Alper BABA* and Orhan GUNDUZ**

* Izmir Institute of Technology, Department of Civil Engineering, 35430-Urla- Izmir-TURKEY, alperbaba@iyte.edu.tr

** Dokuz Eylul University, Department of Environmental Engineering, 35160-Buca- Izmir-TURKEY, orhan.gunduz@deu.edu.tr

Abstract

Groundwater's global role as a vital source of fresh drinking water is well documented, and efforts are underway in many parts of the world to manage groundwater reserves responsibly and sustainably. A large percentage of the world's population lives in cities and either depends on or is affected in some way by groundwater. This ever increasing demand on groundwater has led to overexploitation of the aquifers and degradation of groundwater quality particularly in the last 50 years. Available evidences indicate that regional changes in climate (i.e., increases in temperature and reduction in precipitation totals and patterns) have already affected groundwater resources and ecosystem in many parts of the world. In future, climate change is expected to intensify groundwater related problems due to reduced recharge rates and increased demand for domestic, agricultural and industrial water supply. Thus, the basic concern is the sustainable management of groundwater resources such that it is not depleted while the increasing demand is effectively satisfied. Based on these fundamentals, the purpose of this study is to present an overview of groundwater problem in different parts of the world and to present an overview of the current knowledge in the area of climate change impacts on water resources. Case studies from the Mediterranean Region, the Caspian Sea Region and the Aral Sea where safe water resources are typically scarce and became steadily scarcer are presented. In particular, access to high quality drinking water will become more of a problem than it currently is in these and in many other parts of the world. Decreasing precipitation and reduced recharge of groundwater resources are now considered to be one of the reasons for declining groundwater quality. Finally, these drastic changes in the hydrology of the groundwater system are also responsible for many changes in ecosystems where some are irreversible.

Keywords: groundwater, sustainability, climate change and ecosystem

This paper is a general summary of the outcome of the NATO Advanced Research Workshop on "Climate Change and Its Effects on Water Resources" held in Çeşme-Izmir-TURKEY on 1-4 September 2010.

1. Introduction

National and global security can be assessed in many ways but one underlying factor for all humanity is access to reliable sources of water for drinking, sanitation, agriculture, construction, daily living, energy, fishing, forestry, manufacturing, public health, recreation, and transportation. The world's population is estimated to reach 7 billion in 2011. Projections recently issued by the United Nations suggest that world population by 2050 could reach 8.9 billion (UN, 2004). Therefore, in many parts of the world, population growth and associated increased demand for water already threaten the sustainable management of available resources (Baba et al., 2011). Furthermore, there is increasing evidence that global climate patterns are changing and creating major influences on human survival on earth (Santer et al., 1996; Baba, 2011). Global warming, climate change and sea level rise are expected to intensify problems related to the sustainability of available resources in many water-stressed regions of the world by reducing the annual supply of renewable fresh water and promoting the ingress of saline water into aquifers along sea coasts where 50% of the global population inhabit (Baba et al., 2011).

Climate change is an important factor effecting water resources. Thus, the focus of scientific research in the first half of the 21st century is towards finding ways to mitigate the negative consequences of climate change on water resources (Arnell 2000, Alcamo et al. 2000, Kamara, Sally 2004, Iglesias et al. 2006, Bates et al. 2008). As a consequence, water management is becoming a critical factor and is playing a decisive role in the geopolitical, economic and social grounds (Hrkal, 2011). Most scientists are confident that if current emissions of greenhouse gases continue, the world will be warmer, sea levels will be higher and precipitation distribution will be altered from their current conditions. As a consequence, regional climate patterns will likely to change and influence every day life in many parts of the world. According to Houghton et al. (1996), global temperatures are expected to rise faster over the next century than over any time during the last 10,000 years (Baba, 2011). On the other hand, Hrkal (2011), bring in a different perspective to the issue and link climate change phenomena with geological events. According to him, data from geology show that the mean temperature on the Earth were about 12oC higher during the Eocene period (i.e. roughly 50 million years ago) than its current level (Zachos et al. 2001, Katz et al. 1999) and the content of CO2 reached values fluctuating around 1000 ppm during the same era (Figure 1).

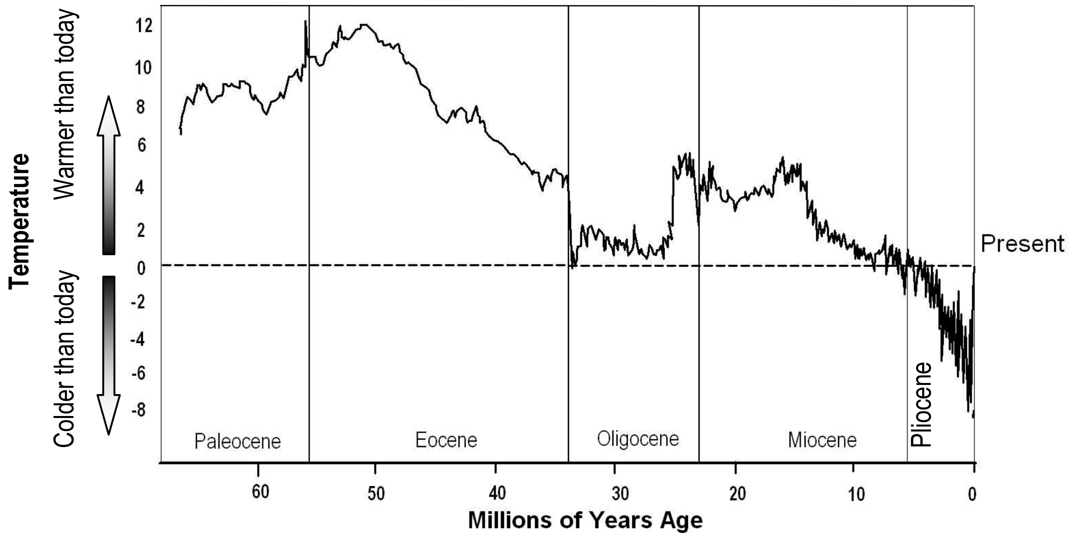


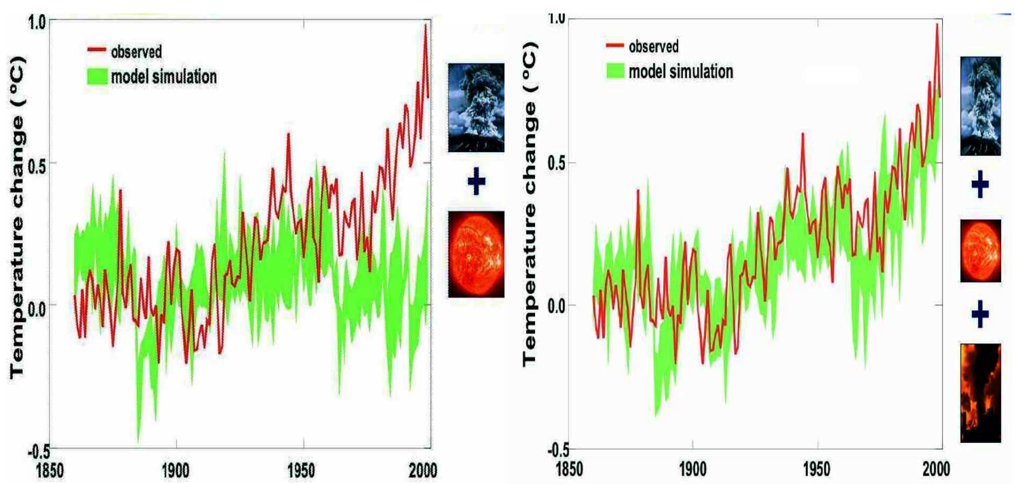
Figure 1. Changes in temperature on the Earth during the last 65 million years (Hrkal, 2011)

According to Hrkal (2011), in the period between the Eocene and Oligocene the climate began to gradually cool down so that the Antarctic was covered with ice for 10 million years. This period was then followed by a warming up interval when the Antarctic glacier melted completely away. Another wave or spell of cooling down arrived as late as in middle of the Miocene, which is characterized by fierce, short-term climate oscillations, by alternating the so- called glacial and interglacial ages (Hrkal, 2011). On the contrary, recent studies on climate change and climate modeling indicate that, with at least a 90% probability, global warming is due to human activities and more specifically to gaseous emissions since the beginning of the industrial revolution in 1750 (IPCC, 2001; Ganoulis and Skoulikaris, 2011).

Recent reports from the Intergovernmental Panel on Climate Change (2007) confirm that climate change is occurring at a larger and more rapid rate of change than was thought before. Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92]°C is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901-2000) (Jia et al., 2010; Baba, 2011). Climate models are able to predict temperature increase after 1950 only if the man-induced gas emissions are taken into account (Figure 2). Climate change primarily and additionally man-made modifications in land use result in modifications of different components of the hydrological cycle, such as evapotranspiration and precipitation. This is already the case in arid or semi-arid climates like the Mediterranean, where data time series recordings have shown a decreasing trend in precipitation over the last few decades (Ganoulis and Skoulikaris, 2011).

Constituting about 30% of all freash water, groundwater is a significant component of the freshwater cycle and its significance is becoming more prominent as the more accessible surface water resources are increasingly more exploited. In many cases, groundwater is a sufficient, secure and cost-effective water supply. However, it is increasingly becoming stressed due to overexploitation, contamination and in some areas of the world due to climate change. It was emphasized in a technical paper by the second working group of the Intergovernmental Panel of Climate Change (Bates et al., 2008) that the information about the water-related impacts of climate change is insufficient, especially with respect to water quality, aquatic ecosystems and groundwater. Therefore, impacts of climate change on groundwater quantity and quality need to be comprehended and determined (Elci, 2011).

Constituting about 30% of all freash water, groundwater is a significant component of the freshwater cycle and its significance is becoming more prominent as the more accessible surface water resources are increasingly more exploited. In many cases, groundwater is a sufficient, secure and cost-effective water supply. However, it is increasingly becoming stressed due to overexploitation, contamination and in some areas of the world due to climate change. It was emphasized in a technical paper by the second working group of the Intergovernmental Panel of Climate Change (Bates et al., 2008) that the information about the water-related impacts of climate change is insufficient, especially with respect to water quality, aquatic ecosystems and groundwater. Therefore, impacts of climate change on groundwater quantity and quality need to be comprehended and determined (Elci, 2011).



(a)

(b)

Figure 2. Comparison between observed and simulated temperature change (a) without and (b) with taking into account human gaseous emissions (Hadley Centre, 2005) (Ganoulis and Skoulikaris, 2011).

The purpose of this study is to present a brief summary of the findings of a NATO Advanced Research Workshop that took place in Cesme-Izmir-Turkey during 1-4 September 2010 to discuss the fundamental effects of climate change on surface and subsurface water resources. The study is complied to emphasize the main points of some of the research presented in this meeting. It also aims to present an overview of groundwater problem in different parts of the world (including case studies from the Mediterranean, Caspian and Aral Sea regions and other parts of the world) and to present an overview of the current knowledge in the area of climate change impacts on water resources.

2. Effect of climate change on groundwater

The most important pressure that climate change will exert on groundwater resources will be the changing rate of recharge which is closely related to the changes in precipitation. Therefore, following similar trends with precipitation, groundwater recharge rates will either decrease or increase for different geographical regions. For instance, IPCC reported that a more than 70% decrease in groundwater recharge is computed in north-eastern Brazil, southwest Africa and along the southern rim of the Mediterranean Sea, whereas more than 30% increase in groundwater recharge is computed in Sahel, the Near East, northern China, Siberia and the western USA (Kundzewicz et al., 2007). However, the most dramatic impacts of changing recharge rates on groundwater resources is foreseen at the locations where precipitation and accordingly recharge is expected to decrease. Decreasing recharge rates will definitely affect the quantity of the available groundwater resources, while the quality of the groundwater resources, especially in coastal regions, will be threatened by the saltwater intrusion and salinisation due to the increased evapotranspiration (Mimura et al.,2007). Consequently, decreasing recharge rates will also enhance the impacts of processes which have already been observed, such as saltwater intrusion (Yazıcıgil et al., 2011).

Climate warming observed over the past several decades is consistently associated with changes in a number of components of the hydrological cycle and hydrological systems such as: changing precipitation patterns, intensity and extremes; widespread melting of snow and ice; increasing atmospheric water vapour; increasing evaporation; and changes in soil moisture and runoff. There is significant natural variability in all components of the hydrological cycle, often masking long-term trends. There is still substantial uncertainty in trends of hydrological variables because of large regional differences, and because of limitations in the spatial and temporal coverage of monitoring networks (Huntington, 2006). At present, documenting interannual variations and trends in precipitation over the oceans remains a challenge (IPCC, 2008; Baba, 2011).

The changes in temperatures and in precipitations levels and distribution will directly affect the water demand, quality and watershed. Pollution will be intensified by runoff in catchments and from urban areas. Rivers will have lower flows particularly in summer, and the sea temperature, salinity and concentration of CO2, nitrates and phosphates will also be affected. The most visible impact will be the floods, which will be higher and more frequent. In addition, increased evapotranspiration will also lead to higher irrigation water withdrawals and declining levels in groundwater aquifers. The changes in the frequency of extreme events might be the first and most important change registered in the Mediterranean and Aral Region. Many scientists have been working about the effect of climate change on water resources. Most studies have been carried out around Mediterranean Region. For instance, Howard (2011) reported on the impact of climate change on Mediterranean Region. He mentioned that the combined population of countries that rim the Mediterranean Sea is projected to increase by over 100 million between 2000 and 2025 with the vast majority of this growth occurring in the 12 drier SEMED countries (Benoit and Comeau, 2005). Due to population growth alone, it is estimated that by 2025, 10 of the 12 SEMED countries will be consuming over 50% of their renewable water resources, with 8 of them exceeding 100%. Most of the demand increase will come from irrigation and domestic supply needs. Yılmaz and Yazıcıgil, (2011) reviewed the situations of the current knowledge in the area of climate change impacts on Turkish water resources with emphasis on past and predicted future trends in atmospheric variables (precipitation, temperature) and hydrologic variables (streamflow and groundwater levels). Prominent long-term observed changes that are consistent over Turkey include increase in annual minimum temperatures and summer temperatures and decrease in winter precipitation. Streamflow and groundwater levels are found to respond to the changes in atmospheric variables, indicating potential water scarcity problems in many regions. This situation is exacerbated due to population growth and over-exploitation of water resources. General Directorate of State Hydraulic Works (DSI) is the main investing institution responsible for the utilization of all water resources of Turkey. DSI have been monitoring water levels in different part of Turkey. Data from DSI demonstrate that groundwater levels of western Anatolia are on a declining pattern from 1970 to 2009 (Figure 3) (Murathan, 2009). The factor responsible for declining water table is the significant increase in groundwater pumping coupled with decreased recharge rates. Gunduz and Simşek (2011) also investigated the influence of declining precipitation totals and anthropogenic stress in The Torbali-Bayindir aquifer in western Turkey (Figure 4). They mentioned that long term analysis of the data demonstrated a general declining pattern in groundwater levels at an average rate of about 0.75 m/year, which is partly associated with decreasing precipitation patterns and partly with overexploitation of the aquifer. The results further indicated a very fast response of the groundwater levels to precipitation events (Gunduz and Şimşek, 2011).

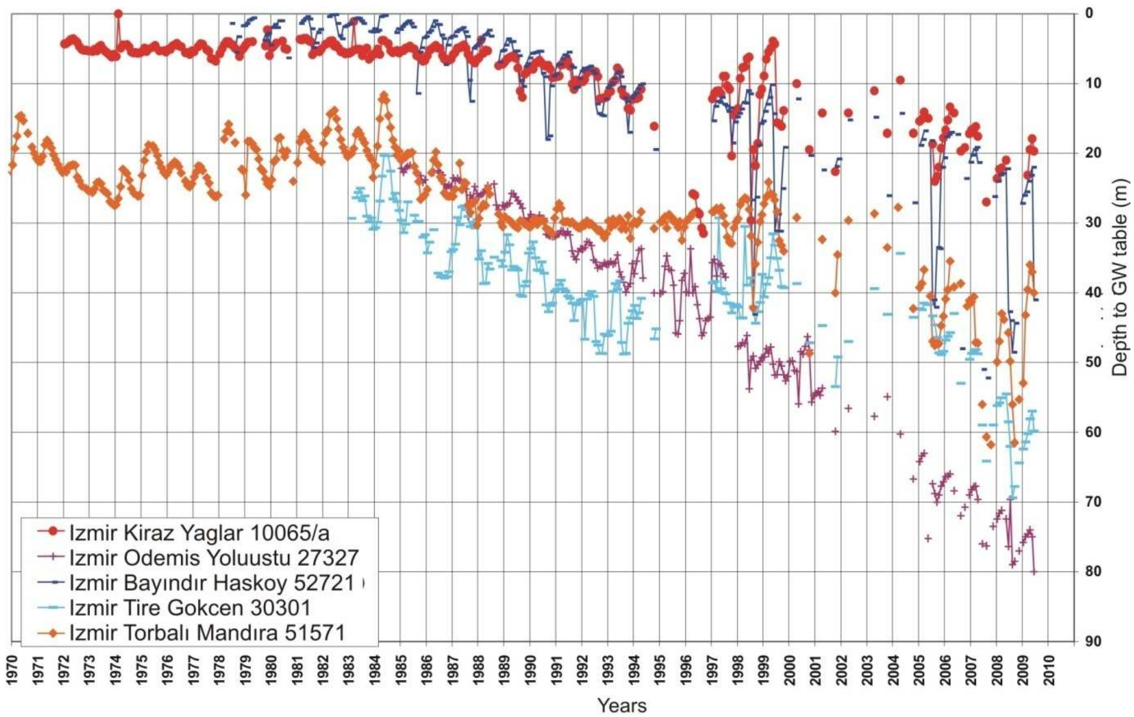
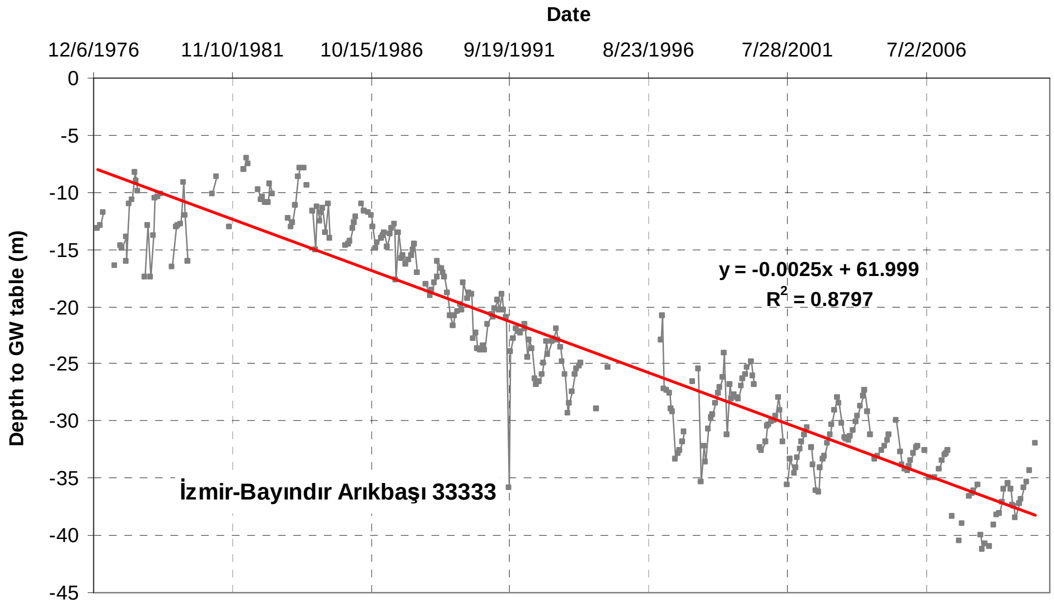


Figure 3. Distribution of groundwater level in Kucuk Menderes plain, Western Turkey, (Murathan, 2009)

Elçi (2011) presented the results of a modeling study on the impact of climate change on Izmir-Tahtali (western Turkey) groundwater system., where Tahtalı dam reservoir was built on the Tahtalı stream to meet about 35−40% of Izmir's total drinking water demand. He used a numerical groundwater flow model by considering the IPCC's "Special Report on Emission Scenarios" (SRES) scenarios. Based on these results he concluded that the largest component in water budget is and will be net groundwater recharge, which is predicted to decrease for the 2050 scenario causing a reduction of 29062 m3/d in the water inflow to the system. Furthermore, he also found out that spring discharge rates are predicted to decrease by 5.2%. Groundwater seepage to the Tahtalı reservoir and Izmir bay is predicted to decrease by 2.4%. Another significant outcome from the water budget analysis is the change in the water interaction between the streams and the aquifer. For the current climate, streams are gaining 6207.20 m3/d of water. The overall net direction of water flow is expected to reverse for the 2050 scenario, as the net loss of water from the streams is predicted to be 477.81 m3/d (Elçi, 2011).

Same problem can be observed in the Caspian Sea Region and in Aral Sea basin. For example, the major potential hazard of climate change on Kyrgyz Republic is expected to be the reduction of the mountain rivers runoff. This statement is correct as agriculture (being a basis of economy of the state) is based on irrigation farming. Mountainous rivers are the main source of irrigation. Because of shortage of surface water resources, the problem arises as to increase of the irrigation systems efficiency and use of ground waters for irrigation (Litvak,



2011).

Figure 4. Change in groundwater levels in a monitoring well in Torbalı-Bayindir plain, Western Turkey

It is also reported that mismanagement of water resources increase the influence of the impacts associated with climate change, particularly around Aral Sea basin. It is determined that the size and water balance of Aral Sea is fundamentally determined by river inflow and evaporation from its surface. Once the world’s fourth largest lake, the Aral Sea has dramatically shrunk since 1960s (Figure 5). In 1900s, the area and the volume of the Aral Sea were 68,320 km2 and 1066 km3, respectively. The Aral Sea Basin receives the bulk of its water from the two major rivers of the region, the Amu Darya and Syr Darya with a combined average annual flow of 115.6 km3. The average annual river flow in to the Aral Sea during 1927-1960 periods was stable. The large-scale development of water resources, mostly for irrigation, has changed the hydrological cycle in the region and caused serious environmental problems in the Aral Sea Basin including but not limited to the shrinkage of the sea (Kokishev, 2011).

3. Groundwater and ecosystem

An economic gain of use has led to a global explosion of groundwater development in the last several decades. Groundwater processes have been severely threatened, mostly by human actions such as changing soil uses and vegetation, modifying surface and groundwater flow systems, and introducing pollutants in the soil and water systems (Arellano, 2005). Consequently, groundwater reserves have been depleted extensively. Continuing use of groundwater, which is initially supplied from the storage, causes increasing derivation of additional water from surface water bodies such as, streams, lakes and wetlands (Bayarı 2005). Groundwater dependent ecosystems can only maintain their current composition and functioning by the groundwater input. Ecosystems are significantly influenced by changes in groundwater depth, pressure, flow rate and quality. Various pollutants such as pesticides, herbicides, fertilizers and other chemicals affect groundwater quality. Other pollutants having highly toxic features for environment such as industrial effluents, irrigation return-waters, and leachate from waste disposal areas may also affect groundwater quality (Yüce, 2005). The quality of groundwater, the main source of drinking water in the most countries, is increasingly threatened by anthropogenic activities such as industrial processes, intensive agriculture, irrigation, tourism, transportation.

Once vulnerability of water resources to climate change is assessed, the reactions of habitats and consequently the ecosystems to these changes are estimated. This requires the essential knowledge of ecohydrological variability of ecosystems. The next step is then to establish a true interdisciplinary study highlighting the ecohydrological approach, to adequately address the questions related to the space-time links between climate-soil-water-landscape and vegetation (Ekmekçi and Tezcan, 2005). For example, the hyporheic zone refers to the saturated pore space in sediments beneath and lateral to a stream/river channel, that is strongly influenced by the interactions between surface and subsurface waters as a biologically important ecotone. The hyporheic zone can be defined in many ways; however, it essentially describes the extent to which nutrient-rich surface waters penetrate the shallow subsurface in the immediate vicinity of a flowing surface water body, to provide essential life support for a distinct and often dynamic community of invertebrates (the hyporheos) and micro-organisms (Howard, 2005). Agricultural activity is the major factor effect quantity and quality in most country. Also, illegal drilling for water and the excessive use of pesticides have been effected water resources. Mismanagement has affected the quality of fresh water, the pollution of resources by pesticides and their residues, the intrusion of seawater into coastal aquifers, and the gradual desertification of land by diverting rivers toward cultivating crops or poorly placed ornamental plants that require huge quantities of water.

4. Sustainability of water resources

Scientific studies show that water challenge, which will be faced particularly by Asian countries in next decades, has to be set in the development strategies in order to ensure a healthy environment and a well being for the local populations. The effective management of a water resource requires us to strike a balance between the water requirements of humans and the natural ecology of catchments. To achieve this objective more data needs to be obtained for a better assessment of the situation. Hence the following tasks are deemed important:

Installation of multi purpose monitoring equipment for measurements of climate conditions such as precipitation and temperature.

Installation of multi purpose monitoring equipment for measurements of groundwater and surface water levels and quality indicators.

Identification, characterization and monitoring of groundwater-surface water interactions.

Monitoring the impacts of groundwater abstractions and contaminants on groundwater fed rivers, lakes and wetlands.

Monitoring and advancing binational cooperation in transboundary groundwater management.

Monitoring efficient use of surface and ground water for irrigation.

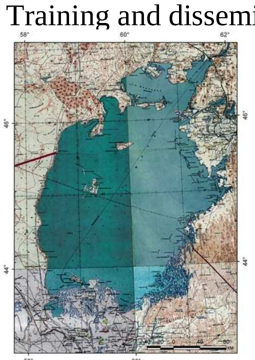
Use of water-saving irrigation technologies.

Reduction in water demands and promoting conservative use of water in agricultural and industrial sectors.

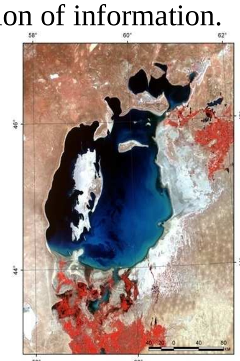
Design of comprehensive water policies and integrated planning

Use of improved technologies for water treatment and re-use.

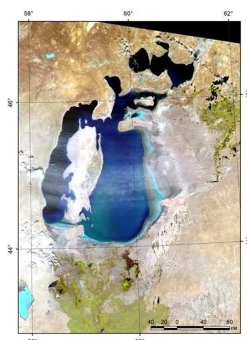
Training and dissemination of information.



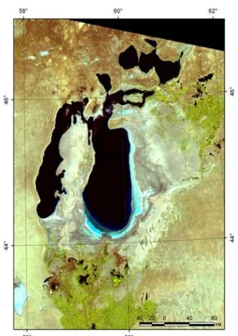
1960



1993

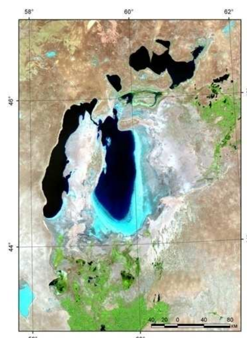


2001

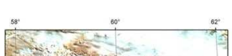


2002

2004



2006



Consequently; water sustainability is crucial problem for all living beings. Therefore it required levels of decision-making, good governance, law, and administration, economic and other policy instruments, roles of users, politicians, and groundwater experts, data collection and monitoring, preferable management regimes. In addition, efforts should focus on water conservation, which includes reducing losses, enhancing saving and promoting management of this resource as an economic commodity (apart from the portion that must be considered as a human right) and less as a political asset or as a national privilege. Increased water prices for all users, particularly for the consumers in agriculture and industrial sectors, would help regulate the demand for water. Consequently, pricing could be used effectively for achieving sustainability in water management.

Consequently; water sustainability is crucial problem for all living beings. Therefore it required levels of decision-making, good governance, law, and administration, economic and other policy instruments, roles of users, politicians, and groundwater experts, data collection and monitoring, preferable management regimes. In addition, efforts should focus on water conservation, which includes reducing losses, enhancing saving and promoting management of this resource as an economic commodity (apart from the portion that must be considered as a human right) and less as a political asset or as a national privilege. Increased water prices for all users, particularly for the consumers in agriculture and industrial sectors, would help regulate the demand for water. Consequently, pricing could be used effectively for achieving sustainability in water management.

Conclusion

Population growth and a changing climate seriously threaten water resources of the world, with particular emphasis on Mediterranean Region, Aral Region, Africa, and South of Asia. Important resource management decisions will be required but any such effort will prove inconsequential unless reliable predictions can be made of the influence that changing conditions will have on the hydrologic cycle and available water reserves (Howard, 2011). By 2050, it is expected that world population could reach about 9 billion and many countries will face water shortage conditions. An inevitable consequence of this phenomenon would be an increase in over-exploitation and increased use of unsustainable water supplies (i.e., deep groundwater). Furthermore, decreased recharge due to changing climate patterns and associated declines in groundwater levels, deterioration in water quality due to increased demand, sea water intrusion along coastal aquifers and salinization could also be other listed as other consequences of this problem. Finally, sustainable management, of water resources should be seen as the key for sustainability of life in this planet.

Acknowledgements

The authors thank the Turkish Academy of Sciences (TÜBA) for their support.

References

1. Alcamo J, Heinrichs T, Rösch T (2000) World water in 2025 – global modeling and scenario analysis for the 21st century. Report A0002, Center for Environmental Systems Research, University of Kassel, Kassel, Germany.
2. Arnell N (2000) Climate change and global water resources. Global Environ Change 9:531–549.
3. Araus J L (2004) The problems of sustainable water use in the Mediterranean and research requirements for agriculture, Ann. appl. Biol. (2004), 144:259-272
4. Arellano M. M (2005) Groundwater-dependent wetlands, Hydrological and ecological aspects, Groundwater and Ecosystem, NATO ARW Abstarct book, p.1.
5. Baba A., Gunduz O., Friedel M.J., Tayfur G., Howard K. W.F. Chambel A (2011) Climate change and its effects on water resources, NATO Science for Peace and Security Series, Springer, The Netherlands. p.1
6. Baba, A (2011) Climate change mitigation with renewable energy: Geothermal, in Climate Change and its Effects on Water Resources (edit by Baba et al.), NATO Science for Peace and Security Series, p.24-33.
7. Bates BC, Kundzewicz ZW, Wu S, Palutikof JP (2008) Climate change and water, technical paper VI of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva, 210 pp
8. Bayari S (2005) Groundwater Age: critical information in the interaction between groundwater and surface aquatic ecosystem, Groundwater and Ecosystem, NATO ARW Abstarct book, p.5.
9. Benoit G, Comeau A (2005) A sustainable future for the Mediterranean: the blue plan's environment and development outlook. UNEP. Earthscan, London, p 464
10. Ekmekçi M. and Tezcan L (2005) Assessment of vulnerability of water resources to climate change: ecohydrological implications, Groundwater and Ecosystem, NATO ARW Abstract book, p.7.
11. Elçi A (2011) Assessing the impact of climate change on groundwater resources using groundwater flow models, in Climate Change and its Effects on Water Resources (edit by Baba et al.), NATO Science for Peace and Security Series, p.63-74
12. Ganoulis J and Skoulikaris C (2011) Impact of climate change on hydropower generation and irrigation: A Case Study from Greece, in Climate Change and its Effects on Water Resources (edit by Baba et al.), NATO Science for Peace and Security Series, p. 87-95.
13. Gunduz O. and Simsek C (2011) Influence of climate change on shallow groundwater resources: the link between precipitation and groundwater levels in alluvial systems, in Climate Change and its Effects on Water Resources (edit by Baba et al.), NATO Science for Peace and Security Series, 225
14. Howard K.W.F (2011) Implications of climate change on water security in the Mediterranean region, in Climate Change and its Effects on Water Resources (edit by Baba et al.), NATO Science for Peace and Security Series,p.9-15.
15. Huntington TG (2006) Evidence for intensification of the global water cycle: review and synthesis. J Hydrol 319:83–95.

16. Hrkal Z (2011) Climate change and water resources –challenge of our civilisation in Climate Change and its Effects on Water Resources (edit by Baba et al.), NATO Science for Peace and Security Series, p.35-41.
17. Iglesias A, Garrote L, Flores F, Moneo M (2007) Challenges to manage the risk of water scarcity and climate change in the Mediterranean. Water Resour Manage 21:775–788.
18. IPCC (2001) Climate change, (2001) The scientific basis. Contribution of working group I to the third assessment report of the Intergovernmental Panel on Climate Change. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds). Cambridge University Press, Cambridge and New York, pp. 881.
19. IPCC (2007) Climate change 2007: synthesis report, 2007, Intergovernmental Panel on Climate Change. http://www.ipcc.ch/
20. IPCC (2008) Climate change and water. In: Bates BC, Kundzewicz ZW, Wu S, Palutik JP (eds) Technical paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva, p 210.
21. Kamara AB, Sally H (2004) Water management options for food security in South Africa: scenarios, simulations and policy implications. Dev South Afr 21(2):365–384.
22. Katz ME, Pak DK, Dickens GR, Miller KG (1999) The source and fate of massive carbon input during the latest Paleocene thermal maximum. Science 286(5444):1531.
23. Kokishev, N (2011) General assessment of surface and subsurface water quality in southern Kazakhstan, Dokuz Eylül University, Graduate School of Natural and Applied Sciences, Thesis of Master Sciences, Izmir.
24. Kundzewicz ZW, Mata LJ, Arnell NW, Döll P, Kabat P, Jiménez B, Miller KA, Oki T, Sen Z, Shiklomanov IA (2007) Freshwater resources and their management. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: impacts, adaptation and vulnerability, contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge,
25. pp 173–210
26. Litvak R.G., Nemaltseva E.I., and Poddubnaya I.V (2011) Trends of irrigation development in the Kyrgyz Republic within the context of climate change, in Climate Change and its Effects on Water Resources (edit by Baba et al.), NATO Science for Peace and Security Series, p.175
27. Mimura N, Nurse L, McLean RF, Agard J, Briguglio L, Lefale P, Payet R, Sem G (2007) Small islands. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: impacts, adaptation and vulnerability, contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 687–716
28. Murathan A (2009) Potential of groundwater resources of Izmir and its surrounding (Gediz, Bakıcay, Kucuk Menderes, Banaz Cay Basin), Izmir water symposium, 2 October 2009, Izmir, p.21-46 (in Turkish)
29. Santer B, Wigley TML, Barnett TP, Anyamba E (1996) Detection of climate change and attribution of causes. In: Houghton JT et al (eds) Climate change 1995: the science of climate change. Report of IPCC Working Group I. Cambridge University Press, Cambridge, pp 411–443.
30. UN (2004) World Population To 2300, Department of economic and social affairs, population division, United Nations New York, 2004
31. Yazicigi H., Yilmaz K.K., Erdemli B.U. and Yagbasan O (2011) Impacts of decreasing recharge rates on sustainable groundwater management, in Climate Change and its Effects on Water Resources (edit by Baba et al.), NATO Science for Peace and Security Series p.43

32. Yilmaz K. K. and Yazicigil H (2011) Potential impacts of climate change on Turkish water resources: a review in Climate Change and its Effects on Water Resources (edit by Baba et al.), NATO Science for Peace and Security Series p.105
33. Yuce G (2005) The Vulnerability of groundwater dependent ecosystems: a study on the Porsuk river basin (Turkey) as a typical example groundwater and ecosystem, NATO ARW Abstarct book, p.44.
34. Zachos J, Pagani M, Sloan L, Thomas E, Billups K (2001) Trends, rhythms, and aberrations in global climate 65 Ma to present. Science 292(5517):686–693.

IMPACTS OF CLIMATE CHANGE ON FRESHWATER RESOURCES AND THEIR ECOLOGY

Melike Gürel, Alpaslan Ekdal, Ali Ertürk, Ayşegül Tanık

Istanbul Technical University, Civil Engineering Faculty, Environmental Engineering Department, 34469 Maslak, Istanbul

gurelme@itu.edu.tr, ekdala@itu.edu.tr, erturkal@gmail.com, tanika@itu.edu.tr

Based on the monitoring data and climate projections scientists highly agree that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change in the long-run. However, there is no consensus about the degree of impact of human activities on climate change. By modeling studies, Intergovernmental Panel for Climate Change (IPCC) estimates the expected changes in the climate on a global scale for different emission scenarios. Then these results are used as an input for regional climate models. If we assume that climate change scenarios will be realized in the future, we can foresee that there will be effects of climate change on watershed ecology and on the water resources. For example variations in precipitation and temperature will increase the risks of flooding and drought in many areas, will directly affect the water demand and water quality. Changes in water quantity and quality will in turn affect food availability, stability, access and utilization. Water quality of surface runoff from urban and rural areas will change. Function and operation of existing water infrastructure (including water treatment, hydropower, drainage and irrigation systems) will be effected. Increase in water demand may result in insufficient capacity of reservoirs and transfer of water from other watersheds might be necessary.

Within the scope of this paper, the impacts of climate change on freshwater resources; their availability, quality, quantity, uses and management is evaluated. Impacts on ecology are mentioned. Several management alternatives to reduce the potential adverse effects of climate change are identified; merits and tradeoffs involved are discussed.