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Name of the Author:

Ashok Kumar Maurya

Research Scholar,

Centre for Studies in Economics and Planning,

School of Social Sciences,

Central University of Gujarat,

Gandhinagar-382 030, Gujarat, India

Mobile-09408640830

E-mail: mauryaashok82@gmail.com

CLIMATE CHANGE AND GROUNDWATER RESOURCES: ITS REASONS AND IMPACT

Abstract

Climate change is a burning issue of the earth at this time. Most of the developed and developing countries have faced numerous problems owing to changing climate scenario in form of temperature fluctuations, uncertain rainfall etc. These changes are affecting directly and indirectly on surface water as well as groundwater. Groundwater resources provide fresh drinking water to nearly half the world's population and worldwide 70 percent groundwater recourses use for the agriculture purpose. Despite their significance, global groundwater resources are vulnerable to human activities and the uncertain and unsustainable consequences of climate change. Climate unpredictability and alter is expected to affect the hydrological cycle. Research has largely focused on the responses in surface water due to climate change but very few is known about the effect of anti constructive climatic factors on groundwater resources and its cascading effects on the current availability and future sustainability of groundwater resources. Groundwater recharge, discharge, storage, saltwater intrusion and transport may be tailored by climate change. Groundwater resources are related to climate change through the direct interaction with surface water resources, such as the storage of surface water like lakes and rivers, and indirectly the effects of climate change on groundwater resources depends upon the change in the volume and distribution of groundwater recharge. Therefore, conclusive the impact of climate change is a long term and indirect changeable process for groundwater resources but in future it will be emerge as an enormous problem for human being as well as other live beings. This paper presents the impact of climate change on groundwater resources in global scenario and analyse the environmental factors those promoting the negative impacts on groundwater resources, status of research studies carried out at national and international level, and methodology to assess the impact of climate change on groundwater resources.

Keywords: *Climate Change, Groundwater, Groundwater Recharge, Environmental Factors, Sustainability*

“Groundwater is the major source of water across much of the world, particularly in rural areas in arid and semi-arid regions, but there has been very little research on the potential effects of climate change.” (IPCC 2001, p. 199)

INTRODUCTION

Water is giver of life, but its availability at a sustainable quality and quantity in form of surface water and groundwater is endangered by many factors like scarcity, pollution, contamination of which climate plays a leading role. Climate is the average weather in a place over many years and it is the pattern of difference in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region but climate takes hundreds, thousands, even millions of years to change means it is a long term process of atmosphere. Changes in future climate will alter regional hydrologic cycles and subsequently impact the quantity and quality of regional water resources (Gleick, 1989). According to Preliminary Consolidated Report on Effect of Climate Change on Water Resources (2007) no distinction has been made between climate change induced because of human activities or natural variability. Some natural factors are changes in the Sun’s intensity; the Earth’s orbit; Ocean circulation; volcanic eruptions etc. Similarly, Human Factors include changes in the land use pattern, burning fossil fuel and release of GHG. The Intergovernmental Panel on Climate Change (IPCC) defines climate change broadly as “any change in climate over time whether due to natural variability or as a result of human activity.”United Nation’s Framework Convention on Climate Change (UNFCCC) defines climate change as “a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere, and that is in addition to natural climate variability over comparable time periods”. BACC has decided to essentially follow the IPCC-definition, and to add explicitly “anthropogenic” to the term “climate change” when human causes are attributable, and to refer to “climate variability” when referring to variations not related to anthropogenic influences. Climate change can have profound effects on the hydrologic cycle through precipitation, evapotranspiration, and soil moisture with increasing temperatures. The hydrologic cycle will be intensified with more evaporation and more precipitation. However, the extra precipitation will be unequally distributed around the globe. Some parts of the world may see significant reductions in precipitation or major alterations in the timing of wet and dry seasons. Information on the local or regional impacts of climate change on hydrological processes and water resources is becoming more important. The effects of global warming and climatic change require multi-disciplinary research, especially when considering hydrology and global water resources (Singh & Kumar, 2010). Arguably, these processes are very difficult to quantify since they are dependent on a multitude of climatic parameters, such as intensity and duration of rainfall, temperature, and wind speed, as well as the physical characteristics of the individual plants (Larcher, 1983).

NIH (National Institute of Hydrology) analyzes the trends of variation in temperature over India/Indian Sub-continent and the results have been compared with global trend. An analysis of temperature data of 125 stations distributed all over India shows an increase of 0.420 ^{o}C, 0.920 ^{o}C and 0.090 ^{o}C in annual mean temperature, mean maximum temperature and mean minimum temperature respectively over the last 100 years. However, the trends are varying on regional basis. It has been observed that the changes in temperature in India/Indian- Subcontinent over last century are broadly consistent with global trend of increase in temperature. The Intergovernmental Panel on Climate Change (IPCC) estimates that the global mean surface temperature has increased 0.6 ± 0.2 ^{o}C since 1861, and predicts an increase of 2 to 4 ^{o}C over the next 100 years. Global sea levels have risen between 10 and 25 cm since the late 19th century. As a direct consequence of warmer temperatures, the hydrologic cycle will undergo significant impact with accompanying changes in the rates of precipitation and evaporation. Predictions include higher incidences of severe weather events, a higher likelihood of flooding, and more droughts. The impact would be particularly severe in the tropical areas, which mainly consist of developing countries, including India.

Groundwater is a key resource for human development

On a global scale, one third of the population depends on groundwater for their drinking water, in urban as well as rural areas. Groundwater also plays a pivotal role in agriculture, and an increasing portion of groundwater extracted is used for irrigated agriculture. It is estimated that at least 40 percent of the world's food is produced by groundwater-irrigated farming, both in low-income as well as high-income countries. In arid and semi-arid areas, the dependency on groundwater for water supply is between 60 and 100 percent. Therefore, the aim of halving the number of people without sustainable access to safe drinking water and basic sanitation

(Millennium Development Goal, MDG 7) depends very much on how groundwater resources are developed and managed.

CLIMATE CHANGE FACTORS IN INDIA

In India several studies have been carried out to determine the changes in temperature and rainfall and its association with climate change. However, investigators used different data length and now studies have been reported using more than a century data. All such studies have shown warming trend on the country scale. Estimates of temperature anomaly were better estimated using long-term series data. Pant and Kumar (1997) analysis the seasonal and annual air temperatures from 1881 to 1997 and it shows that there has been an increasing trend of mean annual temperature by the rate of 0.57 ^{o}C per 100 years. The trend and magnitude of global warming over India over last century has been observed to be broadly consistent with the global trend and magnitude. In India, warming is found to be mainly contributed by the post-monsoon and winter seasons. The monsoon temperatures do not show a significant trend in any part of country except for significant negative trend over Northwest India.

Future scenario of temperature

Future warming scenarios have been generated for the Indian sub-continent using GCM. Lal (2001) developed climate change scenarios over Indian sub-continent under the four SRES based on the data generated in numerical experiments with Atmosphere and Ocean coupled GCM (A-O GCM) of the CCSR/NIES, Japan to predict changes in temperature and temporal and spatial variability of the monsoon rainfall. It is projected that over the inland regions of the Indian sub-continent, the mean surface temperature may rise between 3.5 ^{o}C and 5.5 ^{o}C by 2080. On seasonal basis, the projected surface warming is higher in winter than during summer monsoon. The spatial pattern of temperature change has a large seasonal dependency. The spatial distribution of surface warming suggests that north India may experience an annual mean surface warming of 3 ^{o}C or more by 2050s. GCM models have simulated peak warming of 3 ^{o}C over north and central India in winter. Over much of the southern peninsula, the warming is likely to be under 2 ^{o}C during winter season. The surface temperature rise would be more pronounced over northern and eastern region (~2 ^{o}C) during the monsoon season. Future projection of increase in temperature and changes in precipitation over Indian subcontinent are shown in below table.

Climate Change projections for the Indian sub-continent

Scenario		Increase in temperature (^oC)	Change in Rainfall (%)
2020s	Annual	1.00-1.41	2.16-5.97
	Winter	1.08-1.54	(-) 1.95-4.36
	Monsoon	0.87-1.17	1.81-5.10
2050s	Annual	2.23-2.27	5.36-9.34
	Winter	2.54-3.18	(-) 9.22-3.82
	Monsoon	1.81-2.37	7.18-10.52
2080s	Annual	3.53-5.55	7.48-9.90
	Winter	4.14-6.31	(-) 24.83-4.50
	Monsoon	2.91-4.62	10.10-15.18

Sources- Lal et al. (2001)

Future scenario of rainfall

The projected scenarios for rainfall over Indian subcontinent for different seasons by 2020, 2050 and 2080 are given in above table. The increase in annual mean precipitation over the Indian sub-continent is projected to be 7 to 10 percent by 2080s. Winter precipitation may decrease by 5 to 25 percent in the Indian sub-continent. An increase of 10 to 15 percent is projected in are average summer monsoon rainfall over the Indian sub-continent. Over northwest India, during monsoon season an increase of about 30 percent or more is suggested by 2050s. The western semi-arid margins of India could receive higher than normal rainfall in the warmer atmosphere. It is likely that date of onset of summer monsoon over India could become more variable in future.

IPCC (2001) has indicated that variability in Asian summer monsoon is expected to increase along with changes in the frequency and intensity of extreme climate events in this region. All climate models simulate an enhanced hydrological cycle and increases in annual mean rainfall over South Asia (under non-aerosol forcing). Impact of climate change on the ground water regime is expected to be harsh. Groundwater is the main source of drinking water in the rural areas. About 85 percent of the rural water supply in India is dependent on groundwater. India on the whole has a potential of 45.22 Mha-m/year of replenish able groundwater, unfortunately, due to rampant drawing of the subsurface water, the water table in many regions of the country has dropped significantly in the recent years resulting in threat to groundwater sustainability like contamination and depletion. These regions mainly correspond to the states of Gujarat, Punjab, Haryana, Tamil Nadu and Rajasthan that have registered groundwater development above the national average. The situation in Gujarat is critical and water table in Ahmedabad is reported to be going down at the rate of 4 to 5 meters every year. In some localities of Delhi, the water table has fallen by over 10 meters. Even in Kerala, where the intensity of monsoon rain is heavy, water table has been falling systematically in all parts of the State. The most optimistic assumption suggests that an average drop in groundwater level by one meter would increase India's total carbon emissions by over one percent, because the time of withdrawal of the same amount of water will increase fuel consumption. A more realistic assumption reflecting the area projected to be irrigated by groundwater, suggests that the increase in carbon emission could be 4.8 percent for each meter drop in groundwater levels (Mall *et al.*, 2006). It is recommended to study the aquifer geometry, establish the saline fresh interfaces within few km of the coastal area, the effect of glaciers melting on recharge potential of aquifers in the Ganga basin and its effects on the trans-boundary aquifer systems, particularly in the arid and semi-arid regions.

Climate change is likely to affect ground water due to changes in precipitation and groundwater extraction. Rising sea levels may lead to increased saline interruption into coastal and island aquifers, while increased frequency and severity of floods may affect groundwater quality in alluvial aquifers. Sea-level rise leads to intrusion of saline water into the fresh groundwater in coastal aquifers and thus adversely affects groundwater resources. For two small and flat coral islands at the coast of India, the thickness of freshwater lens was computed to decrease from 25 m to 10 m and from 36 m to 28 m, respectively, for a sea level rise of only 0.1 m (Mall *et al.,* 2006).

Increased amount of rainfall in short heavy spells will lead to low access thereby causing low moisture availability for soil. Furthermore, water management systems in the area like number of reservoirs; boreholes etc. would also modify the water availability. Global warming will also affect the water supply by changes in evaporation and ground water recharge. Finally through sea level rise, the global warming may contribute saline intrusion. Agricultural demand, particularly for irrigation water, which is a major share of total water demand of the country, is considered more sensitive to climate change. A change in field-level climate may change the need and timing of irrigation. Increased dryness may lead to increased demand, but demand could be reduced if soil moisture content rises at critical times of the year. It is projected that most irrigated areas in India would require more water around 2025 and global net irrigation requirements would increase relative to the situation without climate change by 3.5–5 percent by 2025 and 6–8 percent by 2075. In India, roughly 52 percent of irrigation consumption across the country is extracted from groundwater; therefore, it can be an alarming situation with decline in groundwater and increase in irrigation requirements due to climate change. 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. Therefore, change in climate will affect the soil moisture, groundwater recharge and frequency of flood or drought episodes and finally groundwater level in different areas. In a number of studies, it is projected that increasing temperature and decline in rainfall may reduce net recharge and affect groundwater levels. However, little work has been done on hydrological impacts of possible climate change for Indian regions or basins.

In the era of economic development scenarios projected total power generation capacity in India to increase nine times from 96 GW to 912 GW between 1995-2100. As a result of climate change, it is estimated that approximately 1.5 percent more power generation capacity will be required. Additional energy demand may arise from a number of sources like increases in average temperature can result in the need for space cooling for buildings, and variability in precipitation can impact irrigation needs and consequent demand for energy from groundwater pumping. Another side it will promote the more energy production and also create the climate change situation.

IMPACT OF CLIMATE CHANGE ON GROUNDWATER RESOURCES

The relationship between climate change and groundwater resources is not straight. Groundwater will be less directly and more slowly impacted by climate change, as compared to surface water. Because of surface water (rivers, lakes, etc) get replenished on a shorter time scale, and drought and floods are quickly reflected on ground levels but not in underground level. Rosenberg *et al*. (1999) studied the impact of climate change on the water yield and groundwater recharge of the Ogallala aquifer in the central United States. Three different GCMs were used to predict changes in the future climate due to anticipated changes in temperature and CO_2 concentrations. The study found that recharge was reduced under all scenarios, ranging up to 77 percent, depending on the simulation conditions. Groundwater, on the other hand, will be affected much slower. Only after prolonged droughts groundwater levels will show declining trends. This is also why increased groundwater pumping can for a limited time span serve as contingency supply scenario in order to mitigate water shortages during droughts when water courses have run dry. Large variations in recharge can also occur, even across uniform soils, due to topography, resulting in depression-focused recharge (e.g. Freeze and Banner, 1970; Schuh *et al*., 1993). Groundwater levels of many aquifers around the world show a decreasing trend, but this is generally due to groundwater pumping exceeding groundwater recharge rate, and not to a climate-related decrease in groundwater recharge but in future it may be happened that due to climatic factor like uncertain or less rainfall can increases groundwater exploitation in agriculture sector. A smaller amount of rainfall may decrease groundwater recharge in humid areas because more frequent heavy rain will result in the access capacity of the soil being exceeded, thereby increasing surface runoff. In semi-arid and arid areas, however, increased rainfall variability may increase groundwater recharge, because only high-intensity rainfalls are able to infiltrate fast enough before evaporating, and alluvial aquifers are recharged mainly by inundations during floods. Global warming as part of climate change will affect groundwater indirectly. Higher temperature will mean higher evaporation and plant transpiration rates and hence more drying up to soils. This will entail higher losses of soil moisture and groundwater recharge and greater exposure to desertification and soil erosion in already hot and arid areas; these are all negative impacts for the integrity of groundwater storage systems.

Temperature drives the hydrological cycle, influencing hydrological processes in a direct or indirect way. A warmer climate may lead to intensification of the hydrological cycle, resulting in higher rates of evaporation and increase of liquid precipitation. These processes, in association with a shifting pattern of precipitation, may affect the spatial and temporal distribution of runoff, soil moisture, groundwater reserves etc. and may increase the frequency of droughts and floods (Deng *et al*., 1994).

According to 2007-08 developmental report UNDP has highlighted the effect of climate change on different regions of the world covering all the aspects including water availability, rising sea level, flooding, biodiversity, human health, etc. The report has indicated that seven of Asia’s great river systems will experience an increase in flow over the short term, followed by decline due to reduction in the glacier melt. The specific reference with respect to Indian rivers is given below:

1. The flow of the Indus, which receives nearly 90% of its water from upper mountain catchments, could decline by as much as 70 percent by 2080.
2. The Ganges could lose two-thirds of its July–September flow, causing water shortages for over 500 million people and one-third of India's irrigated land area.
3. Projections for the Brahmaputra point to reduced flows of between 14 & 20 percent by 2050.

The Report states that climate change scenarios for glacial melting will interact with ecological problems and put pressure on water resources. In India, competition between industry and agriculture is creating tensions over the allocation of water among States and reduced glacial flows will make stronger those tensions.

In the Report of the World Bank on India's Water Economy Bracing for a Turbulent Future by John Briscoe, it has been affirmed that there are strong indications that climate change is likely to affect India in a number of ways. There is little uncertainty about some of these impacts. As global temperatures continue to rise, this will affect that "water banks" (glaciers) which are a prominent part of the Himalayan water system. While there is clear evidence of de-glaciations across the whole of the Himalayas, the effect on river flows is likely to be substantially different in different areas. Climate change is likely to substantially increase overall monsoonal rainfall in India, but this is likely to be poorly distributed in the sense that much of the additional rainfall will probably be high-intensity storm events. While the exact shape of the future climate regime is uncertain, it is very likely that there will be greater variability -both of droughts and floods.

Stage of Groundwater Development

In India, the `average stage of groundwater development is 58 percent and it is comparatively more critical in Delhi, Haryana, Punjab and Rajasthan, where the stage of groundwater development is more than 100 percent, which implies that in the these states, the average annual groundwater consumption is more than average annual groundwater recharge. In Gujarat, Karnataka, Tamil Nadu and Uttar Pradesh, the average stage of ground development is 70 percent and above. Growing demand of water in agriculture, industrial and domestic sectors, has brought problems of over-exploitation of the groundwater resource, continuously declining groundwater levels, sea water ingress in coastal areas, and groundwater pollution in different parts of the country. The falling groundwater levels in various parts of the country have threatened the sustainability of the ground-water resource, as water levels have gone deep beyond the economic lifts of pumping. With rapid expansion in groundwater extraction, development-related problems have started emerging. Substantial decline of groundwater levels occurs even in blocks with sufficient groundwater resources due to climatic vicissitudes and localized development.

CONCLUSION

Temperature and rainfall two basic of factors are responsible for the climate change especially for groundwater resources. Although the problem of climate change has been widely recognized but the researches of the impacts of climate change on the groundwater resources is comparatively inadequate. The reason is that for research long historical data are required to analyze the characteristics of climate change but these data are not available and estimated. When we compared of surface water to groundwater then found that groundwater is much more compatible with a highly uneven and changing climate. Aquifers have the capacity to store large volumes of groundwater 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. The negative externalities of climate change on groundwater are taking a major concern among environmentalist and due to this the balance of groundwater development is shifting to the negative side. Although many other factors are also responsible for crisis in groundwater resources but climate change is one of them and encouraging in form of groundwater degradation.

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