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SU VAKFI

# Climate Change And Groundwater

# İklim Değişikliği ve Yeraltı Suyu

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**İKLİM DEĞİŞİKLİĞİ BÜLTENİ : SAYI 4**

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# Climate Change And Groundwater

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The effect of climate change on streamflow and groundwater recharge varies regionally and between climate scenarios, largely following projected changes in precipitation.

Groundwater is the major freshwater source especially for arid and semi-arid regions, but unfortunately there has been very little attention or study on the potential climate change effects on these freshwater resources. Most of the works are concentrated on humid regions. Aquifers in arid and semi-arid regions are replenished by floods at possible recharge outcrop areas through fractured and fissured rocks, solution cavities in dolomite or limestone geological setups as well as through main stream channels of Quaternary alluvium deposits. At convenient places along the main channel engineering infrastructures such as levees, dikes, successive small scale groundwater recharge dams may be constructed for groundwater recharge augmentation. The groundwater recharge areas must be cared for isolation from fine silt accumulation after each flood occurrence or at periodical intervals. Furthermore, flood inundation areas are among the most significant groundwater recharge locations in arid and semi-arid regions. Accordingly, their extents must be delimited by considering future climate change effects.

Understanding the relative importance of climate, vegetation, and soils in controlling groundwater recharge is critical for estimating recharge rates and for assessing the importance of these factors in controlling aquifer vulnerability to contamination. Understanding the role of climate and vegetation in controlling recharge will also be valuable in determining impacts of climate change and land use change on recharge.

The aquifers that are in contact with present day hydrological cycle will be affected by climate change. These are referred to as unconfined or shallow aquifers. On the other hand, deep and especially confined aquifers are not in contact with the present day hydrological cycle and consequently their effect from climate change is virtually negligible. They include fossil groundwater storages.

Groundwater recharge depends on several factors such as infiltration capacity, stochastic characteristics of rainfall and climate factors. The spatial and temporal distribution of the rainfall mainly controls the natural groundwater recharge. In arid regions, recharge occurs through the ephemeral streams, which flow through the wadi course but most of the water is absorbed in the unsaturated zone before reaching the aquifer. In semi-arid regions, the recharge is irregular and occurs only in the periods of heavy rainfalls. In humid regions, recharge is mainly in the winter period. In the summer period, most of the rainfall becomes soil moisture and evaporates. In cold areas the melting of ice suddenly recharges the groundwater.

Unsaturated zone has a unique capability in helping to assess impacts of climate change on groundwater resources. The potential impacts of climate change can be assessed by focusing on porous, fractured and karstic (carbonate rock, dolomite, limestone) aquifer systems. Especially, fractured and karstic aquifers are the most responsive to changes in recharge as typically they have low specific yields (i.e. they have drainable porosities) in comparison with porous flow systems. Karstic rocks are soluble and the aquifers might show exacerbated water table lowering if predicted increases in atmospheric $CO_2$ contents along with temperature rise induce rapid enlargement of fracture apertures and enlargement in the solution cavities. Dissolution of carbonate rocks (karstic media) might become more vigorous by time and accordingly the hardness of groundwater sources is expected to increase, leading to possibly unacceptable water quality.

As a result of climate change, in many aquifers of the world, the spring recharge retreats towards winter with more or less the same rates, but summer recharge declines dramatically. Understanding the relative importance of climate, vegetation, and soils in controlling groundwater recharge is critical for estimating recharge rates and for assessing the importance of these factors in controlling aquifer vulnerability to contamination. Understanding the role of climate and vegetation in controlling recharge will also be valuable in determining impacts of climate change and land use change on recharge.

There are two types of groundwater recharge processes, namely, direct and indirect. Direct groundwater recharge mode is more sensitive to climate change than indirect natural recharge. Direct recharge can be defined as water added to the aquifer through the unsaturated zone by direct percolation of rainfall at the spot where it falls. Indirect recharge occurs where water fulfils the soil moisture deficits and evapo-transpiration process before reaching to groundwater reservoir. Indirect recharge occurs from percolation to the aquifer following surface water runoff (surface water category) and localization (localized category) in joints, poundings, and lakes or through the wadi beds. Indirect recharge produced as a result of infiltration during flood pulses is considered as the most important contribution to the groundwater table in wadi channels. The amount of water that is added to the aquifers by such processes is much larger than the direct recharge. Small local floods merely compensate for soil moisture deficits and evapo-transpiration particularly during dry season and therefore the amount of water that goes to the water table will not be a significant contribution. While comparing direct and indirect recharge, Simmers (1990) concluded the following:

1) Estimates of direct recharge can be more reliable than indirect recharge.

2) With increasing aridity, direct recharge becomes less significant while indirect recharge more in terms of total recharge to an aquifer.

3) Recharge occurs to some extent even in the most arid regions, although increasing aridity decreases the net downward flux with greater time variability.

4) Successful groundwater recharge estimation depends on first by identifying the probable flow mechanism and important features influencing recharge for a given locality.

Coupled with the changes in the hydrological cycle and probable inducement of climate change basic elements, the groundwater recharge is also interactively affected due to the following events.

1) Changes in precipitation, evapo-transpiration, and runoff are expected to influence recharge. It is possible that increased rainfall intensity may lead to more runoff and less recharge.

2) Sea-level rise may lead to increased saline intrusion of coastal and island aquifers, depending on the relative position of sea-level to the groundwater table level.

3) Changing in precipitation imply changes in $CO_2$ concentrations, which may influence carbonate rocks dissolution and hence formation and development of karstic groundwater aquifers.

4) Natural vegetation and crops changes reflection of climate change may influence recharge.

5) Increased flood events contribute to unconfined aquifers in arid and semi-arid zones and hence they affect groundwater quality in alluvial aquifers of wadis.

6) Changes in soil organic carbon may affect the infiltration properties above aquifers and consequently the groundwater recharge.

The above mentioned factors indicate that the groundwater-focused organization should take interest in global climate change issues in order to protect the groundwater resources effect from the implications.

Due to the global warming, a smaller proportion of the winter precipitation falls as snow. The spring snowmelt peak therefore is reduced while the flood risk in winter is probably increased. In summer, mean monthly groundwater recharge and streamflow are reduced by up to 50% potentially leading to problems concerning water quality, groundwater withdrawals and hydropower generation (Eckhardt and Ulbrich, 2003). Some water supplies could become unusable due to the penetration of salt water into rivers and coastal aquifers as sea level rises. Changes at the surface water resources frequency and magnitude would influence the aquifer storage replenishment through natural recharge. Water quality may also respond to changes in the amount and timing of precipitation.

Coastal aquifers may be damaged by saline intrusion as salty groundwater rises due to sea-level rise. The movement of the salt-front up in aquifers would affect freshwater pumping plants near the coastal line.

Relative sea-level rise adversely affects groundwater aquifers and freshwater coastal ecosystems (high confidence). Rising sea level causes an increase in the intrusion of salt water into coastal aquifers. Other impacts of sea-level rise are likely to include changes in salinity distribution in estuaries, altered coastal circulation patterns, destruction of transportation infrastructure in low-lying areas, and increased pressure on coastal levee systems.

Higher sea levels associated with thermal expansion of the oceans and increased melting of glaciers will push salt water further inland in rivers, deltas, and coastal aquifers (very high confidence). It is well understood that such advances would adversely affect the quality and quantity of freshwater supplies in many coastal areas.

Another great advantage of groundwater is that as water slowly percolates down into the aquifer it is usually purified of biological pollutants. Thus, groundwater is usually the best source of drinking water, especially in arid, semi-arid and rural areas of developing countries where water treatment facilities or desalination plants are not available. In water resources poor countries, such as the Arabian Peninsula countries, the desalination plants are used to maintain groundwater resources as strategic planning assets for future generations or emergency situations (Al-Sefry, et al., 2004). Groundwater resources assessment for any purpose in arid region wadi drainage basins requires uncertainties to be taken into calculation. Among these uncertainties the climate change impact may well be accounted for future planning, operations and managements. Unfortunately, deterministic crisp approach does not open way for risk assessments under uncertain climate, recharge, and aquifer and drainage basin properties. In arid regions, wadis have Quaternary depositions of different facies and grain size distributions depending on the paleogeologic environmental processes. Consequently, any measurement at a point may be significantly different than other points within the same wadi. For instance, several aquifer test lead to different hydrogeological parameter estimations, and the rainfall variability has temporal and spatial trends. Hence, rather than regional average parameter values, their probabilistic consideration gives rise to determination of any parameter value under an acceptance certain risk level such as 10%. It is necessary to manage the groundwater resources under such risk levels. The application of the methodology is presented for wadi Fatimah that lies in the central western part of the Kingdom of Saudi Arabia (Al-Sefry, et al., 2004).

The critical issue facing many groundwater aquifers today is that the volume of water withdrawal exceeds long-term recharge, resulting in rapidly declining groundwater levels in many areas. Closely related to this is the key issue of managing groundwater access and utilization, since groundwater is a common property concern with individual benefits and collective costs.

The rainfall and infiltration elements of the hydrological cycle in arid regions indicate temporal and spatial variations in a random and sporadic manner. Such variations may be exacerbated groundwater replenishment facilities.

Groundwater recharge estimation has become a priority issue for both developed and underdeveloped countries, especially in dry areas like central Africa, where rainfall is both temporally and spatially irregular. The rapid agriculture and industrial growth in such areas has dramatically changed the groundwater resources withdrawal pattern. Groundwater withdrawal in excess of recharge has lowered the hydraulic heads in the aquifers, and resulted in increased pumping energy costs and reduced the rate of removal. Continual withdrawal in excess of recharge and possible climate change effects will in time ultimately remove all of the recoverable water.

In arid and semi-arid regions, the recharge component in any groundwater balance assessment presents difficulties for direct measurement in the field. It is more difficult, especially, at the upstream portions, because of inaccessibility by routes, heterogeneity in climate variability and porous medium properties. In dry climates the recharge component of hydrologic cycle becomes the most significant element after the rainfall occurrences, but its direct calculation is not possible. The recharge rates in arid and semi-arid regions are small but this small amount must be estimated with care and accuracy. The groundwater storage rates in alluvial aquifers of the middle and lower wadis depend on recharge amount, and consequently, the human activities (domestic, agricultural and man-induced climate change) for survival can be developed based on the storage volumes without significant problems. On the other hand, now in the Middle East, there are plans for strategic exploitation and use of groundwater resources, especially, on the western regions along some potential wadi courses. This makes the recharge estimation more important for such arid and semi-arid regions of the country. Consideration of these difficulties, especially, during the last decade led many researchers to use the simple method of chlorine mass balance (CMB) approach in groundwater recharge estimation studies. This is based on the assumption that the chloride concentrations in the rainfall and recharge area are in steady state balance, i.e., input is equal to output without chloride storage change during a time period, which is taken as a storm duration, month or year. Such a simple and very ideal situation is further physically simplified, and then the recharge estimation is obtained provided that there are field records on rainfall amount and chloride concentrations in the rainfall and groundwater. In thousands of geochemistry studies within the wadis, the chloride is found only in negligible amounts, except after a rainfall event (Bazuhair et al., 2002, Subyani and Şen, 2004). The long-term rainfall and its chloride concentration amounts have a balanced situation, i.e., steady-state condition. This implies stable and long-term averages, as the classical CMB method requires. A hidden assumption is that the fluctuations around the average rainfall and chloride records must be very small so that they are negligible, however by the consideration of climate change such small but accumulatively effective increments must not be ignored.

The average recharge rates, calculated by chloride mass-balance method in the central western wadi aquifer systems along the Red Sea range from 0.52 to 11.57 mm/yr or 0.35 to about 7% of average annual rainfall (Bazuhair, et al., 2002).

All studies related to the estimation of groundwater recharge must be based on strong foundation of comprehensive hydrologic and climatologic data of the study area; otherwise the calculated recharge rates will have large uncertainties. Information about rainfall amount, seasonality, intensity, duration and distribution is of prime importance because infiltration of rainfall is the main source of groundwater recharge. Besides this, there are several factors, which govern the rate of groundwater recharge such as aquifer depth, infiltration capacity of the unsaturated soil profile, confining layers in the wadi beds, slope of the land surface and aspect, temperature, wind, and relative humidity. Unfortunately, in many methods of groundwater recharge estimation we use the literature-derived values of some variables without knowing the reliability of the data.

A Geographic Information System (GIS) methodology coupled with satellite application facilities must be applied in future to estimate regional recharge. The GIS coverage must include a digital elevation model and maps of geology, soils, rainfall, air temperature, relative humidity, stable isotope variations, etc.

Rainfall-based annual recharge maps should be prepared for active aquifer monitoring. The quantity of recharge to an aquifer must be considered in any integrated management program as equivalent to the "safe yield" or quantity of groundwater that could be withdrawn form an aquifer on a sustainable basis. This type of maps will be very helpful in evaluating the effects of climate variability on groundwater recharge and exploitable groundwater resources. Many researchers believe that climatic conditions mainly govern the recharge rates, although vegetation and soils also interactively control the groundwater recharge.

As the rainfall is the main source of groundwater recharge, our understanding of the Middle East and the south eastern Asia spring and summer monsoon mechanism should be developed in order to utilize the water resources more effectively. The onset and withdrawal dates of monsoon rains and their spatial distribution over the southwest of Arabian Peninsula must be studied and published, in order to utilize the undammed floodwaters by establishing the weirs on the major wadis for retaining floodwater for artificial recharge purposes. The groundwater can be stored behind subsurface dams for future exploitations.

Unsaturated zone has a unique capability in helping to assess impacts of climate change on groundwater resources. The potential impacts of climate change can be assessed focused on fractured carbonate aquifer systems (having variable degrees of fracture development, i.e., karstification) because,

- fracture flow aquifers are the most responsive to changes in recharge as typically they have low specific yields (i.e., they have drainable porosities) in comparison with inter-granular flow systems,
- carbonate rocks are soluble and the aquifers might show exacerbated water table lowering if predicted increases in atmospheric $CO_2$ contents along with temperature rise induce rapid enlargement of fracture apertures;
- if dissolution of carbonate rocks does become more vigorous then potentially the hardness of groundwater could be expected to increase, leading to possibly unacceptable water quality.

Application of the climate change scenarios and software is necessary to forecast changes in aquifer geometries, hydraulic parameters (permeabilities, storage coefficients), flows, water balances and water quality.

One of the major advantages of storing water in aquifers is that it can be stored for years, with little or no evaporation loss for use in drought years as a supplementary source of water supply. It also has the advantage that storage can be near or directly under the point of use and is immediately available through wells and pumps on demand.

**References**


Bazuhair, A., S., Nassief, M. O., Al-Yamani, M. S., Sharaf, M. A., Bayumi, T. H., Ali, S. (2002). Groundwater recharges estimation in some wadi aquifers of the western Saudi Arabia. King Abdulaziz City for Science and Technology; Project No. AT-17-63, Riyadh, Saudi Arabia. p. 389.

Subyani, A., and Şen, Z., 2004. Refined chlorine mass balance method and its application in Saudi Arabia. Journal of Hydrology (Submitted for possible publication)

Eckhardt, K, and Ulbrich, U. (2003). Potential impacts of climate change on groundwater recharge and streamflow in a central European low mountain range Journal of Hydrology 284, 244-252.

Al-Sefry, S., Şen, Z., Al-Ghamdi, S. A., Al-Ashi, W., and Al-Baradi, W., (2004). Strategic ground water storage of Wadi Fatimah – Makkah region Saudi Arabia. Saudi Geological Survey, Hydrogeology Project Team, Final Report.

Simmers, I. (1990) Aridity, groundwater recharge and water resources management. In: Lerner, D.N., Issar, A.S., Simmers I., (eds.) Groundwater Recharge: a guide to understanding and estimating natural recharge. International Association of Hydrogeologists (IAH) Publication, International Contribution to Hydrogeology: Vol. 8, 1-20.

# SU VAKFI İKLİM DEĞİŞİKLİĞİ KÜLLİYESİNDE DAHA ÖNCE YAYINLANAN BÜLTENLER

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|---|---|
| SAYI 3<br>2017 Şubat (February)<br>TÜRKÇE | İklim Değişikliğinin Su Kaynaklarına Etkileri<br>*Zekâi ŞEN* |
| SAYI 2<br>2017 Ocak (January)<br>TÜRKÇE | İklim Değişikliğinin Türkiye Su Kaynaklarına Etkisi<br>*Zekâi ŞEN ve Ahmet ÖZTOPAL* |
| SAYI 1<br>2016 Aralık (December)<br>TÜRKÇE | Atmosferdeki $CO_2$ Seviyesi 400 ppm'i Aştı<br>*Ahmet ÖZTOPAL* |

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