



Climate change and its impact on temperature and rainfall trend of India: An overview

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Abstract

Climate change is perhaps the biggest challenge faced by the world today and the very existence of human depends on how effectively this challenge is tackled. There are explicit evidences that atmospheric temperature has been gradually increasing since the beginning of the industrial revolution in 1850's. The Intergovernmental Panel on Climate Change (IPCC) concludes that most of the observed temperature increases since the middle of the 20th century is caused by increasing concentrations of greenhouse gases in the atmosphere resulting from human activity such as fossil fuel burning and deforestation. It also mentioned that the impact of emissions caused by anthropogenic activities on climate is unequivocal. The world community especially developing nations like India is at high risk due to climate change. Present paper gives an overview on the global climate change, the reasons behind climate change, the relationship between CO₂ emission and temperature rise and its immediate effect on Indian climatic factors (temperature and rainfall). Temperature and rainfall both play an important role in shaping the economy of an agricultural based country. The variation of these factors from normal has been discussed in this study. The role of climate change in this variation has also been tried to figure out.

Keywords: climate change, CO₂ emission, temperature and rainfall

1. Introduction

Understanding climate change

As per the IPCC, climate change refers to any change in climate over time, either due to natural variability or as a result of human activity ^[1]. Climate change signifies a statistically major variation in either the mean state of the climate persisting for an extended period, usually decades. Climate change occurs due to natural internal processes, external forces, and persistent anthropogenic changes in the composition of the atmosphere or in land use ^[2]. Since the beginning of the industrial revolution human activities have led to unprecedented changes in the chemical composition of the earth's atmosphere. The global atmospheric concentration of GHGs has increased considerably. As per the IPCC 4th assessment report ^[1], most of the observed increase in global average temperatures since the mid-20th century is most possibly due to the unprecedented increase in anthropogenic GHG emission. Since the pre-industrial era anthropogenic GHG emissions have added large quantities of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) in the atmosphere ^[3].

It is estimated that for temperature rise to remain below 2°C of pre-industrial levels, the world emission should be only about 2,900 Giga tones (Gt) of CO₂ from all sources between the industrial revolution and 2100. However, till 2011, the world has already emitted 1,900 Gt of CO₂. This shows that out of the budget of 2,900 Gt, only 1,000 Gt remains to be emitted between now and 2100, which is not possible ^[3]. Another study by the World Resources Institute, estimates that if emissions continue with this trend, the remaining budget will be over taken in 30 years.

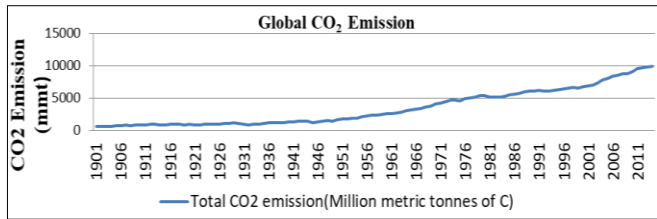
Climate change has become an important area of research not only in the natural sciences but also in the social sciences. It harms not only the environment but also the economic and social aspects. The scientific evidence, including the Fourth Assessment Report (AR4) of the Inter-governmental Panel on Climate Change ^[1], has asserted that it poses unprecedented challenges to human society and eco-systems in the coming decades, particularly in the developing nations whose main occupation is agriculture. It is estimated that climate change will affect the basic elements of life around the world like access to water, food production and healthcare. Millions of people could suffer from hunger, water shortage and coastal flooding, as the world gets warmer. At the same rate of global warming the overall costs and risks of climate change are expected to be equivalent to losing at least 5% of GDP each year. There are certain regions, sectors, ecosystems and social groups which are more vulnerable to climate change. Overcoming the menace of climate change, therefore poses a big challenge to governments and societies ^[4].

2. CO₂ Emission Trend

Among all the GHGs, carbon dioxide's

Concentration has been proved to be more dangerous. Since the industrial revolution, over 400 billion metric tons of carbon dioxide has been emitted to the atmosphere from consumption of fossil fuels. Among which half of the emissions have occurred since the late 1980s. This is due to the rapid increase in the urbanization and land use change in the late 20th century. Globally, liquid and solid both fuels accounted for 75.1% of the emissions from fossil-fuel burning and cement production in 2014. Combustion of gas fuels (e.g.,

natural gas) accounted for 18.5% (1823 million metric tons of carbon) of the total emissions from fossil fuels in 2014. Emissions from cement production (568 million metric tons of carbon in 2014) have more than doubled in the last decade and now represent 5.8% of global CO₂ releases from fossil-fuel burning and cement production [5].



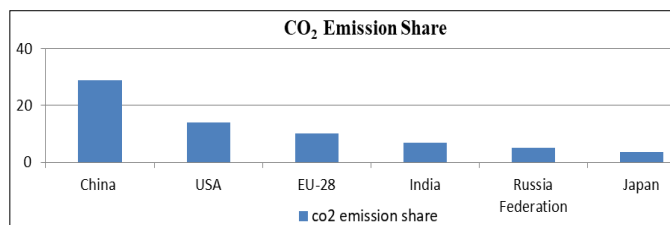
Source: Carbon Dioxide Information Analysis Center

Fig 1

CO₂ emission has been consistently increasing since the industrial revolution. In the last century the increase was slow in the first half. However, in the second half there was considerable increase in the carbon dioxide emission. The graph (figure 1) shows a sudden rise in CO₂ emission after 1980. According to IPCC anthropogenic emission is the main reason behind this rise.

2.1. Top emitting countries

The six largest emitting countries in 2015 were: China (with 29% share in the global total), the United States (14%), the European Union (EU-28) (10%), India (7%), the Russian Federation (5%) and Japan (3.5%). India’s emission growth continued with 5.1% in 2015, compared to 2014. Developing countries like India are characterized by relatively low per capita CO₂ emissions of 1.9 tones CO₂/cap per year which is 60% below the global annual average of 4.9 tones CO₂/cap. This shows that despite of low per capita income, India is one of those countries which are impacted highly due to climate change [6].



Source: Trends in global CO2 emissions: 2016 Report

Fig 2

The graph in figure 2 shows the largest producers of energy-related carbon dioxide emissions in 2015, based on their share of global energy-related CO₂ emissions. China was the biggest emitter of carbon dioxide. The largest CO₂ producers included the United States and three members of the BRIC countries (Russia, India and China) were all ranked among the five largest emitters [7]. Since carbon dioxide remains in the atmosphere for centuries, the impacts of our emissions today will remain long into the future. Among the impacts of climate change, rise in the global temperature is the foremost. In this regard countries around the world have agreed to limit the

warming to well below 2°C.

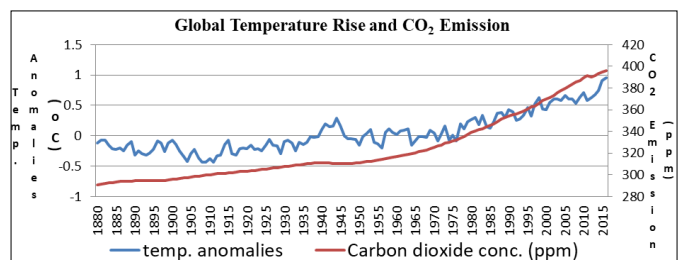
3. Global Temperature

The global annual temperature has increased at an average rate of 0.07°C per decade since 1880 and at an average rate of 0.17°C per decade since 1970. The average global temperature across land and ocean surface areas for 2016 was 0.94°C above the 20th century average of 13.9°C, surpassing the previous record warmth of 2015 by 0.04°C. To date, all 16 years of the 21st century rank among the seventeen warmest on record [8].

During the past five decades, the earth has been warming at a higher rate of 0.08-0.14°C between 1951 and 2012 [9]. This warming trend affects the atmosphere both over the land and over the ocean. As per IPCC reports, this temperature increase is due the greenhouse gas effect and affirms that this is primarily caused by the increase in the atmospheric concentration of CO₂ during the last 200 years. It has been proved that there is direct relationship between human activities and global warming, as during the last 150 years the increasing anthropogenic emission has resulted in rise in global temperature. Natural forcing (solar forcing and volcanic activities) has contributed only marginally to the global temperature during the last 150 years [10].

3.1. Linkage between CO2 and temperature rise

The rate at which surface temperature goes up is not proportional to the rate of CO₂ emissions (figure 3), but to the total amount of atmospheric CO₂ added since the start of the industrial revolution. Small increases in temperature can be hard to measure over short periods, because they can be masked by natural variation. The amount of CO₂ is increasing all the time, the landmark of 400 parts per million concentration of atmospheric CO₂ has just crossed, up from around 280 ppm before the industrial revolution, which is about 42.8% increase. Even a small amount of CO₂ and other GHGs, like methane and water vapor, keep the Earth’s surface 30°C warmer than it would be without them.



Source: National oceanic and atmospheric administration

Fig 3

Anthropogenic factors have added 42% more CO₂ but that doesn’t mean the temperature will go up by 42% too. There are several reasons why doubling the amount of CO₂ does not double the temperature rise. The way the climate reacts is also complex, and it is difficult to separate the effects of natural changes from man-made ones over short periods of time. The IPCC report (AR4) described the likely range as between 2oC and 4.5oC, for double the amount of CO₂ compared to pre-industrial levels. So far, the average global temperature has

gone up by about 0.8oC. The same temperature rise (0.8oC) has been analyzed by scientists at NASA's Goddard Institute for Space Studies (GISS).

3.2. Future Projections

The projected temperature increase by the end of this century is likely to be in the range of 2o C-4.5°C (IPCC). For the next two decades, a 0.2°C increase in temperature per decade is projected. Even if all emissions were stopped now, a further warming of about 0.1°C per decade is expected. It is very likely that hot extremes, heat waves and heavy precipitation events will continue to become more frequent. Variation in precipitation is also expected. Increase in precipitation is expected in high-latitudes while decrease is expected in most subtropical land regions ^[4].

Future greenhouse gas (GHG) emissions are the product of very uncertain compound systems, determined by driving forces such as demographic development, socio-economic development, and technological change. Their future evolution is highly uncertain. IPCC evaluates the temperature rise projection by considering the six SRES emission scenarios. Scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyze how driving forces may influence future emission outcomes and to assess the associated uncertainties. They assist in climate change analysis, including climate modeling and the assessment of impacts. The projection under these scenarios is presented in table 1. The best estimate for the low scenario (B1) is 1.8°C (likely range is 1.1°C to 2.9°C), and the best estimate for the high scenario (A1FI) is 4.0°C (likely range is 2.4°C to 6.4°C) ^[11].

Table: 1

Emission Scenarios	Temperature Change (° C at 2090-2099 relative to 1980-1999)	
	Likely Range	Best Estimate
B1 Scenario	1.1-2.9	1.8
A1T Scenario	1.4-3.8	2.4
B2 Scenario	1.4-3.8	2.4
A1B Scenario	1.7-4.4	2.8
A2 Scenario	2.0-5.4	3.4
A1FI Scenario	2.4-6.4	4.0

Source: ^[12] IPCC AR4

4. Variations in climatic factors of India due to climate change

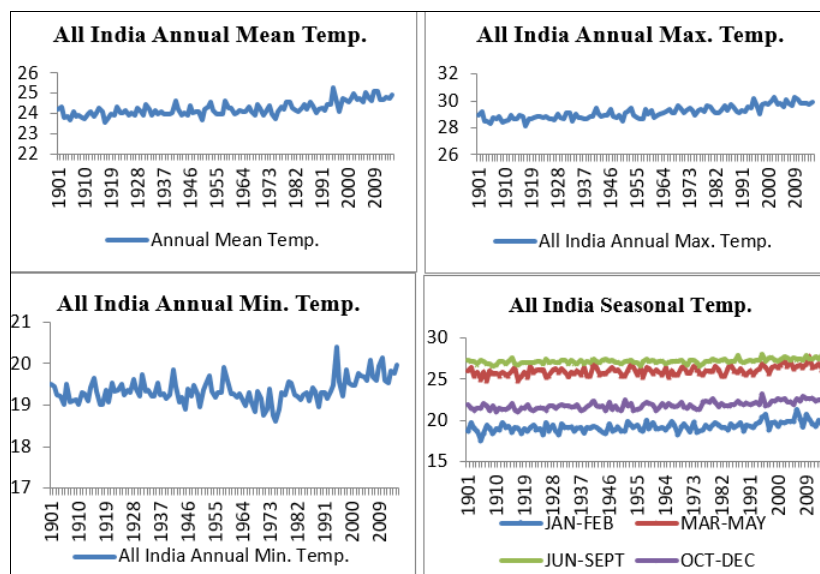
The impact of climate change is highest in the developing world due to certain factors. Apart from being a tropical country, the presence of oceans in the south and the great Himalayas in the north make India one of the most vulnerable regions in the world. Climate change has caused major changes in climatic factors such as precipitation, air temperature, relative humidity, and solar radiation. Due to

these variations, there is a consistent warming trend which is clearly reflected by the increasing occurrence of extreme climate events like droughts, floods and heat waves ^[13]. According to the AR5 of IPCC, the average maximum and minimum temperatures over land have increased worldwide including India, thereby affecting agriculture, water demands, and more rapid melting of glaciers ^[9]. The report also stated that extended intervals of monsoon failures and dry spells have struck India and southeastern Asia. The frequency of heavy precipitation events is increasing while light rain events are decreasing. The climate variability is causing evapotranspiration rates increase, decline in soil moisture, and socio-economic consequences. Further it is also causing longer dry periods, and greater number of extreme events. Studies carried out by several investigators have shown that the trend and magnitude of warming over India/the Indian sub-continent over the last century is broadly consistent with the global trend and magnitude ^[14]. IPCC reported that for India generally temperature, heat waves, droughts and floods and sea levels have increased, while glaciers have decreased. It is projected that by the end of the twenty-first century, rainfall will increase by 15-31 % and the mean annual temperature will increase by 3-6oC. The warming will be more evident over land areas with the maximum increase in northern India. The warming is also projected to be relatively greater in the winter and post-monsoon seasons ^[4].

4.1. All India temperature trend

Annual Mean Temperature: There has been inconsistency in the annual mean temperature of India. In 1901 it was 24.23oC which decreased to 23.96oC in 1911. In 1921 it again increased to 24.33oC and kept on increasing till 1941. After that it decreased in 1951, 1961 and 1971. In 1981 it rose to 24.27 degree Celsius and further rose to 24.28 in 1991. From 2001 to 2014 the average temperature was 24.58oC which was greater than the average temperature of the first decade (1901-2011) of last century 1901 to 2011 (23.9oC).

Annual maximum temperature: The maximum temperature of India has shown an inconsistent pattern of both rise and decline from 1901 to 2014. But, if we look at the visualization, depicting the maximum temperature of India, as a whole, from 1901 to 2014, the long term trend of rise in temperature in India is very much clear. The maximum temperature recorded was 28.96oC in the year 1901 and 28.62oC in the year 1911. The maximum temperature recorded was 28.86oC in the year 1921. Thus, the maximum temperature was around 28oC plus during the decades from 1901 to 1921. Similarly, the maximum temperature rose to around 29oC plus during the decades from 1931 to 1951. In the year 1961 it showed a little decline from 29.09oC (1951) to 28.72oC. The maximum temperature again rose to 29.15oC in the year 1971, which kept on rising till 1995 (30oC). During the period 2001 to 2014, the maximum temperature touched 30oC



Source: ^[16] data.gov.in

Fig 4

Annual minimum temperature: The minimum temperature was around 19°C plus during the decades from 1901 to 1921. It rose to around 19.64°C during the decades from 1931 to 1951. The minimum temperature recorded was 19.27°C in the year 1961 and it declined to 18.77°C in 1971. It again rose to 19.25°C in 1981 and to 19.29°C in 1991. During the period 2001 to 2014 the mean minimum temperature was 19.69°C, which was more than the mean minimum temperature of 1991 to 2011 (19.08°C) ^[17].

All India seasonal temperature: During the period 1901-2014, there was a significant rise in the mean temperatures in all the seasons. Increase in the mean temperatures was the highest in the post monsoon (0.79°C per hundred years) and winter (0.70°C per hundred years) seasons, followed by the pre monsoon (0.55°C per hundred years) season. The mean temperature during the monsoon season showed the least rise of 0.43°C per hundred years. Similarly, there is a significant rise in the maximum temperature in all the seasons and the rate of increase is also almost constant around 1.0°C per 100 years. The minimum temperatures were practically stationary (trendless till 1980) in all the seasons except the post monsoon season during which significant rise was observed (0.39°C per 100 years). Further during the recent three decades (1981-2010), the mean temperature rose significantly in all the seasons ^[18].

Although maximum temperatures increased gradually and consistently over the entire period, the rate of rise during the past 30 years was almost double. It may also be seen that rise in minimum temperatures was very spectacular for the period 1981-2014 as annual minimum temperatures, which was practically trendless till 1980. Thus, maximum as well as minimum temperature both has shown a rising trend in the past few decades. It has been asserted that climate change might have caused this rise.

4.2. Rainfall in India

The Indian climate is subject to the southwest monsoon. About 80% of the rainfall in India occurs during the four

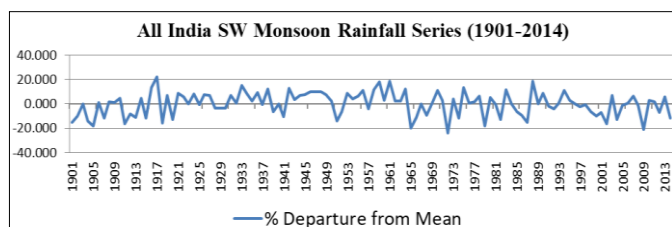
monsoon months (June–September) with large variations over the country. However, despite of such heavy concentration of rainfall sometimes there is scarcity of water in many parts of the country during the non-monsoon period. In India, rainfall variability is a central driver of the national economy as it is predominantly agricultural. Studies have found that anthropogenic emissions have contributed to escalation of heavy rainfall events ^[19]. Long term trends for the last 50 years indicate a significant decrease in the frequency of moderate-to-heavy rainfall events over most parts of India ^[20].

4.2.1. All India rainfall trend

All India rainfall during the SW monsoon season (June–September) for the period 1901-2014 is shown in figure 5. Mean south-west monsoon rainfall is 887 mm which is 75% of the annual rainfall. Around 11% and 10% of the annual rainfall is received during the pre-monsoon and post-monsoon respectively. The all India monsoon seasonal rainfall shows significant multi-decadal variation with periods of above normal and below normal rainfall (figure 5). SW monsoon rainfall was in dry phase during the first two decades (1901-10, 1911-20). However, the next five decades (1921-30, 1931-40, 1941-50, 1951-60 and 1961-70) were in phase with above normal rainfall. Period 1971-1980 was considered to be the dry phase. Beyond 1970, the frequent fluctuations between positive and negative precipitation anomalies follow the dramatic increase of global air temperature. Therefore, we can say that there is a relationship between global increase in temperature and precipitation changes beyond the 1970s.

The rainfall extremes in tropical regions are more sensitive to global warming. Increasing temperature in the late 21st century and early 22nd century will cause frequent changes and shifts to the monsoon precipitation up to 70% below normal levels ^[24]. This will be detrimental to the Indian population as 75% of the total annual rainfall of India is from the summer monsoons. A 2°C rise in the world's average temperature will make India's summer monsoons highly unpredictable ^[23]. Recent studies ^[25] show that, in general, the

frequency of more intense rainfall events in many parts of Asia has increased, while the number of rainy days and total annual amount of precipitation has decreased.



Source: [26] Open Govt. Data (OGD) Platform India

Fig: 5

5. Climate change projections for India

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), future climate change is likely to cause more rapid melting of glaciers which would further affect agriculture, increase the risk of hunger and water scarcity. Fresh water availability in many river basins in India is likely to decrease due to climate change [27]. This decrease, along with population growth and rising living standards, could adversely affect many people in India by the 2050s. Himalayan glaciers and snow covers are projected to recede at an alarming rate causing floods and slope destabilization [1]. Climate change projections for India using the Coupled Model Inter-comparison Project 5 (CMIP5) group found that, by the 2030s, under a business-as usual representative concentration pathway (between RCP6.0 and RCP8.5) scenario, mean warming in India relative to pre-industrial times is likely to be in the range 1.7–2.0 °C [28]. Future climate studies for India based on climate model simulations suggest that greenhouse driven global warming is likely to intensify the monsoon rainfall over a broad region encompassing South Asia [21]. An overview of the IPCC Fifth Assessment report (IPCC, 2013) for India suggests that there is still significant uncertainty about climate dependent activities like agricultural yield impacts due to the difficulties in understanding and predicting monsoon behavior [29].

6. Conclusion

Climate change has the potential to affect all sectors of human and natural systems, depending on the geographical location. It is observed that climate change is the most serious environmental issue that the modern world is going to face in the 21st century. The unprecedented growth in economic activities and change in day to day lifestyle patterns have caused lot of environmental damage to the earth's atmosphere. The earth's climate is frequently changing and leading to degradation of biodiversity, water and soil resources, desertification, coastal erosion, decrease in agricultural productivity etc.

Developing countries like India is facing the dangers of climate change in the form of unprecedented temperature rise and untimely rainfall in the recent past decades. There was a significant rise in the mean and maximum temperature in all the seasons during the period 1901-2014. The all India monsoon seasonal rainfall shows significant multi-decadal variation with periods of above and below normal rainfall. The major cause of climate change is anthropogenic GHG

emission. It is observed that there has been an increasing trend in the anthropogenic emissions of greenhouse gases (GHG) since the beginning of the industrial revolution, with about half of the anthropogenic CO₂ emissions occurred in the last forty years. The period 1983- 2012 was the warmest thirty year period (IPCC). CO₂ emissions from fossil fuel combustion and industrial processes have contributed phenomenally during this period. The magnitude and rate of future impacts of climate change would be dependent significantly on global actions to limit emissions.

High priorities for narrowing gaps between current knowledge and policy-making needs should be given to the quantitative assessment of the sensitivity, adaptive capacity and vulnerability to climate change, with focus on the major agro-economic factors in the developing countries. To scientifically pursue such assessments, the foremost requirement is to assess the estimates of future climatic patterns on the regional scale, which could be readily used to project the climate change impacts. To conduct climate change projection, systematic model simulations and development of suitable regional climate change scenarios is required.

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