Water Resources Assessment and Climate Change

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Abstract: In view of the growing demands of water for various uses, it is important to consider the impacts of climate change on water resources for assessment, planning and management purpose. The present paper highlights the challenges for climate change impact assessment on the water resources. Landuse changes and climate both significantly impact the water resources and thus its management. Human interventions in the form of landuse changes has important role in altering the hydrological processes at local scale however climate change may have its impact on water resources at global scale. In this paper an attempt has been made to present major findings of IPCC and other individual researchers on climate change and its impact on water resources. For mitigating the impact of climate change on water resources and its proper management under climate change adaptation and mitigation strategies have been suggested.

Keywords: Water Resources; IPCC; Climate Change; Landuse changes

1. Introduction

Water is a scarce natural resource and fundamental to life, livelihood, food security and sustainable development. Water is also one of the most manageable natural resources as it may be diverted, transported, stored, and recycled. Because of all these properties of water, it has great utility for human beings. The surface and ground water resources are utilized for meeting the increasing demands in various sectors. Rainfall in India, which is mainly responsible for replenishing our water resources, usually depends on the South West and North East monsoon, on shallow cyclonic depressions & disturbances and on local storms. It is highly variable in time and space affecting the temporal & spatial availability of water to a larger extent. The rivers like Ganges, Brahmaputra and Indus originate from the Himalayas and carry water throughout the year. The snow and ice melt of the Himalayas, spring flows and the base flow significantly contribute to the flows of these rivers during the lean season. Average water yield per unit area of the Himalayan rivers is almost double that of the south peninsular rivers system indicating the importance of snow and glacier melt contribution from the high mountains. Apart from the surface water available in the different rivers of the country, the ground water is also an important source of water for drinking, irrigation and industrial uses etc. It accounts for about 80% of domestic water requirement and more than 45% of the total irrigation in the country.

Climate change has adversely affected the hydrological cycle resulting in significant change in monsoon pattern leading to frequent occurrence of hydrological extremes such as floods & droughts, receding glaciers, reduction in the snow covered areas, increase in evaporation rates, affecting runoff pattern, reduction in natural recharge, reduction in base flow, change in water quality and rise in sea level etc. Human-generated build-up of greenhouse gases are the most significant driver of observed climate change since the mid-20th century. Climate change has a direct impact on water resources, and this has been discussed in the assessment reports of the Intergovernmental Panel on Climate Change (IPCC). Many researchers have used the Global Circulation Models (GCM) and their downscaled output using Regional Circulation Models (RCM) in Hydrological Models to predict the impact of climate change on different

components of the hydrological cycle and analysed their impacts on temporal and spatial variability of ground water and surface water supply.
In addition to the climate change, the infrastructure developments and land use changes may also affect the water resources at different temporal & spatial scales. Thus, there is an urgent research need to carry out the impact studies in order to quantify their individual as well as the combined impacts on available water resources. Such studies would be very much useful to prepare the coping strategies for a country as the coping capacity shall depend on the preparedness. Climate change impacts may be most severe in those countries which have not prepared the plan for adaptation strategies. Number of studies have been carried out in India and different parts of the world to analyse the impact of climate change on water resources. In this paper, the major findings of IPCC and other important studies carried out about water resources assessment, particularly at large spatial scale, have been presented highlighting their usefulness and limitations. It has been followed by a comprehensive review of the studies, attempted by individual researchers on this issue. Finally, adaptation and mitigation strategies, suggested by many researchers & water managers to cope with the impact of climate change have been discussed.

2.0 Causes of Climate Change

Climate of the earth is determined by the rate at which energy is received from the Sun and the rate at which it is lost to space. Due to winds, ocean current etc. this energy is distributed around the globe and thus affecting the climates of different region. According to IPCC climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Various natural internal processes or external forcings, or persistent anthropogenic changes in the composition of the atmosphere or in land use may result in climate change. Burning of fossil fuels, such as oil and coal, which emits greenhouse gases into the atmosphere (primarily carbon dioxide) is the primary cause of climate change. Besides this agriculture and deforestation, also contribute to the proliferation of greenhouse gases and thus may cause climate change.

Climate is also affected by the particles and aerosols present in the atmosphere. Furthermore, burning fossil fuels and biomass contribute to emissions of these substances, however, some aerosols also come from natural sources such as volcanoes and marine plankton. The atmospheric concentration of CO_2 did not rise above 300 parts per million between the advent of human civilization roughly 10,000 years ago and 1900. Today it is at about 400 ppm, a level not reached in more than 400,000 years.

Both natural and anthropogenic factor may influences Earth's climate. The main causes of anthropogenic climate change are given below:

2.1 Greenhouse Gases

Certain gases present in the Earth's atmosphere absorb the heat radiation but allow the sunlight. Due to absorption of heat by the gases in the atmosphere, the average surface temperature on Earth is around 14°C. In absence of these gases, the Earth's average surface temperature would be around -19°C.

According to IPCC report concentration of greenhouse gases has increased in the earth atmosphere (Figure-1) particularly due to industrial revolution and increased human activities. Increases since about 1750 are attributed to human activities in the industrial era. In the figure, concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample (IPCC).

Increase of greenhouse gas concentration causes more heat absorption in the atmosphere leading to increase in global average surface temperatures i.e global warming. The increase in temperature is also leading to other effects on the climate system. Together these affects are known as anthropogenic (human caused) climate change. Concentrations of gases such as CO2, N2O, and CH4 are presently increasing in the atmosphere as shown in Figure 2 (Lal, 2010).

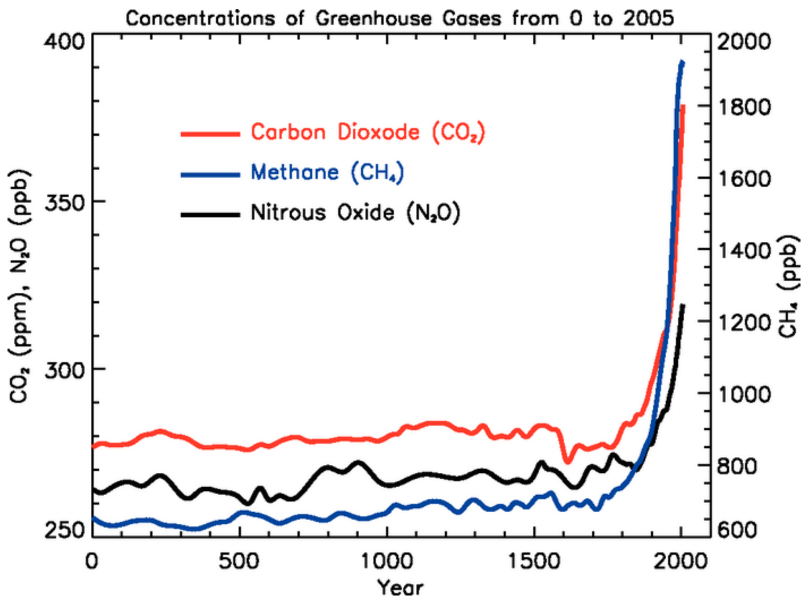

Figure 1. Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years.

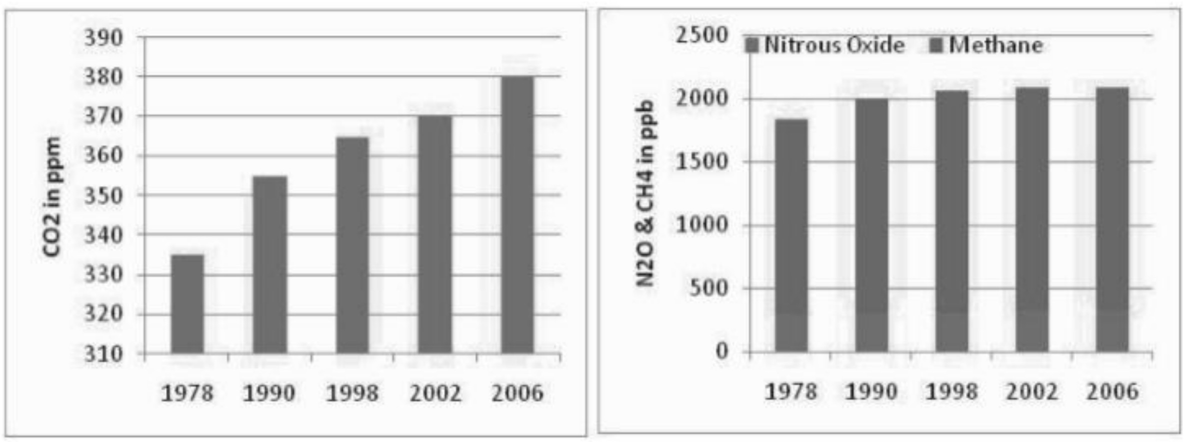

Figure 2. Average concentrations of GHGs for the last three decades (Adapted from Lal, 2010)

2.2 Aerosols in the Atmosphere

Aerosols are minute particles suspended in the atmosphere and they scatter and absorb sunlight. Climate is altered by the atmospheric aerosols in two important ways: direct or indirect effect. As a direct effect, the aerosols scatter sunlight directly back into space. As an indirect effect, aerosols can modify microphysical and chemical properties of clouds and possibly their lifetime and extent, changing how the clouds reflect and absorb sunlight, thereby affecting the Earth's energy budget.

The scattering of solar radiation acts to cool the planet, while absorption of solar radiation by aerosols warms the air directly instead of allowing sunlight to be absorbed by the surface of the Earth. Aerosol that may have a significant effect on climate are classified as: **volcanic aerosol, desert dust and human-made aerosol.** Human activity contributes to the amount of aerosols in the atmosphere in several ways.

- Dust - a bi-product of agricultural processes.
- Biomass burning
- Industrial processes in the manufacturing depending on what is being burned or produced
- Exhaust emissions from transport

The concentrations of aerosols are about three times higher in the Northern Hemisphere than in the Southern Hemisphere. This higher concentration is estimated to result in radiation forcing that is about 50 per cent higher for the Northern Hemisphere.

2.3 Land Use Land Cover (LULC) Changes

LULC influences the surface albedo and thus climate at local, regional, and global scales. Land-use changes have led to changes in the amount of sunlight reflected from the ground back into space (). The scale of these changes is estimated to be about one-fifth of the forcing on the global climate due to changes in emissions of greenhouse gases. There is growing evidence that land use, land cover, and land management affect climate in several ways:

- Change in air temperature and near-surface moisture take place in areas where natural vegetation is converted to agriculture.
- Conversion of rain-fed cropland to irrigated agriculture intensifies the impacts of agricultural conversion on temperature.
- Irrigated agriculture can alter regional precipitation.
- Urbanization is having significant local impacts on weather and climate. Land-cover changes associated with urbanization are creating higher air temperatures compared to the surrounding rural area.
- Land-use and land-cover changes are affecting global atmospheric concentrations of greenhouse gases. The impact is expected to be most significant in areas with forest loss or gain, where the amount of carbon that can be transferred from the atmosphere to the land (or from the land to the atmosphere) is modified.

3. IMPACT OF CLIMATE CHANGE ON WATER RESOURCES

Precipitation distribution in space and time is very uneven, leading to tremendous temporal variability in water resources worldwide (Oki and Kanae, 2006). One side, the Atacama Desert in Chile receives imperceptible annual quantities of rainfall each year. On the other side, Mawsynram, Assam, India receives over 450 inches annually. According to Vorosmarty (2000) if all the freshwater on the planet is divided equally among the global population, there would be 5,000 to 6,000 m3 of water available for everyone, every year. Global warming may have significant impact on earths fresh water supplies. Thus the countries with reliable water supply may face water security. Furthermore, it may increase droughts and/or the risk of flooding. Scarcity of water is expected to be an increasing problem in the future, for various reasons. Most of the developing countries are not ready to take care the existing climate variability. Such countries are more vulnerable to climate change impacts such as high damage to assets and life as compared to developed countries (Shukla et al. 2003).

Second, the rate of evaporation varies a great deal, depending on temperature and relative humidity, which impacts the amount of water available to replenish groundwater supplies. The combination of shorter duration but more intense rainfall (meaning more runoff and less infiltration) combined with increased evapotranspiration (the sum of evaporation and plant transpiration from the earth's land surface to atmosphere) and increased irrigation is expected to lead to groundwater depletion (Konikow and Kendy 2005).

The hydrologic cycle begins with evaporation from the surface of the ocean or land, continues as the atmosphere redistributes the water vapour to locations where it forms clouds, and then returns to the surface as precipitation. The cycle ends when the precipitation is either absorbed into the ground or runs off to the ocean, beginning the process over again. Key changes to the hydrological cycle (associated with an increased concentration of greenhouse gases in the atmosphere and the resulting changes in climate) include:

- Changes in the seasonal distribution and amount of precipitation.
- An increase in precipitation intensity under most situations.
- Changes in the balance between snow and rain.
- Increased evapotranspiration and a reduction in soil moisture.
- Changes in precipitation and temperatures can affect the magnitude and timing of runoff.
- Changes in vegetation cover resulting from changes in temperature and precipitation.
- Consequent changes in management of land resources.
- Accelerated melting glacial ice.
- Affect the frequency and intensity of hydrologic extremes such as floods and droughts.
- Increased coastal inundation and wetland loss from sea level rise.
- Effects of CO_2 on plant physiology, leading to reduced transpiration and increased water use efficiency (Goudie 2006).
- Increased temperatures can cause warming of reservoir and rivers in the region which in turn will increase evaporation as well as will affect their thermal structure and water quality.

3. Major Findings of IPCC

According to Intergovernmental Panel on Climate Change (IPCC) (2007) "*Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer*".
The IPCC reports of the three Working Groups covered the physical science of climate change, vulnerability to climate impacts and adaptation, and mitigation strategies to tackle climate change. According to these reports: (i) Climate change is here, man-made and already having dangerous impacts across all continents and the ocean; (ii) Global warming can still be kept below the politically agreed limit of 2 degrees Celsius compared to preindustrial levels; (iii) securing a safe climate future is possible and economically viable if immediate action taken.
Important findings from these three reports are**:**

1. Primarily cause of Climate change is humans. With 95% certainty it is found that humans have caused most of the observed warming since 1951 (Working Group I).
2. Climate change in acceleration. Many indicators of climate change are indicating increased rate of change e.g. Ice sheet melt, glacial melt, and sea level rise have all accelerated faster than previously predicted.
3. Climate change is impacting extreme weather. Today frequency and intensity of some types of extreme weather have been increased and other types are projected to increase in the future.
4. Nobody is going to be untouched by the impacts of climate change. All the people are vulnerable to extreme climate and weather events as adaptation and preparation remains low, which could result in severe consequences as impacts rise.
5. Climate change is already harming agricultural yields, and this will worsen.
6. Temperature targets to be exceeded. 2ºC target agreed upon by world leaders will soon be out of reach if no further action is taken. If greenhouse gas emissions continue rising at current rates, average projected global temperature will be 2.6-4.8ºC warmer by the end of the century.
7. Solution is renewables in transitioning to a low-carbon economy. Renewable energy will need to triple or quadruple by 2050 to meet temperature targets.
8. Restricting warming to 2ºC is practical and affordable. The cost of renewable energy is falling and deforestation rates have declined.
9. Economic growth will be higher if we invest in clean energy, and it will be lower if we decline to ramp up investments in clean energy. The IPCC is clear that impacts on the conventional fossil-fuel path will be catastrophic.

4. Water resources assessment at large spatial scale

With the advent of satellite remote sensing technology, hydrological information at the macro scale has become increasingly available. Further, the development of macro scale hydrological models have generated useful information for the purpose of water resource assessments and climate change impact studies at the global and continental scale. Furthermore, it is contributing to improved knowledge of the present state of global water resources and variability across large spatial domains covering terrestrial hydrology and continental hydrology. Large-scale hydrological modelling has many challenges which include limited data for ground truth (e.g. soil moisture, groundwater, streamflow), large differences in data availability (Arnell, 1999a; Decharme and Douville, 2006; Doll and ¨ Siebert, 2002; Fekete et al., 2004; Guntner, 2008; Hunger and ¨ Doll, 2008; Peel et al., 2010; Wid ¨ en-Nilsson et al., 2009) and quality across regions, sub grid variability, downscaled and bias-corrected climate data as driving force, etc.. These large- scale hydrological models broadly fall into two categories. Land Surface Models (LSM) historically evolved to provide lower boundary conditions for General Circulation Models (GCM) and their development has focused on solving the surface- energy balance.

In recent years various researchers have applied large scale hydrological models for understanding continental and global water balances, impacts of climate and land-use changes, and for water-resources management (e.g. Jung et al., 2012; Li et al., 2012; Mulligan, 2012; Werth and Guntner, 2010). Many global hydrological models (GHMs) operate at a spatial resolution of 0.5◦ × 0.5◦ longitude and latitude and commonly evaluated against discharge, which represents response of a basin.

Assessment of change detection and trend on monthly, seasonal and annual historical series of different climatic variables have been carried out by various researchers (Jaiswal et al 2014, Jaiswal et al 2015, Lohani et al 2015, Chhabara et al. 2014). The trend and magnitude of warming over India/the Indian sub-continent over the last century is broadly consistent with the global trend and magnitude (Hingane, 1995; Pant & Kumar, 1997, Arora et al., 2008, Dash et al., 2007). Pant & Kumar (1997) analysed the seasonal and annual air temperatures from 1881–1997 and have shown that there has been an increasing trend of mean annual temperature, at the rate of 0.57_C per 100 years. Singh et al. (2008) found a warming trend in seven of the nine river basins in northwest and central India. The monthly maximum and minimum temperature data from 121 stations well distributed over the country for the period 1901–2007 were used by Kothawale et al. (2010) to compute seasonal and annual trends in surface air temperature over the country and seven homogeneous regions (western Himalaya, northwest, north-central, northeast, east coast, west coast and interior peninsula) during 3 periods: 1901–2007, 1971–2007 and 1998–2007.

Trend analysis of rainfall data of 135 years (1871-2005) indicated no significant trend for annual, seasonal and for any monthly rainfall on all-India basis (Kumar et al., 2010). Using 104 years (1901–2004) of high resolution daily gridded rainfall data, variability and long-term trends of extreme rainfall events over central India was examined by Rajeevan et al. (2008). They found statistically significant long term trend of 6% per decade in frequency of extreme rainfall events. Pattanaik and Rajeevan (2010) analysed long-term trend in monsoon season extreme rainfall events for 1951–2005.

5. Adaptation and Mitigation Strategies

In order to plan adaption and mitigations strategies it is required the following follow these steps:

- Identify climate change related problems
- Analyse climate vulnerabilities and associated risks
- Evaluate potential adaptation responses and relevant technologies
- Implement specific measures to mitigate the problems
- Establish integrated management frameworks for adaptation

For mitigating the impact of climate change on water resources proper management of water resources is required. Management strategies may be considered as supply side management or demand side management:

5.1 Water Supply Management

Better use of existing water and development of new water supplies may provide the effective methods for controlling the impacts of climate changes keeping in mind the environmental, economic and social consequences. The water supply conservation and management for reducing drought effects includes the following actions:

- Conjunctive use of surface and ground water
- Agronomic conservation measures and agronomic practices that need less water
- Watershed management
- Control of evapotranspiration
- Supplemental irrigation for reducing drought effects
- Storage reservoirs and tanks.
- Inter basin water transfer
- Recycling of wastewater generated from the domestic uses, industries and municipalities etc.
- Percolation tanks to increase ground water recharge in wet years
- Rainwater harvesting

5.2 Water Demand Management

The demand or water use reduction measures conserves the existing limited water supply through the practices which require less water and reduce wastage and misuse of water. These measures are directed towards making the existing inadequate supply, whatever it may be, serve water users as effectively as possible and a balance between supply and demand is achieved. Thus the fundamental nature of these measures is their effectiveness in accomplishing a temporary allocation of the limited supply in a manner which serves the users to bridge the gap between supply and demand. The various techniques used for the purpose are based either on giving economic incentives or penalties or involve rationing, legal sanctions and various other types of social or political pressures. These maybe based on strategies that include legal restrictions, economic incentives and issuance of public appeals.

5.2.1 Active demand reduction:

Strategies for active demand reduction include the following:

- Provisions of legal restrictions on use of water
- Legal restrictions on proper utilization of ground water resources
- Establishment of thresholds for short-term reductions to various users
- Planning of land use specially in new land developments
- Changes in water pricing structures
- Economic incentives for using small amount of water

5.2.2 Reactive demand reduction:

Use of recycling systems for temporary drought mitigation measures can be taken up as a reactive strategy. However, it is required to be studied whether these measures are to be adopted on continuous basis or on temporary basis. Considerable information exists on time distribution of water requirements for various crops and various planting dates. This knowledge is required to be integrated systematically with water supply probabilities to develop planting strategies. The selection of cropping pattern as per availability of water will reduce adverse impacts of climate change.

Water Conservation

Some of the important water conservation measures include: (i) control of evaporation, (ii) rain water harvesting, (iii) provision of water cisterns. Water conservation campaign through education and information dissemination is must to create awareness in the users and make the adoption of water conservation measures a success by inducing social acceptability.

5.3 Integrated Water Resources Management & Decision Support System

Integrated Water Resources Management (IWRM) is an approach to water resources management that promotes development and management of water, land and related resources in an integrated way (in order to maximize economic and social benefits), an equitable way, and without compromising the health of ecosystems (GWP 2010). Thus, the IWRM approach is an alternative to the traditional sector-by-sector management paradigm, where uncoordinated use can lead to rapid resource depletion and pollution. Decision Support Systems (DSS) are one example of tools that can help create a common knowledge platform for the various users. The main purpose of the surface water planning is to contribute in generating, synthesizing and disseminating useful information and knowledge on basin level water management challenges, for use by practitioners, development agencies, policy makers, and donors. The overall objectives of the decision making in surface water planning and management should address the following crucial issues:

(a) **Water resource development and management** must be geared towards striking a balance between supply and demand. When, in a context where most accessible resources are already tapped, population and water use per capita increase, there is a need to improve management and efficiency in use. This has implications from the farm level to the operation of reservoirs and cuts across technical, economic and organisational issues. In addition, it is necessary to ensure long-term sustainability and regulate the use of groundwater extraction.
(b) **Water allocation and water rights** as users compete for scarce resources, the allocation of water becomes crucial, as it eventually defines who gets what and whether this is equitable and economically efficient. Here, again, several technical, legal, and political factors come into play. A growing water scarcity often cause conflicts and raises uncertainty in supply, and water entitlements or rights need to be increasingly formalised.
(c) **Health and environment** ecological cycles and equilibriums are threatened by over-abstraction of surface waters which affects in-stream environment, exacerbates saltwater intrusion, affects the productivity of land in estuarine areas, and reduces the capacity for diluting waste discharge. Water pollution, caused by poor sanitation and uncontrolled waste discharges from urban, agricultural, mining and industrial development, increases the cost for downstream users and impacts negatively on public health. Watershed degradation caused by poor land use, land clearing, inappropriate cropping techniques, or overgrazing is altering hydrologic factors and increasing the vulnerability of important watersheds. Aquatic ecosystems are degraded by nutrient discharges (from sewage and fertilizers)

which accelerate the eutrophication of water bodies. Wetland ecosystems degradation is affecting important natural functions (hydrologic and ecological), which makes the productive resource base vulnerable.

(d) **Livelihoods enhancement;** access to water is crucial for the livelihoods of many farmers and a reduction of their allotments or a significant rise in the price paid for this access may have severe socio-economic consequences. More generally, water is vital for hygiene and domestic uses and providing poor people with proper sanitation is a basic prerequisite for a better quality of life. Thus, water is also at the core of broader concerns for poverty alleviation and food security. These different dimensions implicitly highlight that any pattern of water resource management is likely to be a trade-off between different objectives, as water is expected to fulfil or contribute to competing purposes: food security and poverty alleviation through irrigation, health and hygiene, non-agricultural economic development, environmental services.

6. Concluding Remarks

In past few decades, greenhouse gases have become the dominant climate force. Increasing greenhouse gases concentrations have direct consequences on earths temperature and thus on the hydrological cycle. Climate change impact on hydrology has been extensively studied by various researchers using downscaling methods. Most of the researchers have concluded that hot extremes, heat waves and heavy precipitation events will become more frequent and it is more likely that future tropical cyclones will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical seasurface temperatures. For understanding the impact of climate change in water resources it is very important to understand the effectiveness of the GCMs and to decide a scenarios which best represent the present and future situation under global warming. It is worth mentioning that large uncertainties exist in GCMs' parameterization of atmospheric processes and surface interactions, and also in evolution of socio-economic scenarios and GHG emissions. For water resources management it is important to IWRM and thus the decision support system considering both supply and demand side water management.

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