IMPACT OF CLIMATE CHANGE ON WATER RESOURCES

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INTRODUCTION

Climate change is one of the most critical global challenges nowadays. Climate change may affect our hydrologic system in various forms, like increase in temperature, evapotranspiration, more uneven distribution of rainfall, frequent occurrence of extreme events (i.e., floods and droughts), etc. The Fourth Assessment report of the Intergovernmental Panel on Climate Change (2007) concluded from direct observations of changes in temperature, sea level, and snow cover in the northern hemisphere during 1850 to the present, that the warming of the earth's climate system is unequivocal. The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005. Multi-model averages show that the increase in temperature during 2000-2099 relative to 1980-1999 may range from 1.1 to 6.4°C and sea level rise from 0.18 to 0.59 meters. These could lead to impacts on freshwater availability, oceanic acidification, food production, flooding of coastal areas and increased burden of vector borne and water borne diseases associated with extreme weather events.Various observed changes in climate and weather events in India, viz. surface temperature, rainfall, extreme weather events, rise in sea level and impacts on Himalayan glaciers have been described by Kumar and Singh (2011).

In order to find ways to mitigate the rising temperatures, it is necessary to examine the primary causes of global and regional warming. This phenomenon is linked to both natural and human causes. A natural cause – water vapor in the atmosphere – contributes the most to natural greenhouse warming (Figure 1). Water vapor and other "greenhouse gases" such as carbon dioxide, methane, and CFCs cause the greenhouse effect by trapping radiant heat emitted at infrared (long) wavelengths (as opposed to shorter, solar wavelengths which can pass through the atmospheric gases) from the earth's surface and reradiating it back to the earth's surface (Schneider, 1989). This trapped energy effectively creates an enclosure around the earth's atmosphere similar to a greenhouse which not only traps heat, but also restricts air circulation that would otherwise cause cooling (Botkin and Keller, 2000). Prior to the IPCC's report in 2001, there was still significant uncertainty about human beings' contribution to global warming. Many scientists believed that natural global cooling mechanisms worked to offset warming. With the release of the IPCC's Third Assessment Report in 2001, however, came new evidence that climate change over the last 50 years was, indeed, attributable to humans, mostly from burning fossil fuels that emit more carbon dioxide into the atmosphere than it should contain to achieve climate equilibrium (5.4 billion metric tons annually). Two additional human causes of global warming include deforestation, which adds another 1.6 billion metric tons, and emission of other greenhouse gases (methane, CFCs, ozone, nitrous oxides) that also contribute to the greenhouse effect (Botkin and Keller, 2000). Urban warming is driven by some of the same factors that create greenhouse gas warming: vegetation loss, increase in mineral-based construction materials, and waste heat emissions from combustion and electricity consumption. The loss of vegetation in urban areas, compared to that in rural areas, reduces in cities the natural cooling provided by evapotranspiration, "the process through which intercepted radiation is utilized by plants, soils, and water bodies to convert water to water vapor" (Stone and Rodgers, 2001). Second, building materials such as asphalt, cement and roofing tile absorb more thermal energy than the vegetation that existed prior to urbanization. This energy is released into the air late in the day and into the evening, keeping the city warmer than it would normally be (Lawrence Berkeley Laboratories, 2000). Finally, some portion of the urban heat island effect is attributable to the heat emissions from air conditioners, industry, automobiles and other sources of heat in urban centers (Stone and Rodgers, 2001). The urban heat island effect is reinforced by increased demand for cooling, consequently raising the level of greenhouse gas emissions from power plants.

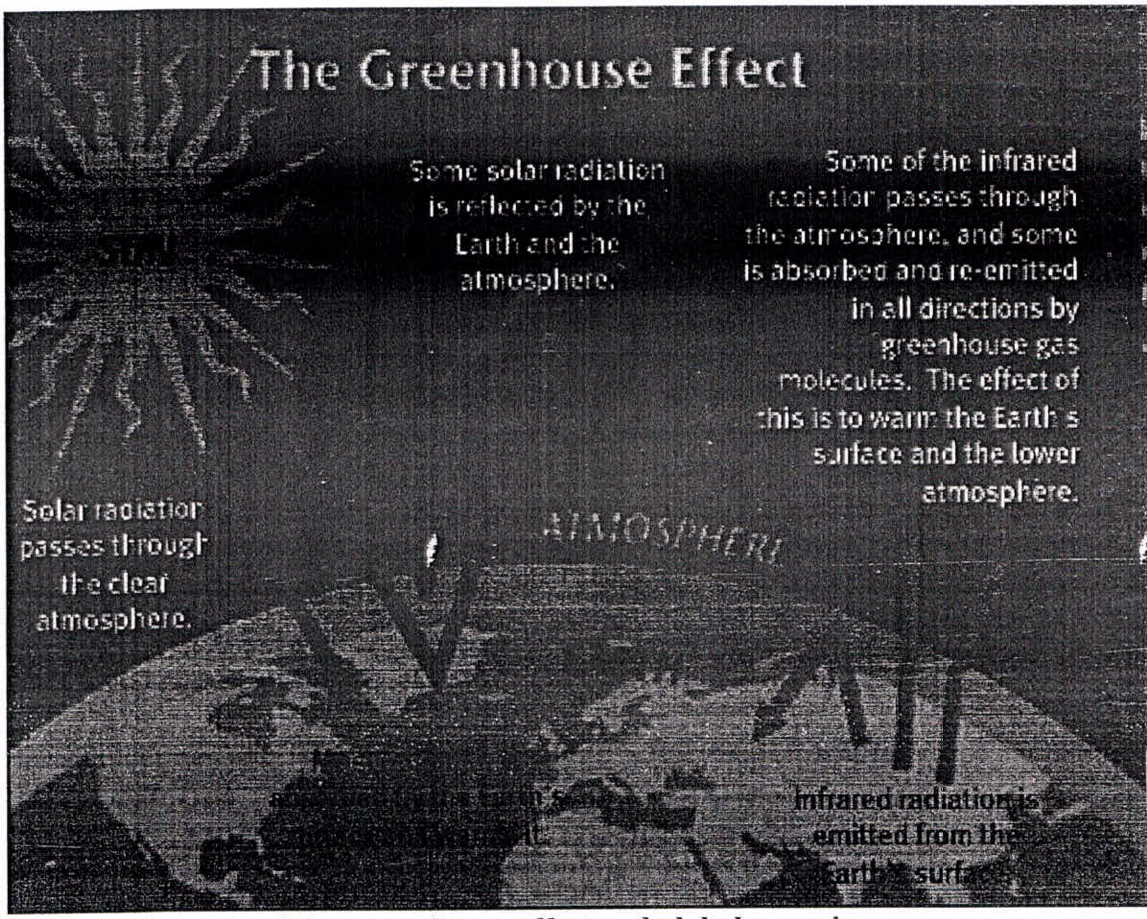

Figure 1. Schematic of the green house effect and global warming

Some Projections of Climate Change over India for the 21st Century (Kumar and Singh, 2011)

Some modeling and other studies have projected the following changes due to increase in atmospheric greenhouse gases (GHG) concentrations arising from increased global anthropogenic emissions:

- Annual mean surface temperature rise by the end of century, ranging from 3 to 5°C under A2 scenario and 2.5 to 4°C under B2 scenario of IPCC, with warming more pronounced in the northern parts of India, from simulations by Indian Institute of Tropical Meteorology (IITM), Pune.

- Indian summer monsoon (ISM) is a manifestation of complex interactions between land, ocean and atmosphere. The simulation of ISM's mean pattern as well as variability on inter-annual and intra-seasonal scales has been a challenging ongoing problem. Some simulations by IITM, Pune, have indicated that summer monsoon intensity may increase beginning from 2040 and by 10%by 2100 under A2 scenario of IPCC.

- Changes in frequency and/or magnitude of extreme temperature and precipitation events. Some results show that fine-scale snow albedo influence the response of both hot and cold events and that peak increase in extreme hot events are amplified by surface moisture feedbacks.

METHODOLOGY

The potential impacts of climate change on water resources have long been recognized although there has been comparatively little research relating to groundwater.The methodology consists of five main steps. First, the climate change scenarios need to be formulated for the future years such as 2050 and 2100. This is done by assigning percentage or actual changes of climatic variables based on GCM predictions on a seasonal and/or annual basis for the future years relative to the present year. Second, generate future climate based on these climate change scenarios. This is done using the statistical techniques. Third, based on these scenarios and present situation, seasonal and annual runoff, evapotranspiration and/orgroundwater recharge are simulated. Fourth, the annual runoff, evapotranspiration, recharge outputs are computed for the present condition and for the future years. Finally, the changes due to the climate change are quantified.

The main tasks that are involved in such a study are:

1. Describe morphology and hydrogeology of the study area.
2. Undertake a statistical analysis to separate climate into regional and local events.
3. Analyze climate data from weather stations and modeled GCM, and build future predicted climate change datasets with temperature, precipitation and solar radiation variables.
4. Define methodology for estimating runoff, evapotranspiration (ET), recharge under both current and future climate conditions and for the range of climate-change scenarios for the study area.
5. Use of a computer code (such as SCS-CN, WHI UnSat Suite or WetSpass, etc) to estimate runoff, ET, or recharge based on available precipitation and temperature records and anticipated changes to these parameters.
6. Quantification of changes due to the climate change impacts.

The methodology is also illustrated using a case study of Sonar sub-basin of Madhya Pradesh in the following section.

QUANTIFICATION OF IMPACT OF CLIMATE CHANGE ON GROUNDWATER – *A Case Study of Sonar Sub-basin, Madhya Pradesh*

Study Area

Sonar sub-basin falls in the Bundelkhand region of Madhya Pradesh and the Sonar river is a tributary of Ken river. Geographically the basin extends from 23° 21' 14" to 23° 50' 05" N latitudes and 78° 35' 48" to 79° 10' 50" E longitudes (Figure 2). The total area of the basin is 1538 sq.km. The Sonar river originates in the Raisen district and its major part 94%

basin area falls in the Sagar district and balance 6 % falls in the Raisen district.Climatically the basin lies under semi-arid to sub-tropical region with a single rainy season (July-September) followed by dry winter and a very dry summer. The landscape of the region is rugged, undulated terrain with low rocky outcrops, narrow valleys and pains. Large portion of the basin falls under rain-fed agriculture. Forest type in the basin is dry deciduous. The region is drought prone with average drought frequency of 01 in every 05 years. Average annual rainfall in the basin is 1100mm with average no. of 45 rainy days. Average annual potential evapotranspiration (PET) is 1852 mm. Mean temperature varies from 18 to 33 °C. Mean relative humidity varies from 27% to 85% and mean wind speed varies from 4.13 km/h in November to 8.45 km in July. Black cotton soil is dominantly found in the basin. The crops largely grown in the basin are wheat, soyabean, maize, arhar, ground nut, etc.

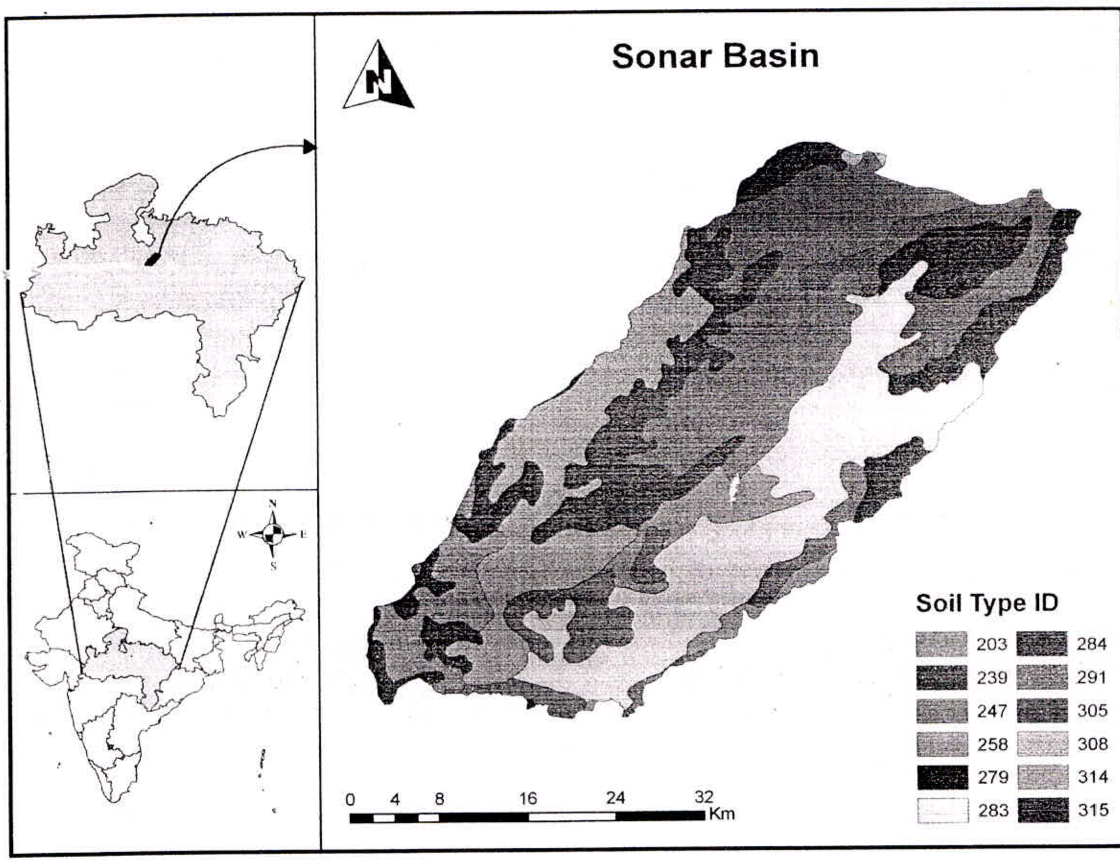

Figure 2. Index map showing the location of the study area

The principle focus of climate change research with regard to groundwater has been on quantifying the likely direct impacts of changing precipitation and temperature patterns. Such studies have used a range of modeling techniques such as soil water balance models, empirical models, conceptual models and more complex distributed models, but all have derived changes in groundwater recharge assuming parameters other than precipitation and temperature remaining constant.

There are two main parameters that could have a significant impact on groundwater levels: recharge and river stage/discharge. To assess the impact on the groundwater system to changes in these two parameters, it is necessary to have a calibrated flow model and to conduct a sensitivity analysis by varying these two parameters and calculating changes to the water balance (e.g., differences in water levels).

A typical flow chart for various aspects of such a study is shown in Figure 3. The figure shows the connection from the climate analysis, to recharge simulation, and finally to a groundwater model. Recharge is applied to a three-dimensional groundwater flow model, which is calibrated to historical water levels. Transient simulations are undertaken to investigate the temporal response of the aquifer system to historic and future climate periods.

Tasks in the upper part of the chart assemble several climate data sets for current and future predicted conditions, which are used to simulate recharge using HELP module of WHI UnSat Suite. Mapped monthly recharge from HELP is then used to simulate transient saturated groundwater flow.

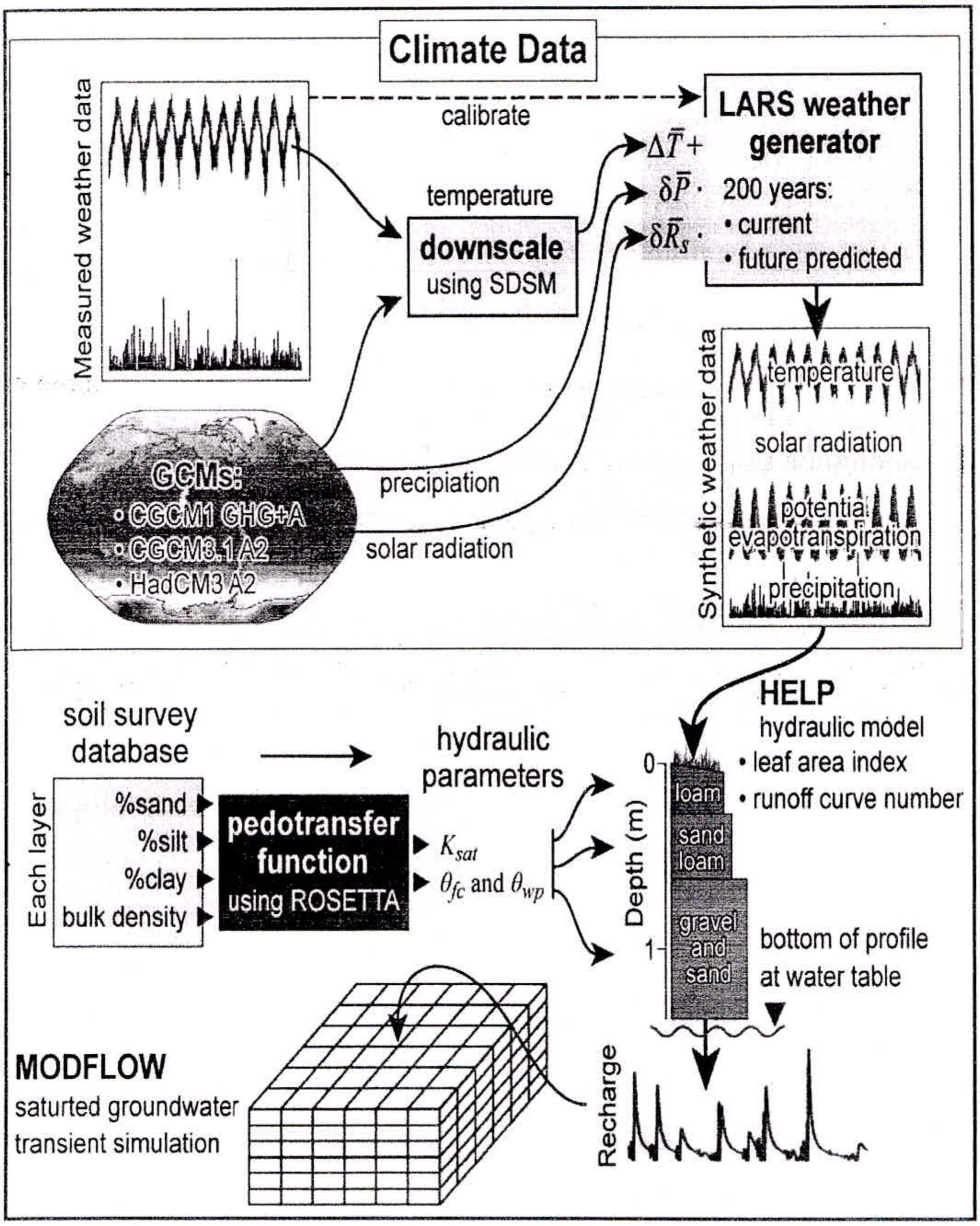

Figure 3. Flow Chart of groundwater flow simulation in response to climate change (Toews et al., 2007)

GENERATION OF CLIMATE FOR FUTURE SCENARIOS

The daily rainfall of the Sagar was available from 1901 to 2007 and temperature was available from 1972 to 2007. For generation of future scenarios of rainfall and temperature, the time period 1972-2003 was considered as the baseline period. Rainfall and temperature have been generated for the year 2039based on Mirza (2002) for GCM SRES scenarios south Asia region (Table 1). The scenarios have been undertaken for winter and summer season for both temperature and precipitation for the two extreme scenarios A1F1 and B1.

Table 1. Projected temperature and precipitation for South Asia in response to climate change (Mirza, 2002)

Season	2010-2039				2040-2069				2070-2099			
	Temp (°C)		Precipitation (%)		Temp (°C)		Precipitation (%)		Temp (°C)		Precipitation (%)	
GCM SRES Scenarios	A1F1	B1	A1F1	B1	A1F1	B1	A1F1	B1	A1F1	B1	A1F1	B1
Winter (Dec-Jan-Feb)	1.17	1.11	-3	4	3.16	1.97	0	0	5.44	2.93	-16	-6
Summer (Jun-Jul-Aug)	0.54	0.55	5	7	1.71	0.88	13	11	3.14	1.56	26	15

Both these scenarios indicate that winter rainfall will decrease while monsoon rainfall will increase but the increase in temperature will be more in winter than in summer.

A complete annual series of rainfall and temperature for both observed and generated data from 1972 to 2039 for all the three scenarios are shown in Figures 4 and 5. These time series have been used in further analysis for estimation of the groundwater recharge and quantification of the impact of climate change.

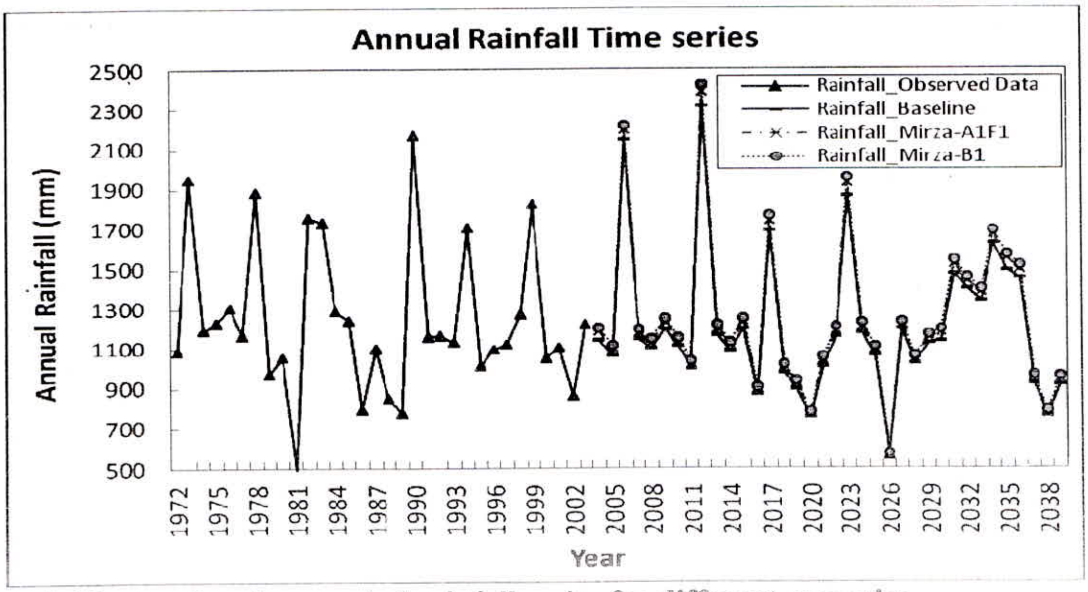

Figure 4. Observed and generated rainfall series for different scenarios

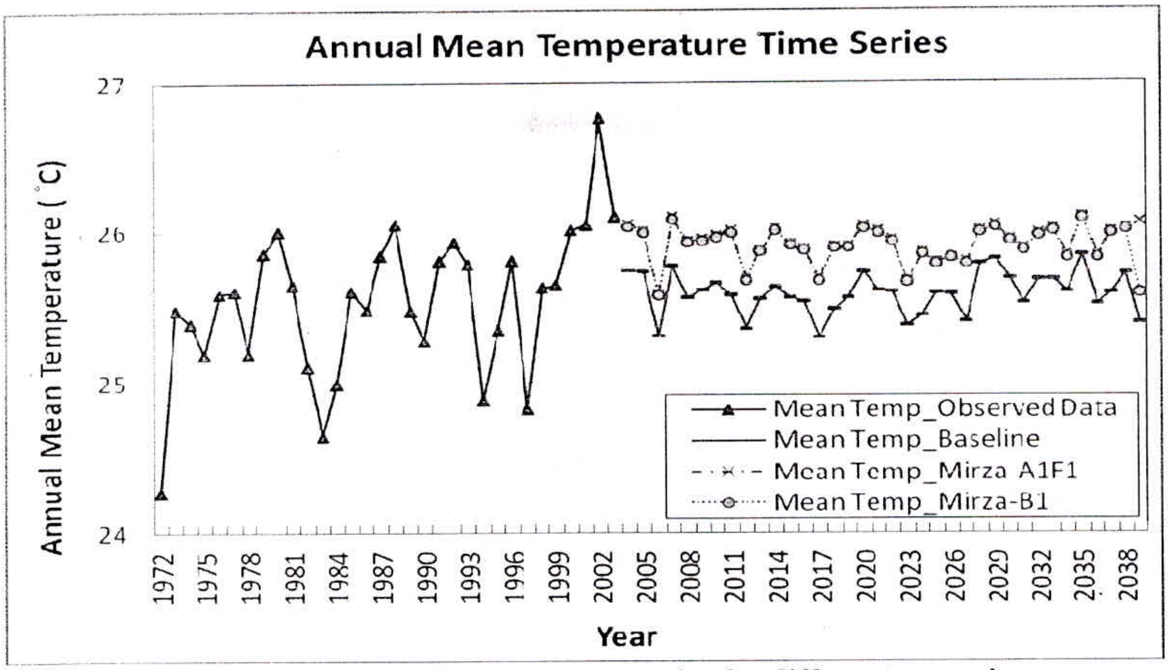

Figure 5. Observed and generated temperature series for different scenarios

ESTIMATION OF GROUNDWATER RECHARGE

Visual HELP (Hydrologic Evaluation of Landfill Performance) model is used to estimate the site-specific groundwater recharge. UnSat Suite contains the subprogram, VHELP which contains a more user-friendly interface for the program HELP that is approved by the United States Environmental Protection Agency (US EPA) for designing landfills. Visual HELP enables the modeler to generate estimates of recharge using a weather generator and the properties of the aquifer column. VHELP model was given weather data, vegetation details and soil profile properties as inputs of twelve different sites. The model was then run to estimate the groundwater recharge at these sites.

The groundwater recharge is estimated for the future projections, i.e., 2004 to 2039 as future periodfor the baseline, A1F1 and B1 scenarios and the difference under the A1F1 and B1 scenarios is estimated as compared to the baseline scenario. The estimated results of groundwater recharge for the baseline, A1F1 and B1 scenarios are presented in Table 2.

Table 2. Average groundwater recharge rates (mm/yr) under different scenarios

S. N.	Site Name	Baseline	A1F1	B1
1	Akala	210.60	216.40	222.76
2	Dadhonia	184.46	189.63	193.23
3	Dhana	163.48	168.83	171.60
4	Ghana	172.55	177.35	180.67
5	Inchalpur	376.90	384.81	389.36
6	Jaitpur	230.67	237.05	240.49
7	Khamaria Khurd	230.77	237.06	241.08
8	Kothi Kha	122.22	126.88	129.69
9	Kukwara	205.43	205.13	209.16
10	Patha Khurd	193.41	198.30	200.90
11	Swarkar	175.61	182.01	184.96
12	Vijaypura	169.70	176.15	179.43

Table 3 shows the changes in groundwater recharge as estimated under the three different scenarios. It is observed that the change in groundwater recharge under A1F1 and B1 scenarios range between +2.1 to +3.8% and +1.8 to +6.1%, respectively as compared to the baseline scenario for the times-slice 2004 to 2039.

Table 3. Percent change in groundwater recharge under different scenarios

S. N.	Site Name	% Change A1F1 vs. Baseline	% Change B1 vs. Baseline
1	Akala	2.8	5.8
2	Dadhonia	2.8	4.8
3	Dhana	3.3	5.0
4	Ghana	2.8	4.7
5	Inchalpur	2.1	3.3
6	Jaitpur	2.8	4.3
7	Khamaria Khurd	2.7	4.5
8	Kothi Kha	3.8	6.1
9	Kukwara	-0.1	1.8
10	Patha Khurd	2.5	3.9
11	Swarkar	3.6	5.3
12	Vijaypura	3.8	5.7

PREDICTION OF GROUNDWATER LEVELS FOR FUTURE CLIMATE

In order to quantify the impact of climate change on the groundwater levels, the groundwater level simulation is done in the Sonar sub-basin. The whole basin is divided into twelve zones (Figure 6). It is seen from the Figure 6 that each zone has at least one observation well except for the zones 2 and 12. Therefore, the groundwater level simulation has been carried out for all the zones except these two zones as there is no observation well.

It was observed that for most the zones, groundwater levels are showing a declining trend which is due to the decrease in amount of future rainfall. However, as stated earlier the groundwater recharge has increased under both the A1F1 and B1 scenarios as compared to the baseline scenario which is in response to the future projections of GCM SRES scenarios for the South Asia region. This increase in ground water recharge has caused a rise in ground water levels under both A1F1 and B1 scenarios compared to the baseline scenario (Figure 7).

Zone	Well Name
1-203	SGR047-OW
2-239	No Well
3-247	SGR074-OW
4-258	SGR111-OW
5-279	SAGAR011
6-283	SGR041-OW
7-284	SGR080-OW
8-291	SGR077-OW
9-305	SGR039-OW
10-308	SGR084-OW
11-314	SGR044-OW
12-315	No Well

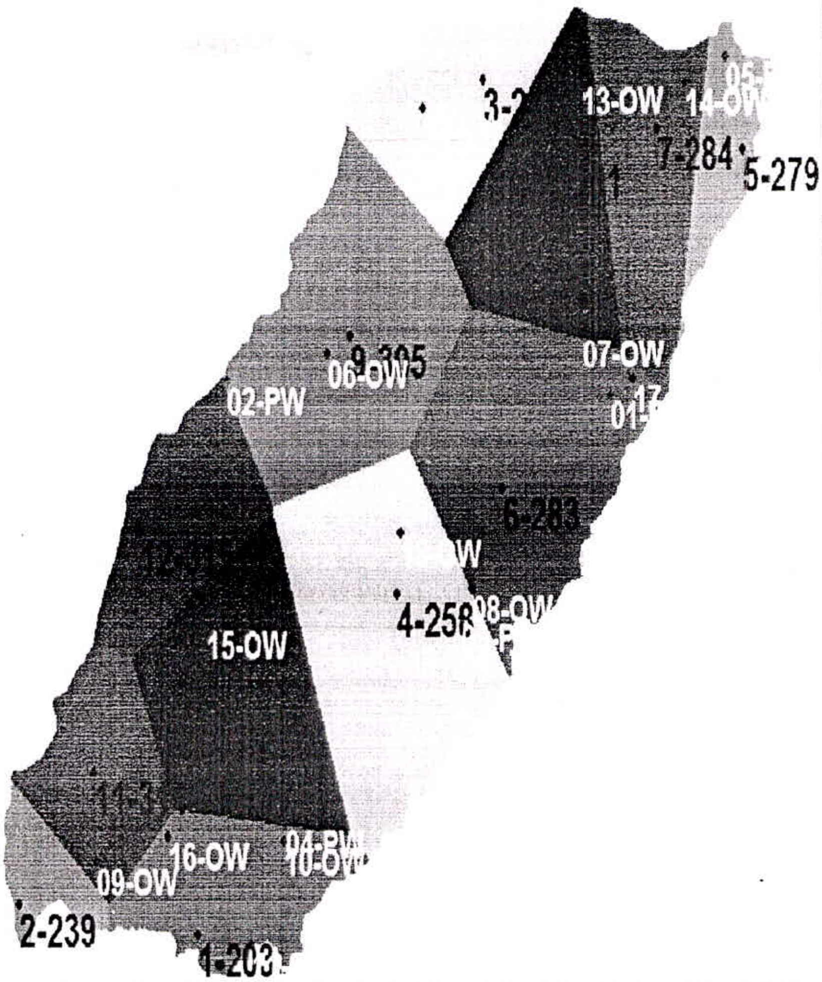

Figure 6. Construction of zones for groundwater level simulation in the basin

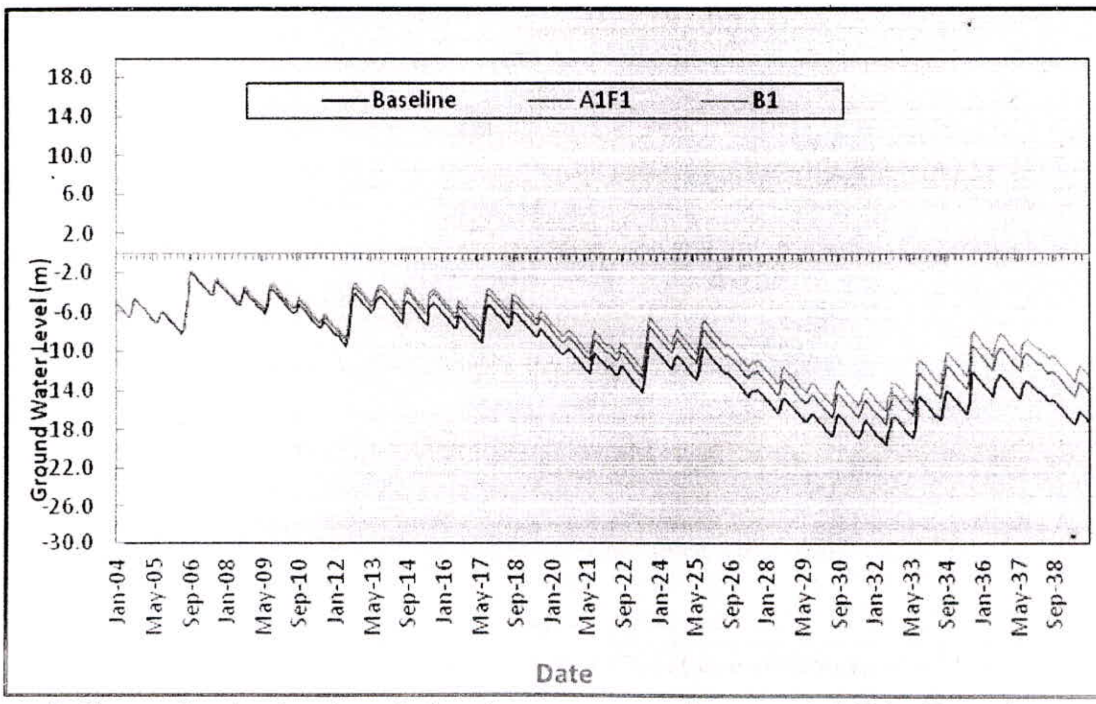

Figure 7. Groundwater level variation in response to future rainfall in Zone-4

It is estimated that the groundwater levels indicate a rising trend in all the zones for the A1F1 and B1 scenarios as compared to the baseline scenario and the estimated change in groundwater levels during the time-slice 2010-2039 under A1F1 and B1 scenarios is +8.0 and +14%, respectively as compared to the baseline scenario (Figures 8 and 9).

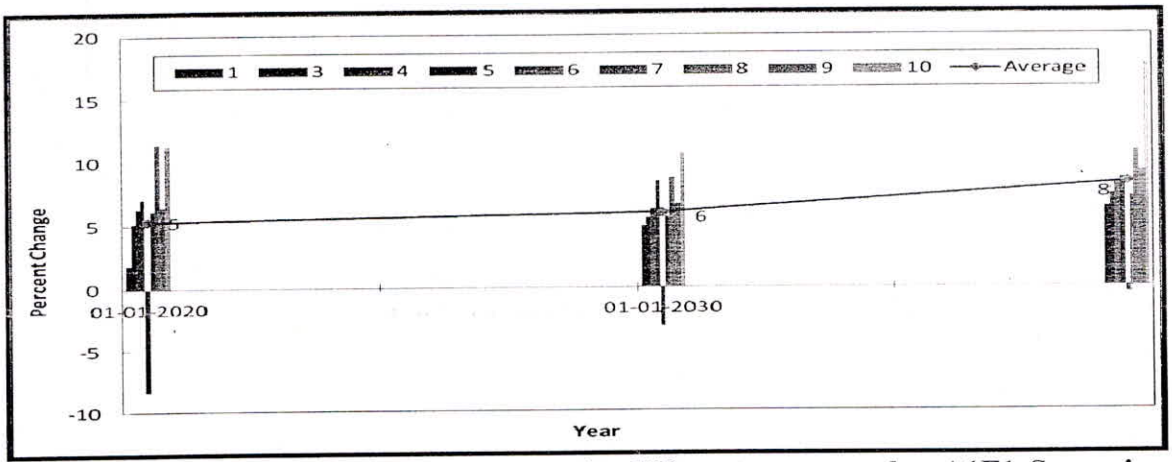

Figure 8. Percent change in groundwater in different zones under A1F1 Scenario as compared to baseline scenario

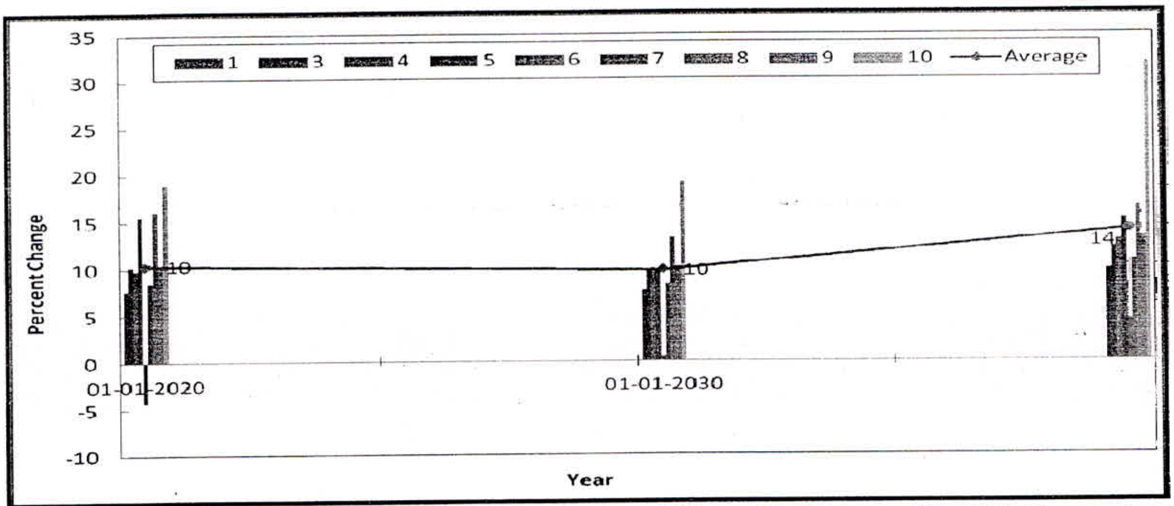

Figure 9. Percent change in groundwater in different zones under B1 Scenario as compared to baseline scenario

CONCLUSIONS

Thispaper presentsa methodology for the quantification of impact of climate change on the water resources. A case study of Sonar sub-basin, Madhya Pradesh is also presented as an example to quantify the impacts of climate change on groundwater.

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A view of NIH building at Roorkee

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