IDRiM (2023) 13 (2) ISSN: 2185-8322
DOI10.5595/001c. 92642

Journal of Integrated Disaster Risk Management

Original paper

Review of Various Climate Change Exacerbated Natural Hazards in India and Consequential Socioeconomic Vulnerabilities

Akhil Charak [1]* Kumar Ravi [2] and Amit Kumar Verma [3]

Received: 04/01/2023 / Accepted: 14/09/2023 / Published online: 13/02/2024

Abstract Climate change has been a major existential threat to humanity, and much-debated predictions of its devastating consequences are becoming a reality. The various natural hazards and disasters are a cause of grave concern, and there is a need to study these hazards, their impact on the society, the nation's economy, and various other vulnerabilities in the future. There is a huge gap in understanding the impact of climate change on the society, and it seems that we all are living in a state of denial. So, there is a strong need to combine all available data in one document to give a holistic view of actual problem. This paper reviewed the various likely vulnerabilities in front of India and how climate change will exacerbate the Natural hazards. It will also bring out the likely impacts of climate change on the India's economy.Moreover, it's evident from this review that India's vulnerability to climate change and consequential hazards is greatly amplified because of its socioeconomic, demographic, and geographic characteristics and large population, which strain the existing infrastructure. Various findings based on review of data is also listed at the end to give the consolidated outcomings of the review, which highlight the major threats as heat waves, erratic precipitation, cyclones and floods. The paper also highlight how developing countries like India are spearheading the drive to decrease the carbon footprint and prevent further impacts on the climate.

Keywords: Natural hazard, Resilience, Sustainability, Vulnerability, Climate change, Socioeconomic, Rural-Urban, Disaster, Urban flooding

[1] Centre of Excellence in Disaster Mitigation and Management, Indian Institute of Technology Roorkee, India
*Corresponding author email: akhil_sc@dm.iitr.ac.in
[2] Department of Mechanical and Industrial Engineering, Indian Institute of Technology Roorkee, India
[3] Silviculture & Forest Management Division , Forest Research Institute, India

DOI10.5595/001c. 92642

1. INTRODUCTION

India is massive, with some of the world's most diverse ecozones, including Himalayan mountains, tropical and temperate forests, vast deserts, a huge coastline, several rivers, vast river beds, and wetlands. India is hence a landmass with extremely varied physical characteristics and geoclimatic zones, rendering it vulnerable to numerous climate-induced calamities, particularly floods, cyclones, storm surges, heat waves, drought, forest fires, *etc.* and unknown pathogen outbreaks(K. Mandal & Dey, 2022). Moreover, it is the most populous country in the world, with a meager per capita income of 2321 USD. The increasing population and poverty put a tremendous strain on its natural environment, encroaching on the natural ecozones balanced on delicate environmental cycles(Gosling and Smart, 2013). Anthropogenic activities have resulted into climate change and hence unprecedented increases in temperature in India (Arora, 2019). Based on the Environmental Vulnerability Index developed by the South Pacific Applied Geoscience Commission (SOPAC) and the United Nations Environment Program (UNEP), India is viewed as being extremely vulnerable due to its climate and population density. (Pacific Islands Applied Geoscience Commission. (2004). South Pacific Applied Geoscience Commission (SOPAC) Annual Report Summary 2003. Pacific Islands Applied Geoscience Commission (SOPAC)., n.d.). This unprecedented climate change and vulnerable population intruding on the ecozones have intensified the magnitude of natural-hazard risk and emphasized the need to build climate resilience. Assessing how new climate-related dangers will be brought about by climate change and taking various measures to better manage these risks are all part of improving a nation's climate resilience(Wong-Parodi, 2016) . Therefore, there is a desperate need to improve climate resilience in India against Natural -hazards and reduce the impact of Climate change-induced Natural Disasters.

This paper will review the various data and research on Climate change,the Risks induced by climate change, and the vulnerabilities faced by India. Based on the review, the paper will give its findings and recommendations to cope up with this glaring issue.

2. CLIMATE CHANGE IN INDIA:

As per Indian meteorological department data, March 2022 was the warmest in India's recorded history, with 33.1°C as the average monthly day temperature surpassing the previous highest of March 2010. Between March and April 2022, India and Pakistan had a catastrophic heat wave that resulted in at least 90 fatalities, extensive crop losses, and wildfires. (Ripple *et al*., 2022). Moreover,Heat waves are predicted to occur 30 times more frequently as a result of climate change in the future.The data from NASA Goddard institute of space sciences, Figure 1 below shows the weather anomaly compared to 50 years' average March Temperature from 1880 to 1930as compared with March 2022 mean temperature.

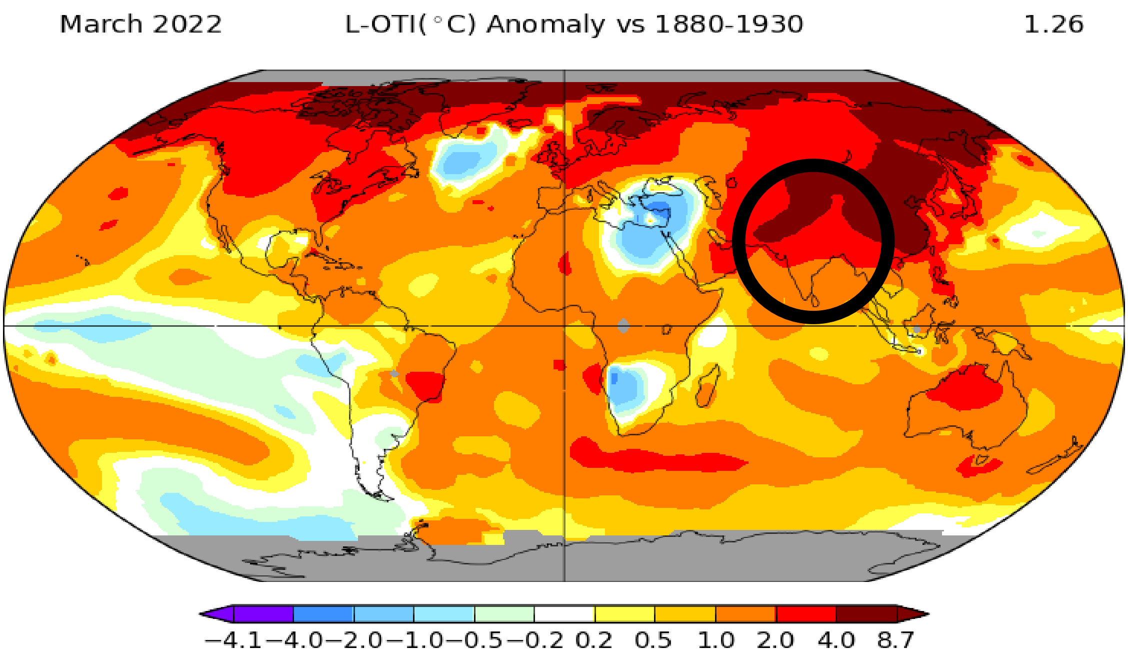

Figure 1: Weather anomaly for Mar 2022 as compared to an average of 1951 to 1980 based on data from NASA Goddard institute of space sciences using GHCNv4_ERSSTv5(Lenssen *et al*., 2019)

Post-Industrial revolution, the world faced unprecedented climate change, whichenhanced the frequency of natural hazards and increased the population's vulnerability. Figure 2 graphically represents data taken from data.gov.in, indicating an almost 1°C rise in mean temperature in India in the last 120 years.

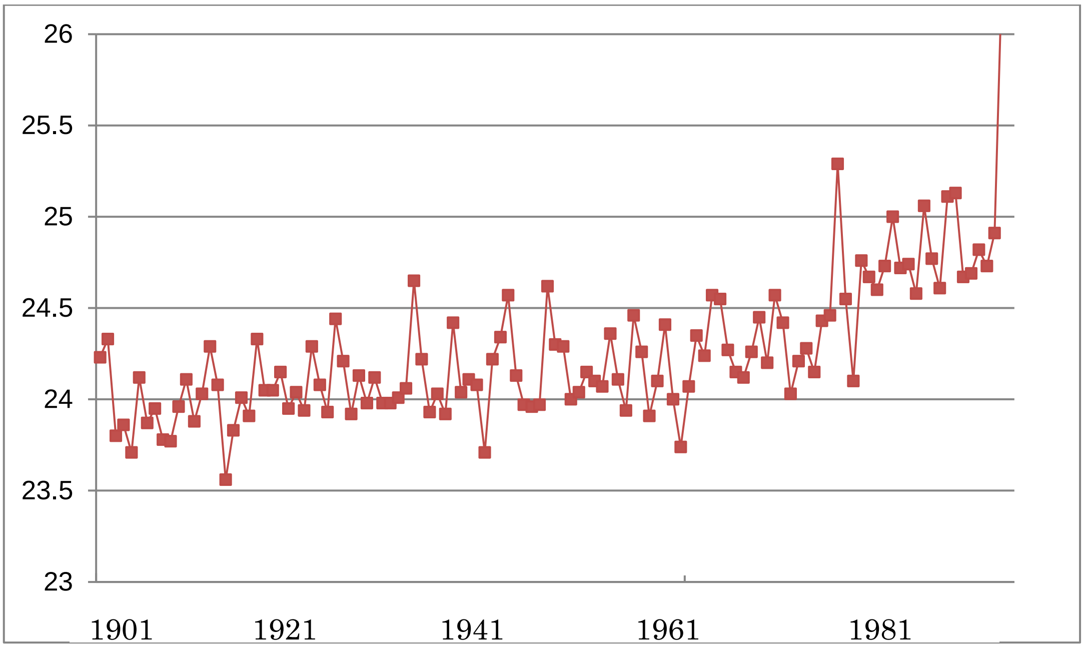

Figure 2: Temperature Variation 1901-2017 in India prepared based on temperature data available at data.gov.in-mean temperature India (℃).

It may be inferred from the mean annual temperature record for India since 1901 (Figure 3) that the nation has gotten warmer over time. The average mean temperature between 1901 and

1910 was 25.16°C (which is shown as 0 at Y axis), therefore winter, summer and spring have progressively gotten warmer with the progress of century. While temperatures in January and February in 1911 to 1920 were still 4.6°C below the norm for the period between 1901 to 1910, they decreased to 4.3°C on average in 2011 to 2020. While the summer-time temperature varied from 1911 to 1920 by 2.6°C, it has recently been 3.1°C higher than the previous average. From a 2.0°C divergence in 1911 to 1920 to a 2.7°C divergence just 100 years later, the spring season of March to May experienced the greatest dramatic average temperature increase.

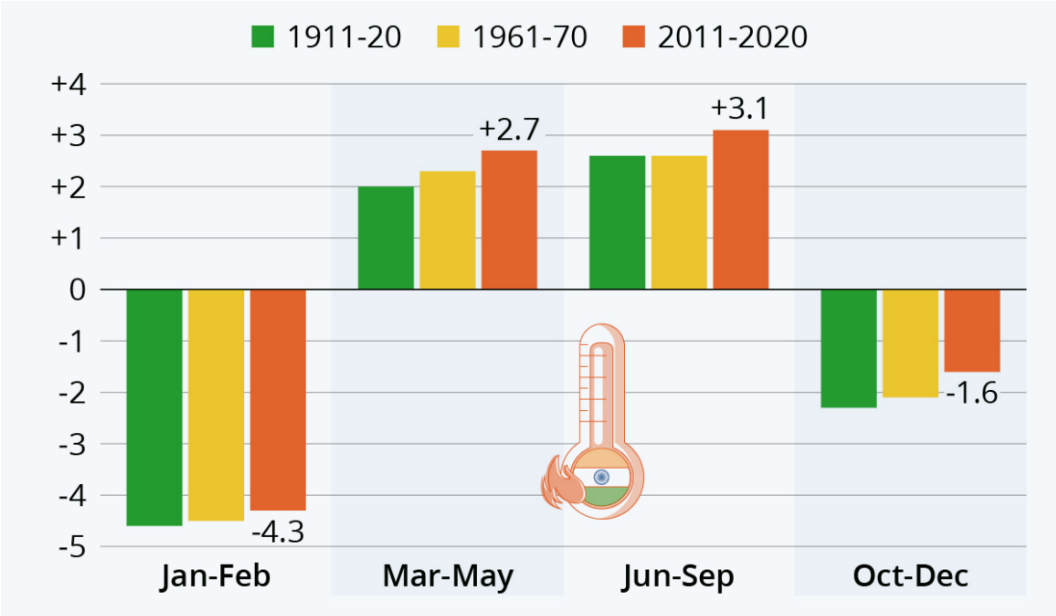

Figure 3: Comparison showing average divergence from the mean temperature at the beginning of the last Century in India by decade.0 on Y-axis is average of mean temperature from 1901-1910 (first decade) in ° C, therefore it is used as a baseline. Source: Indian Met department min of earth sciences via MOSPI EnvuStats India Report. (https://www.statista.com/chart/27379/india-temperature-divergence/)

World Bank Group Climate Knowledge Portal (https://climateknowledgeportal.worldbank.org/) has also developed a Future climate information model from 35 available global circulation models (GCMs) used by the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report Figure4. It indicates an average 1°C increase in temperature in the short term for 2020 to 2039 and an unprecedented 4°C rise in the long term for 2080 to 2099 as compared to the 1986 to 2005 period average. Therefore, the reports and analysis highlight historical and future climate changes, which may enhance the natural multi-hazard and therefore risks in India.

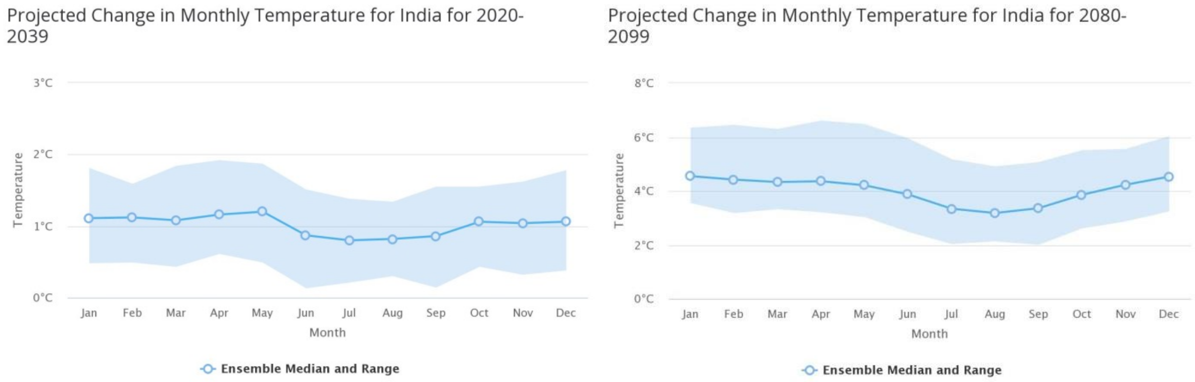

Figure 4: Comparison of Historical monthly temperature data with future projections. (Source: World Bank Group Climate Knowledge Portalhttps://climateknowledgeportal.worldbank.org).

3. CLIMATE CHANGE-INDUCED RISKS IN INDIA:

As per UNDRR (Office report covering 2000 to 2019), India is the third-worst affected country due to natural calamities. In India, 79,732 people lost their lives, and 108 crore people were affected by 321 natural disasters from 2000 to 2019(Deroliya *et al*., 2022). Also, more than 100,000 people lost their lives between 1953 and 2018 due to significant flood events, which incurred $ 3000 billion in damage to public utilities(O'Brien *et al.*, 2004a) (CWC, 2019).India is also among the top nations vulnerable to climate change and related vulnerabilities. As per the global climate risk index 2019, India is the 7th most vulnerable out of 181 countries to the climate change effect (Eckstein, 2018) . Energy research institution council on energy, environment, and water claimed that 75% of districts in India are vulnerable to cyclones, droughts, floods, and cold waves due to climate change. India was placed in the second position in the 'severe risk' nations in the world subjected to environmental and climate change hazards in the Global Climate Change and Vulnerability Index. As per Attri, the leading natural disasters in India are drought, flood, and tropical cyclones, measured by the number of people affected (Attri and Tyagi, 2010). India's vulnerability to climate change and consequential hazards is greatly amplified because of its socioeconomic, demographic, and geographic characteristics and large population, which strain existing infrastructure. It is more enhanced due to cascading effect of climate-related rural-urban migration, and it turns out to be a vicious cycle further straining limited resources of the urban areas. Natural disasters like urban flooding experainced extensively in Indian cities during monsoons in last couple of years is a live example of this phenomenon.

India has a considerable coastline spreading around 7,516 km, of which about 5,700 km is vulnerable to cyclones of different extents and intensities (Kumar *et al.,* 2012) . Around 40%

of the overall population resides on India's coastline and therefore is susceptible to the severely exposed coastline and related vulnerabilities. Cyclones are considered the most damaging of all environmental disasters when viewed in terms of their magnitude, length, and areas of devastation. Off-late it has caused much destruction to life and property in these regions.

Climate change is imposing enormous challenges to the food security and water resources of the 1.3 billion population in India, and extreme events are now more frequent(Ray *et al*., 2021). India's agrarian economy may get adversely impacted due to extreme events which may alter the water availability and distribution(Udmale *et al*., 2014). For instance, a drought event in 2016 affected 330 million people, yielding an economic loss of $100 billion (ASSOCHAM Report, 2016) in India(Goyal &Surampalli, 2018). Similarly, 268 flood events were reported during 1950–2015, affecting 825 million people, and this is a threefold rise in the extreme precipitation events during the same period over the central part of India(Roxy *et al*., 2017). Second largest populated and agrarian-based country in the world, India is also the world's largest consumer of groundwater. India uses 60 % of groundwater for irrigation(Rodell *et al*., 2009). Droughts are expected to become more common in the following decades, and people's exposure to water shortages is projected to rise due to population expansion(Dai, 2011). Groundwater depletion in India might result in food crop losses of up to 20 % across the country and up to 68 % in areas where future groundwater supply is expected to be poor(Roy *et al*., 2022).

Drought has wreaked havoc on India's agricultural, socioeconomic, environmental, and financial systems(Saha *et al*., 2021). Drought has several economic consequences, including increased commodity prices, water demand, and credit availability. It also has societal consequences, including migration, poverty, lower quality of life, and political tensions; environmental consequences include increased pollution, loss of plant diversity, diminished subterranean water, and soil erosion. According to recent statistics given by "Drought Early Warning System (DEWS)," a real-time drought-monitoring technology, almost a fifth of India's geographical area (21.06 %) is experiencing drought-like conditions.

Therefore, it is paramount to investigate the future variability of extreme weather events related to precipitation, as this will provide insight into possible changes in the occurrence and magnitude of floods and droughts. This will then guide suitable adaptation strategies and disaster mitigation policies.

These hazards can impact in isolation or as a multi-hazard which is challenging to manage due to the paucity of resources and lack of planning. Building climate resilience for worst-case scenarios like Multi-Hazards is a significant challenge for India. The key focus should be addressing the vulnerabilities which communities may face at the local, state, and national levels due to climate change. Climate resilience efforts in a Multi-hazard context must encompass social, economic, technological, and political strategies that must be implemented at all levels of the community(Birkmann *et al*., 2010a and Birkmann *et al*., 2010b)

Table 1 below will discuss in detail the various risks posed by climate change and its impact in India. The review of important research is consolidated in one table for better perspective of the impacts.

Table 1: Risk caused by climate change-related factors

Factor	**Impact**	**Paper/Reference**
Temperature Rise	1. 4.4^{O}C Rise by the end of the Century. 2. 0.7^{O}C Rise in the last Century. 3. Glacier melting in the Himalayas, which will lead to less water availability for water bodies downstream 4.Over 52.7% of India's annual minimum temperature indicated warming at 0.24 °C/decade.	(Krishnan, *et al*., 2020;, Bapuji Rao *et al*., 2014a; Rasul, 2014; Ray *et al*., 2021; Yaduvanshi *et al*., 2021)
Drought	1. Drastic national water governance due to emergency. 2. Increase in the number of dry days and dry spells. 3. In the last 85 years, drought-affected areas have been increasing in extent, and the drought is getting more severe. 4. High susceptibility of South India to decreasing precipitation due to climate change. 5. Krishna River basin is facing an increase of drought area extent of about25 to 31% with the increase in the frequency of 5/10 years. 6. Godavari basin experienced decreased precipitation and frequent flooding from 1979 to 2013.	(Bhattacharyya *et al*., 2015; Briscoe, 2005.; Garg and Mishra, 2019; Goyal *et al*.,(2016); A. Panda, 2016; Zhang *et al*., 2020) IPCC Report.
Precipitation	1. Substantial variation in precipitation mainly indicated an increase in rainfall. 2. 34 % increase in rainfall in 35 % of the Indian landscape since 1970	(Bookhagen *et al*., 2005; Donat *et al*., 2016; Gummadi *et al*., 2018)

	3.The tendency of extreme precipitation would significantly rise in the North Sikkim Himalayan region between 2006 and 2100.	
Flooding	1. Displacement of 15 lakh people during the Kerala floods of 2019 has been the biggest in India. 2. Chennai, in 2015, received 490mm of rainfall within a couple of days. 3. Indian floods account for 52% of all tragedies that affect the population as a whole, causing 63% of material damage and 32% of fatalities in what are known as natural disasters. 4. Annually, an average of 7.500.000 hectares area is flooded, and almost 1600 lives are lost. 5. Urban flooding due to informal settlements and strained drainage systems or river bed flooding due to encroachments. All factors are increasing the vulnerability of the population. 6. In 2100, the maximum monthly rainfall will rise by about 40 to 50 mm, and from then on, the areas affected by major flood events will grow by up to 122% (0.15 million sq. km).	Global Report on internal displacement-2019,Kindreny Silvery 2016, Global Climate Risk Index report 2019 (David Eckstein, n.d.; Hallegatte, n.d.; S. C. Pal *et al*., 2022a, 2022b; Rajesh & Rajendran, 2019; Srinivas *et al*., 2018)
Cyclones, Storm Surges, and coastal flooding	1.12 states and 100 districts under cyclone risk. 2. Since 2012, India has experienced 41 cyclones, of which 28 were considered to be severe. 3. In 2020 alone, the country was hit by five super cyclones, severe category cyclones Amphan, Nisarga, Nivar, Burevi, and Gati, and they lost 115 people and 17,000 livestock. 4. Tropical cyclones pose a risk to 119 million people on average each year, with Bangladesh and India estimated to account for nearly 85% of all fatalities. 5. India is considered to be a significant victim of climatic disasters, suffering from the highest	GS Mondal report published by NDMA, IMD (Ahammed and Pandey, 2021; Eckstein *et al*., 2021; Kar *et al*., 2022; Mohapatra *et al*., 2012; Mohapatra *et al*., 2022a; Pradeep *et al*., 2022; Sam *et al*., 2020)

	recorded global death toll from cyclones and floods.	
Sea Level rise	1. Between Pozhiyoor and Anchuthengu on India's west coast, there is an average rate of 3.9 and 3.8 metres per year of shoreline erosion and accretion. 2. Due to the water level increasing, Odisha must lose 5 kilometres of land each year.	(Behera *et al.*, 2023; Kulik *et al.*, 2022)
Heatwaves	1. India may experience unprecedented heat waves exceeding the survivability threshold by 2030-50. 2. The highest ever recorded temperature of 51°C at Phalodi, Rajasthan in India, in May 2016, indicates a particular anomaly. 3. The south-eastern coast, the Indo-Gangetic plains, and a few populous areas near major cities (Mumbai, Delhi, and Kolkata) have been identified as the locations that are the most risky, vulnerable, and risk-prone. 4. Given its location in a tropical or subtropical area, India is one of the nations most at risk from heatwaves. In the past, some of the most severe heat waves were visible in 1998, 2010, and 2015, which resulted in the loss of thousands of lives and had an impact on infrastructures, agricultural methods, and human health. In India, heatwave occurrences have become more frequent and intense over the past few decades, and this trend is expected to continue.	NDMA, Mckinseyglobal institute (Dubey *et al.*, 2021a; Johny and Prasad, 2020; Pattanaik *et al.*, 2017; Rohini *et al.*, 2019)
Forest fires (Fig 5 forest fire loop indicating the relation between forest fire and global warming)	1. Forest fires are increasing in Asia due to an increase in temperature and a reduction in overall precipitation. 2. Record 29,57 fire incidents were recorded in the year 2019 3. Financial loss amounting to Rs 1,110 crore to India due to forest fires yearly.	1. IPCC 2007, Globalforestwatch.com, Ministry of Environment, Forest and Climate Change (MoEFCC), World Bank (Chaturvedi *et al.*, 2011; I K *et al.*, 2011)

	4. Last 12 months' results (April 2020 to April 2021) indicate that in the last 12 months, India has reported the highest number of fire alerts, i.e., 22,457, as compared to other countries, which is 2.0% of all fire signals detected globally and also it is unprecedented and unusually high compared to similar data a decade back.	
Glacial melting, landslide, lake formation, Avalanches.	1. On 7th Feb 2021 incident of glacier melt and sudden flooding of a Rishi Ganga river in Joshimath district in Uttarakhand killed almost 152 people. Many such incidents raise eyebrows about the impact of climate change on the Himalayan glaciers. 2. The data from world weather online clearly indicate a 14 to 16 °C max temperature from the year 2010 to 2014 and an 18 to 19°C maximum temperature from the year 2015 to 2019, which is a difference of 3 to 4°C of maximum temperature in 5 years cycle (Fig 6). Similarly, the minimum temperature increased by 3 to 4 °C in the same period. This warming of glacier regions is a clear-cut reason for glacier melting and landslides.	(Kothyari *et al*., 2022)
Bacterial & Viral Pathogen	1. The various vector-borne and waterborne diseases such as malaria, diarrhea, cholera, dengue, and other common prevalent infectious diseases are increasing due to the climate change effect, which makes the warm and moist environment suitable for pathogens and viruses. 2. The cases of dengue increased in India from 1998 to 2018 abruptly due to climate change 3. Spurt in waterborne diarrhea in India due to climate change impacts. 4. Massive dengue outbreaks could result from a steady rise in dengue transmission risk brought on by climate change in India's Southern, Central, and Eastern regions.	(Das *et al*., 2020; Dhara *et al*., 2013; Kakarla et al., 2020; Karuppusamy *et al*., 2021)

 ISSN: 2185-8322

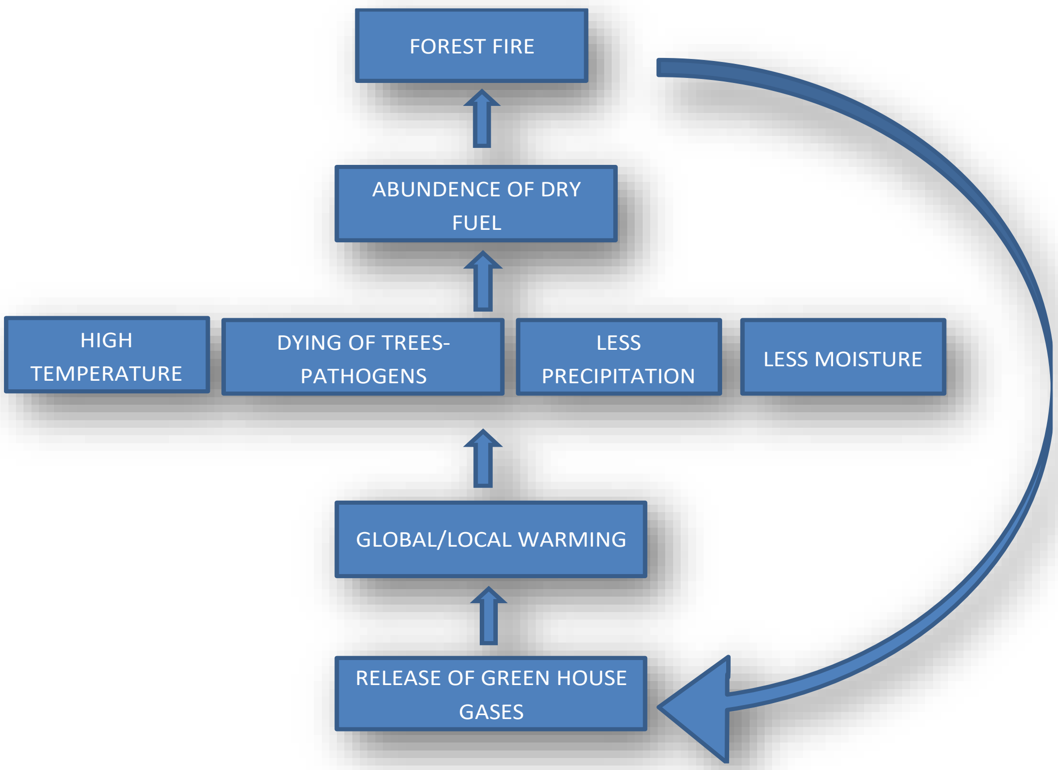

Figure 5: Forest fire loop and global warming

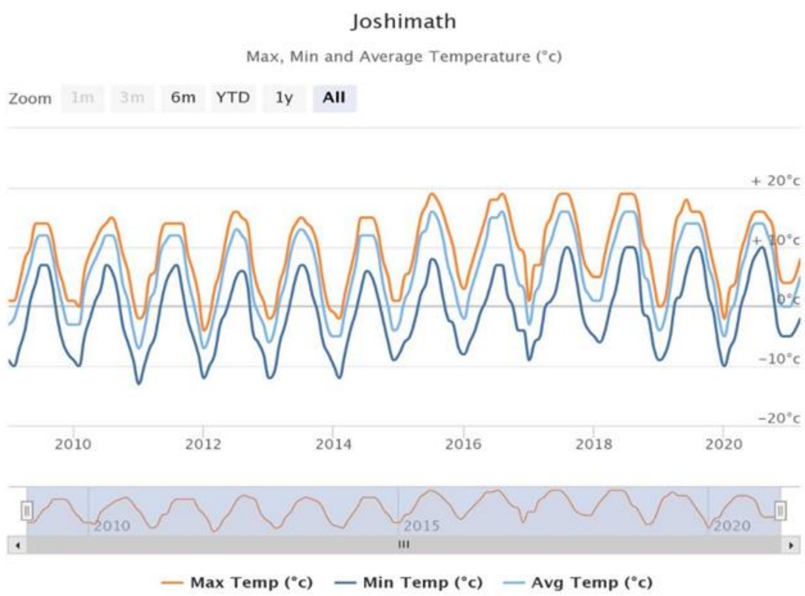

Figure 6: Last decade has seen gradual increase in temperature at High Altitude areas like Joshimathin India. (worldweatheronline.com)

4. SOCIOECONOMIC FACTORS AND CLIMATE CHANGE VULNERABILITIES

Social vulnerability (V), which originated from the natural hazards and geography field and is later widely applied to climate change studies, is a function of biophysical exposure (E), social structure (S), and adaptive capacity (AC), (V = f (E, S, AC). However, vulnerability varies across the region in terms of social structure, economic status, and policymaking and is site-specific (Marshall *et al*., 2013; Berrouet *et al*., 2019; Karunarathne and Lee, 2020) .

The impoverished and marginalised part of society in developing nations with natural and land-based livelihood is highly vulnerable to climate change(Macchi *et al*., 2015; Neil Adger, 1999). These nations are particularly vulnerable because of the pervasive poverty, the lack of technical advancement, and the limited means and options available for coping with the negative effects of climate change (Mirza, 2003; Nath and Behera, 2011) .India, one of the developing nations, has a rural population that relies mostly on agriculture for subsistence and a living, with 82% of farmers being small and marginal farmers(Chandramouli, 2011; Thong *et al*., 2022) . Because it ensures food security and generates jobs, agriculture continues to be a crucial component of the national economy. With 56% of the total cultivated land being used for rain-fed agriculture, Indian agriculture is extremely climate-sensitive(Senapati, 2020).Numerous biophysical and socioeconomic constraints, including erratic rainfall, poor technological input, limited access to power, and sparse farm resources, are associated with these rain-fed regions(Thong *et al*., 2022).

When most of the focus is on physical vulnerabilities to hazards, socioeconomic vulnerabilities are often missed and need emphasis. In India, a developed, economically stable district or community has a bettercoping capacity with vulnerabilities than economically weaker sections or districts(Anees *et al*., 2020). If we consider social vulnerability at a national level, there is a spatial-temporal pattern with Central and Eastern states more vulnerable as compared to Northern and Southern states. It is due to socioeconomic and geographical differentiation among states(Yenneti *et al*., 2016).Moreover, there is a substantial socioeconomic effect of climate change on the household livelihood of thepopulation(Chakraborty *et al*., 2020).

Ten million people experience financial hardship every year as a result of the increasing global temperature(David Satterthwaite, n.d.; Reuveny, 2007; Roberts, 2001).On the other hand, catastrophes brought on by climate change have already forced 13.45 million people to relocate in India. (Mukhopadhyay and Bhattacharya, 2013.; Kabir *et al*., 2022).According to Bhattacharjee's book, indigenous households in India are facing inherent risks as a result of climate change and the loss of their source of subsistence. (Mohapatra *et al*., 2022a). It is widely acknowledged that socioeconomic vulnerabilities are brought on by climate-driven severe events including cloudbursts, flash floods, landslides, heat waves, hailstorms, cyclones, *etc*, Figure 7.

DOI10.5595/001c. 92642

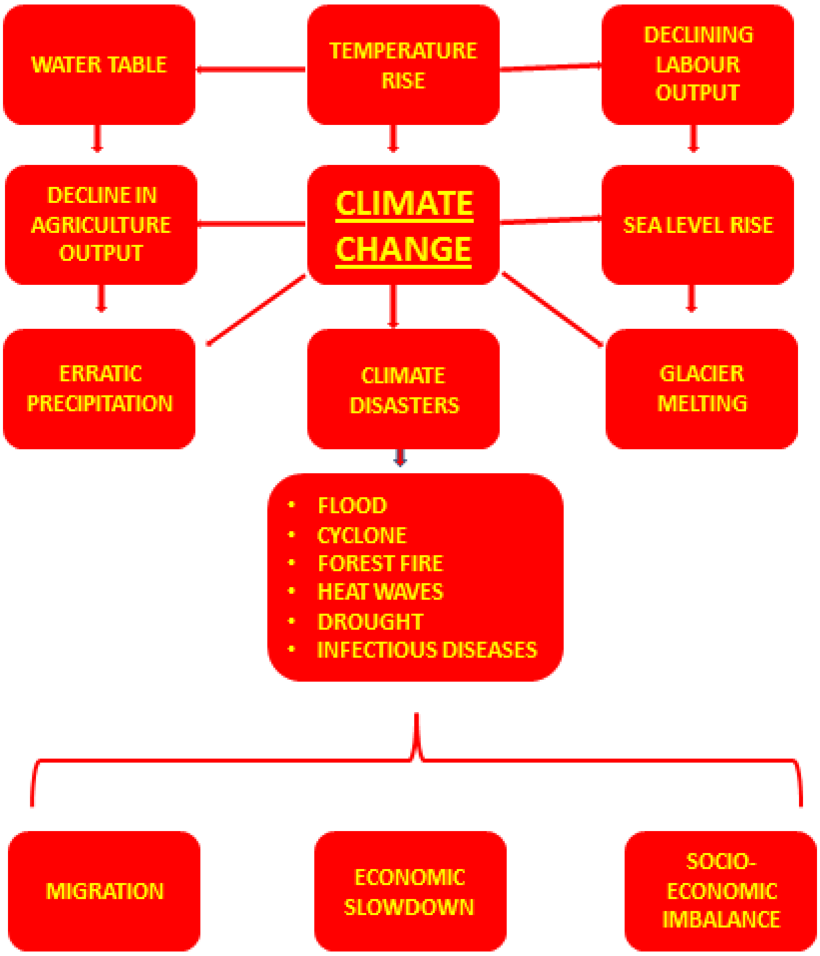

Figure 7: Climate change impact on socio-economic factors.

In many regions, climate change has reduced human capacity, which is a major contributor to the instability of living conditions(Heltberg *et al.*, 2009). Climate susceptibility, reaction capability, and recovery capability can all be predicted by variables.The social and ecological system places a strong emphasis on the sustainability of the environment's relationship to society. Climate change has altered how resources are distributed in the ecosystem, which has led to uncertainty on how people, communities, or an entire nation will survive(Brooks *et al.*, 2005). Figure 8 below explains the various vulnerabilities at individual, community, and national levels with personal, socioeconomic, and global factors, respectively. For example, gender plays a significant role at the individual level, with women more vulnerable than men because of their high dependency on natural resources for their livelihood(Heltberg *et al.*, 2009). Natural catastrophes have a severe negative impact on women because of structural injustices in women's economic, social, and cultural rights as well as their economic and social disadvantages. Water scarcity, flooding, and ineffective water management have a serious negative impact on women. Delivering and maintaining outcomes connected to public health and well-being will come under even more strain as a result of climate change. According to evidence, citizens in developing nations like India will be most affected by changes, especially those who live in vulnerable and marginalised surroundings (Acharya and Porwal, 2020; Yardley *et al*., 2011).

Figure 8: graphical linkage of individual, socio-environmental and national factors that determine livelihoods vulnerability

In contrast to other socioeconomic categories, rural households with structural disadvantages suffer the greatest harm (Ghosh and Ghosal, 2020; Yadav *et al*., 2021). Families engaged in subsistence farming or with little access to land are primarily more vulnerable to the negative effects of climate change and suffer greater losses (Mohapatra *et al*., 2022b). A large underestimating of poverty is also caused by disregarding climate losses in the agricultural sector (Laukkonen *et al*., 2009). When relative losses to incomes quantify vulnerability, we discover that low-income households and those whose primary source of income is subsistence farming or agricultural wage work are more at risk. (Masozera *et al*., 2007; Lioubimtseva and Henebry, 2009; Kuran *et al*., 2020) .

Globally, by 2050, the consequences of climate change combined with economic reactions will cause yields of important crops including maize, rice, wheat, and soybean to be about 11% lower. The yield will fall by 25% in comparison to the climate alone. These studies highlight the significance of integrating crop, economic, and climate models to comprehend the scope and trade-offs of climate change.(Hanjra and Qureshi, 2010; Vermeulen *et al*., 2012; Popp *et al*., 2014).

The mostly agriculture-based Indian Economy also suffers dueto the likely reduction of food grain production in 10 Indian states in the next few decades.Rice and wheat production in the Ganga basin will also be significantly affected(Iizumi *et al*., 2017; Tai *et al*., 2014; Tan &Shibasaki, 2003). The other economic activities, like marine fisheries in the North East coast of India, will be affected due to climate change(Spijkers *et al*., 2021). Also, pest infestation due to climate change will lead to a 15 to 20% reduction in tea yield in North East states(Hasegawa *et al*., 2018; Roudier *et al*., 2011). The rising temperature and heat waves will also affect the Indian Economy as the mortality cost to the Indian Economy may stand at 4% of GDP by 2080. All these factorswill lead to population migration due to socioeconomic reasons (Aryal *et al*., 2016; Black *et al*., 2011; Cai and Sharma, 2010; Lauria *et al*., 2018; Mishra *et al*., 2013) .

Agricultural productivity in a country predominantly depends on the weather. El Nino, ENSO, and sub-divisional monsoon rainfall together with the monsoon's performance are all factors that affect Indian agricultural production(Bapuji Rao *et al*., 2014b; Pradhan *et al*., 2016).Crop production and productivity during the Kharif and Rabi seasons are strongly influenced by the interannual and intraseasonal SW monsoon performance. In addition to rainfall, the impact of temperature on regional agricultural productivity is attracting the attention of both scientists and policymakers. Increased temperatures had a definite detrimental impact on the yields of wheat, maize, and barley around the world (Johnson, 2016; Olesen *et al*., 2011; Peltonen-Sainio *et al*., 2010). Since 1981, warming has resulted in a cumulative loss of these three crops in India of about 40 million tonnes annually(Bapuji Rao *et al*., 2014b).

The Indo-Gangetic Plain is the centre of the world's and India's wheat-growing regions. Due to variations in temperature, precipitation, and reduced water availability for irrigation, wheat output in this area may be impacted(Timsina and Connor, 2001; Wassmann *et al*., 2009a; Yadav *et al*., 2021). It will cause serious issues with food security on a national and worldwide level.Daloz used a regional climate model and a crop model to analyse the direct and indirect effects of climate change on the production of wheat in Punjab, Haryana, Uttar Pradesh, and Bihar. The direct effects included variations in temperature and precipitation(Daloz *et al*., 2021; Mall *et al*., 2017; O'Brien *et al*., 2004b; Wassmann *et al*., 2009b). Depending on the site analysed, the research of the direct impact of climate change led to reductions in wheat production ranging from 1% to 8%. The indirect impact of climate change on water supply was also analysed. Depending on the site being evaluated and the irrigation strategy, the output losses in this situation can range from 4% to 36%.

The highlands' constant climatic change has had a negative impact on water availability, biodiversity, ecosystem structure, ecological processes, and natural disasters(Gómez Martín *et al*., 2020).Given the great reliance on natural resources and the prevailing poverty, surviving in the hilly terrain is therefore extremely difficult. Additionally, during the past few years, the importance of vulnerability and adaptability has frequently been used to clarify the social difficulties of climate change, which eventually result in socioeconomic inequalities in society (Yenneti *et al*., 2016).

Heat waves are excerbated by climate change, which also poses a serious threat to the existing population by decreasing their comfort levels and even causing fatalities(Dubey *et al*., 2021b). Given how silently it affects our society, the risk from heatwave hazards is crucial. Age, gender, and socioeconomic position of the populace, as well as their exposure to and susceptibility to heatwave hazards, all play a role in this (Kabisch *et al*., 2017). Areas with a higher density of people are more vulnerable. The comorbidity, or combination of existing medical disorders, such as heart, circulatory, respiratory, and renal diseases, increases the risk of death during a heatwave. The sort of structure where a person lives also affects the danger of a heatwave(Zuo *et al*., 2015). For instance, urban buildings are warmer than rural ones, increasing the probability of a heatwave there. However, other elements, such having access to air conditioning, can lessen the danger in cities. As a result, the demographic composition—including age, gender distribution, technological development, and economic expansion—will determine the danger in the future. Improved technologies and adaption strategies might lessen the impact of such a risk. Future age distribution, wealth, the male-female ratio, and other factors are difficult to project, but the population and its density are estimated based on a number of hypotheses(He *et al*., 2022) Figure 9.

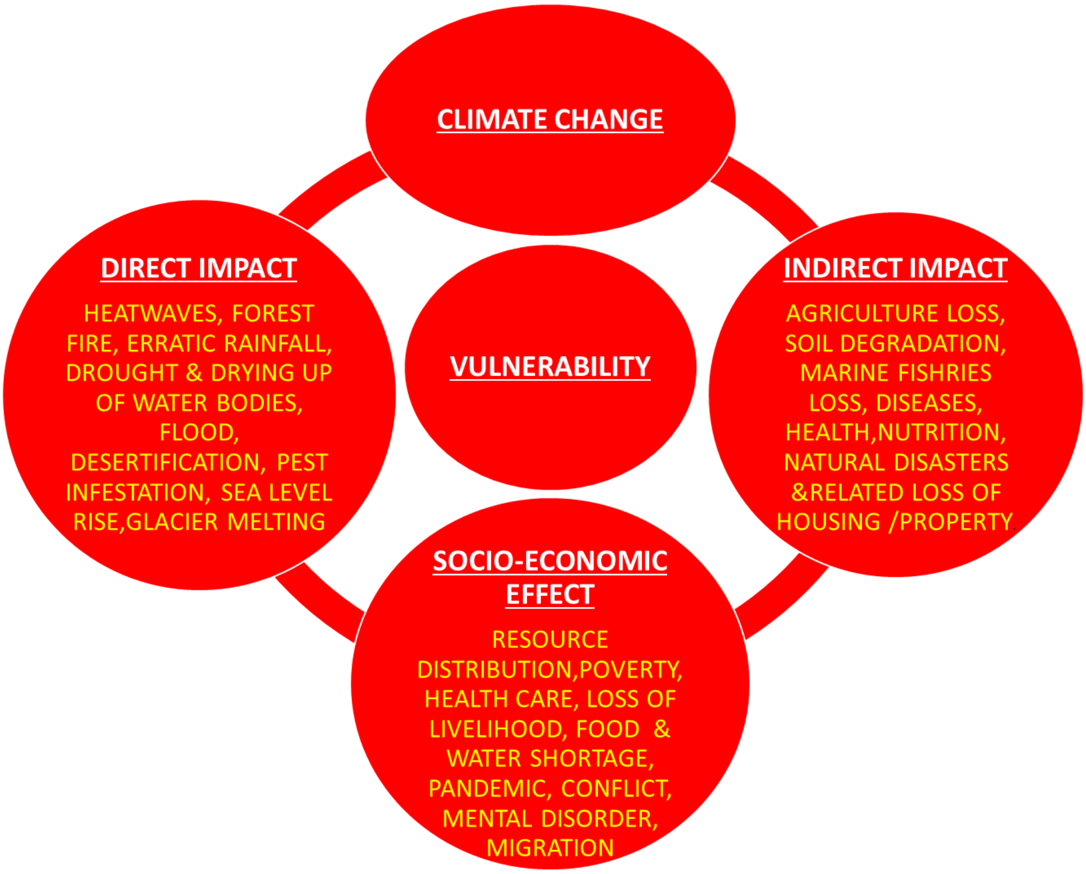

Figure 9: Climate change, its socioeconomic effects, and consequential vulnerabilities

A report on the most costly climate-related disasters in the world was released by the UK-based NGO Christian Aid, and Cyclone "Amphan" came in fourth place with a 13 billion dollar financial loss. In May 2020, it mostly tore through the Eastern state of West Bengal, with the Sunderbans and the capital city Kolkata being the worst-hit areas(I. Pal *et al*., 2022).

India, which has a sizeable heavy labor sector and agrarian farmers, In a path to 4°C rise in temperature, it will likely lose equivalent of 437 billion labor work hours annually (Fig 10).If greenhouse gas emissions continue to rise as they are now, a warming of this magnitude is to be predicted. 200 billion hours of lost labour are predicted if the world maintains its climate objectives and policies, resulting in a temperature of 2 to 3°C.

According to an early study published in Nature Communications, India currently loses roughly 100 billion hours per year of heavy labour owing to heat. However, based on its latest study, its estimatehas already more than doubled to 259 billion hours which is 624 billion dollars in purchase power parity (PPP)(Parsons *et al.*, 2021).

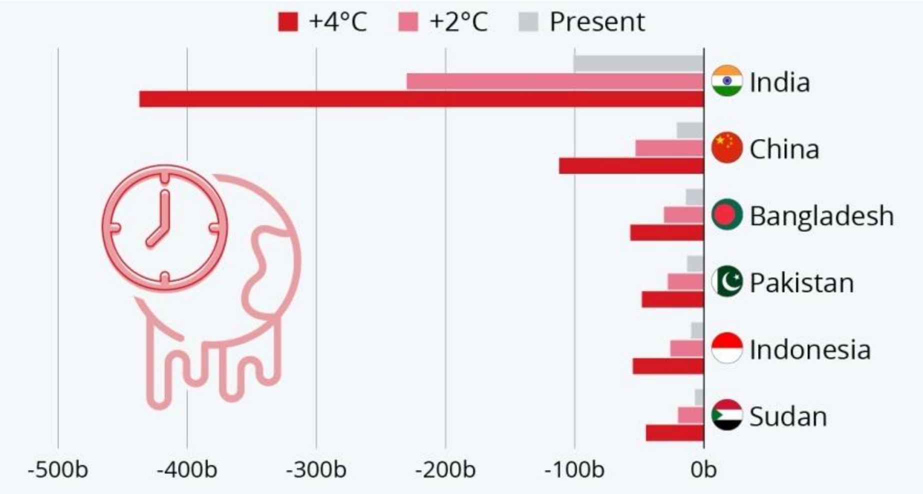

Figure 10: Global warming will impact Indian labor sector depicted by billion labour hours (b), Source nature communications 2021

Climate change will, directly and indirectly, impact the Indian Economy in the future. The various economic effects are enumerated in Table 2 below.

Table 2: Estimating the economic cost of climate change in India

Ser No	Paper/Research/Organization	The economic cost of climate change
1	United Nations Development Program	Loss of 3.6% daytime working hours in 2015 due to heat
2	International labor organization report – Working on a warm planet 2019	By 2030, heat stress would cost India 34 million full-time jobs, with the construction and agricultural industries suffering the most.
3	University of Chicago's climate impact lab & Tata center of development	By 2100, the high temperatures in India could cause 1.5 million deaths annually.
4	Climate risk and response: Physical hazards and socioeconomic impacts by Mckinsey global institute 2020	By 2030, India's Gross Domestic Product (GDP) could lose an average of 2.5 to 4.5 percent yearly due to the reduction in daylight hours.

5	Reserve bank of India Annual Report 2019-20	1. Increase in the extent of crop area damaged due to unseasonal rains and heavy floods. 2. Decline in crop yield due to increase in temperature. 3. Depletion of the water table
6	Global climate risk index 2020-Germanwatch	India suffered an economic loss of almost 37 billion dollars in 2018 due to climate change.
7	Oxford Economics	90% decline in Indian GDP if current environmental policies are not improved
8	Energy Policy Institute at the University of Chicago	2% drop in factory productivity with every 1°C Rise in annual temperature in India
9	Diffenbaugh and Burke, 2019	Global warming caused the Indian Economy to be 31% less than it would otherwise have been
10	Bapuji Rao *et al.*, 2014b	Across regions, the yield of kharif paddy decreased by 411 to 859 kg/ ha for every 1°C increase in minimum temperature. Crop yields will likely be significantly impacted by this warming trend, which necessitates the creation of effective adaptation techniques in order to maintain production.
11	(Singh *et al*., 2014)	Recent research that looked at groundnut yields in 2050 using crop simulation models found that yields could have decreased by up to 25% from 2010 levels.
12	ODI London based thinktank	India may lose 3% of its GDP with a 1°C Rise in temperature. With three °C rises in temperature, GDP may fall by 10%

5. TRANSITION FOR RESILIENCE:

5.1 Changes in India's Vulnerability Landscape Over the Years:

Climate change has been the most significant catalyst in changing the vulnerability landscape of India. Desertification of farmland, Forest fires impact on settlements, Rising sea level and coastal storms, flooding of plains, glacial melts, landslides, changing flora and fauna, and increased precipitation have changed the vulnerability maps. The places historically considered suitable for settlements have been affected by climate-related impacts making them economically, socially, and physically unavailable for living and leading to migrations(Black *et al*., 2011; Gasper *et al*., 2011). Climate migrants are displaced due to climate change impacts such as sea level rise, floods,landslides, and droughts. This can lead to an increase in the number of urban poor and thereby hampering urban development. In 2004-05, National Sample Survey Office (NSSO), estimated an increase of 34.4% in the urban poor population from 1973 to 2004. TheNSSOidentified natural disasters, including floods and droughts, as one of the primary reasons for migration in India. 13 per 1,000 migrant households reported natural disasters as the reason for migration. Increased sea level rise in theSundarbans, drought in central and southern India, and extreme floods in thebasinsof all significant rivers have displaced many people(Renaud *et al*.., 2013).Sedova estimated that approximately 8% of all rural-urban moves in India between 2005 and 2012 can be attributed to weather and most of them are less educated and are from agricultural background(Sedova and Kalkuhl, 2020) . The Census 2011 report emphasises the infrastructural shortcomings in cities. For instance, less than 70.6% of urban households had individual water supply connections, and more than 17% of urban residents resided in slums(Chandramouli, 2011).The majority of the migrant population lives in crowded temporary shelters with limited access to drinking water, sanitation, and healthcare facilities due to the cities' insufficient infrastructure. (Ragheb *et al*., 2016; Raju *et al*., 2021).

Due to the constantly changing climate, arid and humid regions of India have shown extraordinary variance in recent decades. In actuality, the area of the arid region may see a slight increase by the end of the twenty-first century, while the humid zone would grow by 24.28 to 36.09% and the semi-arid and semi-humid zones by 5.52 to 9.74% and 19.94 In-In 28.52%, respectively, in western province of India (Panda *et al*., 2023) .Indirectly contributing to the loss of biodiversity is the movement of a climate zone towards aridity, which lowers available soil moisture, soil fertility, and microorganism activity. Crop output and biodiversity would both suffer greatly from transitions. Additionally, the rate of wind and water erosion would increase in the section of the rise that is parched and humid. Resource degradation, particularly biodiversity loss, may cause scarcities that will cause people to leave their current locations(McNeely, 2003). Poverty is a result of environmental degradation in rural areas where people directly depend on natural resources for their livelihood. The majority of people who live in dry climates are impoverished, but if the region has abundant natural resources, they may be able to have prosperous lives. However, as a result of the arid-humid zone transition brought on by climate change, the region's topsoil degrades and the groundwater level rapidly drops, causing a severe recession in the rural economy and a migration of residents to metropolitan regions in search of alternate sources of income. One of the key drivers of rural-to-urban migration may be the rural economic crisis brought on by climate change(Findlay, 2011).

The sixth assessment report of the IPCC warns that global warming poses an existential threat to low-lying coastal zones, with deltas being particularly vulnerable to increasing sea levels. increasing temperatures, changed rainfall patterns, increasing sea levels, severe erosion, and significant storm surges are all contributing to the human cost of climate change on the low-lying, vulnerable islands of Sundarban, where locals have become the first climate refugees in the area(Magnan *et al*., 2022). The river Hughli of Bengal delta has turned into an estuary of disappearing islands, while other deltas are sinking due to rising seas. Over the past few decades, three nearby islands have sunk, and the largest island, Sagar, is progressively sinking as well. This has led to a high number of environmental migrants(Bera *et al*., 2021; Mandal *et al*., 2019). The negative effects of such occurrences include the loss of land, decreased agricultural output, inundation of low-lying coastal areas, and departure of individuals looking for work in metropolitan enclaves. These islands, which are home to some of the world's poorest people despite having abundant natural resources and biodiversity, are particularly vulnerable to climate change, which has a significant impact on key socioeconomic indices like productivity, food security, poverty, livelihood, migration, and subsistence(Marcinko *et al*., 2022; Abdullah *et al*., 2016).

Evidence already in existence indicates that a number of physical and non-physical issues, such as climate change, extreme weather, and technical shortcomings, have had a negative impact on agricultural output. (Arora, 2019; Aryal *et al*., 2016; Chauhan *et al*., 2014; Peltonen-Sainio *et al*., 2010; Vermeulen *et al*., 2012). Gains in yield are already sluggish due to warming, which will also cause more variation over time and space (Daloz *et al*.., 2021). The Ganges, Brahmaputra, and Meghna delta's subsidence rates rose to their highest levels in recent history close to Kolkata, where the mean jumped to 8.8 mm/y and the standard deviation to 7.5 mm/y(Brown & Nicholls, 2015). Approximately 210 square km of landmass have eroded between 1969 and 2010, according to a National Centre for Coastal Research (NCCR, 2018) research. According to a 2010 study by the WWF, sea levels increased by 2.9 mm/y between 2009 and 2010, exceeding the mean sea level. As a result, five islands vanished in the last 50 years and 6,000 families were forced to leave their homes. This region's refugee issue has reached a breaking point recently as a result of the accelerated erosion pace. A rapidly expanding human population, declining environmental conditions, and the loss of important habitats pose increasingly serious issues for the island's coastline region.

Sagar Island's coastal inhabitants are becoming climate refugees as a result of their growing vulnerability to the threats caused by global climate change, high tides, storm surges, and rising sea levels. Although some areas of this Island of the subsiding delta have nearly lost their struggle with the sea, how the marginal residents are coping with their resilience is one of the real examples for policy and decision makers to handle climate change threats.(Bera *et al*., 2021).

The increasing global temperature rate has pushed millions of people into poverty yearly and climate-induced natural disasters have already displaced 13.45 million people in India(Ghosh and Ghosal, 2020).Due to the effects of climate change and the loss of their means of subsistence, rural households in India have been exposed to several risks.

5.2 Changing Rural-Urban Demographic Pattern Due to Climate Change and Its Effects on The Vulnerability of New Urban Settlements:

With further climate change more areas will become vulnerable due to climate risk and economic impacts. This may lead to accelerated exodus of rural vulnerable and economically poor population towards urban areas which will clutter and cripple already strained urban infrastructure. The effect of climate-related migration of vulnerable populations is highlighted by the 2019 Global report on internal displacement published on May 2019 by the internal displacement monitoring group, which indicates that India with Philippines and China accounted for 60 % of new displacement due to disasters in 2019 with migration in India touching 27 lakh from 15 States. Kerala floods displaced the largest population of15 lacks, title cyclone in Orissa & Andhra Pradesh 4 lakh, and cyclone Gaza displaced 2.5 lacks in Tamil Nadu. It is the highest in South Asia and indicates an increase in climates-related vulnerabilities in India. Also, India is among the leaders in the world for rural-urban migration, with 30% of fresh urban migrants living in informal or temporary settlements and, which is increasing at a rate of 25 % per annum and Delhi, Mumbai and Kolkata are the world's most density population cities(Swerts *et al*., 2018). Although the Govt of India is taking several steps like Pradhan Mantri Awas Yojana to formalize this temporary & haphazard settlement, the extent of migration overwhelms the Government's efforts. The Government must recognize climate change and natural disaster-related migration as future challenges and devise appropriate urban development policies and programs to accommodate them.

Loop 2 (Figure 11) indicates how climate changes are causing migration of population due to various slow and chronic climate change issues like heat waves, drying up of water resources, desertification, drought, and increased intensity and periodicity of natural hazards and also losses in livelihood including agriculture, marine fisheries and other economic losses affecting population socio-economically. This unplanned and informal settlement, especially in urban areas with strained infrastructure and lack of proper planning and policy framework, increases the settlements' vulnerability and leads to natural disasters. The most prominent examples have been the urban flooding of Kerala, Chennai, and Gurugram in 2019/2020. The factors like urban heat islands need to be studied further to analyze their relation with Natural hazards.

Loop 1 is a specific vulnerability to increasing natural hazards causing disasters, ultimately causing losses and migration to safer places. The Loop 2 hazards can be reduced by making good policies and managing the settlement with requisite planning at state and district level intervention. However, Loop 1 hazards can only be reduced by Global and national level intervention as all-climate issues are interlinked at the global level. All national representatives shall comply with the commitment made at various climate accords like the Paris agreement.

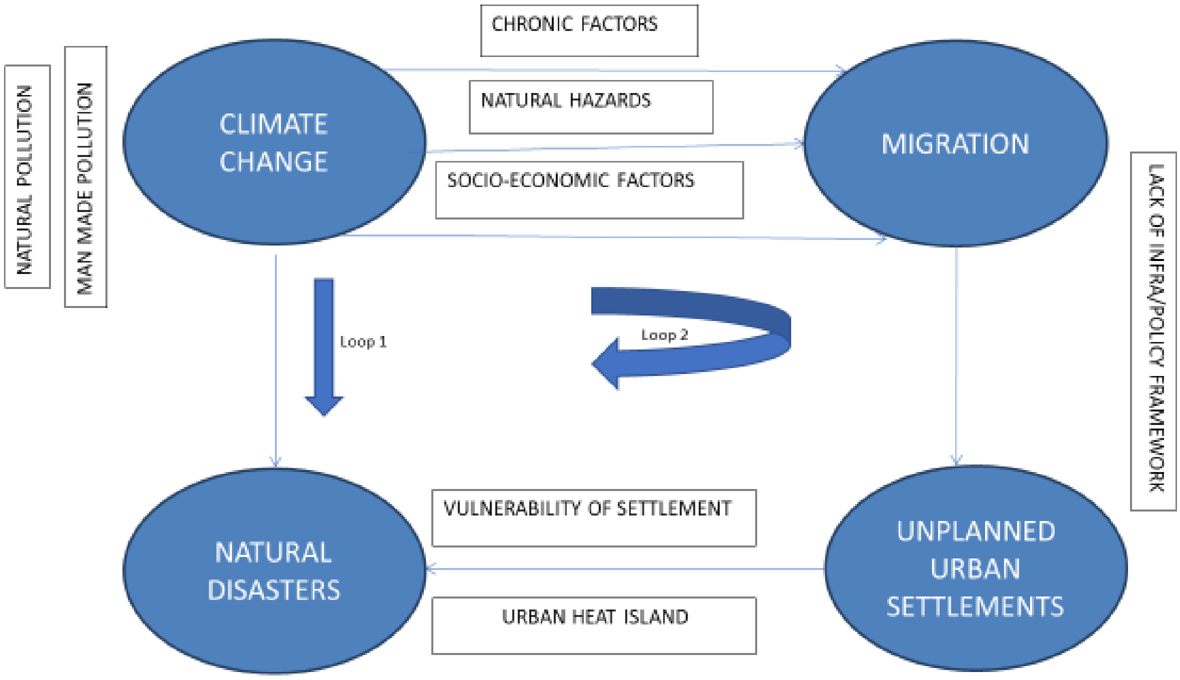

Figure 11: Climate change leading to migration and unplanned urban settlement, thereby increasing vulnerability

5.3 Climate Adaptation and Mitigation in India Over the Years

Climate change effects have been felt in India. According to a report from the United Nations Environment Programme (UNEP) from 2022, India's historical cumulative CO_2 emissions (excluding forestry, land use, and land-use change) are at 3%, while the US and the EU have contributed 25% and 17%, respectively, to all fossil CO_2 emissions between 1850 and 2019.India, however, has a very high risk of natural disasters brought on by climate change due to its geographic and socioeconomic circumstances.India's efforts to combat climate change have been stated in the Planning Commission's Twelfth Five Year Plan, the National Action Plan on Climate Change (NAPCC), State Action Plans on Climate Change (SAPCC), and other documents. It lists many climate-related policies and initiatives.The Climate Change Action Programme, a plan to increase research capacity on climate change and support national and subnational climate measures, is the most significant of them. The aforementioned policy interventions are supported by additional national policies and strategies, such as the National Conservation Act, which encourages energy efficiency and conservation, the National Policy for Farmers, which encourages agriculture's sustainable development, the National Electricity Policy, which aims to ensure everyone has access to electricity, and the Integrated Energy Policy, which encourages the use of renewable energy. There are others that are concerned with managing the coast and conserving wildlife.

If the global mean temperature goes above 1.5°C from the pre-industrial level, the proportion of the entire population and urban area that is exposed to consecutive extremes will quickly rise. To lessen susceptibility and maintain the same level of risk at 1.5°C at higher degrees of global warming, infrastructure and socioeconomic livelihoods will need to be significantly improvedMishra *et al*., 2022) .

6. INDIA'S COMMITMENT TO CLIMATE CHANGE MITIGATION:

India is a signatory to the Paris Agreement, and as it is commitments to the agreement, India proposed the following Nationally Determined Contributions:

a) Increase the proportion of non-fossil fuels in total electricity generation capacity to 40%;
b) Rreduce the economy's emission intensity by 33 to 35% from 2005 levels by 2030
c) Add 2.5 to 3 billion tonnes of carbon dioxide equivalent in additional forests and tree cover.

India created NAPCC and the Prime Minister's Council on Climate Change in 2008. Subsequently, the states were also asked to follow up and create their respective SAPCCs. In addition, India's Disaster Management plan was updated to include considerations concerning climate change. In 2014, the Ministry of Environment and Forests was renamed the Ministry of Environment, Forests, and Climate Change.

The National Disaster Management Plan of 2019 was updated to include detailed provisions about climate change. The document outlines the management of climate change risk for various sectors, such as agriculture, and its effect on wildlife management. Furthermore, it stresses capacity building and outlining state and central government guidelines on climate-related disaster risk reduction.

These efforts taken by India have been appreciated at the international level. As per the India 2020 Climate Transparency report, India is the only country on track among the G20 nations to meet its climate change mitigation commitments. The Report also says that India's Nationally Determined Contributions commitments project it to be compatible with the Copenhagen 2-degree goal but still need to be consistent with the 1.5 degree goal of the Paris Agreement.

India is heavily reliant on fossil fuels, and its emissions have increased by150% from 1990 to 2016. In terms of renewable energy, renewables made up only 11% of the total energy mix in 2018.India's Prime In terms of renewable energy, renewables made up only 11 percent of the total energy mix in 2018.India's Prime Minister at UNCAS said that India would increase its renewable energy capacity to 450 GW in order to contribute to mitigation in this sector.In order to increase the sale of electric and hybrid vehicles and reduce emissions from the automotive industry, India approved a $1.4 billion subsidy programme in 2019. India is phasing out unnecessary automobiles by putting the Bharat Stage regulations into practise. Furthermore, in accordance with the 2018 National Policy on Biofuels, the Government of India seeks to promote the use of biofuels in the energy and transportation sectors. These initiatives are a part of a broader approach to climate action, mitigation, and adaptation at the domestic level, provided by the NAPCC, which broadly outlines eight missions against climate change:

a) **National Solar Mission**: It aims to make solar competitive with fossil-based energy options. By 2030, India aims to create 500 GW of solar energy. India has also initiated the International Solar Alliance, an alliance of 122 countries.
b) **National Mission for Enhanced Energy Efficiency**: By offering energy incentives, such as lower taxes on energy-efficient appliances, it seeks to reduce energy waste in pertinent industries. In order to encourage trading of emissions, it also makes an effort to develop a carbon trading mechanism.
c) **National Mission on Sustainable Habitat:** By enhancing the enforcement of car fuel economy standards, waste management, recycling, and other practises, it intends to promote energy efficiency as a fundamental element of urban design. It also extends the current Energy Conservation Building Code.
d) **National Water Mission:** It seeks to combat the water shortage brought on by climate change by reducing water use by 20% through price and other strategies.
e) **National Mission for Sustainable Agriculture:** By creating crops that are resistant to the effects of the climate, it hopes to aid in agricultural adaptation. The National Initiative on Climate-Resilient Agriculture was launched in India.
f) **National Green India Mission:**6 million hectares of degraded forest lands are intended to be replanted, according to the mission. India wants to increase the amount of forest cover from 23% to 33% of its total area. The UN Convention to Combat Desertification is ratified by India.
g) **National Mission for Sustaining the Himalayan Ecosystem:** The mission's objectives are to stop the melting of the Himalayan glaciers and safeguard the region's biodiversity.
h) **National Mission on Strategic Knowledge for Climate Change:** A new Climate Science Research Fund is also envisioned in the plan, which seeks to better understand climate science, implications, and problems. Through venture capital funds, it supports private sector activities to create adaptation and mitigation technology. In order to help sensitive economic sectors like agriculture, water, sustainable habitat, industry, forestry, and energy efficiency, the mission expects improved climate modelling and increased international cooperation.

Further, at the State level, Since the plans and priorities specified in NAPCC require resonance at the state level to be effective, the Ministry of Environment, Forest and Climate Change (MoEFCC) asked the state governments to create SAPCC in accordance with the priorities of NAPCC in 2009. The developed SAPCC highlights the conditions and vulnerabilities unique to each state and indicates the strategies and actions necessary for sustainable development. To achieve some noticeable outcomes, it is necessary to include and win over departments like power, water, agriculture, and renewable energy at different levels. The NAPCCs and their missions should be relevant to the state-driven SAPCC process.

FINDINGS:

1. Climate change has caused an almost 1°C rise in the average temperature of India.
2. Temperature at high altitude areas is increasing at a faster rate.
3. India is facing an unprecedented increase in climate-exacerbated natural calamities like heat waves, erratic precipitation leading to flooding in urban areas and river beds, drought, and other natural hazards like cyclones, storm surges, cloud bursts, forest fires, and unknown pathogen outbreaks.
4. India's vulnerability to climate change and consequential hazards is greatly amplified because of its socioeconomic, demographic, and geographic characteristics and large population, which strain existing infrastructure. It is more enhanced due to cascading effect of climate-related rural-urban migration, and it turns out to be a vicious cycle further straining limited resources of the urban areas.
5. The rising temperature and heat waves will also affect the Indian Economy as mortality costs to the Indian Economy may stand at 4% of GDP by 2080. All these factors will lead to the migration of the population due to socioeconomic reasons.
6. Climate change has been the most significant catalyst in changing the vulnerability landscape of India
7. The Government must recognize climate change and natural disaster-related migration as a future challenge and devise appropriate urban development policies and programs to accommodate them.
8. India has only contributed 3% to historical cumulative CO2 emissions (excluding land use, land use change, and forestry), while the US and the EU have contributed 25% and 17%, respectively, to the total fossil CO2 emissions from 1850 to 2019.. India, however, has a very high risk of natural disasters brought on by climate change due to its geographic and socioeconomic circumstances.
9. Only India, a member of the G20, is on track to meet its commitments to reduce global warming.
10. Climate change will impact more vulnerable developing counties like India. It will exacerbate the natural hazards, affect the Economy, strain the infrastructure, reduce agricultural output, cause diseases, and induce migration, thereby increasing vulnerabilities. The various countries should take the lead to prevent further climate change by reducing innovative green technologies and carbon footprints.
11. The percentage of the overall population and metropolitan area that is exposed to successive extremes will quickly increase if the global mean temperature rises by more than 1.5°C from pre-industrial levels. Increases in infrastructure and socioeconomic livelihood will be necessary in order to sustain the same level of risk at 1.5°C of global warming while reducing susceptibility.

DOI10.5595/001c. 92642

REFERENCES

A Mukhopadhyay, S. B. (n.d.). *Development and environmental issues vis-à-vis current perspectives of human rights* .

Acharya, R., &Porwal, A. (2020). A vulnerability index for the management of and response to the COVID-19 epidemic in India: an ecological study. *The Lancet Global Health*, *8*(9), e1142–e1151. https://doi.org/10.1016/S2214-109X(20)30300-4

Anees, M. M., Shukla, R., Punia, M., & Joshi, P. K. (2020). Assessment and visualization of inherent vulnerability of urban population in India to natural disasters. *Climate and Development*, *12*(6), 532–546. https://doi.org/10.1080/17565529.2019.1646629

Arora, N. K. (2019). Impact of climate change on agriculture production and its sustainable solutions. *Environmental Sustainability*, *2*(2), 95–96. https://doi.org/10.1007/s42398-019-00078-w

Aryal, J. P., Sapkota, T. B., Stirling, C. M., Jat, M. L., Jat, H. S., Rai, M., Mittal, S., &Sutaliya, J. M. (2016). Conservation agriculture-based wheat production better copes with extreme climate events than conventional tillage-based systems: A case of untimely excess rainfall in Haryana, India. *Agriculture, Ecosystems & Environment*, *233*, 325–335. https://doi.org/10.1016/j.agee.2016.09.013

Bapuji Rao, B., Santhibhushan Chowdary, P., Sandeep, V. M., Rao, V. U. M., &Venkateswarlu, B. (2014a). Rising minimum temperature trends over India in recent decades: Implications for agricultural production. *Global and Planetary Change*, *117*, 1–8. https://doi.org/10.1016/j.gloplacha.2014.03.001

Bapuji Rao, B., Santhibhushan Chowdary, P., Sandeep, V. M., Rao, V. U. M., &Venkateswarlu, B. (2014b). Rising minimum temperature trends over India in recent decades: Implications for agricultural production. *Global and Planetary Change*, *117*, 1–8. https://doi.org/10.1016/j.gloplacha.2014.03.001

Basheer Ahammed, K. K., & Pandey, A. C. (2021). Characterization and impact assessment of super cyclonic storm AMPHAN in the Indian subcontinent through space borne observations. *Ocean & Coastal Management*, *205*, 105532. https://doi.org/10.1016/j.ocecoaman.2021.105532

Behera, J. K., Mishra, P., Bhattacharya, M., Behera, B., & Kar, N. B. (2023). A cross-sectional study about the impacts of climate change on living organisms: A case study of Odisha province of India. In *Visualization Techniques for Climate Change with Machine Learning and Artificial Intelligence* (pp. 399–421). Elsevier. https://doi.org/10.1016/B978-0-323-99714-0.00014-5

Bera, A., Taloor, A. K., Meraj, G., Kanga, S., Singh, S. K., Đurin, B., & Anand, S. (2021). Climate vulnerability and economic determinants: Linkages and risk reduction in Sagar Island, India; A geospatial approach. *Quaternary Science Advances*, *4*, 100038. https://doi.org/10.1016/j.qsa.2021.100038

Berrouet, L., Villegas-Palacio, C., & Botero, V. (2019). A social vulnerability index to changes in ecosystem services provision at local scale: A methodological approach. *Environmental Science & Policy*, *93*, 158–171. https://doi.org/10.1016/j.envsci.2018.12.011

Bhattacharyya, A., Sandeep, K., Misra, S., Shankar, R., Warrier, A. K., Weijian, Z., &Xuefeng, L. (2015). Vegetational and climatic variations during the past 3100 years in southern India: evidence from pollen, magnetic susceptibility and particle size data. *Environmental Earth Sciences*, *74*(4), 3559–3572. https://doi.org/10.1007/s12665-015-4415-6

Birkmann, J., Buckle, P., Jaeger, J., Pelling, M., Setiadi, N., Garschagen, M., Fernando, N., & Kropp, J. (2010). Extreme events and disasters: a window of opportunity for change? Analysis of organizational, institutional and political changes, formal and informal responses after mega-disasters. *Natural Hazards*, *55*(3), 637–655. https://doi.org/10.1007/s11069-008-9319-2

Birkmann, J., Garschagen, M., Kraas, F., & Quang, N. (2010). Adaptive urban governance: new challenges for the second generation of urban adaptation strategies to climate change. *Sustainability Science*, *5*(2), 185–206. https://doi.org/10.1007/s11625-010-0111-3

Black, R., Adger, W. N., Arnell, N. W., Dercon, S., Geddes, A., & Thomas, D. (2011). The effect of environmental change on human migration. *Global Environmental Change*, *21*, S3–S11. https://doi.org/10.1016/j.gloenvcha.2011.10.001

Bookhagen, B., Thiede, R. C., & Strecker, M. R. (2005). Abnormal monsoon years and their control on erosion and sediment flux in the high, arid northwest Himalaya. *Earth and Planetary Science Letters*, *231*(1–2), 131–146. https://doi.org/10.1016/j.epsl.2004.11.014

Briscoe, J. M. R. P. S. (n.d.). *India's Water Economy : Bracing for a Turbulent Future*.

Brooks, N., Neil Adger, W., & Mick Kelly, P. (2005). The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change*, *15*(2), 151–163. https://doi.org/10.1016/j.gloenvcha.2004.12.006

Brown, S., & Nicholls, R. J. (2015). Subsidence and human influences in mega deltas: The case of the Ganges–Brahmaputra–Meghna. *Science of The Total Environment*, *527–528*, 362–374. https://doi.org/10.1016/j.scitotenv.2015.04.124

Cai, X. L., & Sharma, B. R. (2010). Integrating remote sensing, census and weather data for an assessment of rice yield, water consumption and water productivity in the Indo-Gangetic river basin. *Agricultural Water Management*, *97*(2), 309–316. https://doi.org/10.1016/j.agwat.2009.09.021

Chakraborty, L., Rus, H., Henstra, D., Thistlethwaite, J., & Scott, D. (2020). A place-based socioeconomic status index: Measuring social vulnerability to flood hazards in the context of environmental justice. *International Journal of Disaster Risk Reduction*, *43*, 101394. https://doi.org/10.1016/j.ijdrr.2019.101394

Chandramouli, C. ,& G. R. (2011). (n.d.). *Census of India. Rural urban distribution of population, provisional population total. New Delhi: Office of the Registrar General and Census Commissioner, India.*

Chaturvedi, R. K., Gopalakrishnan, R., Jayaraman, M., Bala, G., Joshi, N. v., Sukumar, R., &Ravindranath, N. H. (2011). Impact of climate change on Indian forests: a dynamic vegetation modeling approach. *Mitigation and Adaptation Strategies for Global Change*, *16*(2), 119–142. https://doi.org/10.1007/s11027-010-9257-7

Chauhan, B. S., Prabhjyot, K., Mahajan, G., Randhawa, R. K., Singh, H., & Kang, M. S. (2014). Global Warming and Its Possible Impact on Agriculture in India. In *Advances in Agronomy* (Vol. 123, pp. 65–121). Academic Press Inc. https://doi.org/10.1016/B978-0-12-420225-2.00002-9

D Eckstein, V. K. L. S. (n.d.). *Global climate risk index 2021*.

Dai, A. (2011). Drought under global warming: a review. *WIREs Climate Change*, *2*(1), 45–65. https://doi.org/10.1002/wcc.81

Daloz, A. S., Rydsaa, J. H., Hodnebrog, Ø., Sillmann, J., van Oort, B., Mohr, C. W., Agrawal, M., Emberson, L., Stordal, F., & Zhang, T. (2021). Direct and indirect impacts of climate change on wheat yield in the Indo-Gangetic plain in India. *Journal of Agriculture and Food Research*, *4*, 100132. https://doi.org/10.1016/j.jafr.2021.100132

Das, N., Mahanta, C., & Kumar, M. (2020). *Water Quality Under the Changing Climatic Condition: A Review of the Indian Scenario* (pp. 31–61). https://doi.org/10.1007/978-981-32-9771-5_3

David Eckstein, V. K. L. S. M. W. (n.d.). *GLOBAL CLIMATE RISK INDEX 2020* .

David Satterthwaite. (n.d.). *Adapting to Climate Change in Urban Areas: The Possibilities and Constraints*.

Deroliya, P., Ghosh, M., Mohanty, M. P., Ghosh, S., Rao, K. H. V. D., &Karmakar, S. (2022). A novel flood risk mapping approach with machine learning considering geomorphic and socio-economic vulnerability dimensions. *Science of The Total Environment*, *851*, 158002. https://doi.org/10.1016/j.scitotenv.2022.158002

Dhara VR, S. P. L. (n.d.). *Climate change & infectious diseases in India: implications for health care providers*.

Diffenbaugh, N. S., & Burke, M. (2019). Global warming has increased global economic inequality. *Proceedings of the National Academy of Sciences*, *116*(20), 9808–9813. https://doi.org/10.1073/pnas.1816020116

Donat, M. G., Lowry, A. L., Alexander, L. v., O'Gorman, P. A., & Maher, N. (2016). More extreme precipitation in the world's dry and wet regions. *Nature Climate Change*, *6*(5), 508–513. https://doi.org/10.1038/nclimate2941

Dubey, A. K., Lal, P., Kumar, P., Kumar, A., &Dvornikov, A. Y. (2021a). Present and future projections of heatwave hazard-risk over India: A regional earth system model assessment. *Environmental Research*, *201*, 111573. https://doi.org/10.1016/j.envres.2021.111573

Dubey, A. K., Lal, P., Kumar, P., Kumar, A., &Dvornikov, A. Y. (2021b). Present and future projections of heatwave hazard-risk over India: A regional earth system model assessment. *Environmental Research*, *201*, 111573. https://doi.org/10.1016/j.envres.2021.111573

Eckstein, D. , H. M. L. , & W. M. (n.d.). *Who suffers most from extreme weather events, 36.*

Findlay, A. M. (2011). Migrant destinations in an era of environmental change. *Global Environmental Change*, *21*, S50–S58. https://doi.org/10.1016/j.gloenvcha.2011.09.004

Garg, S., & Mishra, V. (2019). Role of Extreme Precipitation and Initial Hydrologic Conditions on Floods in Godavari River Basin, India. *Water Resources Research*, *55*(11), 9191–9210. https://doi.org/10.1029/2019WR025863

Gasper, R., Blohm, A., & Ruth, M. (2011). Social and economic impacts of climate change on the urban environment. *Current Opinion in Environmental Sustainability*, *3*(3), 150–157. https://doi.org/10.1016/j.cosust.2010.12.009

Ghosh, M., & Ghosal, S. (2020). Determinants of household livelihood vulnerabilities to climate change in the himalayan foothills of West Bengal, India. *International Journal of Disaster Risk Reduction*, *50*, 101706. https://doi.org/10.1016/j.ijdrr.2020.101706

Gómez Martín, E., Máñez Costa, M., &SchwerdtnerMáñez, K. (2020). An operationalized classification of Nature Based Solutions for water-related hazards: From theory to practice. *Ecological Economics*, *167*, 106460. https://doi.org/10.1016/j.ecolecon.2019.106460

Gosling, D. L. (n.d.). *Religion and ecology in India and Southeast Asia. Routledge.*

Goyal, M. K., &Surampalli, R. Y. (2018). Impact of Climate Change on Water Resources in India. *Journal of Environmental Engineering*, *144*(7). https://doi.org/10.1061/(ASCE)EE.1943-7870.0001394

Gummadi, S., Rao, K. P. C., Seid, J., Legesse, G., Kadiyala, M. D. M., Takele, R., Amede, T., & Whitbread, A. (2018). Spatio-temporal variability and trends of precipitation and extreme rainfall events in Ethiopia in 1980–2010. *Theoretical and Applied Climatology*, *134*(3–4), 1315–1328. https://doi.org/10.1007/s00704-017-2340-1

Hallegatte, S. , V.-S. A. , B. M. , & R. J. (n.d.). *Hallegatte, S., Vogt-Schilb, A., Bangalore, M., &Rozenberg, J. (2016). UnbreakablUnbreakable: building the resilience of the poor in the face of natural disasters*.

Hanjra, M. A., & Qureshi, M. E. (2010). Global water crisis and future food security in an era of climate change. *Food Policy*, *35*(5), 365–377. https://doi.org/10.1016/j.foodpol.2010.05.006

Hasegawa, T., Fujimori, S., Havlík, P., Valin, H., Bodirsky, B. L., Doelman, J. C., Fellmann, T., Kyle, P., Koopman, J. F. L., Lotze-Campen, H., Mason-D'Croz, D., Ochi, Y., Pérez Domínguez, I., Stehfest, E., Sulser, T. B., Tabeau, A., Takahashi, K., Takakura, J., van Meijl, H., … Witzke, P. (2018). Risk of increased food insecurity under stringent global climate change mitigation policy. *Nature Climate Change*, *8*(8), 699–703. https://doi.org/10.1038/s41558-018-0230-x

He, B.-J., Zhao, D., Dong, X., Zhao, Z., Li, L., Duo, L., & Li, J. (2022). Will individuals visit hospitals when suffering heat-related illnesses? Yes, but…. *Building and Environment*, *208*, 108587. https://doi.org/10.1016/j.buildenv.2021.108587

Heltberg, R., Siegel, P. B., & Jorgensen, S. L. (2009). Addressing human vulnerability to climate change: Toward a 'no-regrets' approach. *Global Environmental Change*, *19*(1), 89–99. https://doi.org/10.1016/j.gloenvcha.2008.11.003

I K, M., Tiwari, R., &Ravindranath, N. H. (2011). Climate change and forests in India: adaptation opportunities and challenges. *Mitigation and Adaptation Strategies for Global Change*, *16*(2), 161–175. https://doi.org/10.1007/s11027-010-9261-y

Iizumi, T., Furuya, J., Shen, Z., Kim, W., Okada, M., Fujimori, S., Hasegawa, T., &Nishimori, M. (2017). Responses of crop yield growth to global temperature and socioeconomic changes. *Scientific Reports*, *7*(1), 7800. https://doi.org/10.1038/s41598-017-08214-4

Johnson, D. M. (2016). A comprehensive assessment of the correlations between field crop yields and commonly used MODIS products. *International Journal of Applied Earth Observation and Geoinformation*, *52*, 65–81. https://doi.org/10.1016/j.jag.2016.05.010

Johny, C. J., & Prasad, V. S. (2020). Application of hind cast in identifying extreme events over India. *Journal of Earth System Science*, *129*(1), 163. https://doi.org/10.1007/s12040-020-01435-8

Kabir, M., Kabir, Z., & Sultana, N. (2022). Climate change, sustainability, and renewable energy in developing economies. In *Renewable Energy and Sustainability* (pp. 377–415). Elsevier. https://doi.org/10.1016/B978-0-323-88668-0.00001-2

Kabisch, N., van den Bosch, M., &Lafortezza, R. (2017). The health benefits of nature-based solutions to urbanization challenges for children and the elderly – A systematic review. *Environmental Research*, *159*, 362–373. https://doi.org/10.1016/j.envres.2017.08.004

Kakarla, S. G., Bhimala, K. R., Kadiri, M. R., Kumaraswamy, S., &Mutheneni, S. R. (2020). Dengue situation in India: Suitability and transmission potential model for present and projected climate change scenarios. *Science of The Total Environment*, *739*, 140336. https://doi.org/10.1016/j.scitotenv.2020.140336

Kar, N., Samantaray, N. N., Kar, S., & Kar, B. (2022). Anxiety, Depression, and Post-traumatic Stress a month after 2019 Cyclone Fani in Odisha, India. *Disaster Medicine and Public Health Preparedness*, *16*(2), 670–677. https://doi.org/10.1017/dmp.2020.368

Karunarathne, A. Y., & Lee, G. (2020). Developing a multi-facet social vulnerability measure for flood disasters at the micro-level assessment. *International Journal of Disaster Risk Reduction*, *49*, 101679. https://doi.org/10.1016/j.ijdrr.2020.101679

Karuppusamy, B., Sarma, D. K., Lalmalsawma, P., Pautu, L., Karmodiya, K., &Balabaskaran Nina, P. (2021). Effect of climate change and deforestation on vector borne diseases in the North-Eastern Indian State of Mizoram bordering Myanmar. *The Journal of Climate Change and Health*, *2*, 100015. https://doi.org/10.1016/j.joclim.2021.100015

Kothyari, G. C., Joshi, N., Taloor, A. K., Malik, K., Dumka, R., Sati, S. P., &Sundriyal, Y. P. (2022). Reconstruction of active surface deformation in the Rishi Ganga basin, Central Himalaya using PSInSAR: A feedback towards understanding the 7th February 2021 Flash Flood. *Advances in Space Research*, *69*(4), 1894–1914. https://doi.org/10.1016/j.asr.2021.07.002

Krishnan, R. , S. J. , G. C. , M. M. , K. A. , & C. S. (n.d.). *Krishnan, R., Sanjay, J., Gnanaseelan, C., Mujumdar, M.Assessment of climate change over the Indian region: a report of the ministry of earth sciences (MOES)*.

Kulik, L., Auyezova, K., Sushkova, E., &Nurgalieva, G. (2022). Climate Change Policy of India, China and Kazakhstan. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4143662

Kumar, K. A. , W. A. , & C. S. (n.d.). *India disaster report*. .

Kuran, C. H. A., Morsut, C., Kruke, B. I., Krüger, M., Segnestam, L., Orru, K., Nævestad, T. O., Airola, M., Keränen, J., Gabel, F., Hansson, S., &Torpan, S. (2020). Vulnerability and vulnerable groups from an intersectionality perspective. *International Journal of Disaster Risk Reduction*, *50*, 101826. https://doi.org/10.1016/j.ijdrr.2020.101826

Laukkonen, J., Blanco, P. K., Lenhart, J., Keiner, M., Cavric, B., & Kinuthia-Njenga, C. (2009). Combining climate change adaptation and mitigation measures at the local level. *Habitat International*, *33*(3), 287–292. https://doi.org/10.1016/j.habitatint.2008.10.003

Lauria, V., Das, I., Hazra, S., Cazcarro, I., Arto, I., Kay, S., Ofori-Danson, P., Ahmed, M., Hossain, M. A. R., Barange, M., & Fernandes, J. A. (2018). Importance of fisheries for food security across three climate change vulnerable deltas. *Science of The Total Environment*, *640–641*, 1566–1577. https://doi.org/10.1016/j.scitotenv.2018.06.011

Lenssen, N. J. L., Schmidt, G. A., Hansen, J. E., Menne, M. J., Persin, A., Ruedy, R., &Zyss, D. (2019). Improvements in the GISTEMP Uncertainty Model. *Journal of Geophysical Research: Atmospheres*, *124*(12), 6307–6326. https://doi.org/10.1029/2018JD029522

Lioubimtseva, E., &Henebry, G. M. (2009). Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations. *Journal of Arid Environments*, *73*(11), 963–977. https://doi.org/10.1016/j.jaridenv.2009.04.022

Macchi, M., Gurung, A. M., &Hoermann, B. (2015). Community perceptions and responses to climate variability and change in the Himalayas. *Climate and Development*, *7*(5), 414–425. https://doi.org/10.1080/17565529.2014.966046

Magnan, A. K., Oppenheimer, M., Garschagen, M., Buchanan, M. K., Duvat, V. K. E., Forbes, D. L., Ford, J. D., Lambert, E., Petzold, J., Renaud, F. G., Sebesvari, Z., van de Wal, R. S. W., Hinkel, J., &Pörtner, H.-O. (2022). Sea level rise risks and societal adaptation benefits in low-lying coastal areas. *Scientific Reports*, *12*(1), 10677. https://doi.org/10.1038/s41598-022-14303-w

Mall, R. K., Gupta, A., &Sonkar, G. (2017). Effect of Climate Change on Agricultural Crops. In *Current Developments in Biotechnology and Bioengineering* (pp. 23–46). Elsevier. https://doi.org/10.1016/B978-0-444-63661-4.00002-5

Mandal, K., & Dey, P. (2022). Coastal vulnerability analysis and RIDIT scoring of socio-economic vulnerability indicators – A case of Jagatsinghpur, Odisha. *International Journal of Disaster Risk Reduction*, *79*, 103143. https://doi.org/10.1016/j.ijdrr.2022.103143

Mandal, U. K., Maji, B., Mullick, S., Nayak, D. B., Mahanta, K. K., & Raut, S. (2019). *Global Climate Change and Human Interferences as Risk Factors, and their Impacts on Geomorphological Features as well as on Farming Practices in Sundarbans Eco-Region* (pp. 405–437). https://doi.org/10.1007/978-3-030-00680-8_14

Manish Kumar Goyal, V. G. S. E. (n.d.). *Hydrological Drought: Water Surface and Duration Curve Indices*.

Marcinko, C. L. J., Samanta, S., Basu, O., Harfoot, A., Hornby, D. D., Hutton, C. W., Pal, S., &Watmough, G. R. (2022). Earth observation and geospatial data can predict the relative distribution of village level poverty in the Sundarban Biosphere Reserve, India. *Journal of Environmental Management*, *313*, 114950. https://doi.org/10.1016/j.jenvman.2022.114950

Marshall, N. A., Tobin, R. C., Marshall, P. A., Gooch, M., & Hobday, A. J. (2013). Social Vulnerability of Marine Resource Users to Extreme Weather Events. *Ecosystems*, *16*(5), 797–809. https://doi.org/10.1007/s10021-013-9651-6

Masozera, M., Bailey, M., &Kerchner, C. (2007). Distribution of impacts of natural disasters across income groups: A case study of New Orleans. *Ecological Economics*, *63*(2–3), 299–306. https://doi.org/10.1016/j.ecolecon.2006.06.013

McNeely, J. A. (2003). Biodiversity in arid regions: values and perceptions. *Journal of Arid Environments*, *54*(1), 61–70. https://doi.org/10.1006/jare.2001.0890

Mirza, M. M. Q. (2003). Climate change and extreme weather events: can developing countries adapt? *Climate Policy*, *3*(3), 233–248. https://doi.org/10.3763/cpol.2003.0330

Mishra, A., Singh, R., Raghuwanshi, N. S., Chatterjee, C., &Froebrich, J. (2013). Spatial variability of climate change impacts on yield of rice and wheat in the Indian Ganga Basin. *Science of The Total Environment*, *468–469*, S132–S138. https://doi.org/10.1016/j.scitotenv.2013.05.080

Mishra, V., Tiwari, A. D., & Kumar, R. (2022). Warming climate and ENSO variability enhance the risk of sequential extremes in India. *One Earth*, *5*(11), 1250–1259. https://doi.org/10.1016/j.oneear.2022.10.013

Mohammad Abdullah, A. N., Stacey, N., Garnett, S. T., & Myers, B. (2016). Economic dependence on mangrove forest resources for livelihoods in the Sundarbans, Bangladesh. *Forest Policy and Economics*, *64*, 15–24. https://doi.org/10.1016/j.forpol.2015.12.009

Mohapatra, M., Mandal, G. S., Bandyopadhyay, B. K., Tyagi, A., & Mohanty, U. C. (2012). Classification of cyclone hazard prone districts of India. *Natural Hazards*, *63*(3), 1601–1620. https://doi.org/10.1007/s11069-011-9891-8

Mohapatra, S., Harish, V. S. K. V., & Dwivedi, G. (2022a). Climate change, cyclone and rural communities: Understanding people's perceptions and adaptations in rural eastern India. *Materials Today: Proceedings*, *49*, 412–417. https://doi.org/10.1016/j.matpr.2021.02.384

Mohapatra, S., Harish, V. S. K. V., & Dwivedi, G. (2022b). Climate change, cyclone and rural communities: Understanding people's perceptions and adaptations in rural eastern India. *Materials Today: Proceedings*, *49*, 412–417. https://doi.org/10.1016/j.matpr.2021.02.384

Nath, P. K., & Behera, B. (2011). A critical review of impact of and adaptation to climate change in developed and developing economies. *Environment, Development and Sustainability*, *13*(1), 141–162. https://doi.org/10.1007/s10668-010-9253-9

Neil Adger, W. (1999). Social Vulnerability to Climate Change and Extremes in Coastal Vietnam. *World Development*, *27*(2), 249–269. https://doi.org/10.1016/S0305-750X(98)00136-3

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., & West, J. (2004a). Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change*, *14*(4), 303–313. https://doi.org/10.1016/j.gloenvcha.2004.01.001

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., & West, J. (2004b). Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change*, *14*(4), 303–313. https://doi.org/10.1016/j.gloenvcha.2004.01.001

Olesen, J. E., Trnka, M., Kersebaum, K. C., Skjelvåg, A. O., Seguin, B., Peltonen-Sainio, P., Rossi, F., Kozyra, J., &Micale, F. (2011). Impacts and adaptation of European crop production systems to climate change. *European Journal of Agronomy*, *34*(2), 96–112. https://doi.org/10.1016/j.eja.2010.11.003

Pacific Islands Applied Geoscience Commission. (2004). South Pacific Applied Geoscience Commission (SOPAC) Annual Report Summary 2003. Pacific Islands Applied Geoscience Commission (SOPAC). (n.d.).

Pal, I., Ghosh, S., &Tuladhar, N. (2022). Risk Governance Perspectives for compounding hazards: a case study in Megacity Kolkata. In *Pandemic Risk, Response, and Resilience* (pp. 335–349). Elsevier. https://doi.org/10.1016/B978-0-323-99277-0.00005-X

Pal, S. C., Chowdhuri, I., Das, B., Chakrabortty, R., Roy, P., Saha, A., & Shit, M. (2022a). Threats of climate change and land use patterns enhance the susceptibility of future floods in India. *Journal of Environmental Management*, *305*, 114317. https://doi.org/10.1016/j.jenvman.2021.114317

Pal, S. C., Chowdhuri, I., Das, B., Chakrabortty, R., Roy, P., Saha, A., & Shit, M. (2022b). Threats of climate change and land use patterns enhance the susceptibility of future floods in India. *Journal of Environmental Management*, *305*, 114317. https://doi.org/10.1016/j.jenvman.2021.114317

Panda, A. (2016). Exploring climate change perceptions, rainfall trends and perceived barriers to adaptation in a drought affected region in India. *Natural Hazards*, *84*(2), 777–796. https://doi.org/10.1007/s11069-016-2456-0

Panda, K. C., Singh, R. M., Singh, V. K., Singla, S., &Paramaguru, P. K. (2023). Impact of climate change induced future rainfall variation on dynamics of arid-humid zone transition in the western province of India. *Journal of Environmental Management*, *325*, 116646. https://doi.org/10.1016/j.jenvman.2022.116646

Parsons, L. A., Shindell, D., Tigchelaar, M., Zhang, Y., & Spector, J. T. (2021). Increased labor losses and decreased adaptation potential in a warmer world. *Nature Communications*, *12*(1), 7286. https://doi.org/10.1038/s41467-021-27328-y

Pattanaik, D. R., Mohapatra, M., Srivastava, A. K., & Kumar, A. (2017). Heat wave over India during summer 2015: an assessment of real time extended range forecast. *Meteorology and Atmospheric Physics*, *129*(4), 375–393. https://doi.org/10.1007/s00703-016-0469-6

Peltonen-Sainio, P., Jauhiainen, L., Trnka, M., Olesen, J. E., Calanca, P., Eckersten, H., Eitzinger, J., Gobin, A., Kersebaum, K. C., Kozyra, J., Kumar, S., Marta, A. D., Micale, F., Schaap, B., Seguin, B., Skjelvåg, A. O., &Orlandini, S. (2010). Coincidence of variation in yield and climate in Europe. *Agriculture, Ecosystems & Environment*, *139*(4), 483–489. https://doi.org/10.1016/j.agee.2010.09.006

Popp, J., Lakner, Z., Harangi-Rákos, M., &Fári, M. (2014). The effect of bioenergy expansion: Food, energy, and environment. *Renewable and Sustainable Energy Reviews*, *32*, 559–578. https://doi.org/10.1016/j.rser.2014.01.056

Pradeep, J., Shaji, E., Chandran C S, S., H, A., Chandra, S. S. V., Dev, S. G. D., & Babu, D. S. S. (2022). Assessment of coastal variations due to climate change using remote sensing and machine learning techniques: A case study from west coast of India. *Estuarine, Coastal and Shelf Science*, *275*, 107968. https://doi.org/10.1016/j.ecss.2022.107968

Pradhan, P. K., Prasanna, V., Lee, D. Y., & Lee, M.-I. (2016). El Niño and Indian summer monsoon rainfall relationship in retrospective seasonal prediction runs: experiments with coupled global climate models and MMEs.*Meteorology and Atmospheric Physics*, *128*(1), 97–115. https://doi.org/10.1007/s00703-015-0396-y

Ragheb, G., El-Shimy, H., &Ragheb, A. (2016). Land for Poor: Towards Sustainable Master Plan for Sensitive Redevelopment of Slums. *Procedia - Social and Behavioral Sciences*, *216*, 417–427. https://doi.org/10.1016/j.sbspro.2015.12.056

Rajesh, R., & Rajendran, C. (2019). Grey- and rough-set-based seasonal disaster predictions: an analysis of flood data in India. *Natural Hazards*, *97*(1), 395–435. https://doi.org/10.1007/s11069-019-03651-y

Raju, E., Dutta, A., &Ayeb-Karlsson, S. (2021). COVID-19 in India: Who are we leaving behind? *Progress in Disaster Science*, *10*, 100163. https://doi.org/10.1016/j.pdisas.2021.100163

Rasul, G. (2014). Food, water, and energy security in South Asia: A nexus perspective from the Hindu Kush Himalayan region☆. *Environmental Science & Policy*, *39*, 35–48. https://doi.org/10.1016/j.envsci.2014.01.010

Ray, K., Giri, R. K., Ray, S. S., Dimri, A. P., &Rajeevan, M. (2021). An assessment of long-term changes in mortalities due to extreme weather events in India: A study of 50 years' data, 1970–2019. *Weather and Climate Extremes*, *32*, 100315. https://doi.org/10.1016/j.wace.2021.100315

Renaud, F. G., Syvitski, J. P., Sebesvari, Z., Werners, S. E., Kremer, H., Kuenzer, C., Ramesh, R., Jeuken, A., & Friedrich, J. (2013). Tipping from the Holocene to the Anthropocene: How threatened are major world deltas? *Current Opinion in Environmental Sustainability*, *5*(6), 644–654. https://doi.org/10.1016/j.cosust.2013.11.007

Reuveny, R. (2007). Climate change-induced migration and violent conflict. *Political Geography*, *26*(6), 656–673. https://doi.org/10.1016/j.polgeo.2007.05.001

Ripple, W. J., Wolf, C., Gregg, J. W., Levin, K., Rockström, J., Newsome, T. M., Betts, M. G., Huq, S., Law, B. E., Kemp, L., Kalmus, P., &Lenton, T. M. (2022). World Scientists' Warning of a Climate Emergency 2022. *BioScience*, *72*(12), 1149–1155. https://doi.org/10.1093/biosci/biac083

Roberts, J. T. (2001). Global Inequality and Climate Change. *Society & Natural Resources*, *14*(6), 501–509. https://doi.org/10.1080/08941920118490

Rodell, M., Velicogna, I., &Famiglietti, J. S. (2009). Satellite-based estimates of groundwater depletion in India. *Nature*, *460*(7258), 999–1002. https://doi.org/10.1038/nature08238

Rohini, P., Rajeevan, M., &Mukhopadhay, P. (2019). Future projections of heat waves over India from CMIP5 models. *Climate Dynamics*, *53*(1–2), 975–988. https://doi.org/10.1007/s00382-019-04700-9

Roudier, P., Sultan, B., Quirion, P., & Berg, A. (2011). The impact of future climate change on West African crop yields: What does the recent literature say? *Global Environmental Change*, *21*(3), 1073–1083. https://doi.org/10.1016/j.gloenvcha.2011.04.007

Roxy, M. K., Ghosh, S., Pathak, A., Athulya, R., Mujumdar, M., Murtugudde, R., Terray, P., &Rajeevan, M. (2017). A threefold rise in widespread extreme rain events over central India. *Nature Communications*, *8*(1), 708. https://doi.org/10.1038/s41467-017-00744-9

Roy, P., Pal, S. C., Chakrabortty, R., Chowdhuri, I., Saha, A., & Shit, M. (2022). Climate change and groundwater overdraft impacts on agricultural drought in India: Vulnerability assessment, food security measures and policy recommendation. *Science of The Total Environment*, *849*, 157850. https://doi.org/10.1016/j.scitotenv.2022.157850

S. D. Attri and Ajit Tyagi. (n.d.). *CLIMATE PROFILE OF INDIA* .

Saha, S., Gayen, A., Gogoi, P., Kundu, B., Paul, G. C., & Pradhan, B. (2021). Proposing novel ensemble approach of particle swarm optimized and machine learning algorithms for drought vulnerability mapping in Jharkhand, India. *Geocarto International*, 1–32. https://doi.org/10.1080/10106049.2021.1989500

Sam, A. S., Padmaja, S. S., Kächele, H., Kumar, R., & Müller, K. (2020). Climate change, drought and rural communities: Understanding people's perceptions and adaptations in rural eastern India. *International Journal of Disaster Risk Reduction*, *44*, 101436. https://doi.org/10.1016/j.ijdrr.2019.101436

Sedova, B., &Kalkuhl, M. (2020). Who are the climate migrants and where do they go? Evidence from rural India. *World Development*, *129*. https://doi.org/10.1016/j.worlddev.2019.104848

Senapati, A. K. (2020). Evaluation of risk preferences and coping strategies to manage with various agricultural risks: evidence from India. *Heliyon*, *6*(3), e03503. https://doi.org/10.1016/j.heliyon.2020.e03503

Singh, P., Nedumaran, S., Ntare, B. R., Boote, K. J., Singh, N. P., Srinivas, K., &Bantilan, M. C. S. (2014). Potential benefits of drought and heat tolerance in groundnut for adaptation to climate change in India and West Africa. *Mitigation and Adaptation Strategies for Global Change*, *19*(5), 509–529. https://doi.org/10.1007/s11027-012-9446-7

Spijkers, J., Merrie, A., Wabnitz, C. C. C., Osborne, M., Mobjörk, M., Bodin, Ö., Selig, E. R., le Billon, P., Hendrix, C. S., Singh, G. G., Keys, P. W., & Morrison, T. H. (2021). Exploring the future of fishery conflict through narrative scenarios. *One Earth*, *4*(3), 386–396. https://doi.org/10.1016/j.oneear.2021.02.004

Srinivas, C. V., Yesubabu, V., Hari Prasad, D., Hari Prasad, K. B. R. R., Greeshma, M. M., Baskaran, R., & Venkatraman, B. (2018). Simulation of an extreme heavy rainfall event over Chennai, India using WRF: Sensitivity to grid resolution and boundary layer physics. *Atmospheric Research*, *210*, 66–82. https://doi.org/10.1016/j.atmosres.2018.04.014

Swerts, E., Denis, E., & Mukhopadhyay, P. (2018). *Diffuse Urbanization and Mega-Urban Regions in India: Between Reluctant and Restrictive Urbanism?* (pp. 237–262). https://doi.org/10.1007/978-981-10-7799-9_11

Tai, A. P. K., Martin, M. V., & Heald, C. L. (2014). Threat to future global food security from climate change and ozone air pollution. *Nature Climate Change*, *4*(9), 817–821. https://doi.org/10.1038/nclimate2317

Tan, G., &Shibasaki, R. (2003). Global estimation of crop productivity and the impacts of global warming by GIS and EPIC integration. *Ecological Modelling*, *168*(3), 357–370. https://doi.org/10.1016/S0304-3800(03)00146-7

Thong, P., Thangjam, U., Sahoo, U. K., &Pebam, R. (2022). Socio-economic vulnerability assessment of shifting cultivators (Jhumias) amidst the changing climate in Mizoram, northeast India. *Applied Geography*, *147*, 102790. https://doi.org/10.1016/j.apgeog.2022.102790

Timsina, J., & Connor, D. J. (2001). Productivity and management of rice–wheat cropping systems: issues and challenges. *Field Crops Research*, *69*(2), 93–132. https://doi.org/10.1016/S0378-4290(00)00143-X

Udmale, P., Ichikawa, Y., Manandhar, S., Ishidaira, H., & Kiem, A. S. (2014). Farmers′ perception of drought impacts, local adaptation and administrative mitigation measures in Maharashtra State, India. *International Journal of Disaster Risk Reduction*, *10*, 250–269. https://doi.org/10.1016/j.ijdrr.2014.09.011

Ukey, R., & Rai, A. C. (2021). Impact of global warming on heating and cooling degree days in major Indian cities. *Energy and Buildings*, *244*, 111050. https://doi.org/10.1016/j.enbuild.2021.111050

Vermeulen, S. J., Aggarwal, P. K., Ainslie, A., Angelone, C., Campbell, B. M., Challinor, A. J., Hansen, J. W., Ingram, J. S. I., Jarvis, A., Kristjanson, P., Lau, C., Nelson, G. C., Thornton, P. K., &Wollenberg, E. (2012). Options for support to agriculture and food security under climate change. *Environmental Science & Policy*, *15*(1), 136–144. https://doi.org/10.1016/j.envsci.2011.09.003

Wassmann, R., Jagadish, S. V. K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A., Serraj, R., Redona, E., Singh, R. K., & Heuer, S. (2009a). *Chapter 3 Regional Vulnerability of Climate Change Impacts on Asian Rice Production and Scope for Adaptation* (pp. 91–133). https://doi.org/10.1016/S0065-2113(09)01003-7

Wassmann, R., Jagadish, S. V. K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A., Serraj, R., Redona, E., Singh, R. K., & Heuer, S. (2009b). *Chapter 3 Regional Vulnerability of*

Climate Change Impacts on Asian Rice Production and Scope for Adaptation (pp. 91–133). https://doi.org/10.1016/S0065-2113(09)01003-7

Wong-Parodi, G. , K. T. , D. A. , S. D. , & F. B. (n.d.). *A decision science approach for integrating social science in climate and energy solutions. Nature Climate Change*.

Yadav, P., Jaiswal, D. K., & Sinha, R. K. (2021). Climate change. In *Global Climate Change* (pp. 151–174). Elsevier. https://doi.org/10.1016/B978-0-12-822928-6.00010-1

Yadav, R. R., Negi, P. S., & Singh, J. (2021). Climate change and plant biodiversity in Himalaya, India. *Proceedings of the Indian National Science Academy*, *87*(2), 234–259. https://doi.org/10.1007/s43538-021-00034-5

Yaduvanshi, A., Nkemelang, T., Bendapudi, R., & New, M. (2021). Temperature and rainfall extremes change under current and future global warming levels across Indian climate zones. *Weather and Climate Extremes*, *31*, 100291. https://doi.org/10.1016/j.wace.2020.100291

Yardley, J., Sigal, R. J., & Kenny, G. P. (2011). Heat health planning: The importance of social and community factors. *Global Environmental Change*, *21*(2), 670–679. https://doi.org/10.1016/j.gloenvcha.2010.11.010

Yenneti, K., Tripathi, S., Wei, Y. D., Chen, W., & Joshi, G. (2016). The truly disadvantaged? Assessing social vulnerability to climate change in urban India. *Habitat International*, *56*, 124–135. https://doi.org/10.1016/j.habitatint.2016.05.001

Zhang, D., Sial, M. S., Ahmad, N., Filipe, A. J., Thu, P. A., Zia-Ud-Din, M., &Caleiro, A. B. (2020). Water Scarcity and Sustainability in an Emerging Economy: A Management Perspective for Future. *Sustainability*, *13*(1), 144. https://doi.org/10.3390/su13010144

Zuo, J., Pullen, S., Palmer, J., Bennetts, H., Chileshe, N., & Ma, T. (2015). Impacts of heat waves and corresponding measures: a review. *Journal of Cleaner Production*, *92*, 1–12. https://doi.org/10.1016/j.jclepro.2014.12.078