base period (1961 – 1990) meteorological data from the upper reaches of the Tigris-Euphrates Rivers' basins in Turkey were obtained from the Turkish Meteorological Service and discharge measurements records were obtained from Palu and Baağiştas discharge measuring stations in Turkey, and Baghdad and Hindiya discharge measuring station in Iraq. In terms of the reference period (1961– 1990), simulations of 30-year daily surface runoff from the GCMs models and from the dynamically downscaled outputs of the same period were used to drive the HD model. The outputs of the used models are indicated in Figure (6). This Figure shows the mean annual discharge cycle for Palu, Baağiştas, Baghdad and Hindiya stations forced by General Circulation Model's outputs and RCM outputs for the base period (1961–1990). Figure (7) gives the mean annual discharge cycle of the Euphrates for the reference period (1961–1990) and the future period (2071– 2100) at the Palu, Baağiştas, and Hindiya gauging stations from the various simulations. The discharge is projected to increase slightly between November and December; as a result of more pronounced temperature increase at the end of the century resulting in earlier melting of snow. The slight increase in January is related primarily to snowmelt runoff; but, the discharge in general is expected to decrease during the rest of the year.

Further river discharge simulations indicate a striking decrease in the mean annual discharge for the Euphrates River by the end of the current century, ranging from (19 – 58) %, according to the various models used. These results, even with a certain margin of uncertainty resulting from the uncertainties embedded in the GCMs models mean that any future planning within this basin must be treated with caution and prudence.

5 Discussion and Conclusions

Climate Change Impact is evident on a global scale. It is basically driven by global warming, which is resulting from the ever increasing and unwise use of fossil fuel as energy source. Scientific evidence attributes this rise in temperature to increased release of carbon dioxide (CO2) due to the increased use of fossil fuel. Leading researchers have shown that the concentration of CO2 has increased from a relatively constant level of 280 parts per million, where it had been during the period from AD800 – AD1800 to the value of 380 parts per million in the last decade of the previous century: an increase of 36%. Therefore, it may be stated that the warming phenomenon, which is generally called the greenhouse effect is attributed to the increased concentration of CO2 and some other related gases, named collectively as the Green House Gases (GHG) in the atmosphere due to increased human activities. According to the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2000 B), this global warming cannot be separated from the disruptions caused to the weather patterns all over the world, which include higher temperatures, erratic precipitation modes and circulation patterns. This is causing more flooding in some areas compared to decrease in rain and droughts in others.

The East Mediterranean and Middle East Region, which encompasses the Euphrates and Tigris basins is one of the world regions that has been severely hit by these changes with more to occur in the foreseen future. The present measured and projected trends in this region are increasing temperatures with decreasing precipitation over the two rivers catchment areas in South Eastern Anatolia, Syria, northwestern and Eastern Iran and north of Iraq. The many studies performed so far on the link between what is happening in the region and what is happening in the rest of the world have shown that the weather pattern here is closely connected to the North Atlantic and surrounding regions' conditions. These results support the proposition that; among other factors the variations of North Atlantic Pressure oscillation NAO as a result of the Global Climate Change has its bearing on the climate changes expected in the Euphrates and Tigris Basins. Therefore, future studies on the impact of global warming on the two river basins must not neglect the NAO variation's effects. Much research work has been done so far in trying to define the magnitude of the changes to be anticipated in this most sensitive part of the world, which is already characterized by instability and fragile social and human conditions; as such changes could bring more upheavals in the future. Technical modeling studies have concentrated on the purely technical aspects leaving their outcomes to be assessed and handled by politicians. But, even these technical studies could only come up with indications to the negative future trends and have shown wide projections. These widely ranging projections and interpretations of different sources depict an uncertain future for the basin's climatic conditions and indicate the need for further modeling studies to reach more definitive conclusions. It may be said; however, that the use of currently measured conditions and trends serve to lay a foundation for forecasting future changes in climate and hydrology, but it also requires at the same time to develop new models more adapted to the natural conditions of this region.

As a summary of these studies, they show a drastic decline of the Euphrates and Tigris water resources at the end of this century by something like (30 – 70) %; as compared to their values in the last three decades of the previous century. While we do not want to dispute these wide variations in the projections, we do emphasize that the future is dark as far as those two rivers are concerned.

All in all, these studies should bring alarm to all responsible governments in the region to resort to long range planning by adopting rational policies in soils and water resources management to mitigate the adverse impacts that could hit human societies in these events. This may also bring the Wise Men in the region to come together to have mutual cooperation on this most important subject.

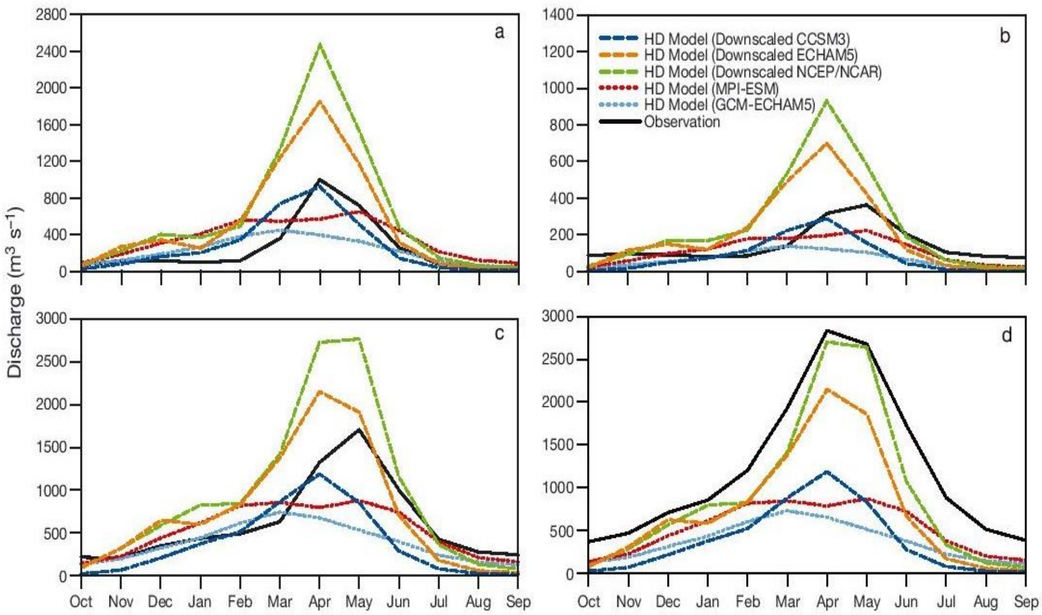

Figure 6: Mean monthly discharge for (a) Palu, (b) Baağiştas¸ , (c) Hindiya and (d) Baghdad stream flow gauging station (black continuous line) and the HD model simulation results (dashed lines) forced by GCM-ECHAM5 (blue), MPI-ESM (red RCM-NCEP/NCAR (orange), RCM-ECHAM5 (green) and RCM-CCSM3 (dark blue). Note differences in y-axis scales (1961-1990).

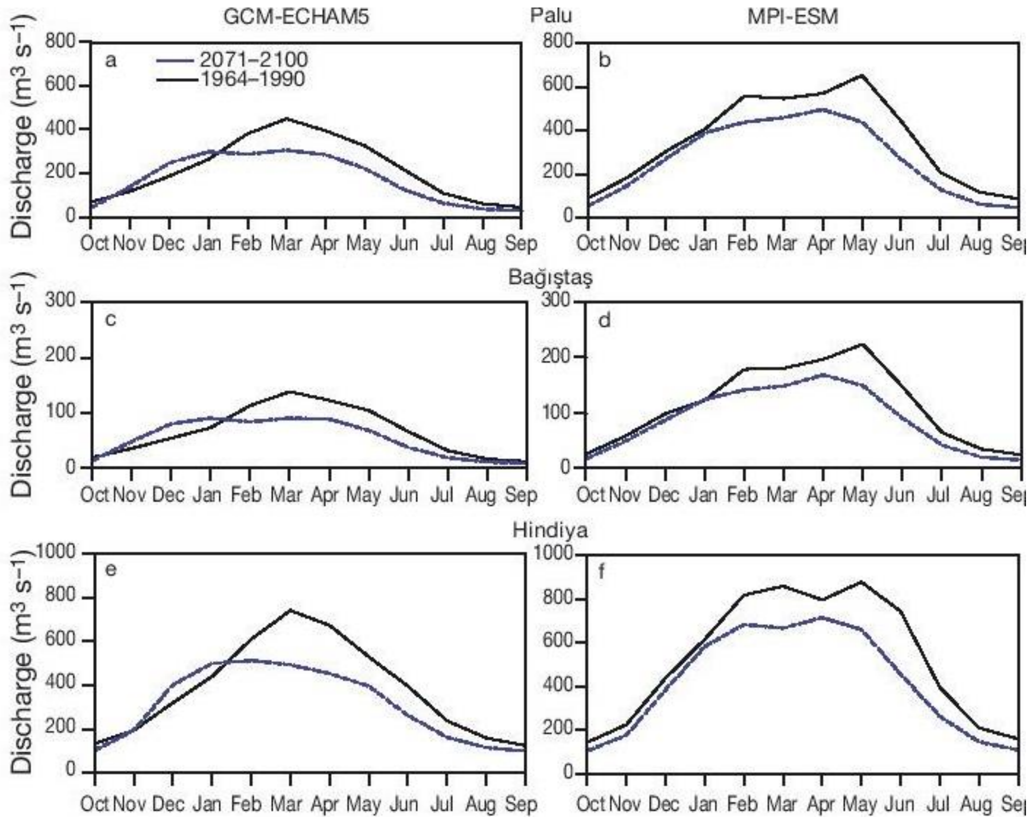

Figure 7: Mean monthly discharge (m3/ s) simulated by the HD model for (a, b) Palu,(C,d) Baağişas¸ and (e, f) Hindiya for the reference (black solid line) and future (blue dashed line) periods. Forcing- (a, c, e) GCM-ECHAM5; (b, d, f) MPI-ESM. (Base period 1969-1990, Future period 2071-2100)

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