MAUSAM, 52,1 (January 2001), 201-212

551.583 : 551.524.34 (540)

Climate change impact : Regional scenario

U.S. DE

India Meteorological Department, Pune – 411005, India

सार - जलवायु परिवर्तन और विश्वस्तरीय ऊष्णीकरण 21वीं सदी की प्रमुख समस्याएँ होंगी। कृषि, जल उपलब्धता और अन्य प्राकृतिक संसाधनों पर पड़ने वाले इनके दुष्प्रभाव गंभीर चिन्ता के विषय हैं। इस शोध पत्र में विश्वस्तरीय ऊष्णीकरण के संबंध में उपलब्ध सूचना भूतकाल की जलवायु की अनियमितताओं और घटित हुई घातक परिघटनाओं के संबंध में जानकारी के साथ-साथ दक्षिण एशिया में सामान्य रूप से तथा भारत में विशेष रूप से पड़ने वाले इनके दुष्प्रभावों का संक्षिप्त विवरण दिया गया है। कृषि के क्षेत्र में पड़ने वाले दुष्प्रभावों के मूल्यांकन के लिए फसल अनुकरण निदर्शों के सहयोग से जी.सी.एम. निदर्शों के प्रयोग के बारे में संक्षेप में बताया गया है। जल उपलब्धता के संबंध में जल क्षेत्र पर तथा भारत के वनों पर पड़ने वाले दुष्प्रभावों के संबंध में भी विचार विमर्श किया गया है। जलवायु परिवर्तन, विश्वस्तरीय उष्णीकरण और समुद्र के स्तर के ऊँचा उठने के संदर्भ को ध्यान में रखकर हमारे नीति निर्माताओं द्वारा नीतियों के निर्धारण में मुख्य परिवर्तन लाने की आवश्यकता है।

ABSTRACT. Climate change and global warming are going to be the major issues for the 21st century. Their impacts on agriculture, water availability and other natural resources are of serious concern. The paper briefly summarizes the existing information on global warming, past climatic anomalies and occurrence of extreme events *vis-a-vis* their impact on south Asia in general and India in particular. Use of GCM models in conjunction with crop simulation models for impact assessment in agriculture are briefly touched upon. The impact on hydrosphere in terms of water availability and on the forests in India are also discussed. A major shift in our policy makers paradigm is needed to make development sustainable in the face of climate change, global warming and sea level rise.

Key words – Global warming, Regional climate variability, Impact assessment, Tropical forest cover, Green house gas emission, Sustainable water management.

1. Introduction

One of the major issues in the present century is the global warming and its impact on agriculture and other natural resources. The second major issue is the rising population of the earth, Whether the planet earth will sustain this rising population in the face of the changing climate is, perhaps, the most crucial area of our concern for the next century.

Studies on global warming, climate change and its impact on the planetary resources is being pursued vigorously as a multi-disciplinary problem including its impact on societal aspects of human dimensions.

Climate has changed in the past and would continue to do so in future. Past geological and vegetation records support the existence of warm and cold climates in the past. The global climate anomalies have indicated that 1998 was so far the warmest year of the present century (0.57°C above the 1961-90 average). The present review summarizes the nature and occurrence of climate anomalies, climate change, global warming and its impact on biosphere and hydrosphere. Policy related adoption measures are also briefly outlined.

2. Climate anomalies

Large departure in any climatic parameter from its long-term mean is referred to as anomaly. These climate anomalies are a part of climate variability and change. Extreme anomalies often lead to disaster. Since 1980s, climatic anomalies on global scale have been monitored closely, Globally speaking, 1980s was the warmest decade as the warming continues into the 1990s (De and Mukhopadhyay 1998). The years 1998 and 1999 saw severe heat wave conditions over India where the number of death was more than that 1995. A heat wave affected the Great Plains in USA to New England from 10-15 July 1995 with Chicago airport reporting temperature of 41°C. This was the highest since the records began there in 1928. June 1994 was the warmest since 1933 over northwest USA and warmest in the last 100 years over southwest USA. The maximum temperature as high as 51.7°C and 53.3°C occurred in Nevada and in death valley Arizona. The year 1995 was also characterized by severe heat wave conditions over north India where 550 people lost their life.

Extreme low temperature episodes were also reported from different parts of the globe. The lowest temperature of the century was recorded in central and eastern states of USA in January and February 1994. Boston received a snowfall of 2.44 mm breaking the 100 year old city record. Downtown Toranto recorded –24.8°C which modified the previous record of –23.0°C set in 1853. Closer to our region, in 1994, a severe cold wave affected northwest India and Kashmir valley in January - February and December 1993. Snow. 3m thick disrupted the Jammu-Srinagar highway which was the heaviest in last 20 years. During May 1993, cold and dusty winds with very poor visibility over China and Mangolia killed 85 people and damaged crops and live stocks, worth US$ 94 millions.

Increase in the frequency and intensity of cyclonic storms in association with global warming has been a matter of debate. Different ocean basins over the world have shown considerable variation. Hurricane Gilbert 1988 which hit the coast of Mexico and Hurricane Andrew 1992 which struck the Florida coast, are examples of such intense systems, Tropical cyclones of 1970 and 1991 caused phenomenal damage in Bangladesh. Very high and devastating floods were recorded in China, in 1999 and in USA in 1993. The flood in 1993 over USA was the highest in last 150 years. The year 1993 also witnessed an unusually large number (19) of tropical storms crossing Philippines, 1994 saw 12 typhoons making landfall in China being the highest number during last forty years. Over the North Indian basin, the decade 1971-1980 had 62 cyclonic storms whereas the decade 1981-1990 had only 35. An analysis of the past data (De and Joshi, 1995) has shown that the number of cyclonic storms and severe cyclonic storms show decadal oscillations with their number fluctuating from as low as 35 for decade 1981-1990 to as high as 62 in decades 1971-1980 and 1921-1930.

The question whether these climatic anomalies are really becoming more frequent or are due to better monitoring of the climate and weather data globally is a matter of debate. Recently Ungar (1999) has raised the issues; (*i*) whether extreme weather events are becoming more frequent or severe? (*ii*) whether these extreme events are discernible to public and policy makers also? According to IPCC "overall there is no evidence that extreme weather events or climate variability has increased, in a global sense, through the 20th century, although data and analyses are poor and not comprehensive (Houghton *et al*., 1996)" but on the regional scale data reveal contradictory findings. According to a report of the Insurance Bureau of Canada (Ungar, 1999) there were no natural disasters before 1987 which caused insured losses of more than US $ 1 billion. On the other hand, during the past decade, there have been 18 such disasters, The finding supports the fact that the impact of these extreme events in terms of economic losses are increasing. This is as a result of development and improved quality of life and infrastructure, Nearly 90% of the loss of life in association with climate anomalies and the associated natural disasters occur in the developing countries (De and Joshi, 1998). Global climate system, highlights some of the interesting trend and consequences of these climate anomalies.

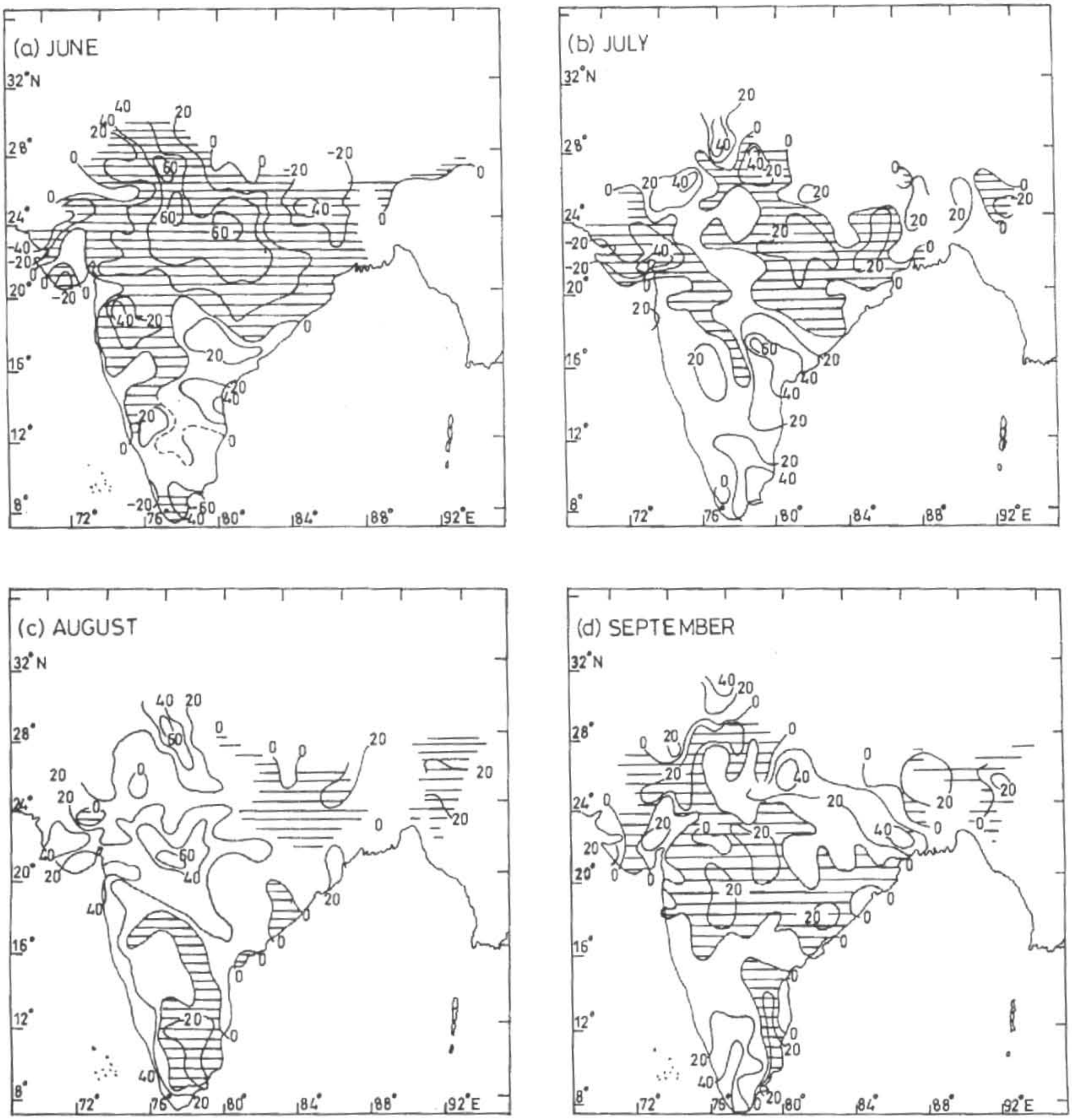
3. Climate change

Global temperatures have increased by about 0.3 to 0.6°C since the late 19th century and by about 0.2 to 0.3°C over the last 40 years, In the last 140 years, the 1990s were the warmest period (Jones and Briffa, 1992).

During 20th century, the surface air temperature over India has shown significant increase trend (Hingane *et al*., 1985). Temperature fluctuations however is not show increasing trend over the entire country in the northeast and northwest India the temperatures show cooling trends also. While Hingane *et al*. (1985) have explained this trend as a result of rise in the maximum temperature, later studies by Sinha Ray *et al*. (1997) have shown that the trend is partly due to rise in the minimum temperature related to urbanization.

Rainfall fluctuations show highly heterogeneous behaviour as a result of global warming. In general, the scenario predicted by various models indicate increased rainfall in high latitudes. Though the models do not, as yet, provide sufficiently reliable information about the likely changes in the distribution of precipitation, they support the idea that in a warmer world the hydrological cycle will be more intense.

Now, we consider some of the studies carried out in India in recent years on climate variability and climate change. Das and Radhakrishnan (1991) reported a rising trend in the sea level at Mumbai (Bombay) during 1940-86 and Chennai (Madras) during 1910-33, based on the



Figs.1(a-d). Linear trend expressed as a percentage of normal per 100-year, 1871-1984, in the rainfall of the four months of the monsoon season. Hatched areas indicate negative trends and stippled areas indicate significance at the 5% level

annual means of tide gauge observations. Srivastava and Balakrishnan (1993) studied the atmospheric and tide gauge data and confirmed a rise of sea level by 8 cm with a corresponding fall in the pressure during 1901-40.

Rupa Kumar *et al.*, (1994) found increase in the mean temperature over India mainly due to increase in the maximum temperature. recent findings by Mukhopadhyay *et al.*, (1999) have however confirmed that there is clear

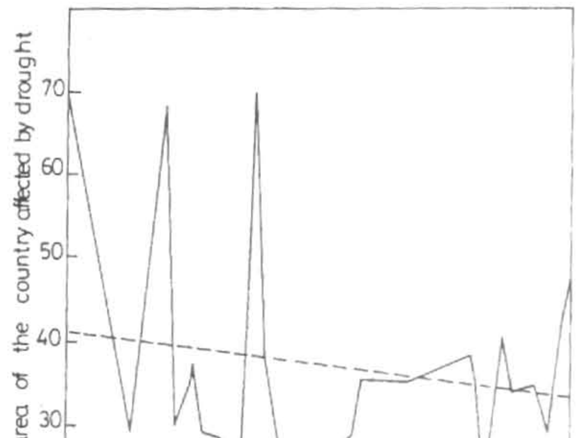


Fig. 2. Percentage of total area of the country affected by drought during all India drought years

signal of urbanization in these warmings *i.e.* that there is a steeper rise in the minimum temperature also in urban locations. This has been noted elsewhere also *viz.* Kukla *et al*., (1986), Oke (1984). Studies have revealed a general rising trend in the mean temperature of the order of 0.35°C during the last 100 years. The northern parts of the country show a decreasing trend while a rising trend is noted for the southern parts.

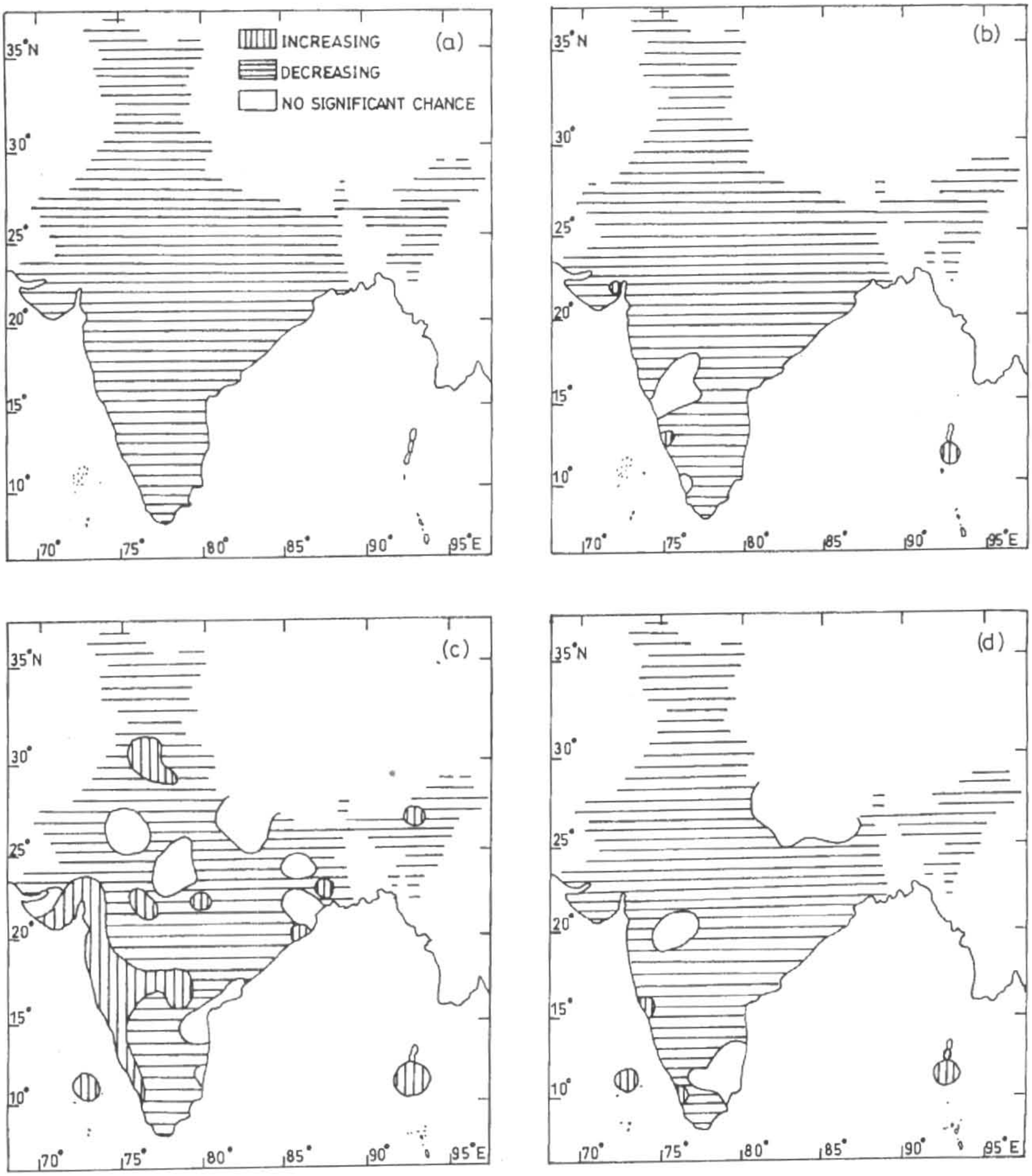
It is now widely accepted that annual global mean temperature of the earth's surface has increased during last 100 years by nearly 0.5°C. The warming has been neither uniform throughout the period nor spatially coherent all over the globe. It shows pronounced differences both between the seasons and various geographical regions (IPCC 1990). The role of natural fluctuations of the climate system or changes in climate including man-made alterations leading to this warming has been debated for a long time (De and Rajeevan, 1997), Karl *et al*., (1984, 1991, 1993) have shown that over large regions of the continents the daily minimum temperatures have increased at a larger rate than daily maximum temperatures. Increased cloud cover and increase in sulphate aerosols could be a possible reason for such an asymmetry in the warming (Karl *et al*., 1993; Charison *et al*., 1991; 1992).

Precipitation intensity is expected to increase during global warming because of the greater moisture holding capacity of a warmer atmosphere (Houghton, 1997). Studies by several author in India *e.g.* Sarker and Thapliyal (1988), Kulshrestha and Thapliyal (1991) and Mooley and Parthasarathy (1984) have shown that there is no statisticaly significant trend in the all India rainfall. The variation shows decadal fluctuations. Decadal variation in meteorological parameters was also brought out in several studies *viz.* Srivastava *et al.* (1992) and Chhabra *et al*. (1997).

Though the monsoon rainfall is trendless over a long period of time, particularly on the all India scale (Mooley and Parthasarathy, 1984), there are pockets of significant long term rainfall changes. These were reported by Koteswaram and Alvi (1969), Jagannathan and Parthasarathy (1973), Raghavendra (1974) and Chowdhury and Abhyankar (1979) etc. A comprehensive study using the monthly rainfall data for 306 stations distributed over India was attempted by Rupa Kumar *et al*., (1992). This data set was the one used by Mooley and Parthasarathy (1984).

Studies by Rupa Kumar *et al.* (1992) have shown that areas of NE peninsula, NE India and NW peninsula show widespread decreasing trend in the Indian summer monsoon rainfall. On the other hand, they reported a widespread increasing trend in the data over the west coast, central peninsula and NW India. The decreasing trend ranges between – 6 to – 8% of the normal per 100 years while the increasing trend is about 10 to 12% of the normal per 100 years. Though these trends are statistically significant, they account for a relatively small part of the total variance in the rainfall. The inter annual variability, however, is the most dominant feature of the overall variability (Fig. 1), Later studies by Srivastava *et al*. (1998), have supported the existence of a definite trend in rainfall over smaller spatial scale.

Recently, Sen and Sinha Ray (1997) have found a decreasing trend in the drought affected areas in India which are located over northwest India, parts of central peninsula and southern parts of Indian peninsula (Fig. 2). Late studies by Sinha Ray and Srivastava (1999) have shown that the frequency of heavy rain during the southwest monsoon show the increasing trend over certain parts of the country. On the other hand, decreasing trend is seen during winter, pre-monsoon and post-monsoon season (Fig. 3). The authors have tried to attribute dynamical and anthropogenic causes for this variation.



Figs.3(a-d). Trends in the frequency of rainfall ≥ 7cm in 24 hours (1901-1990) (a) Winter (b) Pre-monsoon (c) Monsoon (d) Post- monsoon

TABLE 1

Selected crop studies for south Asia

Study	Scenario	Geographic scope	Crop (s)	Yield Impact (%)	Other Comments
Rosenzweig and Iglesias (eds) 1994	GCMs	Pakistan	Wheat	-61 to +67	UKMO, GFDL & GISS +2°C, +4°C and ±20%
		India	Wheat	-50 to +30	Precip, range is over sites and GCM Scenarios
		Bangladesh	Rice	-6 to 8	with direct CO_2 effect
Qureshi and Hobbie 1994	Average of 5 GCMs	Bangladesh	Rice	+10	GCMs included UKMO, GFDLQ, CSIR09, CCC
		India	Wheat	decrease	and BMRC, GCM results scaled to represent 2010
		Pakistan	Wheat	-60 to –10	includes CO_2 effect
		Sri Lanka	Rice	-6	
Matthews *et al*. 1994a, 1994b	3 GCMs	India	Rice	-5 to +28	Range across GISS, GFDL and UKMO. GCM
		Bangladesh		-9 to +14	scenarios and crop models included direct CO_2 effect.
		Myanmar		-14 to +22	Varietal adaptation was shown to be capable of ameliorating the detrimental effects of a temperature increase in currently high-temperature environments.

4. Climate change impact

Global as well as regional agricultural productivity is expected to be influenced by anticipated climate change. Several authors *viz.* Saha and Mooley (1978), Mowla (1978), Chowdhury and Rao (1978) and Goonerathe (1978) have analysed past data to focus the impact of weather anomalies on crop yield in India. Bangladesh and Sri Lanka. Recently Sikka and Pant (1990) have given an overview on the impact of climate variability on agriculture.

Briefiy speaking, the yield could change as a result of : (*i*) changes in temperature, (*ii*) changes in water availability and seasonal distribution of rainfall at the regional level and (*iii*) concentration of atmospheric CO_2. Studies on the effect of higher CO_2 concentration on crops were first made in France in the beginning of the 20th century. Since then, a large number of crops have shown a positive response to the increased CO_2 level. A review of the observations published over several decades by Kimball (1983) has shown that economic yield of mature crops increased by about 26% whereas the increase in immature crops was about 40%. The experimental data review also showed that young plants were stimulated more as compared to mature plants by increased CO_2 level, Studies were carried out using Global Climate Model (GCM) output in combination with Crop Growth Simulation Model for predicting the growth components and yield for various crops like soyabean, wheat and rice (Smith and Tirpak 1989). These results though pertain to specific regions in USA, are relevant to other parts of the world also. Ritchie *et al*. (1989) ran both Crop Environment Resource Synthesis (CERES) model and SOYAGYRO model for rainfed as well as irrigated conditions. His findings are:

(*i*) Rainfall and temperature were the principal causes for modulation in the yield.

(*ii*) Irrigated conditions showed less decrease in yield than those for rainfed conditions.

(*iii*) Prediction of changes in yield with different models is different.

Studies made under Indian conditions have shown that increase in temperature resulted in decreasing the period from transplantation to maturity. Consequently, Seshu & Cady (1984) found a decline in the crop yield. Sinha (1989) had predicted a decline in both rice & wheat productivity in response to a 2°C rise in temperature, The predicted decrease is approximately 0.75 tons/hectare for rice and 0.45 tons/hectare for wheat. The study refers to states of Punjab and Haryana. He also quoted work using a crop growth simulation model 'MACROS' and estimated potential rice yield for years 2000-2100 for representative sites in Asia. The yields rose for low and medium warming scenarios but decreased under high temperature scenarios, since increase in temperature by 2°C or more leads to a shortened 'growth duration' period from transplantation to maturity. This includes 'grain filling' period also. Simulation models considering changes in temperature, precipitation and CO_2 concentration are, however, not the ultimate answer. Changes in solar radiation, wind speed and relative humidity are also important in deciding the ultimate impact of climate change on the rice crop.

Some of the experiments on the impact of higher level of CO_2 and increased temperature was carried out in India for rice cultivation for a typical station (Pantnagar). Rice is grown in various agroclimatic zones of India and Pantnagar is situated in upper Gangetic plains which covers an area of 43 million hectares with an annual production of 75 million tonnes of rice. The average yield is 1751 kg/hectare. The study used the dynamic crop growth simulation model (CERES rice model) in conjunction with GCM generated data from GISS, GFDL and UKMO. The results indicated that the predicted yield was lower than the observed yield in 1987 which was a drought year and in case of 1988, the predicted yield was closer to the observed yield but lower in value, The authors found that increased CO_2 leads to increase yield depending upon water availability and nutritional status. On the other hand, increased temperatures cause a decline in the yield. If they are considered together the rice yield has a possibility of increase. Sivakumar (1993) considered primarily the impact of droughts which are quite periodic in some areas. Such droughts have a significant negative effect on production. Studies by Matthews *et al.* (1994a, 1994b) have estimated the impact of various scenarios on crop production in South Asia (India, Pakistan, Bangladesh, Sri Lanka, Myanmar etc.). The results show substantial variation in impact across the region and among the GCMs (Table 1).

TABLE 2

Difference in yield (kg/ha)

	Crop		
Year	Rice	Wheat	Maize
1982/83	-226	-27	-207
1987/88	-224	-242	-366

In a typical growing season apart from the general temperature rise due to global warming and enhanced CO_2 concentration, interannual climate variability is a crucial issue which will decide the yield actually available, For example, difference in yield of some typical crops in India during two extreme years 1982/83 and 1987/88 is given in Table 2.

Thus calibrations of the models for this factor and also for specific field sites are necessary for a reliable impact assessment.

Tropical forest covers at present nearly 1,900 Mha of the globe as per FAO's estimate. The influence of tropical forests on local and regional climate may be as important as the effects of climate on forest. For example, deforestation could reduce global evapotranspiration and increase run-off. Impact of climate change on tropical forests in India has also been studied by Ravindranath and Sukumar (1998). The authors have considered the projections based on increased greenhouse gas emission using

(a) simple upwelling diffusion energy balance model (MAGICC, Wigley 1994) and

(b) A coupled ocean-atmosphere GCM of Hadley Centre UK (Murphy and Mitchell 1995).

The changes in temperature predicted for India, range between 0.5 - 1.0 to 3.0 - 3.5°C the range being dependant on the season and the particular region of the country. In general the range is more during summer as compared to that during winter or monsoon. Changes in rainfall range from 10-30% to 50-70% again depending on season and particular region of the country. Using this scenario the rainfall is expected to rise during southwest as well as northeast monsoons by varying degrees and the temperature is projected to increase moderately in southern peninsula in winter and early summer while central and northern India may experience warming in the range of 3.0 - 3.5°C during all seasons. Its potential impact on forests in southern India on the windward and

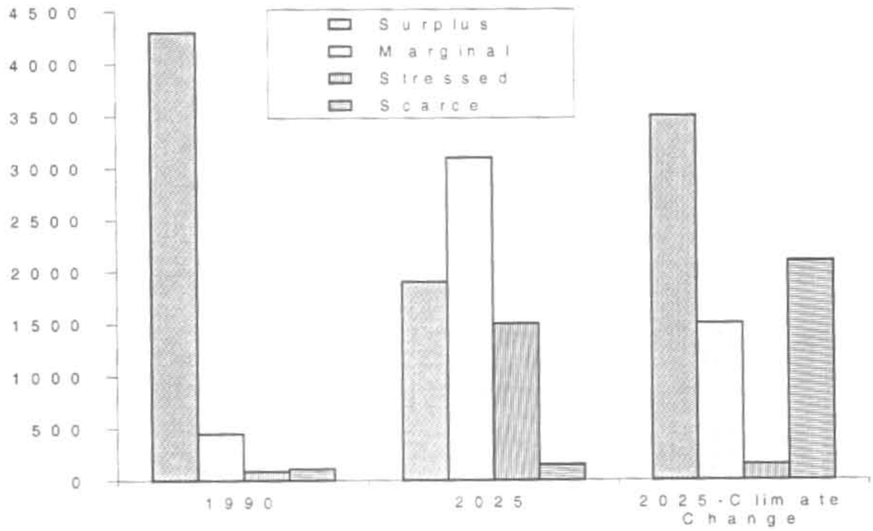


Fig. 4. Global freshwater vulnerability

leeward slopes of the eastern and western ghats have been discussed as follows;

(*i*) High CO_2 level coupled with an increase in rainfall could compensate the potential water stress with the vegetation through increased evapotranspiration in view of the increased temperature during winter and summer. Some of these forested areas on the leeward side of the ghats in the peninsula are the drought-prone regions in India. Recently Sen and Sinha Ray (1997) have shown a decreasing trend in the drought affected regions of peninsula, supports the above projections.

(*ii*) Similarly, for central Indian forests, increase in rainfall and soil moisture predicted through the models could transform the existing forest vegetation to more moist type.

(*iii*) The forest of northeast India does not appear to show an uniform impact scenario in view of large variation in rainfall with the spatial scale but shifts in temperature may produce shift of tropical and sub-tropical forests to higher altitudes. The model also does not give any change in the forest coverage over northeast India.

Lal *et al.*, (1995) have used European Community Hamburg (ECHAM) coupled ocean-atmosphere model to provide a future scenario. The study includes the effect of enhanced CO_2 as well as sulphate aerosols in producing the global warming. In general, the combined effect simulates an overall warming of < 1°C over the Indian subcontinent between 1980s and 2040s. The warming is lower than that simulated by the CO_2 - only model. During winter, the southern, central and northwestern regions are projected to experience a warming of 1.0 - 2.5°C while a cooling of 2°C is simulated over northeastern India. The warming pattern produces a reduction in the land-sea thermal contrast, weakening the summer monsoon with reduced precipitation in parts of the country. The peninsular India shows increased precipitation of upto 2 mm per day while, north of 20° N latitude, the decrease of precipitation of 2 mm/day over central India is predicted. The projected winter precipitation from this model does not show any salient increase or decrease, However, all these projections are dependent on spatial distribution of green house gases which to a large extent is still uncertain.

Water resources are sensitive to climate change. The physical impacts of the climate change are coupled with societal issues and management practices. This makes the evaluation of the total impact difficult and uncertain. With the imbalance in water supply and demand, many nations are in a water scarce situation and face water crisis at local level.

The climatic impact on change in rainfall and run-off will decide the water available in a catchment. Increased amount of precipitation in short heavy spells will lead to low infiltration thereby causing low moisture availability for soil. Furthermore water management systems in the area like number of reservoirs, boreholes etc, would also modify the water availability. Global warming will also affect the water supply by changes in evaporation and ground water recharge. Finally through sea level rise, the global warming may contribute to saline intrusion. Fig. 4 gives the vulnerability of global fresh water resources, mainly as a result of population pressure.

The combined effect of less rainfall and more evaporation would mean less run-off The rivers in these regions have already poor water quality; low run-off and increased input of pollutants due to population rise, is sure to increase the water quality problem. Quantity as well as quality of available water per head would decline. Areas of the south Asian countries with water stress would have to face decrease in farm output.

5. Policy issues

Predicting social and economic impacts of climate change involves imposing another set of probabilities on a picture already characterized by uncertainty, particularly as regards the effects of climatic change at the regional and country level. The policy makers will have to deal with mainly two issues (*i*) Greater climatic variability and more frequent extreme events and (*ii*) climatic change and sea level rise which could be slow. Many future problems will arise because of the heterogeneous distribution of natural resources *vis-a-vis* the oceanic stage of the country, Developing countries appear more vulnerable since their economies are more dependent on agricultural and natural resources. Over some areas benign climatic associated with warmer and wetter condition may produce higher yield but it is difficult to say whether this could offset the losses due to adverse climate change impacts in other regions.

Water availability is likely to worsen by 2050 mainly as result of climatic and population factors in these areas. Several case studies have been carried out by expert groups to show how the sea level rise could have far reaching policy implications for low lying coastal areas as in Guyana, Bangladesh, Maldives and other low lying coastal areas in the sub-continent. A large fraction of the population over the whole world is located in the coastal belt. Large investments in these zones are fraught with increased threat from sea level rise as a result of global warming.

The IPCC assessment reports point out that the major impact of global warming is on agriculture, hydrological cycle, biodiversity and the general eco- system. Important policy decisions both by developing as well as developed countries are needed to ensure that the human factor in this warming is reduced and minimized as much as possible. Environmentally sound technology and clear development mechanism as proposed in Kyoto-Protocal 1997 are needed o contain the growth of green house gases. Transfer of proper technology to ensure this, is a very complex issue. Unless this is ensured the development will not be sustainable and the vulnerability of the region to impacts of global warming is likely to increase.

6. Summary and remarks

(*i*) The impact of global warming and climate change will be a subject of major concern for the South Asian countries in the next century.

(*ii*) Studies with past data indicate that on a regional scale the global warming is not uniform and areas of warming and cooling are located within the same country. The global warming and climate change in our region (South Asia) will manifest themselves in terms of increased temperature, change in rainfall, sea level rise and changes in frequency and severity of extreme events.

(*iii*) The regional scenario of climate change both in terms of temperature and rainfall are not free from uncertainties. These uncertainties arise as a result of inadequate information about the distribution of green house gas induced heating in space and time. The possibility of "Surprises" in climate change projections are not ruled out.

(*iv*) Impact on agriculture depends on many opposing factors like (a) increased CO_2 in the atmosphere (b) changes in temperature (c) changes in water availability to the plants. The existing models take into account some of these factors. The impact of actual inter-annual variability on crops is more and the existing models do not account for this factor. Also incidence of pests and diseases which are sensitive to prevailing weather situations in a growing season are also not considered in most of the models.

(*v*) The impact of climate change on hydrosphere, forestry, health and air quality is more complex. The national and regional development policies have yet to put in place various eco-friendly and environmentally sound technologies, as suggested under Clean Development Mechanism (CDM) of the Kyoto-Protocol of 1997. Some of these impacts are real challenges which are to be faced by policy makers in this part of the World.

Acknowledgements

The author is thankful to Smt. M.M. Dandekar, for her help in data collection and preparation of the manuscript. Thanks ar due to Dr. M. Rajeevan, Dr. K.C. Sinha Ray and Miss. Medha Khole, for providing useful reference material. Smt, Chandrachood type the manuscript and Shri. S.L. Kalamkar, prepared the diagrams and tables. Their contribution is thankfully acknowledged. The DTP unit of the Office of Additional Director General of Meteorology (Research) typeset the manuscript.

References

Charison, R.J., Langer, J., Rodhe, H., Leavy, C.B. and Warren, S.G., 1991, " Perturbation of Northern Hemisphere radiative balance by backscattering from anthropogenic sulphate aerosols", *Tellus*, **43AB**, 152-163.

Charison, R.J., Schwantz, S.E., Hales, J.M., Cess, R.D., Coakley, J.A., Hansen, Jr. J.E. and Hofmann, D.J., 1992, "Climate forcing by anthropogenic aerosols", *Science*, **255**, 423-430.

Chhabra, B,M., Prakasa Rao, G.S. and Joshi, U.R., 1997, "A comparative study of differences in the averages of temperatures and rainfall over the Indian stations during the periods 1931-60 and 1961-90", *Mausam*, **48**, 2, 65-70.

Chowdhury, A. and Rao, G.A., 1978, "Climatic changes and the wheat yield in northwestern parts of India. Proceedings of International Symposium on", "Recent Climatic Change and Food Production", held in Oct. 4-8, 1976 at Tsukuba and Tokyo, 125-136.

Chowdhury, A. and Abhyankar, V,P., 1979, "Does precipitation pattern foretell Gujarat climate becoming arid? ", *Mausam*, **30**, 85-90.

Das, P.K. and Radhakrishna, M., 1991, "An analysis of Indian tide gauge records", *Proc. Indian Acad. Sci. (Earth and Planet Sci.)*, **100**, 2, 177-194.

De, U.S. and Joshi, K.S., 1995, "Genesis of cyclonic disturbances over the North Indian ocean - 1891-90. PPSR 1995/3 issued by IMD".

De, U.S. and Rajeevan, M., 1997, "Identification of anthropogenic climate change", A Review, *Vayu Mandal*, Jan-June, 2-13.

De, U.S. and Joshi, K.S., 1998, "Natural Disasters and their impacts on developing countries. WMO Bulletin", **48**, 4, 336-343.

De, U.S. and Mukhopadhayay, R.K., 1998, "Severe heat wave over the Indian subcontinent in 1998, in perspective of global climate", *Current Science*, **75**, 12, 1308-1311.

Goonerathe, W., 1978, "Recent climatic fluctuations and food problems in Sri Lanka. *Proceedings of International Symposium on, "Recent Climatic Change and Food Production", held in Oct. 4-8, 1976 at Tsukuba and Tokyo*", 111-123.

Hingane, L.S., Rupa Kumar, K. and Ramana Murthy, Bh.V., 1985, "Long term trends of surface air temperture in India", *J. Climatol*, **5**, 51-528.

Houghton, J.T., Meira Fiho, L.G., Calander, B.A., Harris, N., Kattenberg, A. and Maskell, K., 1996, "The science of climate change. Contribution of Working Group I to the second Assessment Report of the Intergovernmental Panel on Climate Change", Climate Change 1995, Cambridge University Press, Cambridge.

Houghton, J., 1997, "Global warming. The complete Briefiing. Cambridge University Press", 242 p.

IPCC, 1990, "Scientific assessment of climate change", Eds.J.T. Houghton, G.J. Jemkins and J.J. Ephraums, Cambridge University Press, 365 p.

Jagannathan, P. and Parthasarathy, B., 1973, "Trends and periodicities of rainfall over India", *Mon. Wea. Rev.*, **101**, 371-375.

Jones, P.D. and Briffa, K.R., 1992, "Global surface air temperature variations during the twentieth century: Part I. Spatial, temporal and seasonal details. The Holocene", **2**, 165-179.

Karl, T.R, Kukla, G. and Gavin, J., 1984, "Decreasing diurnal temperature range in the United States and Canada from 1941 through 1980", *J. Climate Appl. Meteor.*, **23**, 1489-1504.

Karl, T.R., Kukla, G., Razuvayev, V., Changery, M.J., Quayle, R.G., Heim, R.R., Easterling, Jr. D.R. and Fu, C.B., 1991, "Global Warming: Evidence for asymmetrid diurnal temperature change", *Geophysical Res. Lett.*, **18**, 2253- 2256.

Karl, T.R., Jones, P.D., Knight, R.W., Kukla, G., Plummer, N., Razyvayev, V., Gallo, K.P., Lindeay, J., Charison, R.J. and Peterson, T.C., 1993, "A new perspective on recent global warming: Asymmetric trends of daily maximum and minimum temperature", *Bull. AM. Meteorol. Soc.*, **74**, 1007-1023.

Kimball, B.A., 1983, "Carbon dioxide and agricultural yield: An assemblage and analysis of 770 prior observations", pp. 1-5 in WCL Report 14, Phoenix, Arizona, US Water Conservation Laboratory.

Koteswaram, P. and Alvi, S.M.A., 1969, "Secular trends and periodicities in rainfall at west coast stations in India", *Current Science*, **38**, 229-231.

Kukla, G., Gavin, J. and Karl, T.R., 1986, "Urban warming", *J. Climate Appl. Meteor*, **25**, 1265-1270.

Kulshrestha, S.M. and Thapliyal, V., 1991, "Climate changes and trends over India", *Mausam,* **42**, 4, 333-338.

Lal, M., Cubasch, U., Vass, R. and Waszkewitz, 1995, "Effect of transient increase in green house gases and sulphate aerosols on monsoon climate". *Current Science,* **69**, 752-763.

Matthews, R.B., Kropff, M.J. and Bachelet, D., 1994a, "Climate changes and rice production in Asia", *Entwicklung and Landicherraum,* **1**, 16-19.

Matthews, R.B., Kropff, M.J., Bachelet, D. and Van Laar, H,H., 1994b, "The impact of global climate change on rice production in Asia: a simulation study", Report No. ERL-COR-821, US Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR.

Mooley D.A. and Parthasarathy, B., 1984, "Fluctuations of all India summer monsoon rainfall during 1871-1978", *Climatic Change,* **6**, 287-301.

Mowla, K.G., 1978, "Relation between climatic fluctuations and rice production in Bangladesh. Proceedings of International Symposium on, "Recent Climatic Change and Food Production", held in Oct. 4-8, 1976 at Tsukuba and Tokyo, 137-146.

Mukhopadhyay, R.K., Sinha Ray, K.C. and De, U.S., 1999, "Urban influences on surface temperatures in major cities in India during recent decades", *Paper communicated for publication in International Journal of Climatology.*

Murphy, J.M. and Mitchell, J.F.B, 1995, "Transient response of the Hadley Centre coupled ocean - atmosphere model to increasing carbon dioxide part II. spatial and temporal structure of response", *J. Climate,* **8**, 57-80.

Oke, T.R. 1984, "Urban climatology and its applications with special regard to tropical areas", *Proceedings of the Technical Conference,* WMO Note No. 652.

Quershi, A. and Hobbie, D., 1994, "Climate change in Asia: Thematic overview", Asian Development Bank, Manila, Philippines, 351 p.

Raghavendra, V.K., 1974, "Trends and periodicities of rainfall in subdivisions of Maharasthra state", *Indian J. Meteorol. Geophys.,* **25**, 197-210.

Ravindranath, N.H. and Sukumar, R., 1998, "Climate Change and Tropical Forests in India", *Climatic Change,* **39**, 2-3, 562-581.

Ritchie, J. T., Baer, B.D. and Chou, T.Y., 1989, "Effect of global climate on agriculture", In J.B. Smith and D.A. Tirpak (eds.). The potential effects of global climate change on the United States. Appendix C - Agriculture, Vol. 1, pp. 1.1 – 1.30 Washington D.C.: United States Environmental Protection Agency, Office of Policy, Planning and Evaluation.

Rosenzweig, C. and Iglesias (eds), A., 1994, "Implications of climate change for International Agriculture: Crop modelling study", EPA 230-B-94-003, US Environmental Protection Agency, Washington, D.C., 312 p.

Rupa Kumar, K., Pant, G.B., Parthasarathy, B. and Sontakke, N.A., 1992, "Spatial and subseasonal patterns of the long-term trends of Indian summer monsoon rainfall", *Int. J. of Climatology,* **12**, 257-268.

Rupa Kumar, K., Krishna Kumar, K., and Pant, G.B., 1994, "Diurnal asymmetry of surface temperature trends over India", *Geophysical Res. Lett,* **21**, 8, 677-680.

Saha, K.R. and Mooley, D.A., 1978, "Fluctuations of monsoon rainfall and crop production", Proceedings of International Symposium on, "Recent Climatic Change and Food Production", held in 4-8 Oct. 1976 at Tsukuba and Tokyo, 73-80.

Sarker, R.P. and Thapliyal, V., 1988, "Climate change and variability", *Mausam,* **39**, 127-138.

Sen, A.K. and Sinha Ray, K.C., 1997, "Recent trends in drought affected areas in India", Paper presented in INTROPMET-97 held at IIT, New Delhi during 2-5 Dec, 1997.

Seshu, D.V. and Cady, F.B, 1984, "Response of rice to solar radiation and temperature estimated from international yield trials", *Crop Science,* **24**, 649- 654.

Sikka, D.R. and Pant, G.B., 1990, "Global climatic change: Regional scenario over India. Proceedings of Indo-US Workshop on, "Impact of Global Climatic Changes on Photosynthesis and plant productivity", held on 8-12 Jan. 1991 at New Delhi, 551-572.

Sinha, S.K., 1989, "Global warming and food security in developing countries, In R.K. Pachauri and S.Gupta (ds). Proceedings of the International Conference on global warming and climate change: Perspective from developing countires", 101-102, New Delhi, Tata McGRaw Hill.

Sinha Ray, K.C., Mukhopadhyay, R.K. and Chowdhury, S.K., 1997, "Trends in maximum, minimum temperatures and sea level pressure over India", Paper presented in INTROPMET 1997 at IIT, New Delhi.

Sinha Ray, K.C. and Srivastava, A.K., 1999, "Is there any change in extreme events like droughts and heavy rainfall? ", *Paper communicated for publication in Current Science.*

Siva Kumar, M.V. K., 1993, "Global climate change and crop production in the Sundano - Sahelian zone of west Africa", International Crop Science, 1, Crop Science Society of America, Madison, WI.

Smith, J.A. and Tirpak (Eds), D.A., 1989, "The potential effects of global climate change on the United states", Appendix C - Agriculture Vol. I (EPA - 230-05- 89-053) Washington, D.C., United States Environmental Protection Agency, Office of Policy, Planning and Evaluation.

Srivastava, H.N. and Balakrishnan, 1993, "Synthesis of meteorological and tide gauge observations on a decadal scale near the Indian coast", TOGA Notes, 15-17

Srivastava, H.N., Dewan, B.N., Dikshit, S.K., Prakash Rao, G.S., Singh, S.S. and Rao, K.R., 1992, "Decadal trends in climate over India", *Mausam*, **43**, 7-20.

Srivastava, H.N., Sinha Ray, K.C., Dikshit, S.K. and Mukhopadhyay, R.K., 1998, "Trends in rainfall and radiation over India", *Vayu Mandal*, Jan-Jun, 41-45.

Ungar, S., 1999, "Is strange weather in the air ? A study of U.S. national network news coverage of extreme weather events", *Climate Change*, **41**,2, 133-150.

Wigley, T.M.L., 1994, "MAGICC version 1.2 : user's guide and scientific reference manual", OIES/NCAR, Boulder.