IMPACT OF CLIMATE CHANGE ON GROUNDWATER RESOURCES WITH SPECIAL EMPHASIS TO TAMIL NADU – A REVIEW

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ABSTRACT: Climate change studies are one of the most emergency fields in the entire sector to understand the safe living on the Earth in future. Water is crucial for survive, but its availability at a sustainable quality and quantity is threatened by many factors, of which climate plays a foremost role. Groundwater is one of the most utilized resources in India for drinking and irrigation purposes. The Intergovernmental Panel on Climate Change (IPCC) estimates that the global mean surface temperature has increased 0.6 ± 0.2°C since 1861, and predicts an increase of 2 to 4°C over the next 100 years. The present study carried out reviews on impact of climate change on groundwater resources with special emphasis to Tamil Nadu State. The normal annual rainfall fall over the state is 958.4 mm is received. The maximum temperature over Tamil Nadu is projected to increase by 1.1°C, 2.0°C and 3.4°C in the years 2040, 2070 and 2100 respectively with reference to the baseline 1970-2000. Annual rainfall projected for 2040 indicates a general increase in rainfall by about 7cm for the period 2040 to 2070 with reference to the base mean 1970 to 2000 while it increases by 9cm for the period 2070 to 2100. The State depends (75%) on neighbouring States for considerable quantum of flows annually and up to 80% of the groundwater is being used out of total available. This has led to the decline in groundwater table. Due to erratic rainfall and inflation of agricultural inputs many agricultural lands were kept fallow or converted for other uses and agricultural labourers migrated to urban areas for searching jobs to sustain their life. In this context, it is necessary to estimate the climate change impact on groundwater resources in Tamil Nadu State for better sustainable environmental development.

1. INTRODUCTION

Groundwater will continue to be a vital resource in the future as it constitutes an important part of available freshwater on our planet, but also because groundwater is relatively less sensitive than surface water to short term and seasonal climatic variations (Goderniaux et al 2011). The climate change defined as change in climate over time, whether due to natural variability or as a result of human activity. The common impacts of climate change on water resources have been brought out by the Third Assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2000). It revealed that, rise of the global hydrological cycle affecting both ground and surface water supply. The National Communication (NATCOM) study was the first attempt to quantify the impact of the climate change on the water resources in the country (Gosain et al 2003). Climate change is not only a major global environmental problem, but also an issue of great concern to a developing country like India. The present paper highlights the impact of climate change on groundwater resources with special reference to Tamil Nadu State.

1.1 Global climate system and predictions

The components of the global climate system, their process and interactions and some aspects that may change groundwater environment are shown in Figure 1a. The earth's atmosphere, the layer of air that surrounds the earth contains many gases. Short-wave radiation from the sun passes through the earth's atmosphere. Partly this radiation is reflected back into space, absorbed by the atmosphere and remainder reaches the earth's surface, where it is either reflected or absorbed (Fig.1b). In turn the earth's surface emits long-wave radiation toward space. The Green House Gases (GHG) available in the atmosphere, which principally include CO_2, NO_2, CH_4, CFCs and O_3, absorb some of this long-wave radiation emitted by the Earth's surface and re-radiate it back to the surface (Fig.1b). Climate change scenarios in future are usually developed using the General Circulation Models (GCMs) with different scenarios of green house gases (GHG) emissions. GCMs are complex 3-dimensional models of the land, atmosphere and oceans. A single grid of GCM may encompass hundreds of square kilometers and include mountainous and desert terrain, oceans and land areas. Usually, the output of GCMs is given for a scale much larger than that of even a large watershed. There are more than 200 GCMs available which have been developed by different agencies. For generating future climate scenarios on regional basis there are downscaling models called Regional Climate Models (RCMs) which use output of GCMs (Fig.1c). The IPCC observed that global average air temperature near earth's surface rose to 0.74 ± 0.18°C in the last century (Fig.1d). The various types of regional model used to observe global warming projections (Fig.1e).

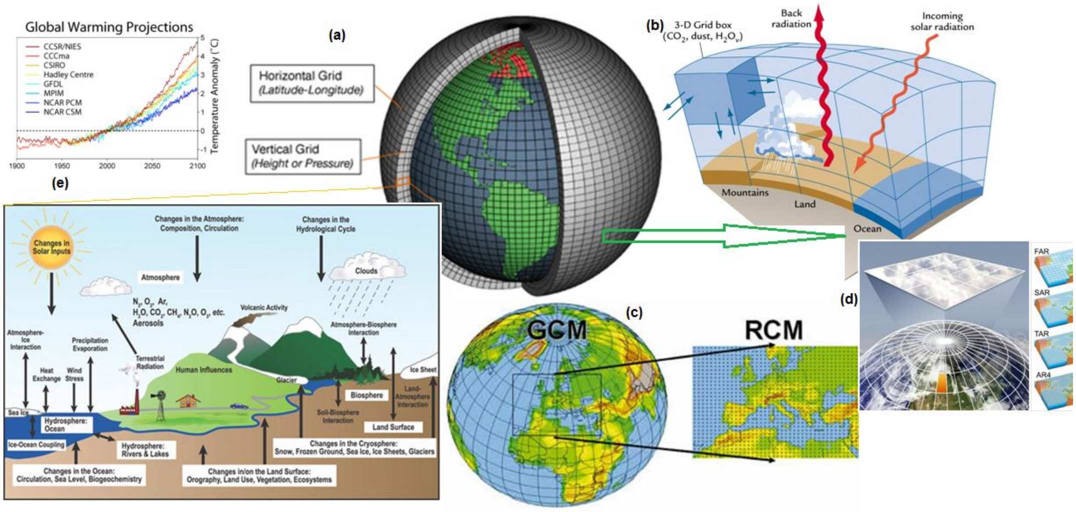


Figure 1 Schematic view of the components of the global climate system, processes, projections and reports (*Source: IPCC, 2001*)

1.2 The Impact of Climate Change on water resources

Different types of hydrologic models have been utilized to understand the impact of climate change on water resources (Wilkinson and Cooper, 1993; Gureghian et al., 1994; Cooper et al., 1995; Bobba et al., 1997; Rosenberg et al., 1999; Kirshen, 2002). In one of the early studies, Vaccaro (1992) used a deep percolation model (DPM) to estimate the influence of climate change on recharge variability in a basin in north-western United States. Bouraoui et al. (1999) developed a methodology to disaggregate the outputs of large-scale GCMs for use in hydrologic models. Brouyere et al. (2004) investigated the impact of climate change on a chalky groundwater basin in Belgium using the integrated hydrological model MOHISE. Klove et al (2013) synthesis current knowledge on the complex interactions between climate, groundwater and ecosystems, and to examine integrated groundwater management strategies that account for human and ecosystems needs. The conceptual model of the effect of GHG and global warming on the hydrologic cycle and phenomena associated with climate extreme are shown in Figure 2. The future climatic change, though, will have its impact globally but likely to be felt severely in developing countries with agrarian economies, such as India.

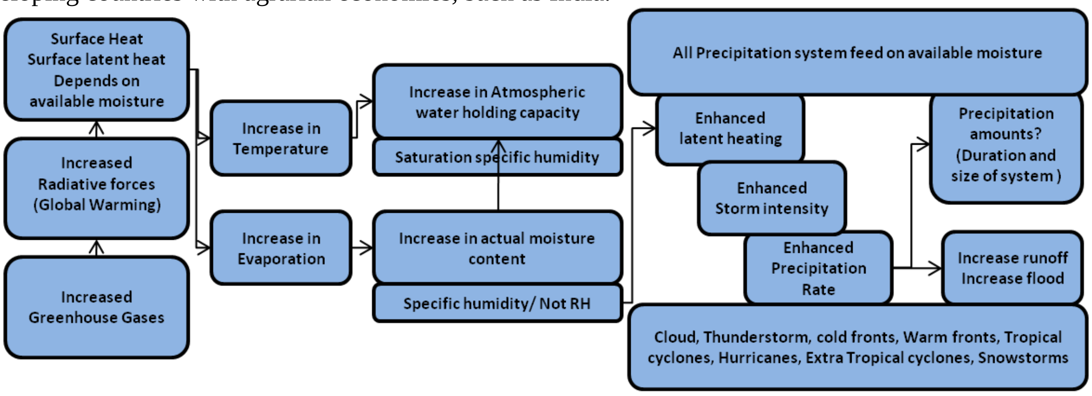


Figure 2 Conceptual model of the effect of GHG and global warming on the hydrologic cycle and phenomena Associated with many climate extremes (after Trenberth, 1999)

1.3 Factors Affecting Recharge

Many factors affect future groundwater recharge including changed precipitation and temperature regimes, coastal flooding, urbanization, woodland establishment and changes in cropping and rotations (Table 1). Holman (2006) described an integrated approach to assess the regional impacts of climate and socio-economic change on groundwater recharge from East Anglia, UK. Toews (2007) modeled the impacts of future predicted climate change on groundwater recharge resources for the arid to semi-arid south Okanagan region, British Columbia. Assessment a accurate spatial and temporal characterization of groundwater recharge is difficult, due to its dependence on a multitude of physical factors such as land use and hydrogeological heterogeneity (Lerner et al., 1990). Groundwater recharge can also be significantly affected by snowmelt and frozen soil conditions. A comparison of the four scenarios in Figure 3 shows that lower emissions do not lead to significant changes in groundwater recharge.

Table 1 Factors Affecting Recharge and their description

Factors	Description
Precipitation	Precipitation is the most important parameter in the groundwater recharge process. It is the driving force in the hydrologic cycle and provides the water that will eventually recharge the groundwater system.
Land Use and Cover	The type of land cover can have a significant impact on infiltration, and hence on groundwater recharge.
Vegetation	Vegetation reduces recharge by directly interfering with the passage of precipitation from the atmosphere to the water table.
Urbanization	The water balance of an area can be drastically altered by urbanization.
Overland Flow	Overland flow is a rare event in humid climates due to less intensive rainfall, well-developed vegetation, and sufficient infiltration capacity of most soils (Knutssen, 1988).
Infiltration and Flow in the Unsaturated Zone	Infiltration is the volume rate of water flowing into a unit area of soil surface. It is generally considered to be one-dimensional in the vertical direction; however, as noted before, local changes in ground cover and near surface permeability can lead to lateral flows.
Soil Properties	The hydraulic properties of the soils in the unsaturated zone are very sensitive to the moisture content and pressure head distributions
Temperature	Similar to rainfall, the spatial and temporal distribution of snow accumulation is very complex, and even further complicated by its high sensitivity to temperature and wind velocities (i.e., drifting) (Deng et al.,1994)

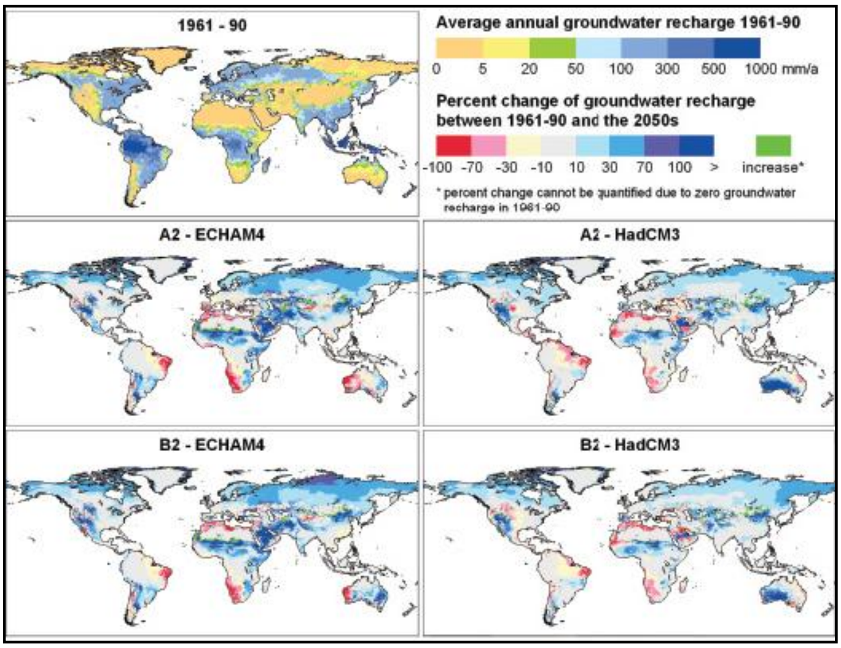
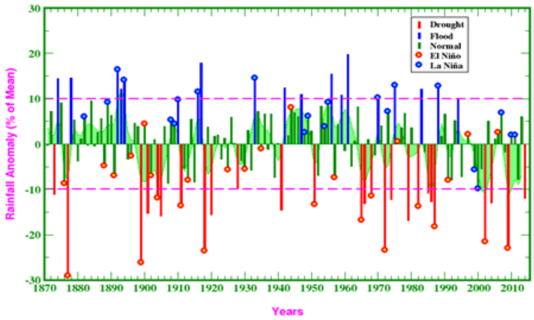


Figure 3 Simulated impact of climate change on long-term average annual diffuse groundwater recharge (after Doll and Florke, 2005)

1.4 Indian freshwater condition

Gosain et al (2006) have done climate change impact assessment on hydrology of Indian river basins. The result of Soil and Water Assessment Tool (SWAT) model revealed that Krishna and Mahanadi one with predicted severe drought conditions and the other with pronounced flood conditions. Mall et al. (2006) have examined the potential for sustainable development of surface water and groundwater resources within the constraints imposed by climate change and future research needs in India. Shah (2009) discussed various opportunities for mitigation and adaptation for climate change on groundwater resources in India. The year to year variability in monsoon rainfall leads to extreme hydrological events resulting in serious reduction in agricultural output and affecting the vast population and national economy. Kumar (2012) assessed the impact of climate change on groundwater resources to assess the soil moisture, groundwater recharge and resources and coastal aquifers. The factors which influenced in climate change and its effects on groundwater resources on a global scale with emphasis on Indian groundwater resources were critically reviewed by Panwan and Chakrapani (2013). A normal monsoon with an evenly distributed rainfall throughout the country is a natural gift, while an extreme event of flood or drought over the entire country or a smaller region constitutes a natural hazard (Fig.4). Hence, variation in seasonal monsoon rainfall may be considered a measure to examine climate variability/change over the Indian monsoon domain in the context of global warming. Figure 5 shows the observed and projected decline in per capita average annual freshwater availability and growth of population from 1951-2050. This clearly indicates the two-sided effect on water resources, the rise in population will increase the demand for water leading to faster withdrawal of water and this in turn would reduce the recharging time of the water table. As a result the availability of water is bound to reach critical levels sooner or later.



RAI	Class description
≥ 3.00	Extremely wet
2.00 to 2.99	Very wet
1.00 to 1.99	Moderately wet
0.50 to 0.99	Slightly wet
0.49 to –0.49	Near normal
-0.50 to –0.99	Slightly dry
-1.00 to –1.99	Moderately dry
-2.00 to –2.99	Very dry
≤ -3.00	Extremely dry

Figure 4 All India summer monsoon rainfall anomalies (1870-2010), light green shadow line shows 10-year moving average (Source: after Mall et al, 2006 and Rainfall Anomaly Index (RAI) Rooy, 1965)

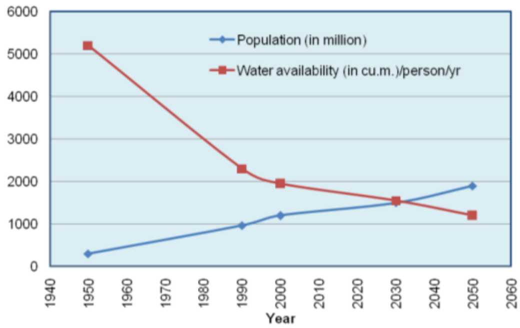


Figure 5 Observed and projected decline in per capita average annual freshwater availability and growth of population from 1951 to 2050 in India (after MoWR, 2003)

2. REMOTE SENSING AND GIS IN CLIMATE CHANGE STUDIES

In recent days Remote Sensing (RS) and Geographic Information System (GIS) play vital role in climate change studies (Fig.6a). The conventional observation of satellite remote sensing is capable of providing more frequent and repetitive coverage over a large area than other observation means (Fig. 6b). Li et al. (2008) assessed land-use/land-cover change pattern in Lake Qinghai watershed between 1977 and 2004 by combining Landsat MSS, TM and ETM data. Chen and Rao (2008) monitored vegetation using multi-temporal Landsat TM/ETM data in an ecotone between grassland and cropland in northeast China between 1988 and 2001. Classification and change detection carried out showed accelerated land degradation of the grassland around the salt-affected soil near the water bodies due to variation in water sizes as a result of both climate change and anthropogenic activities. Ifabiyi and Eniolorunda (2012) assessed the watershed Characteristics of the Upper Sokoto Basin, Nigeria using RS and GIS. Eniolorunda (2014) critically reviewed the role of RS and GIS in climate change analysis and adaptations. The Gravity Recovery and Climate Experiment (GRACE) mission has provided global measurements of monthly gravity change, which can be used to estimate terrestrial water storage (TWS) change, including the lake storage component. Humphrey et al. (2016) investigated the relative importance of linear trend and nonlinear inter annual variability in long-term TWS changes throughout the world. Liu et al (2017) analyzed the effects of climate and land use changes on water resources in the Taoer River using ArcGIS, SRTM DEM and SWAT model. This study can provide a reference for the rational allocation of water resources and the adjustment of land use structure for decision makers.

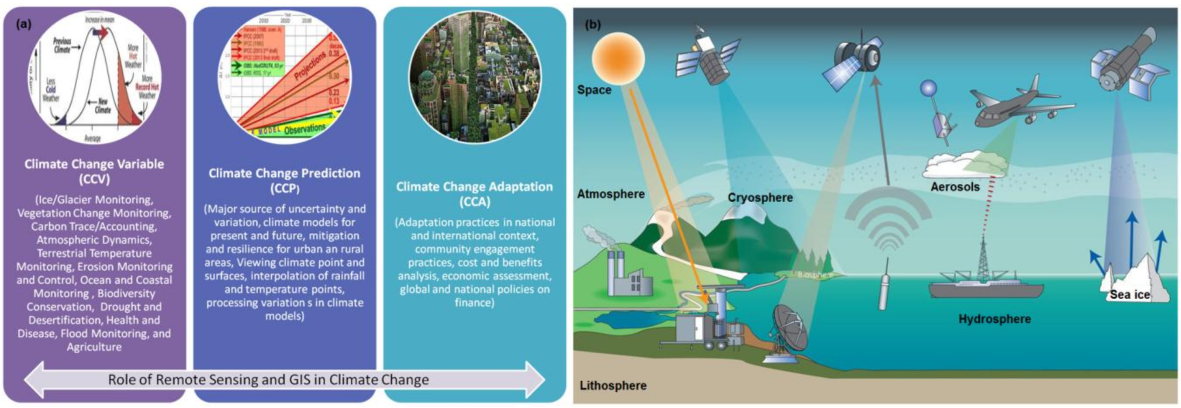


Figure 6 (a) Role of Remote Sensing and GIS in climate change, (b) remote sensing observation of the climate sytem (courtesy of R. He, Hainan University).

3. CLIMATE CHANGE IN TAMIL NADU

3.1 Rainfall pattern

The State of Tamil Nadu received rainfall during south west monsoon (SWM), north east monsoon (NEM) and pre-monsoon season. The normal annual rainfall in the state is 958 mm. About 48% of the total annual average rainfall is received during NEM, while about 35% is received during SWM and the balance in the other seasons (IMD, 2001). Long term studies carried out by Guhathakurta et al (2011), for the period of 1901-2005, indicate, that Tamil Nadu is experiencing more dry days than wet days every year. Spatial distribution of rainfall over northeast and southwest monsoon season shows the variability of maximum SW and NE monsoon rainfall for the period 1971 to 2005 and captures clearly the significant spatial variation of rainfall over the districts (Fig.7).

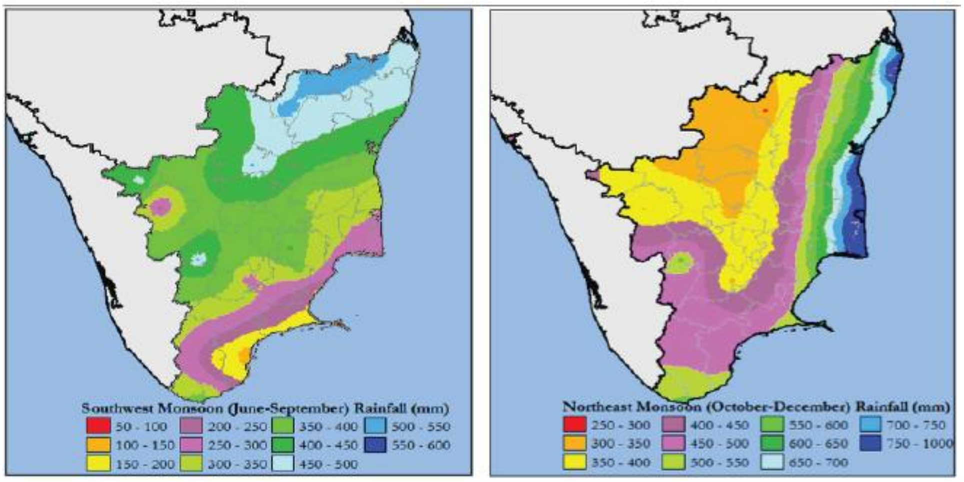


Figure 7 Rainfall pattern (1971 to 2005) during SW and NE monsoon in Tamil Nadu *(Source: UNDP, 2013)*

Figure 8a shows inter annual variation of SW monsoon rainfall from 1901 to 2006. From 1900-2006, excess SW Monsoon rainfall has occurred in 40 years and deficit in 28 years. During October-December, cyclonic storms and depressions over Bay of Bengal are less frequent, which make possible heavy rainfall episodes in Tamil Nadu and thus this season accounts for large part of total rains. Figure 8a shows inter-annual variations of NE monsoon rainfall. From 1990-2006, excess NE Monsoon rainfall has occurred in 36 years and deficient in 28 years. The variability in the withdrawal of monsoon has been greater during the first 30 years period as compared to the latter half, in temporal as well as spatial scales (Attri and Tyagi, 2010).

3.2 Temperature changes

According to IPCC (2001), most Indian landmass below the Ganges plain is likely to experience a 0.5–1°C rise in average temperatures during 2020–2029 and 3.5–4.5°C rise in 2090–2099. Annamalai et al (2011) reported on temperature over Cauvery basin of Tamil Nadu that the average year to year variation in surface temperature lies in the range about 0.4°C with few years warmer or cooler by 0.8°C. Based on the technique of deducting the long time forced component, the temperature series in both the seasons clearly indicates a warming tendency. Long term temperature variability from 1901 to 2005 is showing year to year variation especially in winter and monsoon seasons. Winter (Jan-Feb) and summer (March-May) temperatures show an increasing trend (Fig.8b).

3.3 Climate projection

The maximum temperature over Tamil Nadu is projected to increase by 1.1°C, 2.0°C and 3.4°C in the years 2040, 2070 and 2100 respectively with reference to the baseline 1970-2000. Temperatures and rainfall GCMs GFDL and HadCM3 climate projections for three scenarios A1B, A2 and B1 are as tabulated in Table 2 for three time slices 2020, 2050 and 2080. For 2030, temperature increases of 0.9 to 1.3°C can be expected for most of the State, and annual precipitation will be reduced by around 0.3 percent to -14%. By 2050, warming will reach 1.82 to 2.7°C, and expected annual precipitation reductions range between 8.2 and 24.0%. By the 2080s warming could reach 2.1 to 4.2°C, and rainfall could decrease by 19.4% to 21.1% (Fig.9a). For all time horizons and scenarios, warming trends are generally seen from temperature parameter. Anbazhagan and Jothibasu (2015) analyzed departure of index of aridity (Ia) for the period of 1971 to 2012 in Uppar Odai sub-basin, Tamil Nadu State. The Udumalpet and Sultanpet rainfall stations indicated that the basin affected moderate to disastrous drought condition (Fig.9b). It is evident that trend of future climate change condition in these region.

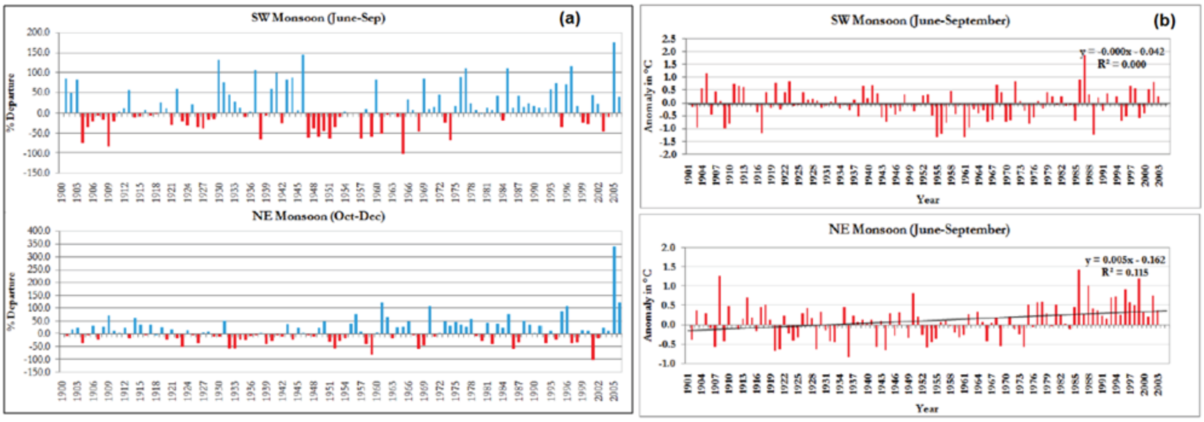


Figure 8 (a) SW and NE rainfall anomaly from 1901 to 2006 in Tamil Nadu, (b) Mean Temperature Anomalies for SW and NE seasons for the period 1901-2005 in Tamil Nadu (*Source: UNDP, 2013*)

Table 2 Climate Projections for Tamil Nadu (*Source: UNDP, 2013*)

Model	Time Slice	Annual mean surface air temperature change in °C			Annual precipitation change in %		
		A1B	A2	B1	A1B	A2	B1
GFDL	2030	0.85	0.86	1.82	-0.32	-5.91	0.54
	2050	1.82	1.71	1.94	-7.48	-1.10	4.29
	2080	2.57	3.02	2.09	0.41	0.76	-3.64
HadCM3	2030	1.25	0.93	1.19	-12.07	-2.62	-13.98
	2050	2.36	2.69	1.84	-8.21	-24.04	-11.59
	2080	3.69	4.19	2.77	-20.71	-24.09	-19.42

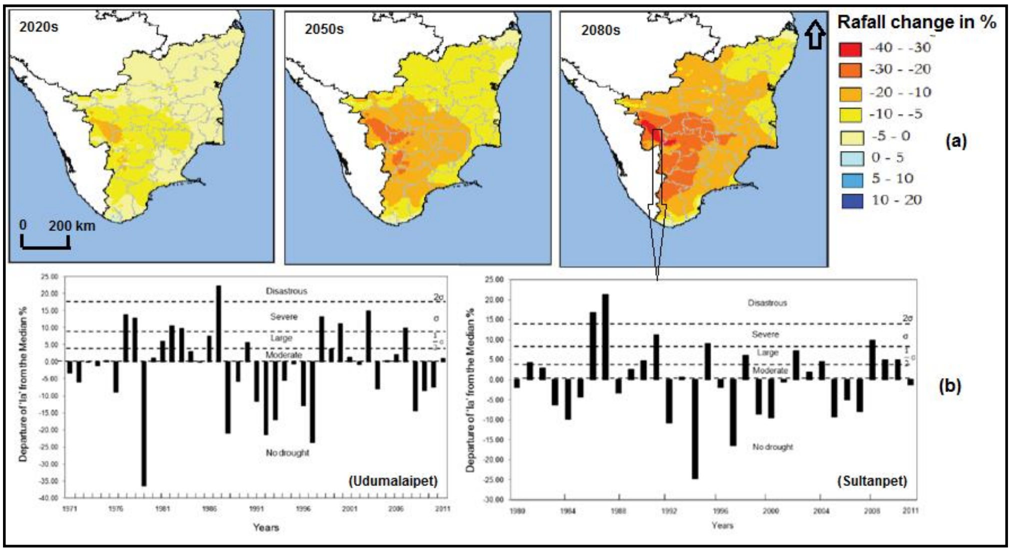


Figure 9 (a) Climate Projections for the years 2020, 2050 and 2080 for Tamil Nadu (CIAT, AR4), annual rainfall change in % (HadCM3, (A1B Scenario) and (b) departure of 'Ia' from the median %

4. FUTURE CLIMATE IMPACTS

Future climate impacts for a number of important sectors have recently been identified and prioritized in the First and Second National Communication to the UNFCCC (NATCOM, 2004 & 2008). Water, agriculture, forests, marine and coastal systems, human health and infrastructure sectors are considered vulnerable to changing climate. The projected climate change is likely to adversely affect the water balance in different parts of India and quality of groundwater along the coastal plains in Tamil Nadu. The annual number of rainy days for the period 2041-2060 is decreasing and overall increase in the highest one-day rainfall (20cm/day) over a major part of the India, including Tamil Nadu, as indicated from the projected scenarios. The existing coastal zone problems, climate variability and climate change could lead to increased rainfall, rainfall intensities, sea level rise and severe cyclones making it even worse because of erosion, flooding, biodiversity threats, impact the estuarine rivers and salinity freshwater balance in Tamil Nadu (ADB, 2011).

5. GENERAL CRITIQUE

During the last decade, several studies have highlighted the potential negative impact of climate change on groundwater reserves, but additional work is required to help water managers' plan for future changes. In particular, existing studies provide projections for a stationary climate representative of the end of the century, although information is demanded for the near future (Chen et al., 2002; Yusoff et al., 2002; Loaiciga et al., 2000). Nyenje and Batelaan (2009) examined the effects of climate change on groundwater recharge and baseflow in the upper Ssezibwa catchment, Uganda, are investigated. The study first examines historical data, which indeed reveal evidence of climate change based on trends observed in temperature and discharge. Rana et al (2014) discussed the impact of climate change on rainfall over Mumbai using Distribution-based Scaling of Global Climate Model projections study and focused on future projections provided by general circulation models (GCMs) suggest the probability of occurrence of intense rainfall will change in the future. However, GCM data generally need to be downscaled and bias corrected for impact studies. Although the domains covered by Regional Climate Models (RCMs) are increasing, statistical downscaling of GCM results is the main alternative in many regions. Variations in climate occur across a range of temporal and spatial scales, making both observation and modeling highly uncertain (Goddard et al., 2001). Nevertheless, advanced remote sensing from Earth observation satellites is providing increasingly detailed images of our current climate, while the growing amount of paleoclimatic core data from trees, sediments, and ice are providing information about the Earth's climate in the distant past. At the same time, the continuing increase in computing power has led to the development of more detailed and sophisticated global climate and general circulation models (GCMs). The micro level climate change studies are needs to understand the basin and sub-basin level information for farmers and scientist for sustainable groundwater development in future.

6. TRADITIONAL ADAPTIVE STRATEGIES

In Tamil Nadu, as most of the production environment is in uncertain climatic environment particularly semi-arid zones, farmers have evolved a range of Ex-ante strategies and Ex-post strategies based on historical experiences to deal with anticipated intra-seasonal and inter-annual rainfall variations. In response to highly uneven concentration of rains, farmers harvest runoff water through water harvesting structures and store it for irrigating and sustaining crops. Farming communities devised to conserve rain water and preserve soil moisture through location specific small and large scale water harvesting structures and agronomics techniques. One of the most effective rain harvesting structures for geographical features and climatic conditions of Tamil Nadu are the tanks, small water harvesting structures to impound water during peak rainy season to irrigate during dry season. They are arranged in a cascade with embankments, built at different elevations and arranged to collect and store the surplus water overflowing from one tank to another tank. Surplus water in upper level tank not only reaches the lower level but ensures continuous seepage to recharge groundwater. In the ex-post strategies, farmers have to preserve the productive assets to anticipate good rainfall in the next season, preserving the productive assets like cattle, seeds for re-planting etc.

7. CONCLUSION

Water resources in Tamil Nadu, even during normal times, the demand for water outstrips the supply. Tamil Nadu has 17 river basins, 61 major reservoirs, 40,000 tanks and 3 million wells. During deficient rainfall years almost all reservoirs experience reduction of water up to 90%, nearly all tanks could become dry and the water level in groundwater system could go down significantly. The deterioration of water quality is significant in few river basins and periodic monsoon rain is a must to keep up the quality. Groundwater aquifers are at risk due to over-withdrawal in northeast, northwest and central Tamil Nadu. The tank irrigation system is also declining and becoming inefficient due to poor maintenance and collapse of traditional irrigation system. Insufficient capacity of tanks makes it difficult to capture rainfall from good and heavy rainfall years thus wasting precious water. In order to avoid overdraft of groundwater, climate information needs to be used to assess recharge potential and to evolve system to tap groundwater with reference to recharge. Poor SW and NE monsoon as well as late or early withdrawals could impact groundwater potentials. The climate change based research is be needed to develop the state as well as basins for sustainable environment in future.

In the present context, modeling impact of climate change on groundwater resources in Southern India is being carried out through hydrological, hydrogeological and meteorological data. The expected output is to assess the past, present and future change of climate and assess the influence on contribution groundwater zones, aquifers (confined and unconfined), recharge and discharge, groundwater quality and sea-water intrusion. The result is useful to understand the groundwater resources in our country and assessed for better planning and management.

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