International Research Journal of Environment Sciences ISSN 2319–1414
Vol. **4(3),** 86-92, March **(2015)** *Int. Res. J. Environment Sci.*

Review Paper

Impact of Climate Change on Groundwater Resources

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Available online at: www.isca.in, www.isca.me
Received 29th December 2014, revised 5th February 2015, accepted 15th March 2015

Abstract

Water is crucial for life, but its accessibility at a sustainable quality and quantity is endangered by many factors, of which climate plays a leading role. Climate change may affect both the long-term availability and the short-term variability of water resources in many regions. Climate change will change the world of the present situation of the hydrologic cycle, and cause the re-distribution of water resources in time and space. Changes in global climate are expected to affect the hydrological cycle, altering surface-water levels and groundwater recharge to aquifers with various other associated impacts on natural ecosystems and human activities. It also will have a direct effect on the evaporation, runoff, and the soil humidity and so on. The impacts of climate change are also likely to be more profound for unconfined aquifer systems, which may respond rapidly to changes in the recharge regime? The redistribution and changes of water resources in space will cause the human society and ecology change a lot. Increases in runoff, flooding, or sea level rise can reduce the quality of water and can harm aquatic organisms that live in cold-water habitats. This paper presents the likely impact of climate change on groundwater resources, climate change scenario for groundwater, status of research studies carried out, and hydrological variability of groundwater resources.

Keywords: Hydrological cycle, recharge, temperature, precipitation, quality and quantity.

Introduction

Water is crucial for life, but its accessibility at a sustainable quality and quantity is endangered by many factors, of which climate plays a leading role. The Intergovernmental Panel on Climate Change (IPCC) defines climate as "the average weather in terms of the mean and its variability over a certain time-span and a certain area" and a statistically significant variation of the mean state of the climate or of its variability lasting for decades or longer, is referred to as climate change. Within the climate change matrix, water resources are at the epicenter of projected climate change impacts. If the observed changes in climate in the last century (IPCC, 2007) persist into the future, the potential impacts on water resources are likely to increase in magnitude, diversity and severity. Climate change can have profound effects on the hydrologic cycle through precipitation, evapotranspiration, and soil moisture with increasing temperatures. Climate change will change the world of the present situation of the hydrologic cycle, and cause the redistribution of water resources in time and space. It also will have a direct effect on the evaporation, runoff, and the soil humidity and so on. Climate change impacts may add to existing pressure on groundwater resources by i. impeding recharge capacities in some areas; and ii. being called on to fill eventual gaps in surface water availability due to increased variability of precipitation. Climate will accelerate the hydrologic cycle, altering rainfall, magnitude and timing of run-off. Warm air holds more moisture and increase evaporation of surface moisture. With more moisture in the atmosphere, rainfall and snowfall events tend to be more intense, increasing the potential for floods. However, if there is little or no moisture in the soil to evaporate, the incident solar radiation goes into raising the temperature, which could contribute to longer and more severe droughts[1]. Groundwater resources in India have traditionally been assessed at the local scale through direct water table measurements[2,3]. Water resources will come under increasing pressure in the Indian subcontinent due to the changing climate. Presently, more than 45% of the average annual rainfall, including snowfall in the country, is wasted by natural runoff to the sea. Rainwater-harvesting schemes are now being implemented in the country to minimize this run-off loss based on present rainfall scenarios over the country, to increase groundwater levels[4]. Climate change is of most concern where aquifers are either heavily allocated or particularly vulnerable to changes in recharge. In these systems the reduction in water availability due to climate change may impact on groundwater use and entitlements. The impacts of climate change are also likely to be more profound for unconfined aquifer systems, which may respond rapidly to changes in the recharge regime. The redistribution and changes of water resources in space will cause the human society and ecology change a lot. At the same time, the water resources system changes will affect the local climate, and will exacerbate climate change in a certain extent. The WMO put forward some test and evaluation method and published the sensitivity analysis report that impact of climate change on hydrology and water resources[5]. Climate change impacts on water resources will have both direct and indirect effects on the socio-economic and the biophysical environments[6-10]. Already, this is evident in several sectors, such as agriculture[11,12] health[13,14] ecosystems and biodiversity[15] and energy generation[16]. While there are diverse views regarding the magnitude of change of climatic characteristics and the possible impacts at the scale at which land and water resources are managed, several researchers have however reported that there is certainty, that, climate change will impact on the availability and use of water resources[17-20].

Groundwater resource variability due to climate change

Both natural and anthropogenic factors control climate change. The role of man is always overemphasized because of the accelerated climatic effects in recent times. However, natural processes play a much bigger and significant role as has been observed during the entire lifespan of the Earth. Climate change affects the components of water cycle such as evaporation, precipitation and evapotranspiration and thus results in large -scale alteration in water present in glaciers, rivers, lakes, oceans, etc. The effects of climate change on subsurface water relates to the changes in its recharge and discharge rates plus changes in quantity and quality of water in aquifers. Climate change refers to the long-term changes in the components of climate such as temperature, precipitation, evapotranspiration, etc.

Effect of climate change on water quality

Most observed changes of water quality due to climate change (figure-1) are known from isolated studies, mostly of rivers or lakes in high-income countries, of a small number of variables. In addition, even though some studies extend over as many as 80 years, most are short-term. For lakes and reservoirs, the most frequently reported change is more intense eutrophication and algal blooms at higher temperatures, or shorter hydraulic retention times and higher nutrient loads resulting from increased storm runoff (high agreement, medium to robust evidence). Greater runoff results in greater loads of salts, faecal coliforms, pathogens and heavy metals[21-24] (medium to high agreement, robust evidence, depending on the pollutant). Increases in runoff, flooding, or sea level rise can reduce the quality of water and can damage the infrastructure that we use to treat, transport and deliver water. Warmer air temperatures can raise stream and lake temperatures, which can harm aquatic organisms that live in cold-water habitats, such as trout and salmon. Additionally, warmer water can increase the range of non-native fish species, permitting them to move into previously cold-water streams. The population of native fish species often decreases as non-native fish prey on and out-compete them for food. Water quality could also suffer in areas experiencing increases in rainfall. Increases in heavy precipitation events could cause problems for the water infrastructure, as sewer systems and water treatment plants are overwhelmed by the increased volumes of water. Heavy downpours can increase the amount of runoff into rivers and lakes, washing sediment, nutrients, pollutants, trash, animal waste, and other materials into water supplies and making them unusable, unsafe, or in need of increased water treatment. In addition, as more freshwater is removed from rivers for human use in coastal areas, saltwater may move farther upstream. Drought can also cause coastal water resources to become more saline as freshwater supplies from rivers are reduced. Water infrastructure in coastal cities, including sewer systems and wastewater treatment facilities, faces risks from rising sea levels and the damaging impacts of storm surges.

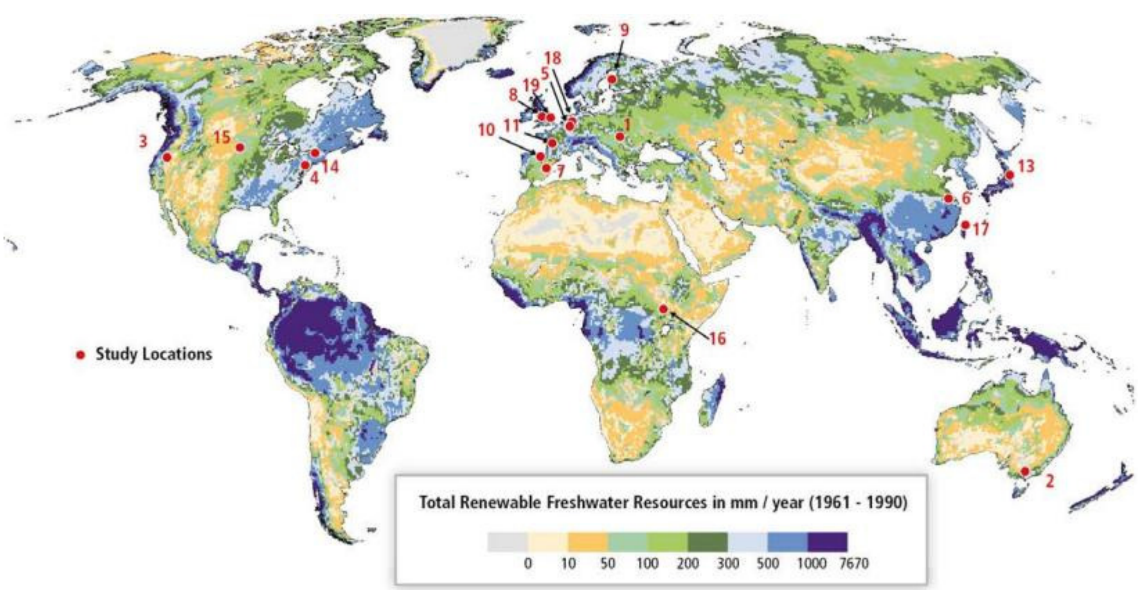

Figure-1
Observations of the impacts of climate on water quality

Effect of climate change on groundwater recharge

Groundwater recharge can occur locally from surface water bodies or in diffuse form from precipitation via the unsaturated soil zone[25]. Precipitation is the primary climatic driver for groundwater recharge. Temperature and CO_2 concentrations are also important since they affect evapotranspiration and thus the portion of precipitation that may drain through the soil profile to aquifers. Other factors affecting groundwater recharge include land cover, soils, geology, topographic relief and aquifer type. Changes in the magnitude of groundwater recharge will not always be in the same direction as precipitation changes. Recharge is not only influenced by the magnitude of precipitation, but also by its intensity, seasonality, frequency, and types other factors, for example changes in soil properties or vegetation type and water use can also affect recharge rates[26] concluded that changes to groundwater recharge rates were highly dependent on the geological setting of the area. During high intensity rainfall events the infiltration capacity of soils may quickly be exceeded, resulting in increased runoff and stream flow with less rain infiltrating to groundwater[27]. Precipitation changes during the major recharge season are likely to be more significant than annual changes. Yet this will also be influenced by antecedent conditions on a seasonal and inter-annual scale. More frequent droughts or reduced rainfall during summer months can result in larger soil moisture deficits, and consequently recharge periods may be shortened. This may be exacerbated by increased temperatures and evapotranspiration, although the effects of climate change on transpiration from vegetation is uncertain. In high latitude regions, recharge may occur earlier as warmer winter temperatures shift the spring melt from spring toward winter. Where permafrost thaws due to increased temperatures, increased recharge is likely to occur[28]. The effects of climate change on groundwater recharge in the Gnangara Mound, Western Australia, by modeling the impacts of increased atmospheric concentrations of CO_2 on rainfall and potential evapotranspiration regimes. They found that the magnitude and even the direction of change in recharge depends on the local soil, vegetation and climatic region and that ratios of the change in recharge to change in rainfall ranged from – 0.8 to 0.6. Aquifers have the capacity to store large volumes of water and are naturally buffered against seasonal changes in temperature and rainfall. They provide a significant opportunity to store excess water during high rainfall periods, to reduce evaporative losses and to protect water quality.

Potential impacts due to change of temperature and precipitation

Spatial and temporal changes in temperature and precipitation may modify the surface hydraulic boundary conditions of, and ultimately cause a shift in the water balance of an aquifer. Variations in the amount of precipitation, the timing of precipitation events, and the form of precipitation are all key factors in determining the amount and timing of recharge to aquifers. In Central Asia, output from coupled atmosphere-sea surface global circulation model for the period 2080-2100 shows a rise in temperature of 3.5−4.5^{o}C and a decrease in precipitation. For South Asia, 2.5−3.5^{o}C increase of temperature and an increase in precipitation are projected. Changes in the amount of precipitation are expected to decrease mean runoff by 1 mm/day in Central Asia and to increase mean runoff by a similar amount in South Asia. Due to the change in the variability of precipitation, surface water resources are likely to become more unreliable, thus precipitating a shift to development of more “reliable” groundwater resources, as has been observed in Taiwan[29]. The changing frequency of droughts or heavy precipitation can also be expected to impact on water levels in aquifers. Droughts result in declining water levels not only because of reduction in rainfall, but also due to increased evaporation and a reduction in infiltration that may accompany the development of dry top soils. Paradoxically, extreme precipitation events may lead to less recharge to groundwater in upland areas because more of the precipitation is lost as runoff. Similarly, flood magnitude and frequency could increase as a consequence of increased frequency of heavy precipitation events, which could increase groundwater recharge in some floodplains.

Effect of climate change on Soil Erosion and Sediment Load

Precipitation extremes in many regions have increased since 1950[30], which suggests an increase in rainfall erosivity that would enhance soil erosion and stream sediment loads. A warmer climate may affect soil moisture, litter cover and biomass production, and can bring about a shift in winter precipitation from snow to more erosive rainfall[31] or, in semiarid regions, an increase in wildfires with subsequent rainfall leading to intense erosive events[32,33]. The effects of climate change on soil erosion and sediment load are frequently obscured by human agricultural and management activities[34]. Only few studies have isolated the contribution of climate change to observed trends in soil erosion and sediment load. In the Yellow River basin, where soil erosion results mostly from heavy rainfall, reduced precipitation (~10%) contributed about 30% to a total reduction in stream sediment loads reaching the sea during 2000-2005, compared to 1950-1968, with the remaining 70% attributable to sediment trapping in reservoirs and soil conservation measures[35,36]. Dai et al. 2008[37], analyzing the decrease in sediment load of the Yangtze River over 1956-2002, found that climate change was responsible for an increase of about 3±2%; most of the decline in its lower reaches was due to dam construction (Three Gorges Dam) and soil conservation measures. Potential impacts of climate change on soil erosion and sediment production are of concern in regions with pronounced glacier retreat[38]. Glacial rivers are expected to discharge more melt water, which may increase sediment loads. However, the limited evidence is inconclusive for a global diagnosis of sediment load changes; there are both decreasing and increasing trends[39]. So far, there is no clear evidence that the frequency or magnitude of shallow landslides have changed over past decades, even in regions with relatively complete event records[40]. Increased landslide impacts (measured by casualties or losses) in south and southeast Asia, where landslides are predominantly triggered by monsoon and tropical cyclone activity, are largely attributed to population growth leading to increased exposure[41].

Effect of climate change on Stream flow

Detected trends in stream flow are generally consistent with observed regional changes in precipitation and temperature since the 1950s (figure-2).

In Europe, stream flow (1962-2004) decreased in the south and east and generally increased elsewhere, particularly in northern latitudes[43]. In North America (1951-2002), increases were observed in the Mississippi basin and decreases in the US Pacific Northwest and southern Atlantic-Gulf regions[44]. In China, a decrease in stream flow in the Yellow River (1960-2000) is consistent with a reduction of 12% in summer and autumn precipitation, whereas the Yangtze shows a small increase in annual stream flow driven by an increase in monsoon rains. These and other stream flow trends must be interpreted with caution (because of confounding factors such as land-use changes[45], irrigation[46] and urbanization. In a global analysis of simulated stream flows (1948-2004), about one-third of the top 200 rivers (including the Congo, Mississippi, Yenisei, Paraná, Ganges, Columbia, Uruguay and Niger) showed significant trends in discharge; 45 recorded decreases and only 19 recorded increases. Decreasing trends in low and mid latitudes are consistent with recent drying and warming in West Africa, southern Europe, south and East Asia, eastern Australia, western Canada and the USA and northern South America. The contribution to observed stream flow changes due to decreased stomatal opening of many plant species at higher CO_2 concentration remains disputed (Box CC-VW). In regions with seasonal snow storage, warming since the 1970s has led to earlier spring discharge maxima (high agreement, robust evidence) and has increased winter flows because more winter precipitation falls as rain instead of snow[47,48]. There is robust evidence of earlier breakup of river ice in Arctic rivers. Where stream flow is lower in summer, decrease in snow storage has exacerbated summer dryness [49,50].

Conclusion

Climate change will change the world of the present situation of the hydrologic cycle, and cause the redistribution of water resources in time and space. Potential climate risks for groundwater include reduced groundwater recharge, sea water intrusion to coastal aquifers, and contraction of freshwater lenses on small islands, and increased demand. Groundwater resources have traditionally been assessed at the local scale through direct water table measurements Aquifers have the capacity to store large volumes of water and are naturally buffered against seasonal changes in temperature and rainfall. They provide a significant opportunity to store excess water during high rainfall periods, to reduce evaporative losses and to protect water quality. Increases in runoff, flooding, or sea level rise can reduce the quality of water and can damage the infrastructure that we use to treat, transport and deliver water. The changes to groundwater recharge rates were highly dependent on the geological setting of the area.

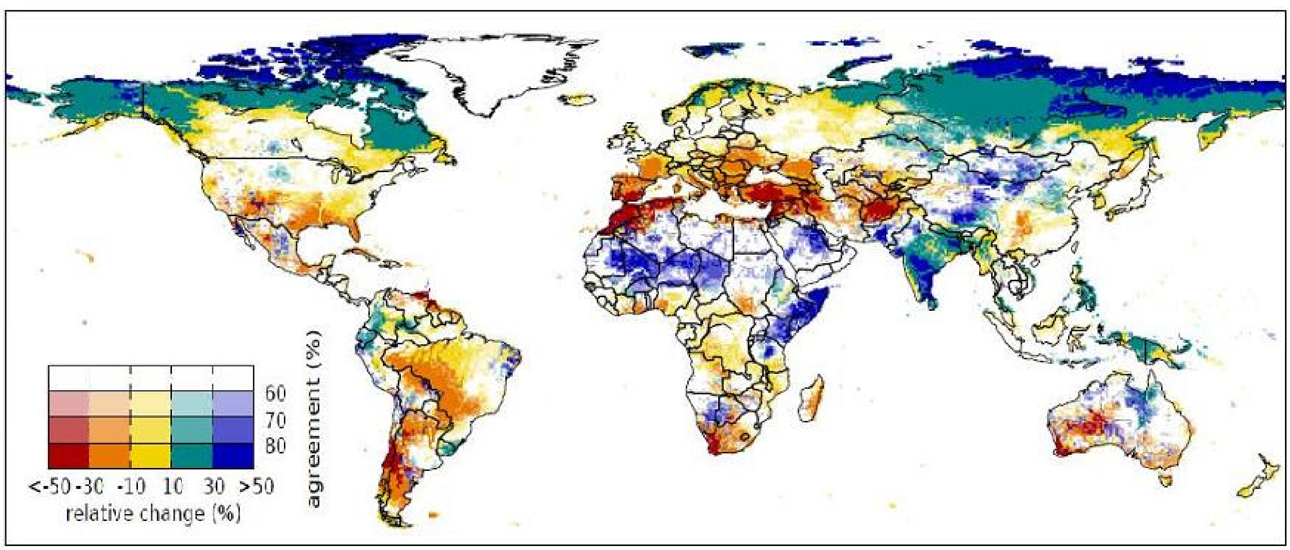

Figure-2
Percentage change of mean annual stream flow for a global mean temperature rise of 2°C above 1980–2010 (2.7°C above pre-industrial) Color hues show the multi-model mean change across 4 GCMs and 11 global hydrological models (GHMs), and saturation shows the agreement on the sign of change across all 55 GHM-GCM combinations (percentage of model runs agreeing on the sign of change)[42]

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