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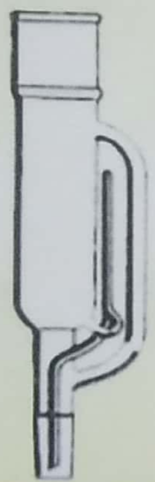

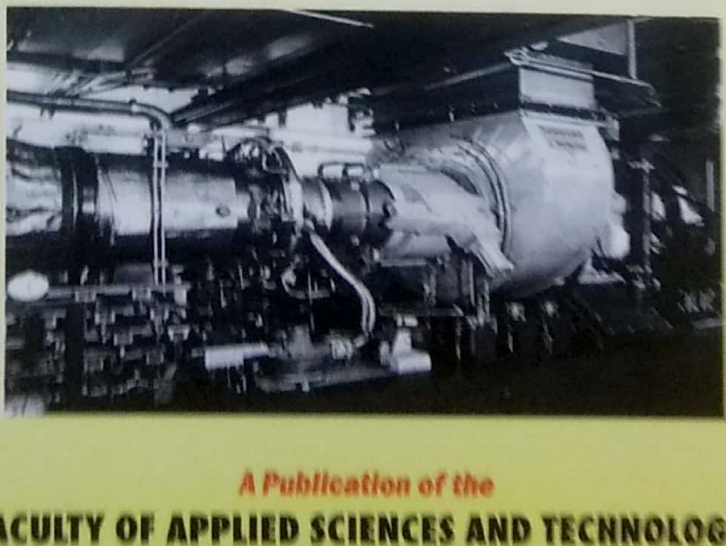

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ASSESSING THE ROLE OF CLIMATE ON WATER RESOURCES DEVELOPMENT

Y. M. Suleiman (Ph.D)[1], A. A. Nagya[2], H. M. Limam[3] and K. Dangana[3]

[1]Department of Geography, Federal University of Technology, Minna, Nigeria
[2]Department of Urban and Regional Planning, Niger State Polytechnic, Zungeru, Nigeria
[3]Department of Geography, Ibrahim Badamasi Babangida University, Lapai, Nigeria
Email: Suleimanym2u@yahoo.co.uk

Abstract
Many water supply sources (rivers, lakes, groundwater, basins, etc) are already over allocated, suffered degraded water quality and are often not in sufficient conditions to support endangered species. Climate change will exacerbate these water challenges; leading to insufficient water for people and the environment and making it increasingly difficulty to meet the needs of both. Implementing actions now to improve water quality and supplies, protect aquatic ecosystems and improve flood management not only make sense, but early will also help reduce future impacts related to climate change. Even if greenhouse gas emissions are reduced today, there is already warming "in the pipeline" that will create additional impacts. Adaptation is not a solution to climate change, however, given the importance of water resources, immediate action is needed to avert significant societal impacts. Reducing the emissions that cause climate change is critical step to be taken and water resource managers and policy makers must act now to adapt to the effects of warming that have already occurred or are unavoidable.

Keywords: Climate change, Water resources, Environment, Adaptation, Hydrological cycle

1.0. Introduction

The importance of water particularly fresh water to our life support system is widely recognized, as can be seen clearly in the international context (e.g Agenda 21, World Water Fora, The Millennium Ecosystem Assessment and the World Water Development Report). Fresh water is indispensable for all forms of life and is needed, in large quantities, in almost all human activities. Climate, freshwater, biophysical and socio-economic systems are interconnected in complex ways, so a change in any one of these induces a change in another. Anthropogenic climate change adds a major pressure to nations that are already confronting the issue of sustainable freshwater use. The challenges related to freshwater are having too much water, having too little water, and having too much pollution (Bates, et al., 2008). Each of these problems may be exacerbated by climate change. Freshwater related issues play a pivotal role among key regional and sectoral vulnerabilities. Therefore, the relationship between climate change and freshwater resources is of primary concern and interest.

1.1. Socio-Economic and Environmental Conditions

The relationship between climate change and freshwater do not exist in isolation, but in the context of and interacting with, socio-economic and environmental conditions (IPCC Assessment and Special Report, 2000). Many non-climatic drivers affect freshwater resources at all scales, including the global scale (UN, 2003). Water resources both interms of quantity and quality are critically influenced by human activity, including agriculture and land use change, construction and management of reservoirs, pollutant emissions and water and wastewater management. Water use is inked primarily to changes in population, food consumption (including type of diet) economic policy (including water pricing), technology, lifestyle and society's views about the value of freshwater ecosystems. In order to assess the relationship between climate change and freshwater, it is necessary to consider how freshwater has been, and will be, affected by changes in these non- climatic drivers (IPCC, 2007). In global scale assessments, basins are defined as being water stressed if they have either a per capita water availability below 1,000 m^3 per year (based on long term average annual runoff) or a ratio of withdrawals to long term average annual runoff above 0.4. A water volume of 1,00 m^3 per capita per year is typically more than is required for domestic, industrial and agricultural water uses, such water stressed basins are located in northern Africa, the Mediterranean region, the Middle East, the Near East, Southern Asia, Northern China, Australia, the USA, Mexico, north-eastern Brazil and west coast of South America. The estimates for the population living in such water stressed basins range between 1.4 billion and 2. 1 billion (Vorosmarty et al 2000; Alcamo el al, 2003 a, b; Oki el al; 2003; Amell, 2004).

Water use, in particular that for irrigation, generally increases with temperature and decreases with precipitation; however, there is no evidence for a climate-related long-term trend of water use in the past. This is due, in part, to the fact that water use is mainly driven by non-climatic factors, and is also due to the poor quality of water-use data in general, and of time-series data in particular. (IPCC, 2007a). Water availability from surface water sources or shallow groundwater wells depends on the seasonality and interannual variability of streamflow, and a secured water supply is determined by seasonal low flows. In snow-dominated basins, higher temperatures lead to reduced streamflow and thus decreased water supply in summer (Barnett et al., 2005). Water-stressed areas, people and ecosystems are particularly vulnerable to decreasing and more variable precipitation due to climate change. In most countries, except for a few industrialized nations, water use has increased over recent decades, due to population and economic growth, changes in lifestyle, and expanded water supply systems, with irrigation water use being by far the most important cause. Irrigation accounts for about 70% of total water withdrawals worldwide and for more than 90% of consumptive water use (i.e. the water volume that is not available for reuse downstream). (IPCC, 2007 a). Irrigation generates about 40% of total agricultural output (Fischer et al., 2006). The area of global irrigated land has increased approximately linearly since 1960, at a rate of roughly 2% per annum, from 140 million ha in 1961/63 to 270 million ha in 1997/99, representing about 18% of today's total cultivated land (Bruinsma, 2003).

Although the rates of regional population change differ widely from the global average, the rate of global population increase is already declining Global water use is probably increasing due to economic growth in developing countries. The quality of surface water and groundwater has generally declined in recent decades due principally to growth in agricultural and industrial activities (UN, 2006). To counter this problem, many countries (e.g, in the European Union and Canada) have established or enforced effluent water standards and have rehabilitated wastewater treatment facilities (GEO-3 2003).

2.0. Climate and the Climate System

Climate is usually defined as the average weather, or more rigorously, as the statistical description of the weather interms of the mean and variability of relevant quantities over periods of several decades (typically three decades as defined by WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. But in a wider sense the climate is the description of the state of the climate system.

The climate system consists of the following major components;
(a) the atmosphere; (b) the oceans; (c) the terrestrial and marine biosphere; (d) the cryosphere (sea ice, seasonal snow cover, mountain glaciers and continental scale ice sheets) and (e) the land surface. These components interact with each other, and through this collective interaction, determine the Earth's surface climate. These interactions occur through flows of energy in various forms, through exchanges of water, through flows of various other radiatively important trace gases, including CO_2 (carbon dioxide) and CH_4 (methane), and through cycling of nutrients. The climate system is powered by the input of solar energy, which is balanced by the emission of infrared ("heat") energy back to space. Solar energy is the ultimate driving force for the motion of the atmosphere and ocean, the fluxes of heat and water, and of biological activity.

The components of the climate system influence global and regional climate in a number of ways: (a) by influencing the composition of the Earths atmosphere thereby modulating the absorption and transmission of solar energy and the emission of infrared energy back to space; (b) through alterations in the surface properties and in the amount and nature of cloud cover, which have both regional and global effects on climate, and (c) by redistributing heat horizontally and vertically from one region to another through atmospheric motion and ocean currents. The climate system; in view of the interactions in not a stable system. It is highly variable. Climate variability therefore refers to variation of the Mean state of climate in all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes in the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). These variabilities as they persist over extended time periods results in climate change. Climate change as defined by the United Nations Framework Convention on Climate Change (UNFCC) in its Article 1, is a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. It has to do with shifts in the mean state of the climate in its variability, persisting for on extended persisting (decades or longer).

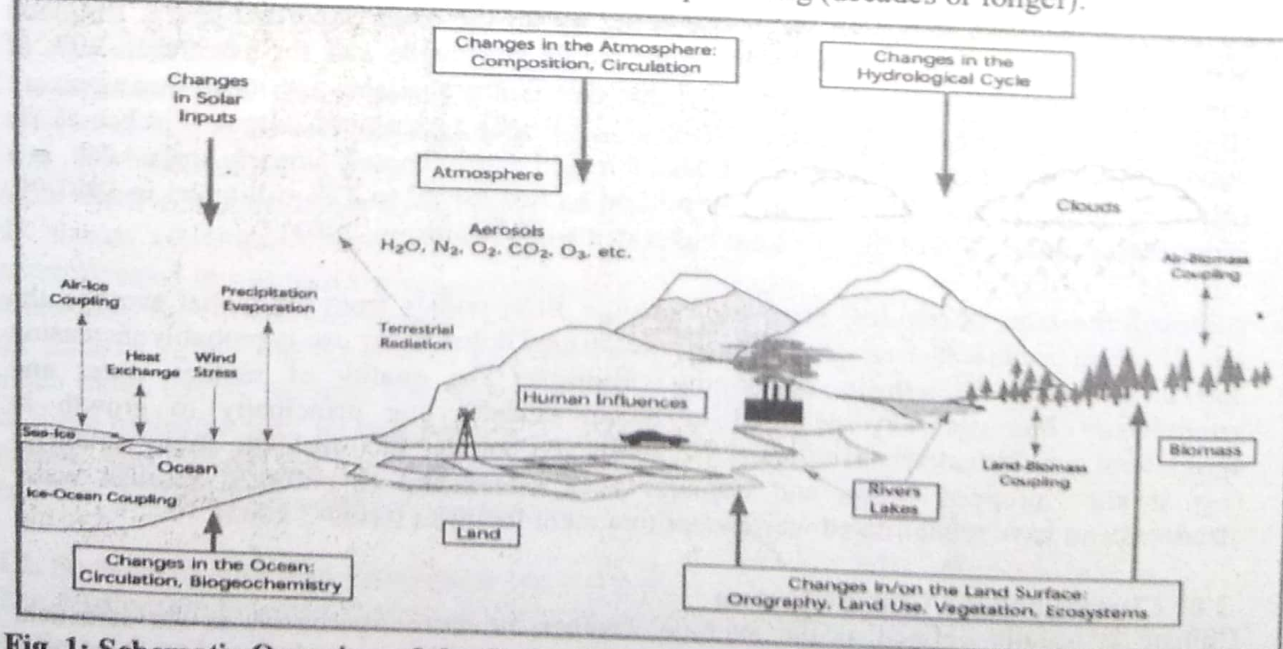

Fig. 1: Schematic Overview of the Components of the Global Climate System (Adapted from IPCC, 1996)

3.0. Water and Climate System

Whatever your view point – as a farmer or industrialist, producer or consumer of electricity, or as a scientist trying to understand the complexities of climate, the link between climate and water is very crucial. Floods and Droughts are climatic extremes and they must be catered for in planning and managing water resources, Any alteration to the intensity, frequency or location of foods and drought that may result from climate change can be expected to have serious consequences for many sectors of the economy. Water is one of the basic needs of human life as such rivers have been good places to locate towns and cities, as well as a source of water. Many of the great civilizations in the past have been centered on rivers such as the Indus, the Tigris and Euphrates and the Nile. Today many of the worlds important cities have grow up on the banks of major rivers. Worldwide it is estimated that there are some 80 countries, with 40% of total world population, which are experiencing water shortages in some regions or at certain times of the year. Nearly one billion people in the world are without clean drinking water and have to rely on whatever other kinds of water they can get, from rivers, lakes, ditches, and shallow wells. Many of these sources are frequently contaminated. While domestic demands for drinking and hygiene are set to increase as populations rise and become move concentrated in urban centers, so too are demands for industry and food processing sectors. Competitions between agriculture, industry and cities for limited water, supplies are already constraining development efforts in many countries. Water is involved in all components of the climate system (atmosphere, hydrosphere, cryosphere, land surface and biosphere). Therefore climate change affects water through a number of mechanisms. An understanding of the involvement of water in the component of the climate system rests upon a consideration of its place within the hydrological cycle, the circulation of water within the earth atmosphere system.

3.1 The hydrological cycle

The hydrological cycle is the full life history of water on earth. About 97.5% of all water on earth is in the oceans. The other 2.5% is fresh water. It in found in four main places: (a) In the ice sheets of the Artic, Antarctic and high mountain areas (solid state). (b) In the ground and soil, (c) In the rivers and lakes (liquid state), (d) As water vapour in the atmosphere (gaseous state). Water is constantly moving between these storage places. The water cycle, also known as the hydrological cycle therefore is defined as the continuous circulation of water from the sea, through the air, to the land and back to the sea. The process is elaborated below. Since the water cycle is truly a "cycle", there is no beginning or end. Water can change state among liquid, vapour, and ice at various places in the water cycle. Although the balance of water on Earth remains constant over time, individual water molecules can come and go. Water evaporates from oceans, lakes and rivers, and transpires from vegetation. In the atmosphere, water vapour condenses into clouds, which precipitate rain or snow, returning water to the land. While discussion of hydrologic cycle could begin at any point, a logical starting point is of a drop of water from the sea, through the cycle, and back to the sea. As it begins its travels, the drop of water leaves the ocean surface through evaporation, passing upward into the atmosphere as invisible water vapour. This process requires a large amount of heat energy, provided by incoming radiation from the sun.

Solar radiation provides practically all the heat energy at the earth's surface; because oceans occupy about 70% of the earth surface, they receive the majority of the sun's rays. In fact, an estimated 80% of the incident heat energy from the sun goes to heat the surface water and hence to cause evaporation from the sea. As it rises from the sea, the water vapour will be picked up in the global windstream that blows continuously around the earth. At some point, the vapuor-laden air may rise to a cooler region of the atmosphere where it can no longer retain its load of invisible water vapour, the vapour then gives up its latent heat of vaporization and revert to a liquid state through condensation. If the temperature is low enough, it will freeze and become an ice crystal. Tiny particles called condensation nuclei facilitate the process, providing a surface on which the liquid water may form. These ever-present nuclei may consist of tiny salt crystals (borne aloft by wind during evaporation process at sea), smoke or dust particles from the land. Even though our tiny drop of water is now visible, these drops in billions joined to form cloud. Droplets in clouds are so small that even though they have mass and are affected by gravity, the lightest breeze can keep them aloft indefinitely. To form rain or snow and fall as precipitation, many of these tiny drops must join to form drops of ice crystals large enough and heavy enough to fall from clouds. Once rain or snow begins to fall, the water enters the grip of earth's gravity, and except for a possible short circuit back to the atmosphere through evaporation, gravitational forces will largely govern it until its final return to the sea.

The little particle of water has several avenues to follow once it reaches the ground. It could land on a tree (a process called interception) and evaporate again to the atmosphere. It could drop on dry soil and go immediately into the ground in the process of infiltration. It could fall on a rock surface where it might begin to flow downhill towards a stream, initiating the process of Runoff. Water that falls into a running stream or on the land and immediately into the stream generally has a short journey back to the sea. Water that infiltrates the soil below the land surface, however, could go several ways. A plant could absorb it, carrying it upwards. Thus the plant tissue could incorporate it, or the water could pass through the leaves, returning to the atmosphere in the process of transpiration. Water falling on vegetated areas may be lost to the atmosphere through transpiration or through evaporation from soil surface. Since it is nearly impossible to separate these losses into two components, they are usually combined in one process called Evapotranspiration. Water escaping evaporation from the soil or transpiration from growing vegetation may eventually pass down through the unsaturated soil zone to water table, which is the top of the underground water. Below the water table, water completely saturates the pores of soil and rock. The little drop of water would now have joined the component of the water cycle known as Groundwater. Water seeping out of the ground into stream keeps most streams flowing between storms. In any case, the water is now in running stream and is finally on its way back to the sea. When it reaches its home in the sea, the cycle will be complete.

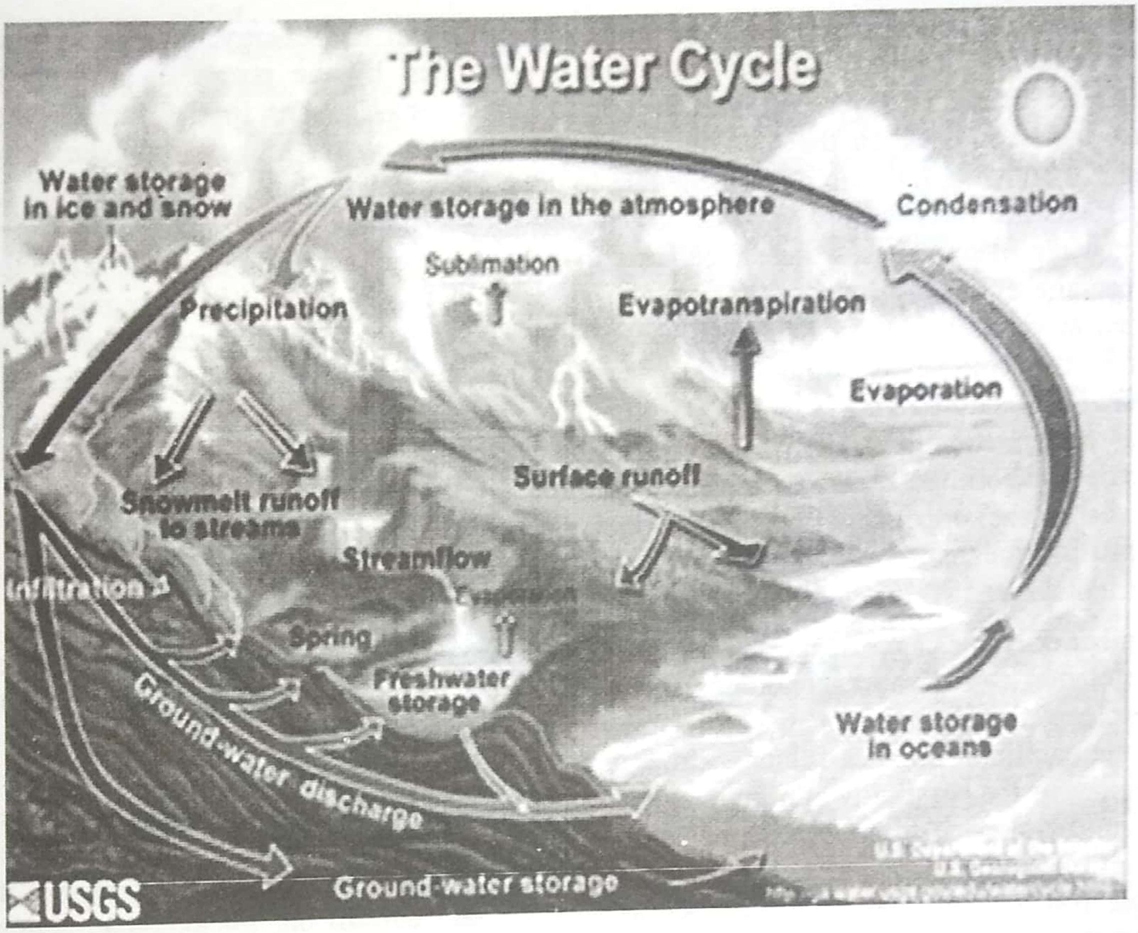

Fig. 2: The Hydrological Cycle (Adopted from http://en Wikipedia.org, 2010)

4.1. Observed Changes in Climate as they Relate to Water

The hydrological cycle is intimately linked with changes in atmospheric temperature and radiation balance. IPCC Report (2008) asserted that climate warming observed over the part several decades is consistently associated with changes in a number of components of the hydrological systems such as changing precipitation patterns, intensity and extremes, wide spread melting snow and ice; increasing atmospheric water vapour; increasing evaporation; and changes in soil moisture and runoff.

Theoretical and climate model studies suggest that, in a climate that is warming due to increasing greenhouse gases, a greater increase is expected in extreme precipitation, as compared to the mean. Hence, anthropogenic influence may be easier to detect in extreme precipitation than in the mean. This is because extreme precipitation is controlled by the availability of water vapour, while mean precipitation is controlled by the ability of the atmosphere to radiate long-wave energy (released as latent heat by condensation) to space, and the latter is restricted by increasing greenhouse gases.

Some robust correlations have been observed between temperature and precipitation in many regions. This provides evidence that processes controlling the hydrological cycle and temperature are closely coupled. At a global scale, changes in water vapour, clouds and ice change the radiation balance of the Earth and hence play a major role in determining the climate response to increasing greenhouse gases.

4.1 Land Surface Effects

Surface water balances reflect the availability of both water and energy. In regions where water availability is high, evapotranspiration is controlled by the properties of both the atmospheric boundary layer and surface vegetation cover. Changes in the surface water balance can feed back on the climate system by recycling water into the boundary layer (instead of allowing it to run off or penetrate to deep soil levels). The sign and magnitude of such effects are often highly variable, depending on the details of the local environment. Hence, while in some cases these feedbacks may be relatively small on a global scale, they may become extremely important at smaller space or time-scales, leading to regional/local changes in variability or extremes. (IPCC, 2000). The impacts of deforestation on climate illustrate this complexity. Some studies indicate that deforestation could lead to reduced daytime temperatures and increases in boundary layer cloud as a consequence of rising Aledo, transpiration and latent heat loss. However, these effects are dependent on the properties of both the replacement vegetation and the underlying soil/snow surface and in some cases the opposite effects have been suggested. The effects of deforestation on precipitation are likewise complex, with both negative and positive impacts being found, dependent on land surface and vegetation characteristics. . (IPCC, 2000).

A number of studies have suggested that, in semi-arid regions such as the Sahel, the presence of vegetation can enhance conditions for its own growth by recycling soil water into the atmosphere, from where it can be precipitated again. This can result in the possibility of multiple equilibria for such regions, either with or without precipitation and vegetation, and also suggests the possibility of abrupt regime transitions, as may have happened in the change from mid-Holocene to modern conditions. . (IPCC, 2000). Soil moisture is a source of thermal inertia due to its heat capacity and the latent heat required for evaporation. For this reason, soil moisture has been proposed as an important control on, for example, summer temperature and precipitation. Feed backs between soil moisture, precipitation and temperature are particularly important in transition regions between dry and humid areas, but the strength of the coupling between soil moisture and precipitation varies. A further control on precipitation arises through stomata closure in response to increasing atmospheric CO_2 concentrations. In addition to its tendency to increase runoff through large-scale decreases in total evapotranspiration this effect may result in substantial reductions in precipitation in some regions. (IPCC, 2000).

4.2. Droughts

The term drought may refer to a meteorological drought(precipitation well below average), hydrological drought(low river flows and low water levels in rivers, lakes and ground water), agricultural drought (low soil moisture), and environmental drought (a combination of the above). The socio economic impacts of droughts may arise from the interaction between natural conditions and human factors such as changes in land use, land cover, and the demand for and use of water. Excessive water withdrawals can exacerbate the impact of drought. Droughts have become more common, especially in the tropics and sub-tropics, since the 1970s. The IPCC (2000) concluded that it is likely that the area affected by drought has increased since the 1970s, and it is more likely than not that there is a human contribution to this trend. Decreased land precipitation and increased temperatures, which enhance evapotranspiration and reduce soil moisture, are important factors that have contributed to more regions experiencing droughts. (Dai et al., 2004b). The regions where droughts have occurred seem to be determined largely by changes in sea surface temperatures, especially in the tropics, through associated changes in the atmospheric circulation and precipitation. Droughts affect rain-fed agricultural production as well as water supply for domestic, industrial and agricultural purposes. Some semi-arid and sub-humid regions, e.g., Australia, Western USA and Southern Canada and the Sahel (Nicholson, 2005), have suffered from more intense and multi-annual droughts.

4.3. Groundwater

Climate change affects groundwater recharge rates (i.e., the renewable groundwater resources) and depths of groundwater tables. However, knowledge of current recharge and levels in both developed and developing countries is poor; and there has been very little research on the future impact of climate change on groundwater, or groundwater–surface water interactions. At high latitudes, thawing of permafrost causes changes in both the level and quality of groundwater, due to increased coupling with surface waters. (IPCC, 2001). As many groundwaters both change into and are recharged from surface water, impacts of surface water flow regimes are expected to affect groundwater. Increased precipitation variability may decrease groundwater recharge in humid areas because more frequent heavy precipitation events may result in the infiltration capacity of the soil being exceeded more often.

4.4. Freshwater Availability

With respect to water supply, it is very likely that the costs of climate change will outweigh the benefits globally. One reason is that precipitation variability is very likely to increase, and more frequent floods and droughts are anticipated. The risk of droughts in snowmelt-fed basins in the low-flow season will increase. The impacts of floods and droughts could be tempered by appropriate infrastructure investments and by changes in water and land-use management, but the implementation of such measures will entail costs (US Global Change Research Program, 2000). Water infrastructure, usage patterns and institutions have developed in the context of current conditions. Any substantial change in the frequency of floods and droughts, or in the quantity and quality or seasonal timing of water availability, will require adjustments that may be costly, not only in monetary terms but also in terms of societal and ecological impacts, including the need to manage potential conflicts between different interest groups (Miller et al., 1997).Hydrological changes may have impacts that are positive in some aspects and negative in others. For example, increased annual runoff may produce benefits for a variety of both instream and out-of-stream water users by increasing renewable water resources, but may simultaneously generate harm by increasing flood risks. Climate change poses a conceptual challenge to water managers by introducing uncertainty in future hydrological conditions. It may also be very difficult to detect an underlying trend (Wilby, 2006), meaning that adaptation decisions may have to be made before it is clear how hydrological regimes may actually be changing. Water management in the face of climate change therefore needs to adopt a scenario-based approach (Beuhler, 2003; Simonovic and Li, 2003).

5.0. Conclusions

It is evident that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change. However, the ability to quantify future changes in hydrological variables and their impacts on systems and sectors, is limited by uncertainty at all stages of the assessment process. Uncertainty comes from the range of socio-economic development scenarios. Decision making needs to operate in the context of this uncertainty. Capacity for mitigation of climate change and adaptation to its impacts is limited by the availability and economic viability of appropriate technologies. Management strategies that adapt as the climate changes require an adequate observational network to inform them. There is limited understanding of the legal and institutional frameworks and demand-side statistics necessary for mainstreaming adaptation into development plans to reduce water-related vulnerabilities and of appropriate channels for financial flows into the water sector for adaptation investment . It is recommended that continuous monitoring of changes in the hydroclimatic variables be intensified to provide early warning system for effective water resources management and to minimize its vulnerability to climate change.

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