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GLOBAL CLIMATE CHANGE AND ITS EFFECTS ON REGIONAL AND GLOBAL HYDROLOGY

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NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAVAN
ROORKEE-247667

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PREFACE

The National Institute of Hydrology established the Atmospheric Land Surface Modelling Division with the major objective of carrying out studies and research on coupled atmosphere land surface processes. In the present report an attempt has been made to review the status of studies carried out on global climatic change and its impact on regional and global hydrology.

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Satish Chandra

(SATISH CHANDRA)
DIRECTOR

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ABSTRACT

Concentrations of several gases viz. carbon dioxide, methane, nitrous oxide, chlorofluorocarbons in the atmosphere have significantly increased since the dawn of the industrial era. The observed built up of the gaseous pollutants has enhanced the so called greenhouse effect and hence increased the radiative heating of the globe. The global warming is expected to have profound impact on meteorological parameters as absolute humidity and precipitation , annual rainfall regime, and net terrestrial and global solar radiations etc. This, in turn ,would also have profound impact on various hydrological parameters ,viz. runoff, evapotranspiration ,soil moisture, ground water etc.The direct assessments of impacts and realistic evaluations of the climate sensitivities of water resource systems, specially on a regional scale are a matter of concern and need considerable study.

Various methodological approaches as the coupled general circulation -hydrologic models ,analysis of long term variations in runoff and meteorological elements over the past years ,use of water balance methods over a long period of time and use of deterministic hydrological models have been used to study the hydrologic consequences of future climatic changes by different research groups in the recent years .Inspite of enormous work being done in the subject area there still exist gaps in the knowledge of expected changes in future water resources .

In the present status report a review has been carried out on changes in meteorological parameters due to increasing concentrations of greenhouse gases and the hydrological impacts of global climate change .The status of studies in the subject area has been presented for the world with special emphasis on Indian context and the need of future studies has been emphasized.

1.0 Introduction

The problem of increasing concentrations of CO_2 and other infrared absorbing gases present in the troposphere, as methane (CH_4), nitrous oxide (N_2O), Ozone (O_3) and chlorofluorocarbons (CFC).and possible future climate change has attracted the scientific workers and the policy makers in the recent years. A number of assessments have been made on the problem of climatic change due to increasing greenhouse gases by various national groups notably in United States. The World Meteorological Organization (WMO) has co-ordinated various research activities under an over-arching framework- the World Climate Programme (WCP) to study world's climate system and possible major changes in global climate. The research activities in this area have also been convened by United Nations Environmental Programme (UNEP) and the International Council of Scientific Unions (ICSU). The water related activities as the impact of climate change on water resources have been implemented by World Climate Programme - Water (WCP-Water). The conferences held in Villach (1985), Toronto (1988), New Delhi (1989) and Hamburg (1989) have identified the problems in this complex subject area. It was concluded in these conferences that if the present trends continue, the carbondioxide in the atmosphere would double from its pre-industrial levels by the year 2030.

1.1 Nature and extent of the problem

It has become clear by now that by strengthening the so called 'greenhouse effect', the observed CO_2 increase may affect the meteorological parameters and hence the climate appreciably. Global warming and the climate changes would also have considerable influence on hydrological regime. Based on different methodological approaches, a number of impacts on hydrological parameters viz. precipitation, evapotranspiration, soil moisture storage, runoff etc. have been predicted in the literature. It has also been emphasized that the expansion of sea water due to warming and from melting of ice around poles would result in sea level rise, which in turn, would affect the population in coastal areas.However , there still exist gaps in research in the subject area as different methods/models used for the study of future climate changes and hydrological impacts have certain limitations.

Realizing the importance and need of research in the area of global warming and its hydrological impacts ,with emphasis on Indian scenarios ,National Institute of Hydrology has initiated studies and research in the subject area .In this status report ,attempts have been made to review the available research findings on the subject area with an objective to clearly spell the present state of knowledge and to identify the technological gaps so as to plan the future research needs in this direction.

2.0 Role of greenhouse gases in affecting the radiation balance

The solar radiation absorbed by the earth's atmosphere and surface is radiated to space at much longer wave lengths than those at which it is absorbed because of the much lower temperature of the earth-atmosphere system as compared to temperature of the sun (255 K as compared, to 6000 K). The sun emits most radiation in the range of 0.2-4 μm (including ultraviolet visible and near infrared wavelengths), whereas the earth emits mainly in the range 4-100 μm (longwave radiation).

Carbon dioxide, water vapour and other greenhouse gases play an important role in keeping the earth warm. Except for the 'windows' between about 8×10^{-4} and 13×10^{-4} cm, these gases block the direct escape of the infrared energy emitted by the earth's surface .Although the atmosphere absorbs only a small percentage of the shortwave solar radiation, it is quite opaque to the long wave terrestrial radiation. The long wave radiation emitted from the surface is absorbed by greenhouse gases, and is re-radiated both back to the surface producing an additional warming and to space maintaining the balance with the incoming solar radiation . The heat-retaining behaviour of the atmosphere is somewhat analogous to what happens in the greenhouse, where the glass roof and sides permit the sun's energy to enter and be absorbed by the plants and earth but prevent much of the interior heat from escaping thus blocking mixing of the inside air with that on the outside. To a lesser extent, it also prevents escape through the glass of energy radiated at long wavelengths from inside the greenhouse. The role of CO_2 ,moisture and other greenhouse gases in the atmosphere, allowing solar energy to pass through while absorbing much of the earth's long-wave radiation, has thus come to be known as the GREENHOUSE EFFECT.

The concern about global warming due to rapidly increasing concentrations of other greenhouse gases as methane, nitrous oxide, chlorofluorocarbons besides carbondioxide has also received considerable attention in the recent years. Table 1 gives the origin of the greenhouse gases ,their present rate of increase and the projected future concentration. According to the analysis of world wide energy consumption released in 1989 by a study group of Japan's Ministry of International Trade and Industry, a large contribution to the atmospheric CO_2 comes from United states (23% of total emissions) followed by Soviet Union (18%) and China (11%). Developing Countries account for about 26% of the total emission (Swinbanks, 1989).

3.0 Climate change due to increasing greenhouse gases

The changes in the future climate have been set on the basis of the changes that have occurred over the past 100 years. Both regionally and in terms of global mean values, climatic conditions have fluctuated noticeably on annual to decadal and longer time scales. The greenhouse effect is expected to cause major changes in global mean temperature, which will necessarily be accompanied by the changes in various climatic variables as absolute humidity and precipitation , annual rainfall regime and net terrestrial and global solar radiations. However, superimposed on these changes, will also be the inter-annual and inter-decadal variability (which arises due to complexity of interactions between the oceans, cryosphere, atmosphere and land surface). This variability is a natural characteristic of the unperturbed climate system and is less as compared to the changes due to external forcing factors as greenhouse effect.

The changes mentioned in the previous paragraph will differ from region to region. The best information on the overall response of the atmosphere to increasing CO_2 and other trace gases and the possible future climate can be obtained with the use of General Circulation Models (GCM) (Dickinson, 1982; Meehl, 1984). Some broad scale GCM results that can be expected with confidence for possible future changes in the climate due to doubling or quadrupling of CO_2 are given in Table 2.

Table 2:Possible future climate changes due to doubling or quadrupling of CO_2 in GCMs with the degree of confidence (WMO ,1987)

Model Results	Confidence
Global scale (i.e. global mean values)	
Warming of lower troposphere	High
Increased precipitation	High
Cooling of stratosphere	High
Warming of upper troposphere (specially the tropics)	Moderate
Zonal-mean to regional scale	
Reduced sea-ice	High
Enhanced polar warming in Northern Hemisphere (specially winter half year)	High
Increased P-E (precipitation minus evapotranspiration) in high latitudes	h
More absolute high temperature extremes	H

Increased continental summer dryness	Moderate
Stronger monsoons	Moderate
More tropical storms	Unknown
Greater/less interannual variability	Unknown
Spatial details in general	Unknown
Rainfall extremes	Unknown

In recent years, five major groups in the world have carried out studies on changes in surface temperature and precipitation due to doubling of carbon dioxide based on GCMs. These studies have been done by Goddard Institute for Space Studies (GISS), National Centre for Atmospheric Research (NCAR), Geophysical Fluid Dynamics Laboratory (GFDL), Meteorological Office (MO) and Oregeon State University (OSU). Table 3 lists the results obtained regarding surface temperature and the precipitation changes.

Table 3- Recent CO_2 doubling studies by five major groups assessing global mean changes (Mitchell,1989)

Study	Source	Surface Temp. Change, K	Precipitation Change, %
GISS	Hansen et al (1984)	4.2	11.0
NCAR	Washington and Meehl (1984)	4.0	7.1
GFDL	Wetherald and Manabe (1986)	4.0	8.7
MO	Wilson and Mitchell (1987)	5.2	15.0
OSU	Schlesinger and Zhao (1987)	2.8	7.8

3.1 Temperature

Manabe and Wetherald (1975) have shown that doubling of CO_2 in their model raises the temperature of the troposphere and cools the stratosphere. The increase in the average global surface temperature is 3^oC- with maximum of 10^oC in polar regions. In tropics this warming is spread throughout the entire troposphere by intense moist convection and so the temperature rise is smaller. Lal and Jain (1988) have found that the warming due to doubling of CO_2 is pronounced in the lower troposphere in high latitudes and in upper troposphere in low latitudes.

Jones et.al. (1986) have shown that the near surface air temperature has increased by about 0.5^oC since the late 19th century. Figure 1 shows the observed changes in temperature relative to the 1950-79 reference period mean for the northern, southern hemispheres and the globe (WMO, 1987). Linear trend in temperature over northern hemisphere land masses (1967-86) in units of degree centigrade per decade is shown in Figure 2. The curves show a long time scale warming trend, which is consistent with the hypothesized warming due to increased greenhouse gases. Current rate of emissions of greenhouse gases are expected to increase global warming by 0.2-0.5^{o}C per decade.

Mabbutt (1989) reviewed the postulated effects of carbondioxide warming on semi-arid tropical climates .Mabbutt (1989) mentioned that overall warming could be most marked in a rise in dry season temperatures, including both daytime maxima and overnight minima, in semi arid tropics.

3.2 Precipitation

The quantization of large scale area average precipitation changes is difficult as compared to that of temperature changes because of the higher spatial variability of the former. Bradley et.al. (1987) have shown an upward trend for land based data from 1920 in mid to high latitutdes (35-70^{o}N) and a marked downward trend in tropical to sub-tropical latitudes (5-35^{o}N) of the northern hemisphere (Figure 3). Barnett (1985) has concluded that it is extremely difficult to establish the trends over the ocean. On smaller spatial scales some regions of the world have experienced marked changes in precipitation on decadal time scales, for example - Sahel region of Africa (Figure 4).

Mitchell (1986), using the Meteorological Office's 5-layer and 11-layer GCM have studied the effects of enhanced CO_2 concentrations with prescribed increase in sea surface temperature (2^{o}K) (the increase in sea surface temperatures were those expected to accompany the given increase in CO_2). The changes, due to increasing CO_2 and enhancing sea surface temperatures, in tropospheric temperature, atmospheric humidity, land surface temperatures and precipitation are shown in Table 4.

Table 4: Changes (increase) due to increasing CO_2 and enhancing sea surface temperatures

Experiment	Tropospheric temperature (°C)	Atmospheric humidity (%)	Land surface temperature (°C)	Precipitation (%)
$2xCO_2$ (5LM)	3.02	18	2.86	5.0
*$4xCO_2$ (5LM)	2.05	16	4.00	3.5
$2xCO_2$ (11 LM)	3,08	20	3.05	5.6

*Differences halved to allow comparison.

Manabe and stouffer (1980) have shown that the CO_2 induced warming of the atmosphere results in the enrichment of the moisture content in the air (hence, humidity) and an increase in the poleward moisture transport. The additional moisture is picked up from the tropical oceans and is brought to high latitudes where the precipitation increases throughout the year. The increase in zonal mean precipitation rate is larger in high latitudes than the corresponding increase in lower latitudes and has significant latitudinal variations. The global mean increase in the precipitation rate is found to be 0.018 cm/day which implies a 6.7% increase in the overall intensity of hydrologic cycle.

Manabe et al. (1981) demonstrated the possible advent of summer dryness, due firstly to the reduction of precipitation in summer and secondly to the rise in temperature leading to disappearence of snowcover is winter and hence, an earlier start of the summer drying season .

The consequences of surface warming for zonal climates including semi arid tropics remain uncertain. This is mainly due to the limitations in the numerical models on which the predictions have been based (Tucker, 1988).Some of the forecasts for precipitation changes by various numerical models in the semi arid tropics are:

(i) tropical summer rains may increase in general (Manabe and Wetherald, 1980);

(ii)there may be a diminished summer rainfall in tropical Australia (Meehl and Washington, 1986);

(iii)there may be an intensification of rainfall within an existing rainy period (Mitchell, 1983; Mitchell et al., 1987);

(iv)a poleward displacement of rainfall belts may take place

(Manabe et al, 1981).

Pittock (1980, 1985) found a link between the already observed southern hemisphere mid-latitude warming and, an increase in summer rainfall in northern Australia between 1913-45 and 1946-78, as linked with a poleward shift of the sub-tropical anticyclonic belt and a more positive southern oscillation Index (SOI). He postulated a poleward extension of the area of summer rains by about 2 degrees of latitude in northern Australia and suggested increases in near annual rainfall of between 10% and 20% and some increase in mean daily rainfalls and a lengthening of the rainy season by 2-4 weeks. However ,Pittock (1988) admitted to greater uncertainty regarding changes in rainfall variability and in secondary climatic effects such as the evaporation balance.

3.3 Other climatic parameters

The change in surface heat budget also shows latitudinal variations . Chou et al (1982) have studied the change in the surface heat budget (which include the solar radiation, infrared radiation, sensible heat flux, latent heat flux and heating due to ocean transport) due to the change in CO_2. With the doubling of CO_2 content, the solar radiation, absorbed at the surface in the tropics decreases slightly, because of the more humid atmosphere, which reduces the solar radiation reaching the eath's surface (Figure 5). The absorption of solar radiation increases poleward of $40^{o}N$ reaching a maximum at $75^{o}N$. This is consistent with the decrease in surface albedo as shown in Figure 6. Except in the polar region where the increase in surface temperature is the largest, the increase in the downward IR flux exceeds that in the upward flux due to the increase in water vapor content. This results in a reduced net upward IR flux for a doubled CO_2 content. Chou et al (1982) have shown that net upward IR flux at the surface decreases by 4.7 W/m^2 for a doubled CO_2 content. The changes in surface sensible heat flux and oceanic transport of heat are comparatively of less importance.

The change in the surface latent heat flux is found to be large at almost all latitudes except in the polar region with large surface portion covered by ice and snow. The significant change in latent heat at the surface points to the importance of evaporation in regulating the climate sensitivities. This can be understood as follows. There exists a nonlinear relationship between evaporation and surface temperature, a small increase in temperature at a wet surface will lead to a considerable increase in evaporation. This cools the surface and heats the atmosphere through the release of latent heat. The resulting increases in atmospheric temperature and hence the humidity intensify the downward IR flux and heat the surface. Thus a feedback loop is formed between evaporation, temperature and humidity. The studies of Newell and Dopplick (1979) and Chou et al (1981) also show that the nonlinear relationship between evaporation and surface temperature greatly reduce the surface temperatures response to variations in the CO_2 content.

The thermal structure of the earth-atmosphere system is considerably changed due to changes in solar and IR radiation at the top of the atmosphere. The absorption of the solar radiation increases at all latitudes (Figure 7). Comparing the dashed curve in Figure 7 with SR curve in Figure 5, it can be seen that the increase in absorption of solar radiation at low latitudes is in the atmosphere (due to higher water vapour content) and the increase at higher latitudes is mostly at the surface (due to smaller ice/snow cover). The change also increases from low latitudes to high latitudes in the infrared radiation.

Besides latitudinal variations, the radiation components show seasonal variations also. In spring and summer the net terrestrial radiation decrease over the daylight period, induced by CO_2 doubling is such that it induces a slight increase of the net radiation.The changes of different climatic parameters under the hypothesis of a doubling of the atmospheric CO_2 concentration (with sources) are shown in Table 5.

4.0 Hydrological impacts of global climatic change

As a consequence of changes in meteorological parameters due to enhanced greenhouse effect ,significant impact on hydrological parameters viz. runoff,evapotranspiration , soil moisture, ground water etc.is expected.Figure 8 shows the impacts of greenhouse effect on the hydrological cycle .To evaluate the hydrological effects of increasing greenhouse gases , one needs the predictions/forecasts of changes in climatological parameters,specially air temperature and precipitation for different regions and periods of time.As the accurate forecasts of regional climatic changes are still not available , various scenarios of future climatic changes are used.These are -

(a) hypothetical scenarios - Many researchers prescribe hypothetical scenarios for climatic change without taking into account a particular time interval.Most of the scenarios assume an air temperature increase from 0.5^{o} C to 4 ^{o} C and precipitation change(increase or decrease) in the range of 10% to 25% .

(b) scenarios obtained by using atmospheric GCMs - These are obtained by models considering doubling of CO_2 in the atmosphere.The scenarios are usually applied to the regions for which similar simulations have been repeatedly carried out by using different methods.

(c)simulations based on palaeoclimatic reconstructions -The paleoclimatic records provide information about the effects of CO_2 forcing as some aspects of past climatic changes are undoubtedly related to past changes in atmospheric CO_2 levels.

The projected climatic changes need to be regarded as the possibilities to study the sensitivity of hydrological and water resources to such changes.This has been evaluated by many methods.The large scale general circulation models have been used to prescribe possible changes in the content of trace gases in the atmosphere(2 x CO_2 usually) and to directly obtain the possible changes in climatic and hydrological characteristics for large regions. By using atmospheric GCMs possible changes in runoff,soil wetness and evaporation have been estimated for USA and Canada(USEPA,1984;Sanderson and Wong,1987;Singh,1987;Stakhiv and Lins,1989)

4.1 Limitations of GCMs for direct evaluation of hydrological impacts

The direct use of GCM output in grid scale hydrologic assessment is generally restricted due to two important limitations.Firstly, the hydrological variables such as precipitation,runoff,soil moisture are computed as secondary variables in GCMs in contrast to primary variables such as temperature,humidity and transfer of energy and hence their realism is limited .Secondly ,GCMs have limited spatial resolution(100 x 100 km^2) and most of the hydrological phenomena occur on scales far smaller than the spatial resolution of GCMs.

Besides these two major limitations a few additional limitations further restrict the use of GCM output in hydrological modelling .For example in GCM studies of greenhouse effect only the equilibrium response of doubled or quadrupled CO_2 has been considered and the climate change due to transient response of CO_2 increase has not been taken into account.This study requires the study of an atmospheric GCM coupled to a realistic ocean GCM which are still in their early developmental stages. Furthermore, the GCMs currently used for greenhouse studies are not able to simulate the current atmospheric circulation.

4.2 Coupling of GCMs with hydrologic models

To obtain the sub-grid scale information that supplements the coupling of coarse resolution output of GCMs with hydrologic models ,various methods were suggested in the Meeting of Experts on the Sensitivity of Water Resource Systems to Climate Variability(WMO ,1987). These were

1) Development of regression equations using existing instrumental data bases and their application to GCM results for doubled CO_2 scenarios.
2) Embedding of higher resolution model within the coarse resolution GCMs to produce subgrid scale information.
3) Improvement of the resolution of existing models or development of new high resolution GCMs,which incorporate better hydrologic parameterizations and regional topographical detail.

These methods have several limitations and the progress is being made to improve the hydrologic parameterizations in GCMs.As the hydrological parameters such as soil moisture ,vegetation evapotranspiration etc. would be incorporated in GCMs more realistically the evaluation of hydrologic effects of climatic change is likely to become more reliable.

4.3 Other methodological approaches

Hydrologists from many countries have used various other methodological approaches besides atmospheric GCMs to study the hydrologic consequences of future anthropogenic climate change.These are as follows :

1) Analysis of long term variations in runoff and meteorological elements over the past years

The approach has been realised in two ways .In the first approach , various statistical models of hydrologic characteristics and regression interactions between runoff ,air temperature ,and precipitation are applied .Using this method, studies have been carried out for western regions of the US and the Colorado river basin (Stockton and Boggess ,1979 ;Revelle and Waggoner,1983) and for the annual river runoff in the USSR (Anthropogenic Climatic Changes,1987).

In the second approach , the hydrologic consequences for the past very warm or cold ,wet or dry years periods have been studied.The analysis has been carried out by Schwartz(1977) and Glantz(1988) for the US and by Chunzhen(1989) for the northern China.Studies have also been made for some regions of the Sahelian zone using this approach.

2) Using water balance methods over a long period of time

These methods have been used by Vinnikov et al (1989) for the USSR and Griffiths (1989) for the New Zealand and Babkin(Shiklomanov,1988)

3) Using deterministic hydrological models

This approach has been used by many workers for basins located in various hydroclimatic environments (Nemec and Schaake, 1982; Gleick, 1986, 1987; Mather and Feddema,1986;Cohen,1986;Flashka et al.1987;Bultot et al.,1988;Kuchment et al,1989). Here different models of runoff formation in river basins (including water balance models)are employed for the time intervals of one hour to one month.The deterministic hydrological models seem to be preferable under modern conditions (Linz et al,1990).

4.4 Sensitivity of hydrological cycle to expected climatic changes

Linz et al (1990) reviewed the results obtained in different countries on the estimation of influence of climatic change on hydrological characteristics ,water resources and the problems associated with their use.They mentioned that the investigations carried out on changes in annual and seasonal runoff since the late 1970s primararily point to a great sensitivity of river watershed even to insignificant changes in climatic characteristics. This is specially true for the watersheds located in arid and semiarid regions .Studies have also suggested that the annual runoff appears to be more sensitive to changes in precipitation than to changes in temperature.In the regions with seasonal snowfall and snowmelt as a major part of total water supply ,the monthly distribution of runoff and soil moisture is more sensitive to temperature rather than precipitation .Linz et al.(1990) mentioned that the global warming would lead to changing all the lake water- balance components(precipitation,evaporation, inflow ,and outflow),their levels and heat budget.

One of the most profound impact of climatic changes may be the major alterations in regional hydrologic cycle and changes in regional water availability.Gleick (1986) reviewed different approaches for evaluating impacts of global climatic changes on the regional hydrology .He mentioned six criteria for evaluating the applicability of hydrologic models to climatic impact assessment (Table 6).

Gleick (1986) suggested that the use of modified water balance models offers significant advantages over other methods in accuracy, flexibility and ease of use. These are specially useful for assessing the regional hydrologic consequences of changes in temperature, precipitation and other climatic variables. These models can incorporate month to month or seasonal variations in climate and snowmelt algorithms, groundwater fluctuations and soil moisture characteristics. These can also be combined with the state of the art information from GCMs to generate information on hydrological response of future climatic changes using the plausible hypothetical climate change scenarios.

Gleick (1987) using the basin specific assumptions for precipitation, temperature, runoff, storm runoff, watershed log, soil moisture, ground water developed a modified water balance model for the Sacramento basin. The results showed that the magnitude of winter runoff predicted by the model was too high and it occurred too early in spring, as compared to observed values. The principal reason for the discrepancy in the monthly runoff distribution was the absence of snowfall and snowmelt from the model .

Thus the Sacramento watershed was split into two sub-basins based on the above parameters: upper basin - where precipitation during the winter months was almost entirely snow and the soils and terrain rocky; and the lower basin - where all precipitation as rain and the soils are deeper and runoff. Two distinct water balance models were developed and run, one for each of upper and lower basins. The monthly temperature and precipitation data for 50 years were introduced and continuous water balances were computed for the 600 months period. The total Sacramento basin runoff was computed by combining the monthly runoff values from each sub-basin as a function of their relative areas. The results for average monthly runoff & average annual runoff were well within the limits of accuracy of the available data and the water balance method itself (Fig.9) .

The results of some of the early studies on effects of climatic changes on runoffis given in Table 7.These assessments have used different methods of approaches to study the climatic impact on runoff.

4.4.1 semi arid and arid regions

The hydrological response to greenhouse warming in the semi-arid tropics needs considerable study as there is an uncertainty about the amount, duration, intensity and interseasonal variability of rainfall and in the magnitude, frequency of extreme rainfall events and precipitation-evaporation ratio. The partitioning of precipitation into infiltration and runoff will be affected by the changes in vegetation cover, which itself is linked with uncertainty in rainfall. The change in rainfall alone tends to be amplified in the runoff response by a factor approximately the inverse of the runoff coefficient. Wigley and Jones (1985) suggested a 25% increase in runoff on a 10% increase in precipitation for an area with a runoff coefficient of 0.4, evapotranspiration remaining the same. For semi arid tropics, which have prevailing low to moderate runoff coefficients, any small change in rainfall could bring very significant changes in river discharges .

Linz et al (1990) mentioned that the analysis of annual precipitation data from stations in the Sahel region for the period 1970-85 has revealed this period to be extremely dry; the reason for Sahelian droughts being the decrease in annual precipitation. Ojo (1987), analysing the precipitation trends for 1901-85 for 60 stations of western Africa found that the average precipitation for 1970-79 and 1981-84 were 0.62 and 0.5 of the normal. Mabbutt (1989) mentioned that some indication of the hydrological consequences of rainfall decrease in the semi-arid tropics is given by the reduction in discharges and seasonal flooding in the Niger and Senegal rivers and drastic shrinkage of Lake Chad after two decades of low rainfalls in Sahelian Africa .

A tendency of decrease in total annual precipitation during the period 1972-87 for arid zones of Northern Africa was observed and the total annual amounts of precipitation were found to be much lower then the normal. The succession of dry years led to a decrease in water resources in the region. This tendency may represent a potential risk of drought which may contribute to the process of desertification and extension of deserts. The changes in precipitation due to the increase in trace gas concentration in the atmosphere may lead to changes in the future water resources ,ecology and economy of the countries in Sahelian and arid and semi arid zones.

For the large rivers having source in rainier uplands in adjoining humid areas and traversing the semi-arid tropics, the hydrological response will be complicated. This will be true for the rivers like Nile and Niger (Mabbutt, 1989).

Nathan et al. (1988) simulating the flood frequency curves for a selected river catchment in summer rainfall zone of north-eastern Australia suggested that the greenhouse effect could have a greater impact on more frequent floods than on extreme events. He had taken the assumptions of increases in seasonal rainfalls and various changes in evaporation and neglected the possible changes in rainfall intensity - frequency - duration relationships .The increases in peak discharges would lead to extent and duration of flooding, which would have potential consequences for riverine landscapes and land use and for the design and performance of man made structures as storage reservoirs and bridges etc. (Mabbutt, 1989).

Chunzhen (1989) analysed the hydrometeorological observational data for Northern China and found that the warmest period over the last 250 years started since 1981 and the mean air temperature over 1981-1987 was 0.5°C above the normal. The precipitation was somewhat lower than the normal (by 4% for Beijing) for the same period. The estimates for the scales of influence of increasing CO_2 in the atmosphere on the climate of northern China are as yet unavailable (Linz et al, 1990).Chunzhen(1989) showed that a 10% increase in precipitation and a 40% decrease in evaporation would increase the runoff by 27% in semi-arid regions, whereas a 10% increase in precipitation and a 4% decrease in evaporation would result in runoff rise by 18% .

Soviet climatologists, on the basis of paleoclimatic reconstructions, have found for northern Africa that the annual precipitation is expected to increase considerably in the near decades thus influencing the total moisture, river runoff and accompanying ecological changes (Anthropogenic climatic changes, 1987). However, these estimates are quite approximate and need considerable improvement.

4.4.2 humid tropics

In the tropical humid condition simulations were conducted in the basin of Lake Victoria in Africa (Nemec and Schaake, 1982). Kite and Waititu (1981) used the Nzoia River basin to study the changes in streamflow as a function of changes in precipitation and potential evapotranspiration. An increase of 25% in precipitation and a 6% decrease in evapotranspiration produced an increase in runoff of about 170%; whereas a 12% increase in evapotranspiration and a 25% decrease in precipitation produced a 75% decrease in runoff (Fig.10) The possible effects of climatic change on level of lake victoria were obtained from these altered in flows. Nemec and Schaake (1982) mentioned that the maximum increase in precipitation could produce a rise of over 3 m above the maximum recorded lake level and climate changes, in the case of maximum reduction precipitation could lead to a fall of about 1 m below the minimum recorded level.

Goma (1989) examined the 50 years data from 1937-1988 to access any effect of climate variation on public water supply in Zambia. He opined that at the moment the weather fluctuations do not affect the water supply from the main source public water reservoir.

4.4.3 water resource changes in large regions

Linz et al. (1990) reviewed the impact of climatic change due to greenhouse warming on hydrology and water resource changes in large regions and countries .The most probable tendencies in the changes of water resources for certain regions are as follows :

Pacific Northwest	: some increase in annual runoff and floods
California	: increase in winter and decrease in summer runoff with insignificant rise in annual runoff
Colorado and Rio Grande river basins ,the great basin	: decreasing runoff
Great Lakes basin	: decreasing runoff
Great Plains ,northern and southeastern States	: uncertain changes in water resources
Northern Africa ,Sahel, Western Eurasia, USSR,most regions of Australia and New Zealand	: increasing runoff
Central European USSR and western Siberia	: decreasing trend

Linz et. al.(1990) also presented the case studies of impacts in critical or sensitive environments as large water bodies,critical agricultural regions ,intensively urbanised areas and regions of snowmelt generated runoff . The results are presented in tabular form in Table 8.

The surface warming due to increase in greenhouse gases is likely to alter the evaporation (EV) and evapotranspiration (ET) patterns ,which is a major component of water budget after precipitation .The way in which ET may change is complicated as it depends on radiation ,windiness ,and humidity besides temperature,all of which are expected to change due to enhanced greenhouse effect .The climatic changes may affect the plant growth ,plant cover and plant rooting and therefore ET .(Martin et al ,1989; Rosenberg et al ,1989a ,b) .The increasing concentrations of carbon dioxide will also affect plant physiological parameters.

The possible impacts of climatic change on hydrological regime may be summarized as below (WMO ,1990):

- increase in evaporation in the summer months caused by temperature rise
- higher evaporation and lower amounts of summer precipitation may cause low water periods to be prolonged
- more rainstorms caused by increased convective precipitation in the summer months could lead to an increase in local floods in temperate climates

- increase of heavy floods and in frequency of floods caused by stronger tropical cyclones
- higher precipitation may cause an increase in mean runoff, higher floods, longer flood periods (e.g. in Northern Europe)
- shorter icecover periods in lakes and coastal zones
- the thickness of ice may be smaller
- the energy content of lakes, reservoirs and rivers will rise It will influence biological production and the energy content of the water
- increase in stormsurges on coasts may cause floods in estuaries
- less snowfall may result from a temperature rise in winter months
- higher floods in winter months may be caused by more rain and less snowfall
- smaller spring floods may be caused by less snowmelt.

5.0 Greenhouse effect and its impacts in Indian context

The contributions to greenhouse effect from India is only about 4% and is due to the following factors: agricultural practices, biomass burning, power generation from thermal plants ,transportation, and deforestation. India, has the largest area of paddy cultivation, and thus is the largest producer of methane in the world. India is also the fourth largest user of nitrogenous fertilisers. Within the sector of biomass burning India is seen as a significant contributer. The contribution due to power generation is from coal based thermal plants, which account for about 65% of total power generation. Out of the above parameters deforestation is contributing least to the greenhouse effect (Hai et al ,1990)

The mean annual temperature for India during the period 1901-1982 is shown in Figure 11 (Hingane et al, 1985). The trend line indicates a trend of about $0.4^{o}C$ warming during recent 8 decades. This trend changes seasonally,being $0.7^{o}C$ in post monsoon and winter seasons and during pre-monsoon and monsoon seasons become $0.4^{o}C$ and - $0.3^{o}C$ respectively. In contrast to the post 1940 cooling which has been observed for the northern hemisphere, a steady increase in mean annual temperature has been observed for Indian subcontinent for the last 8 decades.

The precipitation patterns over India have been intensively studied over the years notably at India Meteorological Department and Indian Institute of Tropical Meteorology ,Pune. These studies have been centered mainly on prediction of monsoon rainfall. Mooley et.al.(1981) examined the time dependence of coherent rainfall pattern using 36 rain gauges. They inferred the time series to be both homogeneous as well as random ,but there was no significant trend in the Indian precipitation fields. The large noise levels (Figure 12)(the 90% confidence levels on the mean) indicate the difficulty of detecting the rather small changes that may be due to CO_2 effects. Analysis of data available on precipitation from 1901 onwards has not shown any definite pattern (TERI ,1989) .There have been decades with 7 to 9 years of good precipitation out of 10 ,the average rainfall being 84 cm during the monsoon period and 100 cm per annum .The scenarios for future climatic changes for India are still not avilable.

Studies related to global climate modelling and climate change have been initiated at the National Centre for Medium Range Weather Forecasting ,DST ,India .Using a R - 40 version of global spectral model a pilot study related to impact of deforestation on the atmospheric circulation and precipitation is being carried out (DST ,1991).

Global warming would also result in sea level rise - due to thermal epansion of sea water and melting of ice from high altitudes and latitudes ,which would add to the total volume of water .India ,with a coastline of about 6000 km ,has a wide continental shelf with an area of about 310000 km^2 on the western coastline .This is nearly twice that of the eastern shelf .Figure 13 shows the distribution of some of the ecosystems in the coastal region and their vulnerability to sea level rise (Ahmed and Sengupta ,1984) .Studies have pointed out towards the following conclusions on implications of sea level rise in India (NIO ,1988):

(i) Low lying coral atolls of Lakshadweep archipelago are the most vulnerable regions to sea level rise ;

(ii) Indian east coast ,with a larger frequency of storms and lower continental slopes is more vulnerable to storm surges and coastal floodind than the west coast.

(iii) On the west coast ,the stretch between approximately 12^o to 18^o N is the least vulnerable .The coastline to the south of this belt has shown a tendency of erosion and denundation ,which is likely to increase with sea level rise .

Studies have not been carried out on the hydrological impacts of climatic change for India.

6.0 Concluding remarks

6.1 state of knowledge

On the basis of review made the state of knowledge on the subject can be summed up as below :

1. A warming of about 0.7 - 2 ^oC of earth's surface has taken

place upto the early eighties and at current rates of emissions ,the global warming will increase by 0.2 - 0.5 ^{o}C every decade.

2. Consequently precipitation and other meteorological parameters will also be affected .However, the exact magnitude of the changes in these parameters as predicted by General Circulation Models is still uncertain,specially for regional scale.

3. The changes in meteorological parameters will result in alterations in the hydrological parameters .

4. The forecasts of changes in climatological parameters ,specially temperature and precipitation are needed to evaluate the hydrological effects of increasing greenhouse gases .

5. For assessment of changes in hydrological parameters on a regional scale,the scenarios of future climatic changes are used.The methodological approaches used in the studies on hydrologic consequences of future climatic changes include the coupled general circulation and hydrologic models ,analysis of long term variations in runoff and meteorological elements over the past years ,use of water balance methods over a long period of time and use of deterministic hydrological models.

6. The watersheds located in arid and semiarid regions point towards a great sensitivity in annual and seasonal runoff for even insignificant changes in climatic parameters .

7. Studies have suggested that annual runoff appears to be more sensitive to changes in precipitation than to changes in temperature.

8. For regions with seasonal snowfall and snowmelt as a major part of the total water supply ,the monthly distribution of runoff and soil moisture is more sensitive to temperature rather than precipitation .

9. Studies carried out on impact of climate change on hydrology for various regions and countries show different trends.

10. The analysis of mean annual temperature for India during the period 1901-1982 has indicated that about 0.4 ^{o}C warming has taken place during recent 8 decades .

11. The studies on precipitation fields for India have not led to inference of any significant trend.

12. Studies point out that the coastal regions especially Lakshadweep followed by eastern coast are more vulnerable than the

western coast to sea level rise - which is a result of snowmelt and thermal expansion of sea water.

3.2 Need of future study

The information on expected changes in hydrological cycle and its components is greatly needed for water resources development and management so that plans could be made in good time and preparations made to meet the changes in streamflow regime. The informations needed are -probable changes in monthly mean evaporation ,soil moisture ,ground water and discharges of watercourses as well as on water level on coasts ,in estuaries and inland lakes, probable changes in duration of values exceeding or falling below certain threshold values (e.g. 10% and 90%)and probable changes in frequency of extreme events. These informations can only be obtained using spatially distributed simulation models,with reliable climatic scenarios.

In order to obtain reliable climate change scenarios from general circulation models, land surface parameterization has to be realistically incorporated in the models; as the interactions and feedbacks between land surface/biospheric and atmospheric processes play an important role in providing informations regarding climatic change scenarios.As the hydrological parameters such as vegetation ,soil moisture ,evapotranspiration will be more realistically incorporated in the GCMs ,the evaluation of impact of climate on hydrology and water resources will become more reliable .

3.3 Problem identified for training and expected output

For India, the temperature and precipitation change scenarios are still not available and also, there is a great research demand to study the possible impact of climate change on hydrological regime .

During the training at Colorado State University (CSU) under UNDP assissted project it is proposed to study the one dimensional climate model based on Community Climate Model (CCM) of National Centre for Atmospheric Research (NCAR) available at CSU whose land surface hydrology has been modified and greatly improved .This will be used for studying interactions and feedbacks between land surface /biosphere and the atmospheric processes and to define sensitivities of climate processes to land surface dynamics ,and thus a land surface parameterization will be defined which is optimal with respect to climate change predictions. Improved land surface parameterization will be coupled with the mesoscale atmospheric models available at CSU and improved predictions of global climate change obtained with CCM will be used to force the mesoscale models to obtain predictions of climate change effects on the local and regional hydrology and water resources .

The studies carried out on the role of atmosphere /land surface interactions in global and regional hydrologic cycles using the soil - plant - atmosphere coupled model will be used as the guidelines for carrying out similar studies for different agroclimatic zones of India.

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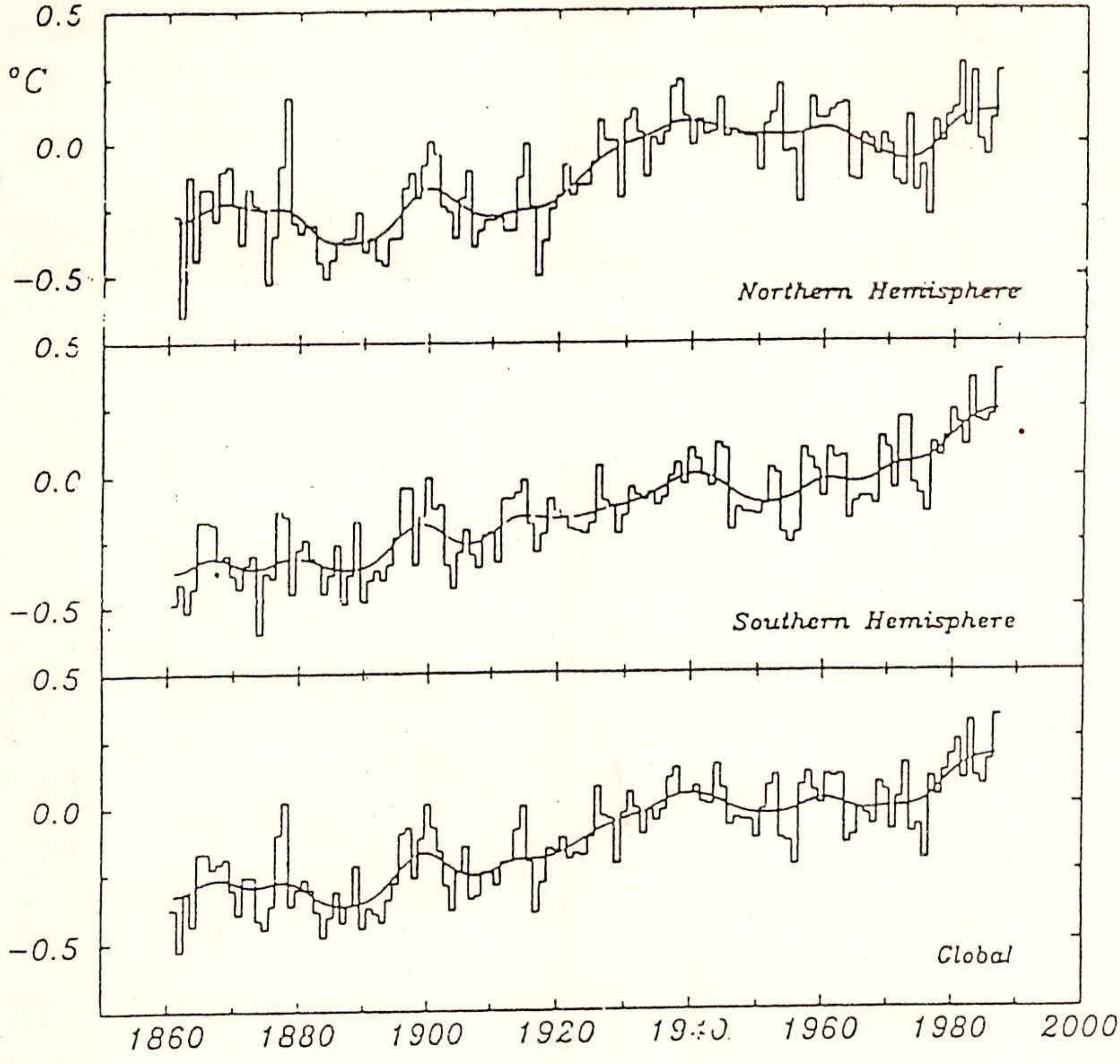

Fig. 1 - Observed changes in temperature relative to the 1950-79 reference period mean (WMO ,1987)

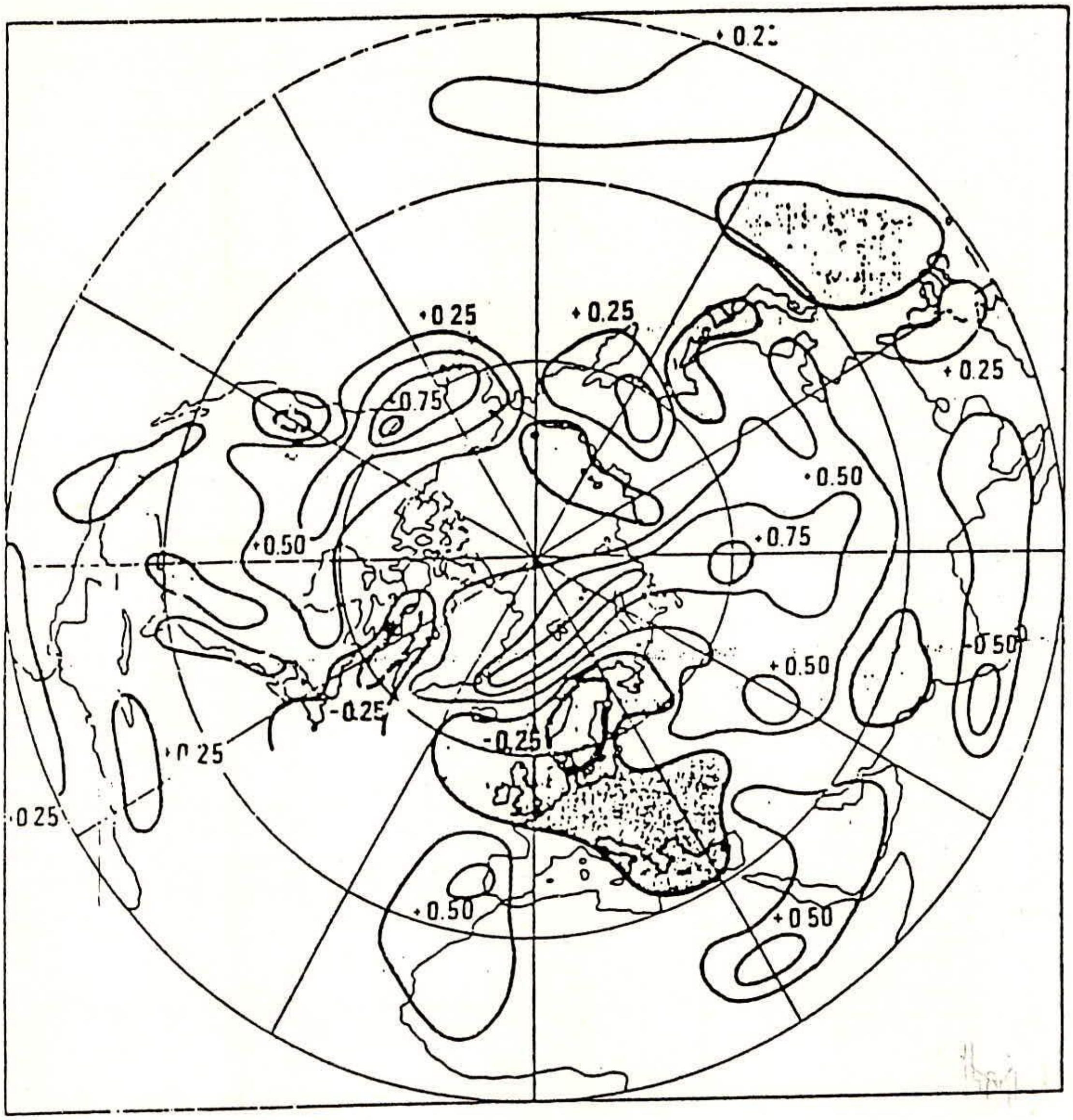

Fig. 2 - Linear trend in temperature over northern hemisphere land masses, 1967-86 (units in °C per decade, shaded areas show regions of cooling)(Jones ,1988)

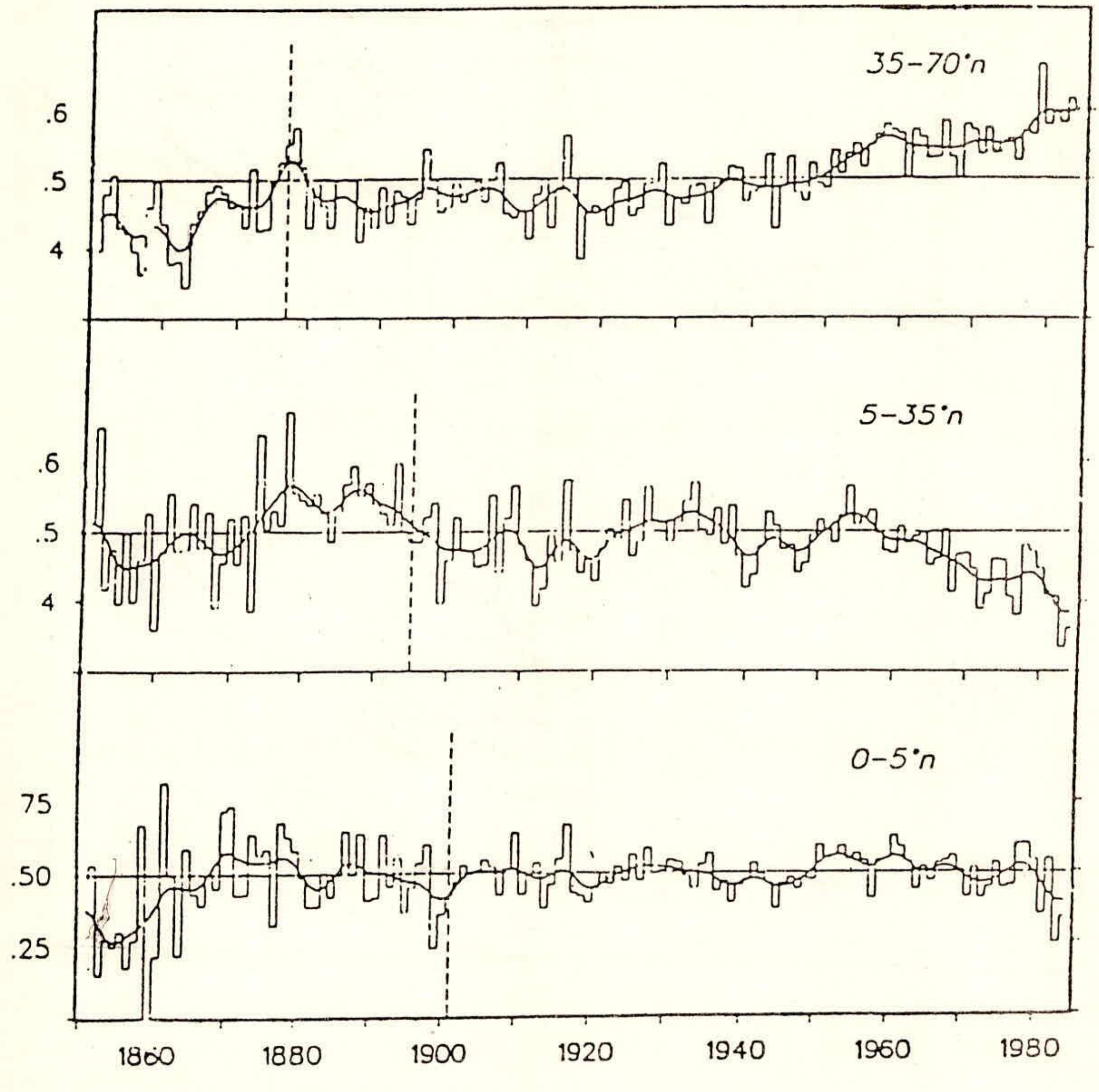

Fig 3.- Precipitation indices showing changes in area averaged precipitation over the land areas (Bradley et al ,1987)

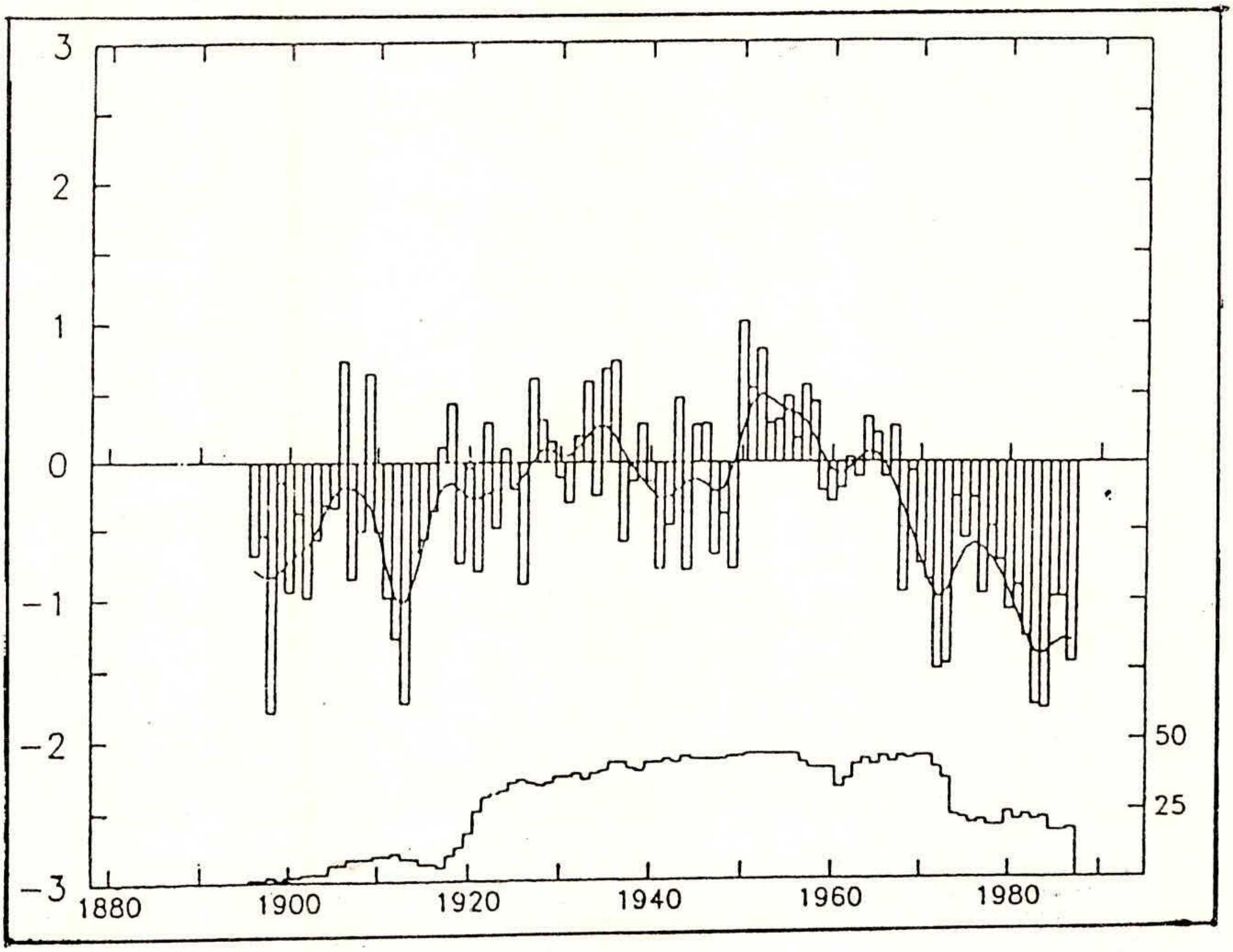

Fig. 4 - Time series of May-October rainfall in the Western Sahel for 1896-1987. Rainfall is epressed as a normalized anomaly from the 1941-70 base period (WMO,1987)

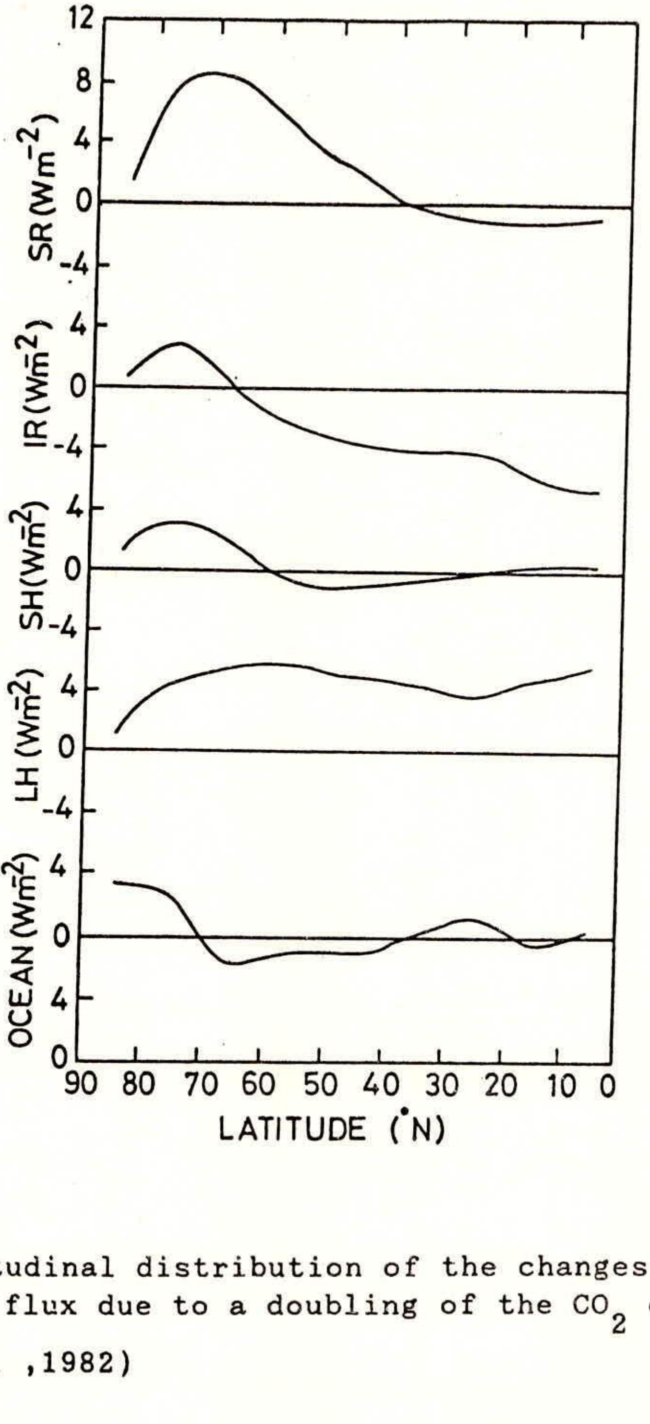

Fig. 5 - Latitudinal distribution of the changes in surface heat flux due to a doubling of the CO_2 content (Chou et al ,1982)

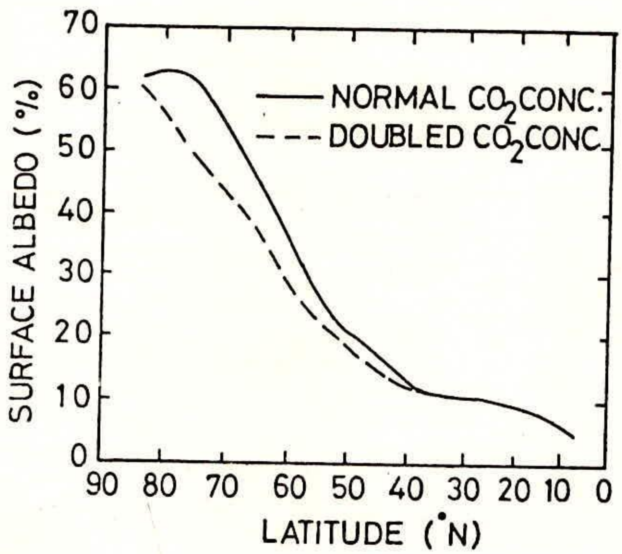

Fig 6 - Latitudinal distribution of the surface albedo for normal and doubled CO_2 concentrations (Chou et al,1982)

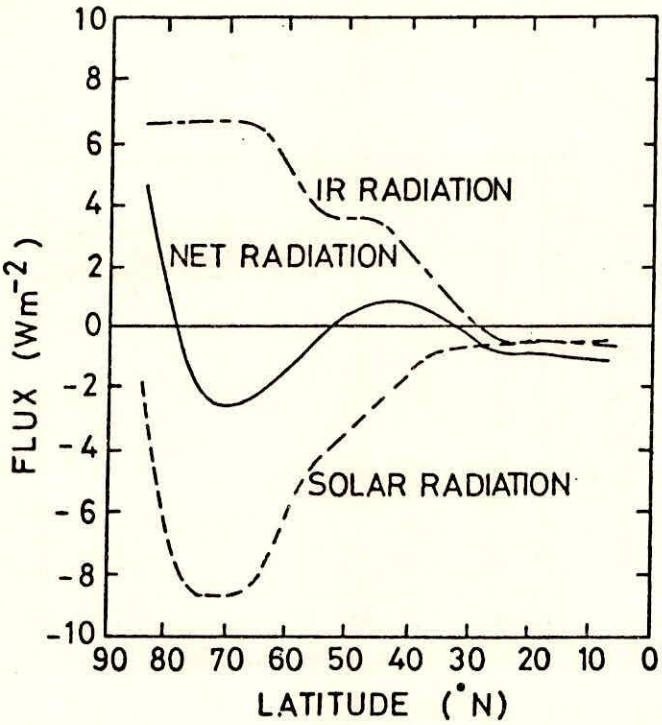

Fig 7 - Changes in upward radiation fluxes at the top of the atmosphere for doubling of CO_2 content(Chou et al,1982)

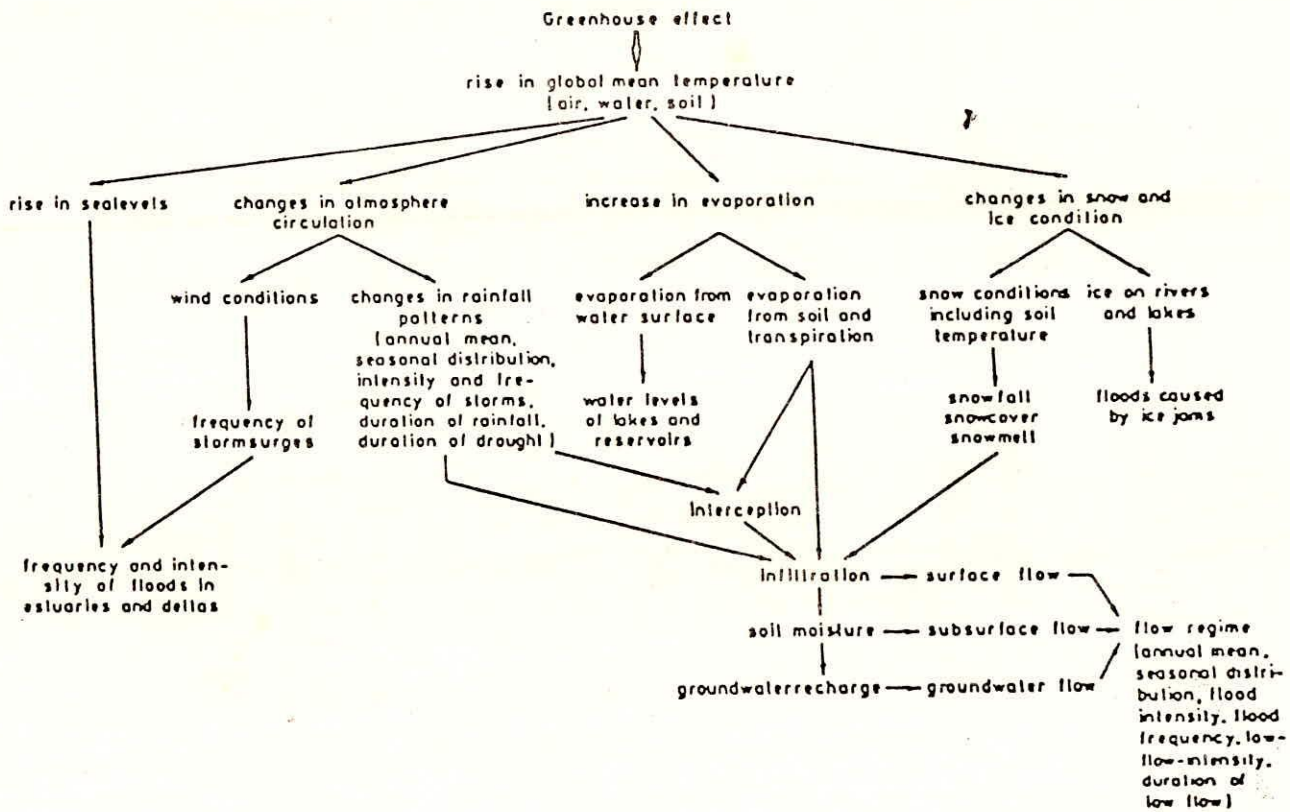

Fig. 8 : Impacts of Greenhouse Effect on the Hydrological Cycle

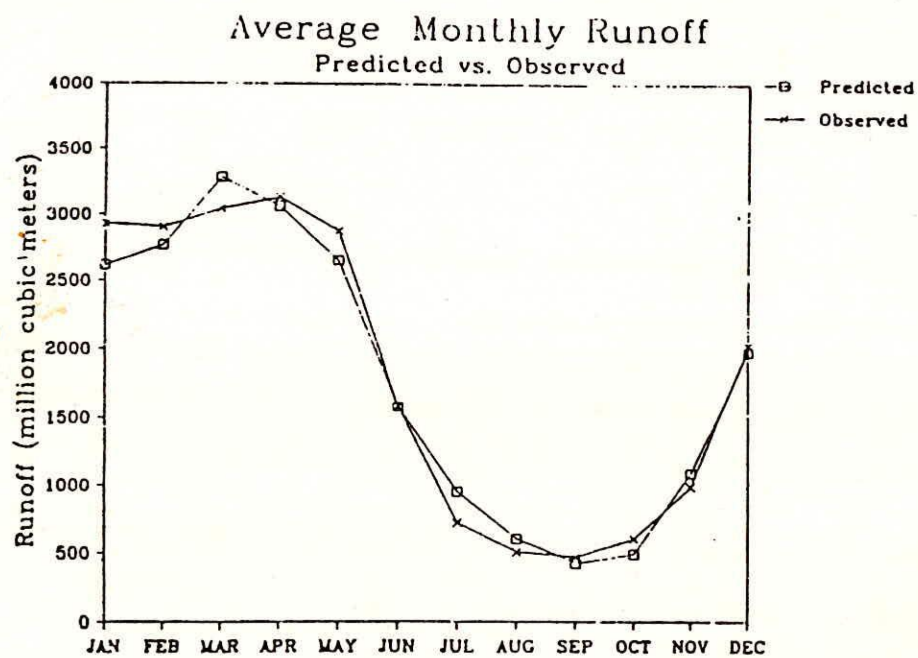

Fig. 9 : Average Monthly Runoff (Observed and Predicted) by two basin model (Gleick, 1987)

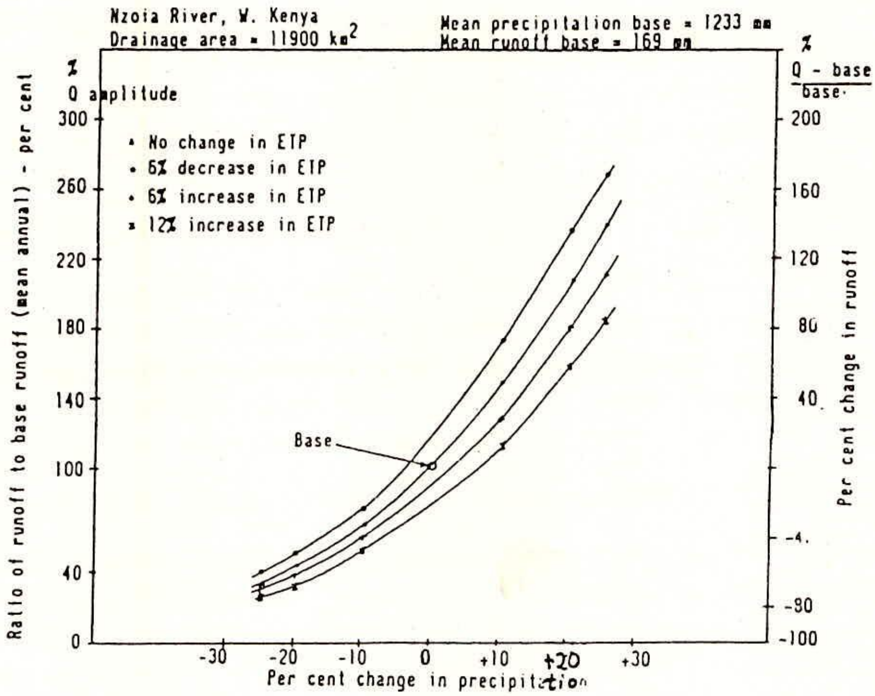

Fig. 10 - Changes in streamflow due to changes in precipitation and potential evapotranspiration for Nzoia river (Nemec and Schaake ,1982)

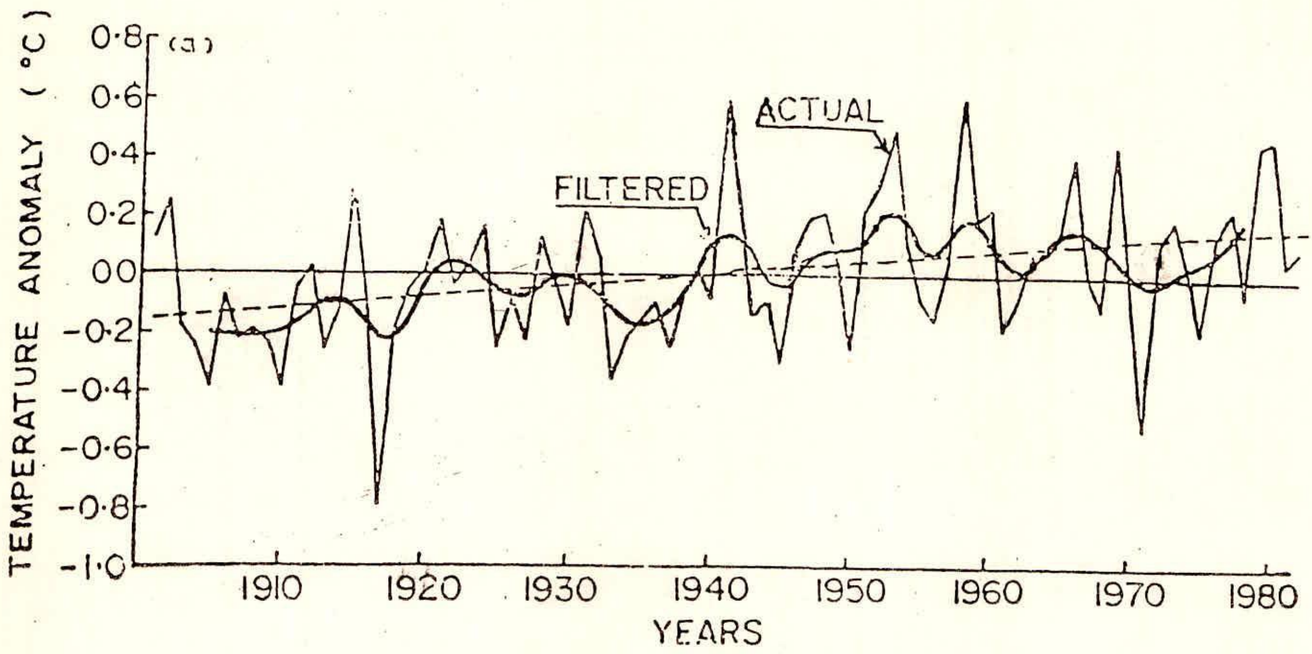

Fig 11 - Actual and filtered values and the trend line of annual temperature anomalies in India during the period 1901-1982 (Hingane et al ,1985)

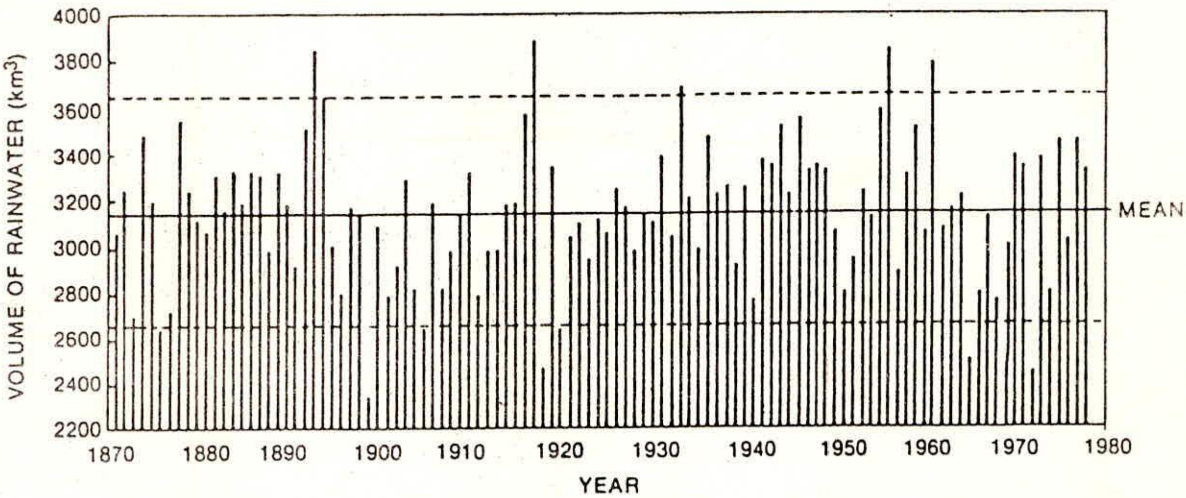

Fig. 12 - Time series of annual average precipitation anomaly for India from 1871 to 1978. 90 % confidence limits on the mean (=3143.5 km^3) are shown by the dashed lines (Mooley et al ,1981)

Bold: Mangrove forests
Hatched: Coral reefs
DD: Deltas
xxx: Rias and estuaries
-: Major estuaries
HR: High risk
MR: Medium risk
VHR: Very high risk

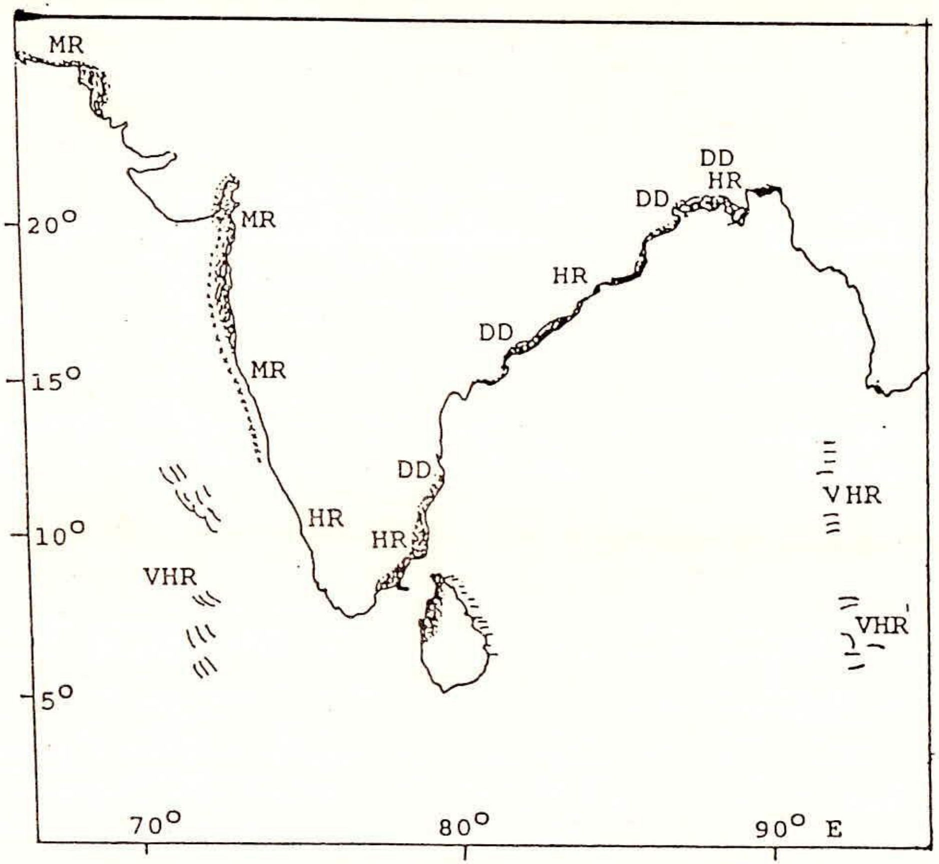

Fig. 13 : Ecosystems and areas vulnerable to sea level rias in India (relative vulnerabilities) [Ahmed & Sengupta, 1984]

Table 1 -Origin , present rate of increase and projected future concentration of greenhouse gases

greenhouse gas	origin (manmade sources)	present rate of increase	projected future concentration
carbon dioxide	mainly from fossil fuel use and deforestation	0.4% per year	expected to reach 600 ppmmv in the next century
methane	rice paddy fields, domestic ruminants, biomass burning, coal mining, organic wastes	1.1 - 1.3% per year	2.0 - 2.5 ppmv during next 50 years
nitrous oxide	fertilizer application and combustion of fuel	0.3% per year	0.34 - 0.40 ppmv by middle of next century
chlorofluorocarbons	solvents in manufacture of paints and as refrigerants	5 - 6% per year	expected to decline provided the use of CFCs is curtailed.

Table 5- Specific changes in climate under the hypothesis of a doubling of the atmospheric CO_2 concentration (Bultot et al.,1988)

	Decrease	Increase	Sources
Net terrestrial radiation	3.1 Wm^{-2}		Chou et.al., 1982
Global solar radiation	2.5 Wm^{-2}		Chou et.al., 1982
Flux of sensible heat	8%		Manabe and Wetherald, 1975
Flux of latent heat of evaporation.		7%	Manabe and Wetherald, 1975
Cloudiness		1.5%	Washington and Meehl,1984
Air temperature		See below	Manabe and Stouffer, 1980
Water vapour pressure		Linked to air temperature, the relative humidities being assumed invariant.	Manabe and Wetherald, 1975 Washington and Meehl, 1984
Precipitation, P	See blow	see below	Manabe et.al. 1981 Washington and Meehl,1984

Monthly increments

	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Air temperature (deg K)	+3.1	+3.4	+3.4	+3.1	+2.8	+2.7	+2.5	+2.3	+2.3	+2.7	+2.8	3.2	2.86
Precipitation (mm/month)	+9.3	+10.5	+9.9	+10.2	-1.2	-2.7	-1.6	-2.2	0.0	+5.3	+8.1	+8.7	54.3

Table 6. six criteria for evaluating the applicability of hydrologic models for climatic impact assessment (Gleick, 1986)

The inherent accuracy of the hydrologic model
The degree to which model accuracy depends upon the existing climatic conditions for which the model was initially developed and calibrated
The availability of input data including comparative historical climatic data
The accuracy of the input data
Model flexibility, ease of use and adaptability to diverse climatic and hydrologic conditions
Compatibility with existing general circulation models

Table 7 : Effects of climatic changes on runoff : some early results (Gleick, 1986)

Author *1	Region	Scale (km^2)	Climatic change	%Change in runoff *2
Stockton and Boggess (1979)	Average for seven western U.S. regions	10^5	+2C;-10% precip.	-40 to -76
Nemec and Schaake (1982)	Arid basin	10^4	+1C +10% precip.	+50
			+1C;-10% precip.	-50
	Humid basin	10^3	+1C;+10% precip.	+25
			+1C; -10% precip.	-25
Revelle and Waggoner (1983)	Colorado River Basin	10^5	+2C;+10% precip.	-18
			+2C;-10% precip.	-40+ 7.4
Flaschka (1984)	Great Basin	10^5	+2C;-10% precip.	-17 to -38
U.S. EPA (1984)	Central U.S.	10^5	Doubled atmospheric carbon dioxide	-26
	NW U.S.	10^5		+20 to + 60

* 1 Each assessment uses different method, hence the direct comparison of results is not possible.
* 2 annual average changes in runoff

Table 8 -Case studies of impact of climatic change on hydrology for critical or sensitive environments

Critical or sensitive environment	Region	Future changes	Remarks
Large water bodies	Great Lakes basin(US/ Canada)	decrease in precipitation decrease in runoff	lake levels expected to be lower and hence navigation would be affected.
	The Caspian Sea	The dynamics of the sea would change in 15 - 20 years	
Critical agricultural regions	South Pla- tte river basin	less certain cons- equences of global warming,increases or very large decreases in precipitation.	
	Murray- Darling basin	precipitation increases in spring autumn and summer.	slight reduction in demand for irrigation water
Intensivly urbanised areas	Delaware river basin,USA	Probability of occurrence of drought	
Regions of snowmelt generated runoff	The Sacramento- San Joaquin River basin (USA).	Total annual runoff to remain near current levels or to increase Higher runoff in winter months and considerably less in the spring snow- melt - runoff season.	

Organizations in India ,involved in the area related with climatic change and its implications

1. India Meteorological Department (IMD)

Studies carried out/being carried out or proposed studies***

* Total ozone ,vertical ozone profile and surface ozone measurement ,turbidity measurements

** Monitoring of CO_2 for trend determination and its effects on Indian climate

* Measurements of different climate related parameters

** Establishing scenarios of regional climate changes and trends over different regions of India

Major findings

- No clear trend established in variation of total ozone over India
- Maximum ozone concentration at heights of 26 - 27 km ,25 -26 km and 23 -25 km. over Thiruvanthapuram ,Pune and New Delhi respectively
- Vertical distribution of ozone all over India is very similar during summer monsoon months and significant changes occur during nonmonsoon months
- Same tropospheric ozone concentration throughout the year ,from equator to 20^{o} N
- Year to year variability in annual and monsoon rainfall ;no systemetic (increasing or decreasing) long term trend observed
- Year to Year variability and slight warming trend observed in temperature

2. National Centre for Medium Range Weather Forecasting (NCMRWF), DST

Studies carried out/being carried out or proposed studies***

* Development of medium range weather forecasting capability and its operationalisation using global spectral model operational at the Centre

** Preparation and dissemination of weather based agrometeorological advisories

** Establishment of a suitable satellite based telecommunication network for communication of the information

** Impact of deforestation on the atmospheric circulation and precipitation using global spectral model

** Study of the effect of vegetation /deforestation ,aerosol ,

CO_2, SST anomalies and snow cover on global weather

Major findings

- Latitude pressure cross - section of the mean zonal component of wind and temperature
- Warmer tropical upper troposphere by about 5 to 10 ^{o}C while cooler polar night region by about 10 ^{o}C ,than climatology
- Simulation of latent and sensible heat and momentum fluxes for 70 days of the 100 day model

3. Survey of India (SOI)

Studies carried out/being carried out or proposed studies***

* Monitoring of sea level changes

Major findings

- Mean sea level data is being obtained using tide gauges at 22 functional tidal stations under the technical control of SOI
- Rising trends noticed of the order of 1 mm / year based on the studies conducted till 1978

4. Indian Institute of Tropical Meteorology (IITM)

Studies carried out/being carried out or proposed studies***

* Distribution of atmospheric ozone over India
* Interannual variability in ozone in the Antarctic atmosphere
** Distribution of ozone in the atmosphere ,its variation and control by physical processes
* Measurement of atmospheric aerosols using Lidar technique
* Acid rain in India
** Detailed studies of atmospheric chemical effects of rapid human activity
* Stratosphere troposphere interaction with biosphere
** Detailed studies on effect of stratospheric changes on climate
* Estimation of anthropogenic emission of CO_2 ,CO and CH_4 over India due to consumption of fossil fuel and biomass
* Analysis of long time series of all India surface air temperature
** Effect of CO_2 on the environment through the observational and theoretical studies
* Construction of the past climate based on the analysis of growth rings of the Indian trees
* Examination of past records of rainfall ,temperature and other selected atmospheric ,physical parameters for evidence of trends,changes and relationships

** Studies of the biosphere aspect of the hydrological cycle
** Documentation of the regional climatic changes on India

Major findings

- Possible anthropogenic effect in the troposphere is indicated
- Precipitation in India is by and large alkaline and acid rain problem localized within few sq. km. of industrial complex
- For Nilgiri biosphere reserve in Kerala ,evergreen forest is a major source of release of sub micron sized gaseous pollutants
- Rainfall extremes are detectable in the ring width series and past rainfall variabilityof the region
- Isotope ratio of hydrogen is related to meteorological elements such as season ,rainfall and temperature

5. Centre for Atmospheric Sciences (CAS) ,IIT ,Delhi

Studies carried out/being carried out or proposed studies***

* Examination of potential climatic effect of changes in the concentration of greenhouse gases on the thermal structure of the Antarctic atmosphere using steady state and time dependent single climate models
** Developement of two dimensional radiative - photochemical - transport model for predicting future possible variations in tropospheric ozone and the associated global temperature changes
* Study of impact of atmospheric aerosols on the earth's climate
* Development of numerical models for prediction of storm surges associated with severe cyclonic storms in the Bay of Bengal
** Application of coastal upwelling model to the west coast of India
* Calculation of mean seasonal and annual zonally -averaged temperature profiles for 18 latitudinal belts using a 2 -D radiative -convective model

Major findings

- Increases in CH_4 ,N_2O ,CO_2 ,CFC with O_3 decrease at the level of maximum concentration results in a surface warming
- Presence of aerosols in the atmosphere causes substantial reduction in the solar heating of the earth's surface at all latitudes
- Studies indicate the implications of the mean sea level on the surges generated by tropical storms and consequently the coastal flooding

6. Tata Energy Research Institute (TERI)

Studies carried out/being carried out or proposed studies***

* Functioning as a think tank for policy analysis of economic and social issues pertaining to global environmental problems

Major findings

- Dissemination of information through Teri Information Service on Global Warming (TISGLOW) ,workshops ,networking with other institutions ,audio visual materials etc.
- Development of databases on socio economic indicators useful for computing greenhouse gas emissions

7. National Institute of Oceanography (NIO)

Studies carried out/being carried out or proposed studies***

* Sea level rise due to greenhouse effect

** Geoscientific investigations on the Indian coast : their application to interpret the paleoclimates and future sea level changes with special reference to greenhouse effect

** Impact of accelerated sea level rise on mangrove resources of India : assessment and action plan

Economic evaluation of the subject

Climatic change due to increasing concentrations of greenhouse gases will have a socio economic effect. One of the major impact will be the changes in hydrological regimes .Probably the most important implications of climate change for water resources would arise through the effects on droughts and floods,both their frequency of occurrence and their severity. Such changes could have potentially devastating effects - such as on agriculture. The other impacts may be categorized as -physical security, drinking water supply and energy supply. Changes in hydrological regimes which would have implications for physical security are those that relate to dam safety and flood protections works . These are designed considering present climate conditions and may prove to be inadequate for the runoff regimes which may be experienced under warm world conditions . Regarding drinking water,two vulnerable environments can be distinguished -areas which have minimal recourse to groundwater reserves and coastal regions where sea level or climate change might increase the risks of salinization of water supply. The climate change could also increase the risk of disruption of energy sources -particularly those dependent on hydropower.

India is an agricultural country ;of the 342 millian hectares of land area in India ,142 is cultivated .About 80% of the total rainfall is provided by the summer monsoon ,which starts in June and withdraws by September . During the period from April to June ,when mean minimum and maximum temperatures are high ,no crop production is possible without frequent irrigation.Almost all foodgrain production is from two main crop seasons kharif (July - October) and rabi or post rainy (November - March). Any adverse effect on production may affect the food security in the country. The increasing concentrations of greenhouse gases including CO_2 ,CH_4 ,N_2O ,CFCs ,increase in temperature ,uncertainty in precipitation and thus the changes in various hydrological parameters as runoff ,evapotranspiration ,soil moisture ,ground water resources could have considerable impact on crop production . Thus, there is an urgent need to study the problem of climate change on regional hydrology and water resources for India.

DIRECTOR	.....	SATISH CHANDRA
TECHNICAL CO-ORDINATOR	.....	S. M. SETH
PROJECT CO-ORDINATOR	.....	P.V. SEETHAPATHI
SCIENTIST	.....	DIVYA