Comprehensive and up to date information is essential for any research work. Plethora of studies has been conducted by the scientists and researchers to assess the impacts of climate change on hydrology of various river basins.

2.1 Green house gases and climate change

Global concentration of greenhouse gases has increased exponentially since the advent of industrial era (Dentener et al., 2001). The CO₂ and other green house gases (GHGs) emission have been dramatically increased over the previous century and if the present rate of increase continues, the equivalent CO₂ concentration will double by the middle or the end of 21st century (Loukas et al., 2004). Since the beginning of the 20th century, the atmospheric concentration of carbon dioxide has increased from 280 parts per million by volume (ppmv) to about 395 ppmv. The increase in radiative forcing of the atmosphere results in the warming of the earth’s surface (Meehl et al., 2005).

Unsustainable consumption patterns of the rich industrialised nations are responsible for the threat of climate change. Population of these countries is only the 25% of the global but they emit more than 70% of the total global CO₂ emissions and consume 75 to 80% resources of the world (Parikh et al., 1991). An assessment of the current and projected trends of GHGs emission of India indicates that there was an increase at the rate of 4% per annum during 1990 to 2000 and projected will be three times in 2020, to meet the national developmental needs. The absolute level of GHGs emission in 2020 will be below 5% of global emissions and the per capita emissions will still be lower compared to most of the developed countries as well as the global average (Sharma et al., 2006).

Various changes in the surface temperature, rainfall, evaporation and extreme events have been observed over the period and the global
temperature of the earth has increased by about 0.6°C (Mall et al., 2006). The coincidence of rising temperature with industrial revolution compelled many experts to believe that more than 90% probability of climate change is anthropogenic in nature (Crowley, 2000; De, 2001). However, the rise in surface air temperature was felt to be real in the last two decades (Karl et al., 1993; Easterling et al., 1997).

Global climate models have demonstrated significant impacts on local and regional hydrological regimes (Gleick 1999; Arnell et al., 2001; Arora and Boer 2001). Climate change may increase precipitation and evapotranspiration which will enhance the hydrological cycle. Under these scenarios, glacier melt would shift the snowline upwards, affecting discharge rates and timing (IPCC 1997). With the acceleration of the scientific response to global climate change in recent years, numerous studies are now available which document the sensitivity of streamflow to predicted climate change for river basins on a global scale (Houghton et al., 2001).

Milly et al., (2002) demonstrated that, for the fifteen out of sixteen large basins worldwide, the control 100 year peak volumes are projected to be occurred more frequently as a result of CO₂ quadrupling. Heavy precipitation events show largest increase in the mountainous regions. Increased cold season precipitation in the form of rainfall at the expense of snowfall in the projected warmer climate will result in large increases in high runoff events in the Sierra Nevada river basins (Kim, 2005).

2.2 Trends in climate change

The IPCC’s fourth assessment report (2007) concludes that it is 90-99% likely that the rise in global atmospheric temperature since the mid 19th century has been caused by human activities. The most likely, global average surface temperature increase by the 2020 will be around 1°C relative to the pre-industrial period. The global average temperature of the earth increased by 0.6°C over 20th century. The projected temperature will be 1.8°C to 4.0°C
by the end of 21st century. Over the last 50 years, the rise in temperature was
0.1°C per decade and expected will be 0.2°C per decade. By the end of the
21st century, the most likely increases are 3 to 4°C for the A2 emission
scenario and around 2°C for B1 (IPCC, 2007).

Geographical pattern of projected warming show the greatest
temperature increases at higher northern latitudes and stronger in summer
than in winter except for Arctic latitude. Globally, mean precipitation will
increase due to climate change. Current climate models tend to project
increasing precipitation at high latitudes (e.g., the south-east monsoon region)
and in the tropics and decreasing precipitation in the sub-tropics (Meehl et al.,
2007). A warmer climate will change rainfall and snowfall patterns. The 10

The analysis of meteorological measurements in India indicates large
differences in trends of minimum temperature between North and South.
There is also asymmetry in the increasing temperature trends between
different seasons in a year. These observations along with the occurrences of
extreme weather events lead to the importance of regional climate changes
(Das and Hunt, 2007).

In India, there is increasing trend in surface temperature (Rupakumar
et al., 1994; Pant et al., 1995; Singh et al., 2003). But there is no significant
trend in rainfall (Mooley and Parthasarathy, 1984; Thapliyal and Kulshrestha,
1991; Pant et al., 1999). From the various studies, it was found that the
surface temperature in the Indian region was increased by 0.5°C to 0.6°C
during 1901 to 2005, with considerable regional variations. The projected
ambient temperature will be 2°C to 5°C by the end of 21st century. Studies
show that the heating of atmosphere will not be uniform across the country.
The average annual increase in temperature will be about 1°C. The winters of
North and Northwest India may be more than 2°C warmer by the mid of 21st
century. The monsoon season is likely to be about 1°C warmer, on an average (Lai, 2001).

Warming of the Indian sub-continent by 0.4°C over the period 1901-1982 was reported by Hingane et al. (1985), indicating that this warming since 1900 is broadly consistent with observed global warming over the last century. IPCC (1990) reported that the warming will be between 1 and 2°C by 2030 in the Indian region. Lal and Singh (2001) reported that the average annual mean surface temperature is likely to increase by about 2.7°C and 3.8°C during the decades of 2050s and 2080s, respectively. Moreover, it is likely that over inland regions, the mean surface temperature may rise between 3.5 and 5.5°C by 2080 (Lai, 2001).

On seasonal basis, the projected surface warming is higher in winter than in summer. The increase in annual mean precipitation over the Indian sub-continent is projected to be 7 and 11%, respectively, during the decades of 2050s and 2080s. IPCC (1990) projected that precipitation will change little in winter and will generally increase throughout the region by 5–15% in summer. The spatial distribution of surface warming suggests that north India may experience an annual mean surface warming of 3°C or more by 2050s. GCM models simulate peak warming of 3°C over north and central India in winter.

Simulation studies made by Lal et al. (1992) using Hamburg global coupled-atmosphere-ocean circulation model indicated the possibility of an increase of rainfall in parts of northern India while decrease in rainfall in southern parts of peninsular India. As such under warmer climate, variability in Asian summer monsoon is expected to increase along with changes in the frequency and intensity of extreme climate events in the northern region.

A state-of-art regional climate modeling system, known as PRECIS (Providing Regional Climate for Impacts Studies) is applied for India to develop high-resolution climate change scenarios. PRECIS simulations under
the scenarios of increasing greenhouse gases concentrations indicate the marked increase in both rainfall and temperature towards the end of 21st century. It is also projected that the warming is monotonously wide spread over the country, but there are substantial spatial differences in the rainfall pattern (Rupakumar et al., 2006). PRECIS simulation for 2071-2100 indicates an all round warming over the Indian subcontinent in relation to increasing greenhouse gases concentrations. The annual rise in the mean surface air temperature by the end of century ranges from 3 to 5°C in A2 scenario whereas, the rise lies between 2.5 and 4°C in the B2 scenario. The warming seems to be more pronounced over the northern part (Rupakumar et al., 2006).

An analysis of temperature data of 125 station’s distributed all over India shows an increase of 0.42°C, 0.92°C and 0.09°C in annual mean temperature, mean maximum temperature and mean minimum temperature respectively over the last 100 years. However, the trends are varying on regional basis. It has been observed that the changes in temperature in India over last century are broadly consistent with the global trends (Arora et al., 2005).

In comparison to a modest increase (0.5°C-1.1°C) in global surface air temperature during the 20th century, the northwestern Himalayan (NWH) region has warmed at much higher rate i.e. 1.6°C per 100 years (Pant et al., 1999; Bhutiyani et al., 2007). The increase in air temperature is significantly higher during winter season (1.7°C per 100 years) than monsoon season (0.9°C per 100 years). The winters in the last two decades (1981-2000) have been unusually warm, with a total rise of about 4.4°C in average temperature (Bhutiyani et al., 2007). The rise in winter temperature over western Himalaya demonstrates the changing climate of the region (Pant et al., 2003). There are some evidences which show the changes in the discharges of the Himalayan region. The temperature increase in the Himalayan region has been greater than the global average of 0.74 °C over the last 100 years (IPCC, 2007a).
On regional basis, various studies show the increasing/decreasing trends in rainfall (Rupakumar et al., 1992; Kripalani et al., 1996; Singh et al., 2003). Projected climate changes using the Global Climate Models (GCMs) and Regional Climate Models (RCMs) over India during 21st century generally showed changing patterns in rainfall and increase in temperature (Lal et al., 2001; Rupakumar et al., 2003). The important implications of climate change are expected to be on the hydrological balance and water resources, especially the timing of runoff (Gleick and Chalecki, 1999; Arnell et al., 2001; IPCC, 2001b).

Studies by the Himachal Pradesh Agricultural University, Palampur indicates that the impacts of climate change in the Himachal Pradesh uplands are higher than on the lowlands. From the studies covering over 30 years of records, average air temperatures were found to be 0.7 to 2.4°C higher than that in the 1980s, as against the global average of 0.5°C; the Himachal Pradesh trend indicates an increase of 0.06°C per year (ADB, 2010). Land surface temperature and its lapse rate were determined in the Satluj River Basin using National Oceanic and Atmospheric Administration/Advanced Very High Resolution Radiometer (NOAA/AVHRR). The determined TLRs for the study area were in range of 0.6-0.74°C/100m but the calculated using air temperature from meteorological stations for the Western Himalayan region was found to be 0.65°C/100m. Such study will be useful for snowmelt runoff modeling for the Himalayan region (Jain et al., 2008).

2.3 Climate change and hydro-meteorological disasters

Global climate changes induced by increases in greenhouse gases concentrations are likely to increase temperatures, change precipitation patterns and probably raise the frequency of extreme events (IPCC, 2001a). It is likely that global climate change will lead to increased climatic variability, thus affecting the frequency and magnitude of extreme events. This would lead to an increased risk of natural disasters (Becker and Bugmann, 1997). A warmer climate, with its increased climatic variability, will increase the risk of
both floods and droughts (Wetherald and Manabe, 2002). The changes in the hydrological cycle under conditions of enhanced global warming are likely to be complex and spatially diverse (Beare and Heaney, 2002).

The climate change is expected to cause an intensification of the global water cycle (Cubasch, 2001) with a consequent increase in flood risk (White et al., 2001). This implies higher rates of evaporation, and a greater proportion of liquid to solid precipitation. These physical mechanisms, associated with potential changes in precipitation amount and seasonality, will affect the frequency of flood episodes (Beniston, 2003). One of the most significant potential consequences of changes in climate may be alterations in regional hydrological cycles and subsequent changes in the river quantity and quality regimes (Xu, 2000). The changes in temperature, amount and distribution of precipitation and other climatic parameters are expected to have significant implications on the hydrologic balance and water resources (Loukas et al., 2004). An increase in heavy precipitation might lead to an over-proportional increase in runoff due to non-linear processes (Ashagrie et al., 2006).

In view of climate change it is necessary to integrate knowledge about catchment characteristics, the prevailing flood regime and the trends of weather patterns in the estimation of extreme events (Petrow et al., 2007). The spatial and temporal variations of snow cover distribution and snowmelt runoff are considered as sensitive indicators for climatic change (Wang et al., 2010). The flash flood hazards are expected to increase in frequency and severity in many areas of world, through the impacts of global change on climate and river discharge conditions (Marchi et al., 2010). Hydrological extremes are expected to become more common in a changing climate (Kundzewicz et al., 2007).

The projected general increase in flood magnitude and frequency is a consequence of projected general increase in the frequency of heavy precipitation events, although the effect of given change in precipitation depends upon the characteristics of catchment area (IPCC, 2001b). Climate
change will affect not only changes in the precipitation amount and its proportion of rain and snow but also the spatial distribution of precipitation (Loukas et al., 2002). It was observed that the extent of snow cover decreased by 10% since late 1960s (IPCC, 2001a). Under the warmer climate, the amount of precipitation in the form of snowfall will reduce, resulting in the decrease of snow accumulation (Singh and Bengtsson, 2005).

In India, a river is said to be in flood when its water level crosses the Danger Level (D.L.) at that particular site. Generally, danger levels are 1 m above the Warning Level (W.L.). According to Dhar and Nandargi (2003), flood classification system based on danger level is given in Table below:

**Table 2.1 Flood classification system**

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Water level above Danger Level</th>
<th>Nature of flood</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt;= 1m</td>
<td>Major flood</td>
</tr>
<tr>
<td>2</td>
<td>&gt;= 5m</td>
<td>Severe flood</td>
</tr>
<tr>
<td>3</td>
<td>&gt;= 10m</td>
<td>Devastating flood</td>
</tr>
</tbody>
</table>

(Source: Dhar and Nandargi, 2003)

2.4 Climate change, precipitation and flooding pattern

Nevertheless, global climate models claim that climate change would drive up extreme precipitation and river discharge (Nijssen et al., 2001). Global warming is expected to significantly affect the runoff regime of mountainous catchments (Huss et al., 2010). Identifying relationships between large-scale climatic circulation, and river basin-scale precipitation and discharge provides insight into understanding the hydro-climatological processes (Kingston et al., 2009). Glacial melt is expected to increase under changed climatic conditions which could lead to increased summer flows in some river systems, for a few decades, followed by a reduction in flow as the glaciers may disappear (IPCC, 2007b).
Floods can be caused by intense and/or long lasting precipitation, snowmelt and landslides built dam break. Floods depend on precipitation intensity, volume, timing, antecedent conditions of rivers and their drainage basins. The frequency of severe floods in large river basins has increased substantially during the 20th century. The emergence of statistically significant positive trends in risk of floods which are consistent with the climate model results and the model suggests that the trend will continue (Milly et al., 2002). Flood magnitude and frequency are likely to increase in most regions (Arnell et al., 2001). The flooded area in Bangladesh is projected to increase at least by 23-29% with a global temperature rise of 2°C (Mirza, 2003). Up to 20% of the world's population lives in river basins that are likely to be affected by increased flood hazard by the 2080s in the course of global warming (Kleinen and Petschel-Held, 2007).

The atmospheric warming and changes in land use/land cover may exacerbate future flooding by altering river regimes in the direction of large runoff volumes and shorter low water to flood peak intervals (Mitchell, 2003). The impacts of most extremes are typically felt at a local or regional scale; so regional studies of climate extremes are of the highest priority for most countries for assessing potential climate impacts.

The shifting pattern of precipitation may affect the spatial and temporal distribution of runoff, and may increase the intensity and frequency of hydro-meteorological hazards. The projections indicate that there would be changes in the variability of climate from region to region, and changes in the frequency and intensity of some extreme climatic phenomenon. The flood magnitude and frequency are likely to increase in most regions.

There is wide spread concern regarding the weakening of the Indian summer monsoon (Ramesh and Goswami, 2007) and possible increase in the number and intensity of heavy rainfall events in response to global warming (James and Ericksen, 1992; Palmer and Raisanen, 2002). Some studies indicated that there will be decline in monsoon rainfall over the North and
central plains of India in the decades ahead because of general weakening of monsoons. This might be due to decrease in land-sea thermal gradient (Lai et al., 2001).

Against a backdrop of rising global surface temperature, the stability of the Indian monsoon rainfall over the past century has been a puzzle. By using a daily rainfall data set, it was shown that (i) a significant rising trends in the frequency and the magnitude of extreme rain events and (ii) a significant decreasing trend in the frequency of moderate events over central India during the monsoon seasons from 1951 to 2000. The seasonal mean rainfall does not show a significant trend, because the contribution from increasing heavy rainfall events is offset by decreasing moderate events. A substantial increase in hazards related to heavy rain is expected over central India in the future (Goswami et al., 2006).

The impact of future climate change on Indian summer monsoon using a super high resolution Global General Circulation Model (GCM) showed the spatially varying increase in rainfall over the interior regions. The model also projected the substantial, spatially heterogeneous increase in both extreme hot and heavy rainfall events over most parts of India by the end of the 21st century (Rajendran and Kitoh, 2008). Most models project enhanced precipitation during the monsoon season, particularly over the northwestern part of India. As far as the temperature trends are concerned, all the models show positive trends indicating widespread warming in future. The different experiments generally indicate that the increase of temperature would be the order of 2-5°C across the country (Rupakumar et al., 2006).

The enhanced surface warming over the Indian subcontinent by the end of 21st century would result in an increase in pre-monsoonal and monsoonal rainfall and no substantial change in winter rainfall over the central plains. This would result in an increase in the monsoonal and annual runoff in the central plains, with no substantial change in winter runoff (Lal and Chander, 1993). It is only a spell of heavy rains which may last for a period of
several hours to few days that generates large runoff in the catchment areas of rivers (Kale, 1998).

Recent studies have reported increases in precipitation across the Indian sub-continent. These increases have been observed over a range of precipitation intensities, and particularly as heavy and extreme. This has led to extreme hydrological events, particularly floods, may be increasing in frequency and/or magnitude as well. The basis for this is related to climate change, as the increasing temperatures will accelerate the hydrologic cycle and increase the occurrence of hydro-meteorological events. One of the anticipated effects of climate change is the possible increase in both frequency and intensity of extreme weather events.

In India, on an average, the area actually affected by floods every year is 10 million hectares out of the total area prone to floods i.e. 40 million hectares. Several recent studies suggest an increase in the inter-annual variability of daily precipitation in the Asian summer monsoon with increasing atmospheric concentration of greenhouse gases. The intensity of extreme rainfall events over the Indian sub-continent is likely to be higher in future as a consequence of increased convective activities during the summer monsoon period, thereby suggesting the possibility of more frequent flash floods in parts of India (Chaskar and Verma, 2006).

The increase in rainfall during monsoon, as well as increases in the magnitude of extreme rainfall events, both of which have been projected with climate change, is expected to increase the frequency and intensity of floods (Lal et al., 2001). Climate change is likely to affect the hydrological cycle which will result in more rainfall in lesser time; decrease in number of rainy days; overall increase in precipitation; increased glacial melt runoff initially and then afterwards decrease; increase in flood events particularly of flash floods; increase in drought like situations and increase in landslide events in hilly areas (MoWR, 2008). Damages from weather related disasters are
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projected to increase, due to a combination of increasing exposure of people and assets, and expected changes in the global climate (Bouwer et al., 2010).

2.5 Climate change impacts on Himalayan Region

Climate change is affecting the temperatures, amount of snow and ice in the Himalayan region as well as rainfall patterns in the densely populated downstream regions. Causes for climate change over the Himalayas include aerosols with black carbon and dust, deforestation, forest fires, human-induced pollution and many other anthropogenic activities besides the emission of greenhouse gases (UNEP, 2009).

Climate change has impacted the glacial ecosystem tremendously. 67% of the glaciers are retreating at an astonishing rate in the Himalayas and the major causal factor has been identified as climate change (Ageta and Kadota, 1992; Yamada et al., 1992; Fushimi, 2000). Glacial melt will affect the flow of rivers with dramatic adverse affects and possible long-term implication at regional scale. The impact of climate change on river morphology identified a complex series of interactions between the physical processes.

Direct climate change impacts are on intensity, duration and frequency of precipitation, leading to change in runoff. The indirect impacts of climate change are through precipitation, temperature and wind affecting land surface cover and erosion (Goudie and Huntington, 1999). Global warming and its impact on the hydrological cycle and nature of hydrological events have posed an additional threat to Himalayan mountain region. Extreme precipitation events have geomorphic significance where they may cause wide spread slope failures (Ives and Messerli, 1989).

The precipitation in the northwestern Himalayan region more or less remained trendless during 20th century. The variations in both temperature and rainfall are translated into changes in the hydrological regimes of river basins by way of variability in snow melt runoff, glacier melting and monsoon runoff and increase or decrease average annual and annual peak flood
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discharges (Bhutiyani et al., 2008). The melting of the Himalayan glaciers as a result of the rise in the earth’s temperature will first increase the drainage into the major river systems, followed by reduction in their volumes once the glaciers begin to disappear. It is projected that some of the mightiest Himalayan Rivers might end up as seasonal, monsoon-fed rivers like those in southern India (Pai, 2008).

Numerous studies have been carried out in the Himalayan region to find the linkage between climate change and shrinkage of glaciers. These studies indicate that most of the glaciers are retreating discontinuously with subsequent increase in runoff of Himalayan Rivers. Change in glaciers and snow cover pattern can be considered as the direct indicators of rise in temperature. Various reports suggest that a significant number of Himalayan glaciers are retreating due to climate change. Few studies have been conducted to quantify the snow and glacier contribution to the flow of Himalayan Rivers. The glaciers are considered as the best recorders of climate change. The climatic variability in the glaciated region is best reflected by the depletion in snow cover, volume and snout fluctuation. Shift of snowline towards higher altitude will result in lesser input to glacier mass balance during summer months. With the retreating of glaciers in the higher reaches, considerable changes have occurred in the hydrological system of river.

Many rivers draining glaciated regions are sustained by glacier melt during the summer season (Singh and Kumar, 1997; Mark and Seltzer, 2003; Singh, 2003; Barnett et al., 2005). Higher temperature generates increased flow from glacier melt. As the glaciers retreat due to global warming, river flows are increased in the short term, but the contribution of the glacier melt will gradually decrease over the next few decades.

The Himalayan glaciers form the largest body of ice outside the polar caps with nearly 10,000 glaciers. Undoubtedly, the glaciers are retreating due to climate change, but not at a catastrophic rate that disappear in near future (Jain, 2008). Himalayan glaciers have been in a state of retreat since 1850.
(Mayewski and Jeschke, 1979) and many confirmed that the rate of retreat is accelerating. But a dramatic increase in the rate seems to have occurred in the last three decades. The immediate responses of dynamic glaciers to weather make them an important indicator of climate change. So it is climate change which seems to be the key factor influencing the glacio-hydrological characteristics of the Himalayan glaciers in the recent years (Kulkarni 2001; Hasnain, 2002). The retreat of glaciers might affect the runoff of the streams originating from these areas (Bahuguna et al., 2004). The fast recession of Himalayan glaciers would lead to ecological imbalance with the threatening of water balance in the region.

Greater melting of glaciers during the coming years could influence water flows in the Himalayan Rivers. The water resources of the Himalayan region may be highly vulnerable to climate change, because more than 50% of the discharge in the various tributaries of the Ganges, Indus and the Brahmaputra river system are highly dependent on snow and glacier melting (Singh et al., 2006). The quantity of surface runoff due to climate change would vary across the river basins as well as sub-basins in India. However, there is general reduction in the quantity of the available runoff (Gosain and Rao, 2004). Arora et al. (2003) projected an increase in discharge in the Chenab River with increase in rainfall at higher altitudes. The study on the impact of plausible hypothetical scenarios of temperature and rainfall on the melt characteristics and daily runoff of the Chenab river basin shows that the melt is much more sensitive to increase in temperature than to rainfall (Arora et al., 2008).

For the range of climatic scenarios, the changes in runoff of the Himalayan Basin are more sensitive to changes in temperature, compared to rainfall which is likely due to the major contribution of snow and glacier melt water in runoff (Singh et al., 2006). As global warming continues to increase the atmospheric temperature, it will lead to a continuous shift to snow line towards higher altitude of the Himalayas. Thus the glaciated region will receive more rainfall and less solid precipitation in the form of snow. This will
lead to rapid retreat of glaciers and downstream flooding in the coming future (Hasnain, 2002). The enhanced rate of retreating of glaciers is attributed to the increased anthropogenic contribution to climate change on account of greenhouse gas emissions.

A vast area of the Himalayan river basins is covered by snow during winter (Singh et al., 1997a; Singh and Jain, 2002), making it highly vulnerable to climate change. Warming of the Indian sub-continent by 0.4°C over the period 1901-1982 has been reported by Hingane et al. (1985). Lal et al. (1992) studied the impact of increasing greenhouse gases concentrations on the climate of the Indian sub-continent and reported an increase of over 2°C over the monsoon region in the next 100 years.

The Himalayan glaciers are receding at an accelerating rate, currently at 10-15 meters per year on an average. The rapid melting will first increase the volume of water in rivers, causing widespread floods. But in few decades, this situation will change and the water level in the rivers will decline (WWF, 2005). The global warming has led to receding of most glaciers in the mountainous region such as the Himalayas, substantially during the 20th century. The mapping of Himalayan glaciers with reference to 1962 as benchmark showed that about 67% glaciers have shown retreating trends (Kulkarni et al., 2005). This has influenced the stream runoff of the Himalayan Rivers (Kulkarni et al., 2002).

The shrinking of glaciers is accompanied by the formation of unstable glacial lakes that threaten downstream areas with outburst floods (UNEP, 2007). Glacial Lake Outburst Floods (GLOF) are one of the most immediate and visibly dramatic effects of climate change in the Himalayan region. The frequency of the occurrence of GLOF events has increased in the second half of the 20th century (WWF, 2008). In the Himalayan region, the glacial lakes are increasing in number and volume due to thinning and recession of glaciers (Mool et al., 2001).
The glaciers in the Himalayan region are retreating in the face of accelerating global warming which result in formation of lakes and their subsequent breaching due to instability of dam. The impact of these Glacial Lake Outburst Floods (GLOF) in downstream are quite extensive in terms of damage to roads, bridges, trekking trails, villages and agricultural lands along with great loss of human and animals lives (Bajracharya et al., 2006). The increase in atmospheric average temperature will have the direct impact on retreating of glaciers and formation of glacial lakes in Hindu Kush Himalayan (HKH) region.

The glaciers of HKH region are retreating at high pace and as a result, the formation of glacial lakes are increasing in number and size with the potential increase in glacial lake outburst flood events (Bajracharya et al., 2006). In addition more melting is expected to increase the frequency of catastrophic events such as glacier lake outburst floods (GLOF) that have devastating consequences for civil works like bridges, dams and powerhouses, and communities living at downstream. Also, the increase in phenomena such as cloudbursts is widely noted.

Using remote sensing data to investigate glacier thickness changes in the Himachal Pradesh, Western Himalaya, Berthier et al. (2007) found an annual ice thickness loss of about 0.8 meters water equivalent (m.w.e.) per year between 1999 and 2004, about twice the long-term rate of the period 1977-1999 (UNEP and WGMS 2008). Due to climate change, there is increase in flooding events, resulting from excessive rainfall within a short duration of time and excessive melting of glaciers and consequent high river discharge (Sanyal and Lu, 2004).

High-magnitude rainfall events in the Himalaya are responsible for mass movement on slopes which block the rivers that cause massive floods when failure. Numerous examples of breach floods have been recorded on many Himalayan rivers such as Indus, Satluj, Bhagirathi, Alaknanda etc. (Wohl and Cenderelli, 1998). Scientific projections indicate that the magnitude
and frequency of flash floods in the great Himalayan region may increase in the future as a result of change in climate and its variability (Lhasa Declaration, 2006). The frequency of extreme rainfall events in the highly vulnerable and fragile environment of Himalaya is increasing in late monsoon season due to possible climate change which proves to be highly disastrous (Joshi and Kumar, 2006).

2.6 Snowfields and glaciers in Satluj River Basin

The total area under glaciers and permanent snowfields was calculated to be 2,697 km$^2$ in which there are 334 glaciers in the Satluj Basin covering an area of nearly 1,515 km$^2$ and 1,987 permanent snowfields covering an area of about 1,182 km$^2$. The permanent snow cover and glaciers are distributed in 169 sub basins. 164 deglaciated valleys could be mapped in the Satluj Basin covering an area of 133 km$^2$ (Kulkarni et al., 1999).

Table 2.2 Distribution of glaciers and snow fields in Satluj River Basin and sub-basins of its main tributaries.

<table>
<thead>
<tr>
<th>Basin name</th>
<th>No. of glaciers</th>
<th>Aerial extent (Km$^2$)</th>
<th>No. of snow fields</th>
<th>Aerial extent (Km$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satluj</td>
<td>151</td>
<td>616.299</td>
<td>857</td>
<td>544.173</td>
</tr>
<tr>
<td>Spiti</td>
<td>71</td>
<td>258.237</td>
<td>597</td>
<td>368.366</td>
</tr>
<tr>
<td>Baspa</td>
<td>25</td>
<td>203.300</td>
<td>66</td>
<td>64.964</td>
</tr>
</tbody>
</table>

(Source: Kulkarni et al., 1999)

The major contribution to the stream flow occurs in the months of July and August due to melting of snow cover present on glaciers (Dobhal and Kumar, 1996). The inventory of Himalayan glaciers prepared by Kaul (1999) shows that the Satluj River Basin has 224 glaciers, having an area of 420 Km$^2$ and ice volume of 23 Km$^3$. Only about 11% area of total catchment of Satluj River is covered by glaciers (Upadhyay et al., 1983). Satluj River has the
mountainous area of about 47,915 Km² and the area covered under the glaciers is 1,295 Km² (UNEP, 2009).

Table 2.3 Distribution of glaciers in the Satluj River Basin on the basis of their aerial extent.

<table>
<thead>
<tr>
<th>Aerial range (Km²)</th>
<th>No. of glaciers</th>
<th>Total area of glaciers (Km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.5</td>
<td>41</td>
<td>10.254</td>
</tr>
<tr>
<td>0.5-1.0</td>
<td>47</td>
<td>37.167</td>
</tr>
<tr>
<td>1.0-2.0</td>
<td>75</td>
<td>108.641</td>
</tr>
<tr>
<td>2.0-5.0</td>
<td>92</td>
<td>296.208</td>
</tr>
<tr>
<td>5.0-10.0</td>
<td>51</td>
<td>377.649</td>
</tr>
<tr>
<td>&gt; 10.0</td>
<td>28</td>
<td>687.202</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>334</strong></td>
<td><strong>1517.121</strong></td>
</tr>
</tbody>
</table>

(Source: Kulkarni et al., 1999)

The total numbers of glaciers in Satluj River Basin are 945 with the total area of 1,217 Km² and ice reserve of 94 Km³. The Govind Sagar Reservoir (Bhakra Dam) in the Satluj River stores 6,900 million m³ water (ADB, 2010). Glaciers in Satluj Basin are 55, covering an aerial extent of 154.762 Km² and total number of permanent snowfields are 194 covering aerial extent of 110.843 Km² (SCST & E, 2009). On an average about 14,498 Km² (65%) of the total drainage area of the Satluj River up to Bhakra Dam is covered by snow in the month of March. About 4,528 Km² (20.3%) remains covered by perpetual snow and glaciers in the month of September. However the range of seasonal snow covered area and permanent snow covered areas varied between 58 to 72% and 12 to 35% respectively. It shows that a major portion of the basin is covered by snow in the month of March and on an
average about 9,970 Km² area become snow free during the melt season (NIH, 1998-99).

2.7 Climate change and Satluj River Basin

The contribution of snow and glaciers melt to the annual flow of Satluj River was recorded as 49.10%. 80% of the annual flow occurs between May and September (Sharma et al., 1991) and the snow/glacier melt contribution is about 59% at Bhakra dam (Singh and Jain, 2002). A critical region is the Western Himalaya where a modeling study for the Satluj River Basin by Singh and Jain (2003) suggests that about 75% of the summer runoff is generated from snowmelt.

Singh and Kumar (1997) studied the effect of climate change on snow water equivalent, snow melt runoff, total stream flow and their distribution for a high altitude Spiti River, in the Western Himalayan region. The results of the simulation of the hydrological response of the basin under changed climatic scenarios showed that the snow melt runoff, glacier melt runoff and total stream flow for the high altitude Himalayan Basin increased linearly with changes in temperature, but the most prominent effect of increase in temperature was noticed on glacier melt runoff. The effect of change in precipitation suggested a linear increase in snow melt runoff and total stream flow, while, in general, glacier melt runoff is inversely related to changes in precipitation.

Singh and Kumar (1997b) studied the precipitation distribution with altitude for the Satluj and Beas Basins in the western Himalayas. Rainfall increases linearly with the elevation for both basins in the outer Himalayan region. Different trends of rainfall variation with elevation are observed in different seasons in the middle Himalayan range with a linear increase in annual rainfall. Rainfall follows an exponential decreasing trend with altitude in the greater Himalayan range. In the greater Himalayas, average annual rainfall is about one-sixth of the outer Himalayas rainfall in the Satluj Basin.
Extrapolation of the relationship indicates that snow and rain contribute equally at about 2,000 m, and all precipitation occurs as snow above 5,000 m. Singh and Jain (2002) have reported that annual flow of the study basin is about 550 mm, in which about 60% contribution derived is from the melting of snow and glaciers. The mean annual rainfall in the outer, middle and greater Himalayan ranges of the basin is about 1,300, 700 and 200 mm respectively (Singh and Kumar, 1997b).

Singh et al. (2003) investigated the effect of warmer climate on the depletion of snow-covered area for the Satluj River Basin located in the western Himalayan region. In order to study the impact of three warming scenarios (T+1, T+2 and T+3° C), more than 160 new snow depletion curves were prepared for different elevation zones of the basin over the study period of nine years (1985/86-1990/91 and 1996/97-1998/99). The impact of warmer climate on accelerating the depletion of snow-covered area is found to be higher in the early and late parts of the ablation season. Singh and Bengtsson (2005) studied the impact of warmer climate on melting and evaporation for rainfed, snowfed and glacierfed basins located in the western Himalayan region. Hydrological processes were simulated under current climatic conditions using a conceptual hydrological model which accounts for the rainfall-runoff, evaporation losses, snow and glacier melt.

Based on the future projected climatic scenarios in the study region, three temperature scenarios (T+1, T+2 and T+3° C) were adopted for quantifying the effect of warmer climate. The comparison of the effect of warmer climate on different types of basins indicated that the increase in evaporation was the maximum for snowfed basins. For a T+2° C scenario the annual evaporation for the rainfed basins increased by about 12% whereas for the snowfed basins it increased by about 24%. The high increase of the evaporation losses will reduce the runoff.

It was found that under a warmer climate, melt was reduced from snowfed basins, but increased from glacierfed basins. For a T+2° C scenario,
annual melt was reduced by about 18% for the studied snowfed basin, while it increased by about 33% for the glacierfed basin. Thus, Impact of warmer climate on the melt from the snowfed and glacierfed basins was opposite to each other. The study suggests that out of three types of basin, snowfed basins are more sensitive in terms of reduction in water availability due to a compound effect of increase in evaporation and decrease in melt. The water availability from the complex basins will be reduced on long-term basis, when the areal extent of glaciers will decrease due to higher melt rate at initial stages.

Singh and Kumar (1997) examined the affect of climate change on snow water equivalent, snowmelt runoff, glacier melt runoff and total streamflow and their distribution for the Spiti River. The total streamflow of this river has a significant contribution from snow and glacier melt runoff. Snow water equivalent reduces with an increase in air temperature. However, no significant change is found in the snow water equivalent of the Spiti Basin by the projected increase in air temperature. An increase of 2°C in air temperature reduced annual snow water equivalent in the range of 1 to 7%. Changes in precipitation caused proportional changes in snow water equivalent.

It is found that annual snowmelt runoff, glacier melt runoff and total streamflow increase linearly with changes in temperature (1-3°C), but the most prominent effect of increase in temperature has been noticed on glacier melt runoff for this high altitude. For example, an increase of 2°C in air temperature has enhanced annual snowmelt runoff, glacier melt runoff and total streamflow in the range of 4-18%, 33-38% and 6-12% respectively. The effect of change in precipitation (P-10 to P+10%) suggests a linear increase in snowmelt runoff and total streamflow, while in general, glacier melt runoff is inversely related to changes in precipitation. Snowmelt runoff is found more sensitive than glacier melt runoff to changes in precipitation (P-10 to P+10%). Under a warmer climate scenario, snowmelt runoff and glacier melt runoff cause an earlier response of the total streamflow and a change in flow and a
change in flow distribution. The seasonal analysis of total streamflow indicates that an air temperature produces an increase in the pre-monsoon season followed by an increase in the monsoon season.

Singh and Bengtsson (2004) investigated the sensitivity of water availability to climate change for the Satluj River Basin which receives contributions from rain, snow and glacier melt runoff. About 65% of the basin area is covered with snow during winter which reduces to about 11% after the ablation period. The hydrological response of the basin was simulated using different climatic scenarios over a period of 9 years. Adopted plausible climate scenarios included three temperature scenarios (T+1, T+2, T+3° C) and four rainfall scenarios (P-10, P-5, P+5 and P+10%).

Under warmer climate, a typical feature of the study basin was found to be reduction in melt from the lower part of the basin owing to a reduction in snow covered area and shortening of the summer melting season and, in contrast, an increase in the melt from the glacierized part owing to larger melt and an extended ablation period. Thus, on the basin scale, reduction in melt from the lower part was counteracted by: the increase from melt from upper part of the basin, resulting in a decrease in the magnitude of change in annual melt runoff. The impact of climate change was found to be more prominent on seasonal rather than annual water availability. Reduction of water availability during the summer period which contributes about 60% to the annual flow, may have severe implications on the water resources of the region.

Precipitation distribution with elevation for Satluj Basin has been studied by Singh and Kumar (1997). Examination of rainfall distribution in the Satluj reveals a distinct pattern for the outer, middle and greater Himalayan ranges. Snow distribution with altitude also has been studied for the greater Himalayan range of Satluj Basin.

The important conclusions drawn from the study carried in the Satluj River Basin by Singh and Kumar (1997) as follows:
The rainfall distribution with altitude on the leeward side of outer Himalayas has shown that annual rainfall increases linearly with elevation. It was observed that rainfall on the windward side is higher than leeward side. Both higher number of rainy days and high rainfall intensity are found responsible to increase rainfall with altitude in this range.

Rainfall analysis has revealed that there is little rainfall in the greater Himalayan range. It is because most of the moisture of monsoons is precipitated over outer and middle Himalayan range. Rainfall variation with altitude has shown that it exponentially decreases with elevation in the post monsoon and pre monsoon seasons. Rainfall distribution in the monsoon season has shown no specific decreasing trend. Winter season rainfall decreases linearly with elevation. Negligible rainfall is observed above 3,000m elevation.

It was observed that orographic effect has led to maximum rainfall in the Himalayan range. Average annual rainfall decreases considerably from the outer to middle Himalayan range and further drastically reduced in the greater Himalayan range. Contribution of seasonal rainfall to annual rainfall has shown that over all the ranges in the Satluj basin, monsoon rainfall contributed maximum to the annual rainfall which is 45-71%. Minimum rainfall is experienced in the post monsoon season in the outer and middle Himalayas because of less moisture content availability. In the greater Himalayan range minimum rainfall is experienced in the winter season because most of the precipitation falls in the form of snow. Contribution of pre monsoon rainfall increases from outer Himalayas to greater Himalayas and becomes significant there.

Snowfall has shown different trends of increase with elevation in different parts of Satluj Basin. Snow increases linearly with elevation in the Spiti and Baspa Basins whereas for the upper sub-basin it first increases and then decreases.
In the greater Himalayas, the ratio of snowfall to annual precipitation varies linearly with altitude. An extrapolation of this linear relationship indicated that above 6,000m elevation, whatever precipitation occurs may be falling as snow.

Temporal variability in discharge is an outstanding feature of the Himalayan Rivers. The snow melt contribution in the river flow starts from about mid of March and lasts until June/July depending upon the snowpack water equivalent accumulated in the preceding winter season and prevailing temperature in the summer season. The glacier melt runoff contribution starts from July when glaciers are becoming snow free and continue till September/October. In the annual flow of the Satluj River, a substantial contribution is provided by snow and glacier melt runoff.

During pre monsoon season, after middle of March, snowmelt exceeds the rainfall component which leads to a significant rise in the gradient of river runoff. Snowmelt contribution increases continuously as the season advances. During monsoon season, flow is augmented by monsoon rains to produce higher discharge and occasional peak floods. In the post monsoon season, flow is believed to be from the glaciers and occasional rainfall in the region. Glacier melt runoff in the stream coincides with the monsoon period. Thus, glacier melt runoff from the higher reaches and high runoff from the rain in the lower and middle part of the basin occurs between July and September. Peak values of total discharge in July and August are essentially due to rainfall in the lower part of the basin. Flooding in the middle and lower reaches of the river is from the excessive rainfall and snowmelt. During winter season, snowmelt contribution is less than rainfall runoff.

The catchment area is fed by western disturbances in the form of winter precipitation comprising snowfall at high altitude and rainfall in the lower catchment area. The main snowfall period for Satluj catchment is from December to March and sometimes extending from October to April. Due to large differences in seasonal temperature and
great range of elevation variation in the catchment, the snowline changes its position considerably.

- Based on 25 years (1986-2010) flow data analysis, the average quarterly distribution of the annual flow volumes from Indian part of Satluj River at Bhakra Dam (also calculated for other gauge sites) has been computed. Higher contribution from pre monsoon season and monsoon season into annual flow are because of contribution of rain, snow and glacier melt runoff.

It was found that the average contribution of snow and glacier runoff in the annual flow of the Satluj River at Bhakra Dam is about 59% and the remaining 41% being from rain. It was observed that on an average about 65% area of the basin is covered with snow in the month of March/April which reduces to about 20% in the month of September/October (Singh and Jain, 2002). So the majority of the streamflow in the Satluj River is generated from snow melt and glacial melt. Even during the monsoon period, significant amount of this melt is available from the high altitude region. Based on 10 years (October 1986- September 1996) of data analysis, it was found that about 65% (14,498 km²) of the total basin area of Satluj River (22,305 km²) is covered by snow by March/April and after the melt season; it reduces to 20.3% (4,528 km²). It indicates that about 9,970 km² area becomes snow free during the melt season (Singh and Jain, 2002).

The discharge data of river Satluj at Khab indicate that the discharge is highly variable and the average daily discharge fluctuates between 7.49 m³/s and 27.48 m³/s during January-March, it begin to rise from the end of April or beginning of May and reaches at maximum level of about 200 m³/s during July-August and then recede during September-December. The maximum daily discharge recorded is 207 m³/s during July and the minimum is 7.5 m³/s during February (Gupta and Sah, 2008). The flow in the Satluj River typically range from about 70-130 m³/s in the winter to 400-1500 m³/s in the summer at Rampur. Much of flow is derived from glacial and snow melt as the upper reaches are not affected by monsoons. But the downstream from Karchham,
the flow is affected by monsoonal rainfall which typically occurs from early July to late August (Kumar et al., 2006).

The maximum flow in Satluj River occurs during June-August resulting from combined contribution of rainfall and snowmelt. Three floods that submerged the entire Satluj Basin in 1997, 2000 and 2005 have affected the Satluj catchment area immensely. It not only led to damages in the area but the entire topography has also changed with heavy erosion of the riverbanks. During last 12 years (1991-2003) nearly 36 major cloudbursts and flash floods have been recorded (CIA, 2006). The analysis of rainfall and runoff data revealed that the flow of water is declining at Harke wetland, at the confluence of Beas and Satluj River (Jain et al., 2008).

The seasonal variations in precipitation have consequences for discharge formation in the Satluj River. There exists a transitional zone between a lower-elevated rainfall zone and a higher-elevated snowfall dominated zone. This transitional zone between 1.2 and 1.6 km, Sutlej-river elevation receives considerable amounts of summer rainfall (~1 m/yr) as well as large amounts of snow and glacier melt. It sustains high, melt-derived discharge throughout the ablation season (May to September). In the higher-elevated snowfall zone (upstream of 2 km Sutlej-river elevation) snowmelt contributes 80 to 90% of the mean annual discharge in tributary catchments, while glacial melts account for 10 to 20% of their annual budget. The transition zone is likely to have reacted sensitively to past climatic variation. This increases the likelihood of future natural hazards such as landslides or floods (Wolf et al., 2008).

There was significant number of high magnitude flood events in the rivers of NWH during 20th century with high frequency in the last 4-5 decades. All ten flood events in the Satluj River have occurred in this time span. During this century, majority of years have shown above average annual temperature index values, indicating a direct relationship between climate change and annual flood discharges (Bhutiyani et al., 2008). In Satluj River Basin, a shift
of the climatic patterns in the form of large area falling under the influence of rainfall was observed. The valley was devastated many times by number of cloudbursts along with two major flash flood events due to breaching of landslide generated lakes in the Tibetan Plateau during 2000 and 2005 (Gupta and Sah, 2008).

It has been observed that there is increase in the frequency of landslide associated flash floods in the present day climatic scenarios. This trend could possibly related to the high discharge in the river due to melting of glaciers by the effect of climate change and by the shifting of climatic trends in the form of precipitation towards upstream. Precipitation data indicate that in the semi-arid to arid temperate zone, the amount of rainfall has increased while in sub-humid to humid temperate zone, high intensity rainfall and cloud burst phenomenon are quite frequent, making the entire area highly vulnerable to hazards, especially floods and landslides (Gupta and Sah, 2006).

Floods are most devastating natural disaster in the area of Satluj river causing huge loss in terms of human lives, infrastructure loss, investment loss in the form of failure of hydro power projects, loss of agriculture etc. The frequency of floods has increased in the past few years. Climate change phenomenon compounds the existing challenge in managing the flood loss (CIA, 2006). Singh and Ouick (1993) carried out stream flow simulation for the Satluj River using the University of British Columbia (UBC) watershed model and concluded that spatial distribution of precipitation is the most important factor in stream flow simulation.

As glaciers retreat, glacial lakes are formed and rapid accumulation can lead to a sudden breaching of the unstable dam behind which they have formed. The resultant discharges of very large amounts of water and debris, a glacial lake outburst flood (GLOF) often have catastrophic effects downstream. Over the last half century, many glacial lakes and the related floods are known to have formed in the IHRR. The catastrophic flood events
from a GLOF in the Satluj Basin in the last few years raised awareness about the problem considerably (ADB, 2010).

The Satluj River is prone to extreme flash floods resulting from localized cloud bursts, failure of debris dams or sudden glacial melt. As a result a flood warning system is needed to measure, transmit and forecast water levels in order to assist in flood mitigation. Through a collaborative effort of several government agencies in India and the United States of America, a pilot flood warning system is being implemented for the upper basin of river (Kumar et al., 2006).

The Satluj River Flash Flood and Mitigation Project have developed a prototype flash-flood warning system for the upper Satluj. Flow monitoring of the Satluj at Rampur shows the flows to be very bi-model, ranging from 70-130 m³/sec in winter to 400-1500 m³/sec in summer. The upper part of the Satluj is not affected by monsoon rains but the lower part is, resulting in extreme peak flows. The estimated peak discharge at Rampur was about 5000 m³/sec (more than twice any peak measured at the site over 28 years from 1972 to 2000) (ADB, 2010). The most flood prone areas in the state of Himachal Pradesh are in the basins of Satluj and Beas Rivers (Sharma, 2006).

2.8 Miscellaneous

In spite of the uncertainties about the precise magnitude of climate change and its possible impacts on the water resources of India, particularly on regional scales, mitigation and adaptation measures must be taken to anticipate, prevent or minimize the causes and adverse effects of climate change. Risk and associated vulnerability towards flood hazards arise from the inherent variability of geophysical processes and changes in complex socioeconomic factors. Most of these catastrophic events were caused by unusually intense precipitation in mountainous areas (Kaczmarek, 2003).
Future flood damages will depend heavily on settlement patterns, land use decisions, the quality of flood forecasting, warning, response systems, the value of structures and other property located in vulnerable areas (Pielke and Downton, 2000). There is a widespread perception that the risk arising from flooding is externally driven by natural disaster; however, the reality is that flood risk is wholly of human origin as people continue to settle in the disaster risk zones (Gahey et al., 2008). The Climate Forecasting System (CFS) component of the Disaster Management Support (DMS) project supports the use of climate and weather forecasts as tools to enhance prediction and early warning of hydro-meteorological events. This will promote better decision making at the local level with scarce natural resources and develop more effective plans to mitigate the adverse effects of these events (Kumar et al., 2006).

In recent years, flood management policy in many countries has shifted from protection towards enhancing society's ability to live with floods (Kundzewicz and Takeuchi 1999). This may include implementing protection measures, but as part of a package including measures such as enhanced flood foresting and warning, regulations, zoning, insurance and relocation. Each measure has advantages and disadvantages, and the choice is site specific: there is no single one-fits-all measures (Kundzewicz et al., 2002).

Resilient strategies for flood management, such as allowing rivers to temporarily flood and reducing exposure to flood damage, are preferable to traditional resistance (protection) strategies in the face of uncertainty (Klijn et al., 2004; Oslen, 2006). There are major uncertainties in quantitative projections of changes in hydrological characteristics for a drainage basin. Adaptation procedures need to be developed in the face of these uncertainties regarding the projections of changes in river discharge. It is well established that precipitation variability and future temperature increases due to climate change which affect the snowmelt and runoff in rivers (Kundzewicz et al., 2007).
For the last two decades, the advancement in the field of remote sensing and GIS have greatly facilitated in the preparation of flood hazard maps and risk assessment. It is evident that GIS has a great role to play in natural hazard management because these are multi dimensional in nature and the spatial component is inherent (Coppock, 1995). With the advancement in RS and GIS analysis techniques, it is easy to delineate flood hazard risk zones in a spatial context. The main advantage of using GIS for flood management is that it not only generates the flood risk maps but also creates potential for further analysis to estimate probable damage due to flood (Clark, 1998).

The conclusive result of above review makes it clear that the problem of climate change is real with many alarming consequences. The impact of projected future climate change may be felt more severely especially by developing countries such as India, whose economy is largely dependent on agriculture and is already under stress due to high population with their associated demands for energy, water, food etc.