Assessment of observed temperature trend patterns of Bhubaneswar city, India with special prominence on future projections using SimCLIM climate model and farmer's perception

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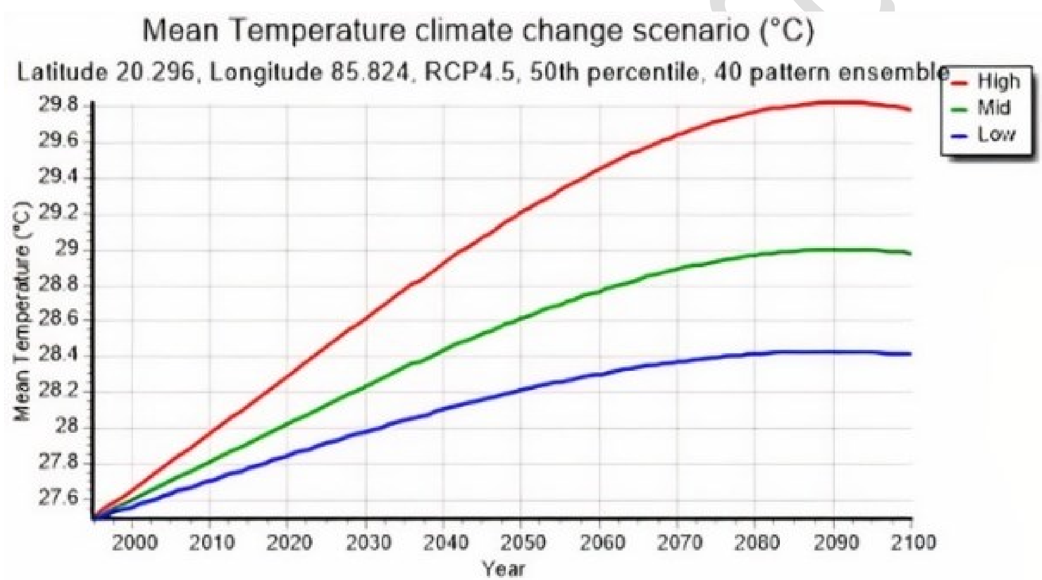
Graphical Abstract



Abstract

Temperature dynamics is a widely recognized indicator of the global warming phenomenon. Changes in temperature patterns in Bhubaneswar, India, were assessed by examining the monthly minimum and maximum temperature data for 60 years (1956–2015) sourced from the Indian Meteorological Department. SimCLIM climate change risk assessment software was used for projecting the temperature regime for four different representative concentration pathways. Further, a survey of 112 farmers was conducted to understand their perceptions of temperature variations in and around Bhubaneswar city using a multi-stage sampling technique. Mann–Kendall statistics and linear regression were used to analyze the monthly temperature data and trend detection. The study reveals a change of +4%,-4.44%, and +1.09% in the mean monthly maximum, minimum, and annual temperature. The results of the future projection show a temperature change of 0.81°C for RCP 2.6, 1.12°C for RCP 4.5, 1.03°C for RCP 6.0, and 1.54°C for RCP 8.5 for the year 2050. Confirming the analysis findings, most of the interviewed farmers also perceived increasing temperatures and decreasing precipitation in and around the city. The study outcome of temperature trend analysis and future projections will be helpful for farmers and policymakers in formulating adaptation strategies to climate change.

Keywords Climate Change; Multistage Sampling Technique; Future Projection; Mann–Kendall; SimCLIM; Temperature Variations

Introduction

Anthropogenic activities contributing to recent climate changes have significantly impacted ecosystems, natural resources, and humans. According to the AR6 IPCC report (IPCC, 2021), under very high GHG emissions, the estimated warming will be 2.4^0C (2041-2060) and 4.4^0C (2081-2100). Furthermore, the very likely range will be 3.3-5.7^0C from 2081 to 2100. The average global temperature estimates based on linear interpolations illustrate that the global temperature has risen by 0.85°C from 1880 to 2012 (IPCC, 2014). The degree to which urbanization affects climate at a regional scale has not yet been determined.

Nevertheless, the urban heat islands and their impacts on life support systems have remained a topic of debate in many scientific forums across the globe. Agriculture is the most vulnerable industry to climate change due to its enormous size and susceptibility to weather variables, resulting in significant economic consequences (Mendelsohn, 2009). Over the past few decades, global warming has threatened crop productivity (Hussain *et al.,* 2021). Climate change is an extreme natural hazard faced by humankind, and the changes have become abrupt and devastating in the recent past, aggravated by natural factors and unconstrained anthropogenic activities (Prusty, 2011). Small-scale subsistence farmers are the most affected by climate change and its consequences because of their low levels of adaptive capability and dependence on rain-fed agriculture (Ifejika *et al.,* 2010; Hillel *et al.,* 2011). The Intergovernmental Panel on Climate Change (IPCC), in early 1990, reported that the highest impact of climate change would be reflected in the unseen levels of climate migrants. The rising interest in vulnerability indices is part of a broader effort to measure the degree of vulnerability of individual countries to natural hazards.

In India, notable variations in natural temperature patterns have been observed, and frequent and devastating disasters have become common in recent times. Analysis of temperature data from weather stations across India illustrates a notable rise in temperature over the last century (Dash *et al*., 2009). Kumar et al. (2006) predicted a temperature increase of 3–4°C toward the end of this century, with the pressure projected to be higher in the northern states of India. According to a World Bank report (2013), India faces a warmer climate with repeated spells of hot weather occurring at regular intervals. Furthermore, the report predicts a 4°C rise in temperature. It is projected that some regions of India might shift to high-temperature climatic systems, influencing agriculture.

Climate change affects many sectors of the economy, but agriculture has been the worst. Climate change significantly affects the poor's living situations because they cannot adapt; furthermore, their livelihoods are heavily based on agriculture, which is very susceptible to climate change

(Ali *et al*., 2019). Agriculture contributes to the global economy, creating employment opportunities for billions of people (Allahyari *et al*., 2016). Agricultural activities in India contribute about 17% to the national GDP and employ over 60% of the population (Arjun, 2013). Thus, climate change-induced disasters such as drought and extreme temperatures are the costliest in India regarding the loss of natural resources and property, leading to overall economic decline. India experienced 41 droughts between 1801 and 2009 (Attri & Tyagi, 2010). Agriculture and its allied sectors are highly vulnerable to climate change; temperature and rainfall directly affect farm production (Thorton *et al*., 2014). These two phenomena also directly affect soil erosion, decreasing water supply, groundwater level, and irrigation (IPCC, 2001). More significant changes in the rainfall patterns, less diversified agriculture, and increasing frequency of droughts and floods directly affect food production and supply. These issues would seriously affect farmers and other stakeholders. Thus, a better understanding of (i) farmers' perceptions of temperature trends and variation, (ii) their current adaptation measures, and (iii) other allied factors is essential for policymaking and facilitating sustainable agricultural practices for successful mitigation of climate change and to develop adaptation strategies in this sector (Jin *et al.,* 2015).

To predict the climate of the 21st century and beyond, an estimate of future changes in the forcing is essential (Gosse *et al.,* 2010). The global mean surface temperatures are predicted to be 0.3–1.7°C, 1.1–2.6°C, 1.4–3.1°C, and 2.6–4.8°C under four representative concentration pathways (RCP), i.e., RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, respectively, for the period between 2081 and 2100 (IPCC, 2013). Global circulation model (GCM) projections have provided warnings about the occurrence and severity of these temperature variations in the forthcoming years (Amin *et al*., 2016). Considering GCM projections, better adaptation strategies must be developed to withstand climate hazards such as heat waves, droughts, and cyclones. Many cities in India and beyond in the subcontinent have been affected by the fury of such risks. Bhubaneswar, a city in the eastern coastal state of Odisha in India, has also experienced its shares of severe climatic hazards, such as the Super Cyclone (1999) and Phailin Cyclone (2013), and Hudhud Cyclone (2014). These extreme events could be assessed by employing integrated models and tools. SimCLIM is an "open-framework" piece of software that can be used to study climate change impacts over time and space (Figure 4). The SimCLIM risk assessment software tools can be used for site-specific climatic data analysis (Bao *et al.,* 2015; Ramachandran *et al.,* 2017).

The United Nations Development Programme (UNDP) 2014 cautioned that climatic variations would profoundly impact small-scale and marginal farmers in developing countries. Bhubaneswar, a second-tier city in India, as classified by the Fifth Central Pay Commission of India in 1997, offers an opportunity to explore the issue along the above mentioned lines. Several researchers have examined temperature change and its variation in Odisha and Bhubaneswar city to understand the severe natural events. Panda and Sahu (2019) reviewed the seasonal rainfall and temperature change in two districts of western Odisha (i.e., Balangir and Kalahandi) and one district of southern Odisha (i.e., Koraput). Their study reveals that annual minimum and maximum temperatures increased during 1980–2017. Gogoi *et al.* (2019) studied the Land Use Cover Change (LULC) impacts on surface temperature and found that the mean temperature has increased significantly in Odisha.

The temperature trend analysis of Bhubaneswar city was studied in some previous works (Majhi & Rath, 2018; Dash, 2016). However, no research has been conducted into future temperature trends and farmer views. What are local farmers' perceptions of climatic trends, how well do these perceptions match meteorological records, and what would be the future temperature trends based on various RCP scenarios? These questions must be answered to understand farmers' perceptions of climate change better and provide empirical evidence for policies aimed at improving farmers' adaptive capacity by improving their ability to perceive climate change correctly. As a result, the present study aims for a better understanding of recent changes and variability in temperature, future temperature trends, and the farmers' perception of climate change in Bhubaneswar city with three distinct objectives, i.e. (i) to investigate the trends of monthly maximum, minimum, and mean temperatures of Bhubaneswar, (ii) to project future temperature trends at the local level under different RCP scenarios of Bhubaneswar city (iii) to identify the farmers' perceptions on climate change and temperature variability. Thus, the present study is the first of its kind from Bhubaneswar.

Study Area

Bhubaneswar city (20° 14' 0" N, 85° 50' 0" E, Fig. 1) is situated on the western side of the "Mahanadi Delta" on the banks of River Kuakhai and at the southwest of Cuttack city in the state of Odisha, India. River Daya, which branches off River Kuakhai, flows along the southeastern part of the city. It was one of the earliest planned cities of India, after Chandigarh and Jamshedpur, designed by German architect Otto Konigsberger in 1946. Historically, the city dates back to 300 BC and has a geographic area of 135 km^2 (Fig 1). It is located at an average altitude of 45 m above the mean sea level and is close to the sea; the weather remains hot and humid all year round. UNDP (2014) reveals that the city experienced a maximum temperature of 47°C in May 2013. The maximum atmospheric temperature is more than 38°C during summer. The city received 1406.1–1958.91 mm of rainfall during the study period of 1991–2012, with maximum precipitation occurring in July and August (Dash & Chakraborthy, 2016). The relative humidity of the city is very high (around 80%) from July to October. Recently, with the upsurge in economic activities and associated requirements of fossil fuel-based energy sources, a considerable increase in greenhouse gas emissions has been reported in the city (Jena, 2018). The Suspended Particulate Matter (SPM) in the ambient air in the city ranged from 156.7µg/m^3 to 280.6 µg/m^3 from February 2013 through January 2014 (Mohapatra & Biswal, 2014). The Ministry of Road Transport and Highways (MoRTH, 2016) reveals that the number of vehicles registered in the city is 1.08 Million. Different activities in Bhubaneswar contribute to 0.97 million tons of CO_2 equivalent ($TeCO_2$) annually, whereas per capita emissions were 0.84 T/year in 2007–08. Bhubaneswar city, with a population of 837,321 per the 2011 Census of India, has a population density of 2131.4/km^2. The spatial growth of Bhubaneswar was 176. 7% from 1961 to 1971 is the highest in India (Naik, 2013). The city has become a socio-economic hub and cultural centre for many people from Odisha and beyond.

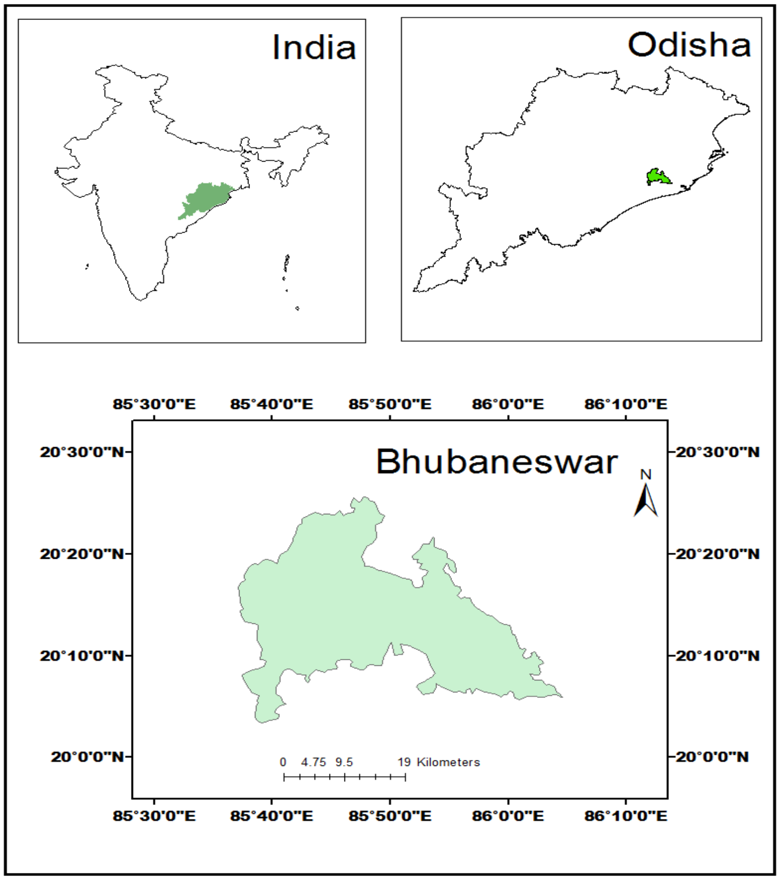


Figure 1. Map of Bhubaneswar city

Methods

Following Hou *et al.* (2015) and Chombu *et al.* (2020), the present study examined the observed temperature using statistical techniques and farmers' perceptions of climate change. To develop policy recommendations for future adaptation plans, it is necessary to assess changes in climate characteristics based on past scientific records and the perceptions of the local community (Mubangizi *et al.,* 2017). In addition, the study attempts to forecast future temperature trends. Advances in weather and climate forecasting offer opportunities for proactive risk management at the local level (Fao, 2014).

Statistical Analysis

To examine the historically observed temperature trend, monthly temperature data were obtained from the Indian Meteorological Department (IMD) for 60 years (1956–2015). For ease of understanding and interpretation, the datasets were split into the whole study period (1956–2015) and two phases: 1956–1985 (First Phase) and 1986–2015 (Second Phase). Monthly mean maximum, mean minimum, and mean temperature along with standard deviation (SD) were computed for the whole study period following Jeganathan *et al.* (2013), and the dataset was subjected to the Mann–Kendall Trend (MKT) test to assess the significance in such variability.

Most studies have used the non-parametric MKT test to find trends in hydro-meteorological observations that do not follow a normal distribution of data points (Girma *et al.,* 2020). Trend detection and analysis were performed using linear regression (LR) models. Trend detection and analysis were performed through statistical tools LR and MKT test.

Climate Model- SimCLIM

SimCLIM desktop version 4.0 was used with 40 GCMs for temperature scenario generation of Bhubaneswar city for 2050–2100. The "site-specific temperature scenario" tool was used to obtain the local temperature projection. Geographical coordinates of the area of interest given along with the locally observed temperature trend were obtained from IMD, Pune. Further, all the 40 GCMs were organized hierarchically by pattern scaling to perform sensitivity analysis. The central tendency was measured based on the median value of constructed ensembles, i.e., 40 selected GCM patterns finalized for the study area. Analysis of the weather data (1956–2015) record helped generate local-level baseline data compared to SimCLIM. In a changing climate, the SimCLIM modeling system can be used to examine the implications and dangers of climatic extremes (Warrick, 2009; Amin *et al*., 2016).

Farmer's Perception of Climate Change

A multi-stage and simple random sampling method following Ndambiri *et al*. (2014) was applied to identify and select the villages around Bhubaneswar city and analyze the farmers' perceptions of climatic change. Finally, a sample of 112 farmers, i.e., 16 from Nuagan, Paikarapur, Madanpur, Durgapur, Padasahi, Sundarapada, and Bainchuan on the periphery of Bhubaneswar city, was selected randomly. The present survey was carried out using a questionnaire customized for the purpose. The survey included a pre-tested structured questionnaire format following Kabir *et al*. (2016) that explored residents' perceptions of temperature change, the frequency and magnitude of climate-related hazards in the last 30 years and their livelihood impacts. It helped obtain information on the socio-demographic condition of the farmers. It included questions about temperature change perceptions and the related effect on different aspects of the source of their income. Based on the landholding size, the sample households were classified into five categories, viz., (i) no land, (ii) owning ≤1 acre, (iii) owning 1–2.5 acres, (iv) owning 2.5–5 acres, and (v) owning 5–10 acres. With the help of XLSTAT statistical software, descriptive statistical tests following Jha and Gupta (2021), which included mean, percentages, and frequency counts, were conducted to summarize the socioeconomic conditions of farmers and their perceptions of temperature change and variability. A frequency table was used for statistical analysis to record the reason behind different climatic constraints. The data analysis included the application of correlation and regression, percent analysis, and a composite index developed in the study.

Results and Discussions

Observed temperature trend analysis

A monthly, seasonal, and annual temperature trend significance test was performed using the Mann–Kendall non-parametric statistical test for 60 years (1956–2015) for Bhubaneswar city (Table 1). The change in maximum, minimum, and mean temperatures for the period 1956- 2015 were 1.64±0.21°C, 1.10±0.14°C, and 0.85±0.10°C, respectively (Fig. 2). According to a previous study by Majhi and Ratha (2018), the mean monthly maximum temperature in Bhubaneswar city increased faster than the average and minimum temperatures from 1970 to 2017. For the monthly maximum temperature, positive trends were observed except for June. Similarly, a positive trend was observed for the whole study period except for May for the monthly minimum temperature. The negative trends in maximum and minimum temperatures for May and June may be attributed to higher atmospheric humidity, as relative humidity is inversely related to air temperature. The average relative humidity in Bhubaneswar is roughly 77%, ranging from 68% in winter (February) to 88% during the monsoon season (July). Moreover, UNDP (2014) indicated that between 1959 and 2009, cyclonic storms and depressions occurred nine times between May and June, which may be one of the reasons for the negative temperature trends in Bhubaneswar City during these months.

Table 1. Mann-Kendall Test results

Month	Maximum Temperature	Sen's Slope	Minimum Temperature	Sen's Slope
January	0.27*	0.02	0.06	0.01
February	0.18*	0.02	0.02*	0.00
March	0.22*	0.02	0.19*	0.01
April	0.06	0.01	0.00*	0.00
May	0.04*	0.00	-0.05*	0.00
June	0.06	0.01	0.16*	0.01
July	0.27*	0.02	0.19*	0.01
August	0.36*	0.02	0.21*	0.01
September	0.32*	0.02	0.27*	0.01
October	0.18*	0.01	0.12*	0.01
November	0.24*	0.02	0.18*	0.02
December	0.33*	0.03	0.08	0.01
JF	0.31*	0.02	0.06	0.00
MAM	0.19*	0.01	0.17*	0.01
JJAS	0.26*	0.02	0.26*	0.01
OND	0.23*	0.02	0.13*	0.01
Annual	0.39*	0.02	0.21*	0.01

**significant at 0.1 level*

Furthermore, the city receives 26 mm of rain in April, 67 mm in May, and 209 mm in June (CSE, 2020). This significant shift in rainfall pattern compared to April may be one of the reasons for the negative trends. The linear temperature trends exhibit a positive change over the whole study period (1956–2015) (Fig. 3). The first phase (1956–1985) witnessed an increasing mean temperature (a=0.009, R2= 0.038). Similarly, the second phase (1986–2015) also experienced an increasing mean annual temperature (a=0.025, R2= 0.353). The temperature pattern of the city showed positive trends for mean maximum temperature, mean minimum temperature, and mean annual temperature for the whole study period (Fig. 4). The mean maximum temperature pattern (a=0.017, R2= 0.334) and the mean minimum temperature anomaly (a=0.007, R2= 0.084) revealed a significantly increasing trend. Similar to the above two variables, the mean annual temperature anomaly also exhibited an increasing trend (a=0.012, R2= 0.26). A positive trend in the observed temperatures was found in the mean maximum, mean minimum, and mean annual temperatures over the whole study period. The trend lines indicate that the mean annual temperature over Bhubaneswar city has increased by about 0.59°C (60-year mean value).

A previous study by Jeganathan *et al.* (2013) showed that Chennai's mean annual temperature trend increased by about 1.3°C (60-year mean value) from 1951 to 2010. Kolkata, Mumbai, and Chennai had an annual mean temperature of 1°C, 0.6°C, and 0.56°C, respectively Dhorde *et al.* (2009). The highest recorded temperature for the city was 40°C in May 1957, and the lowest minimum temperature was 12.1°C in December 1970. Further, the warmer years on record are in the order 2010 (0.9°C) > 1979 (0.7°C) > 2006 (0.6°C) > 2012 (0.6°C) 2005 (0.5°C) > 2002 (0.4°C) > 2003 (0.3°C) > 1980 (0.4°C)> 1998 (0.4°C) > (0.3°C), which depicts the long-term variation in the average temperature for the period 1956–2015. Similarly, the highest mean minimum temperature was observed to be 32.05°C±0.83 for May. The study reveals a change of +4%, –4.44%, and +1.09% in the mean monthly maximum, minimum, and annual temperature.

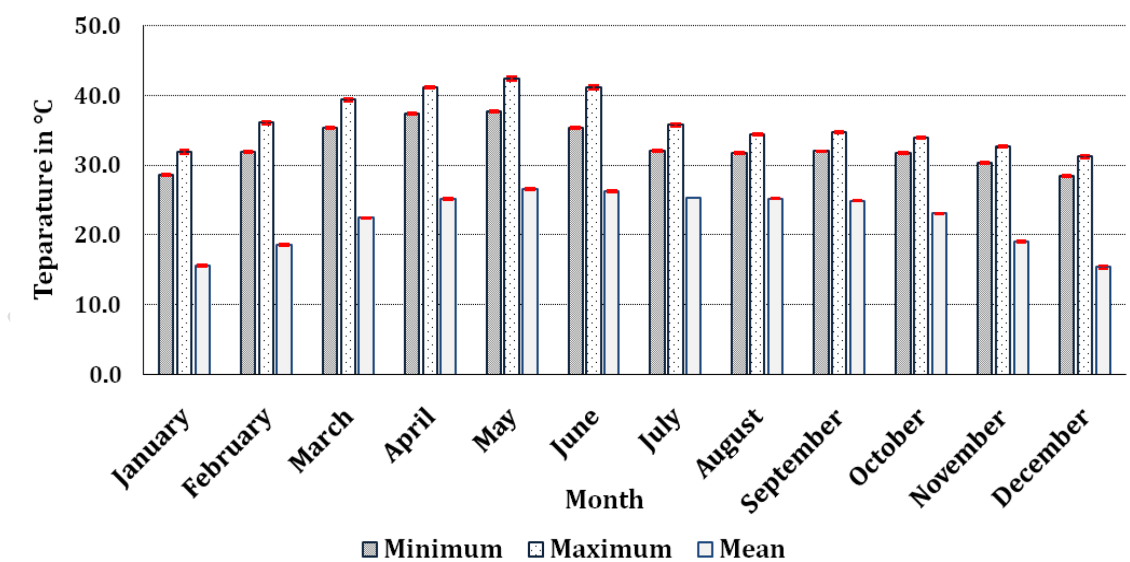


Figure 2. Cluster column chart showing monthly temperature mean and standard error

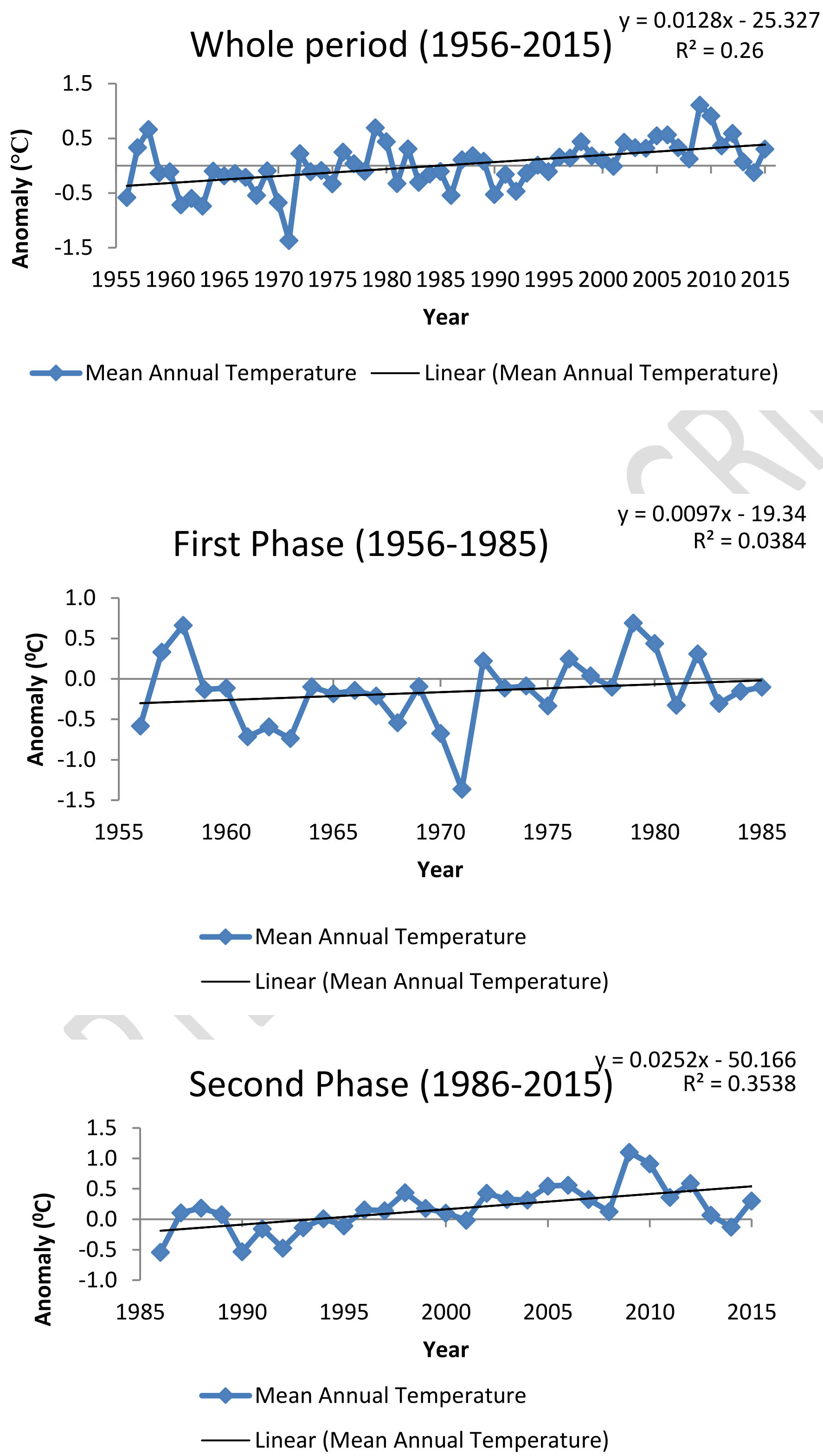
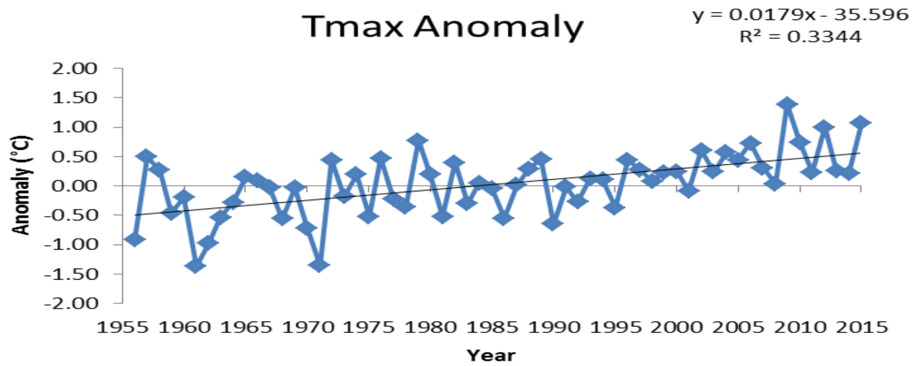
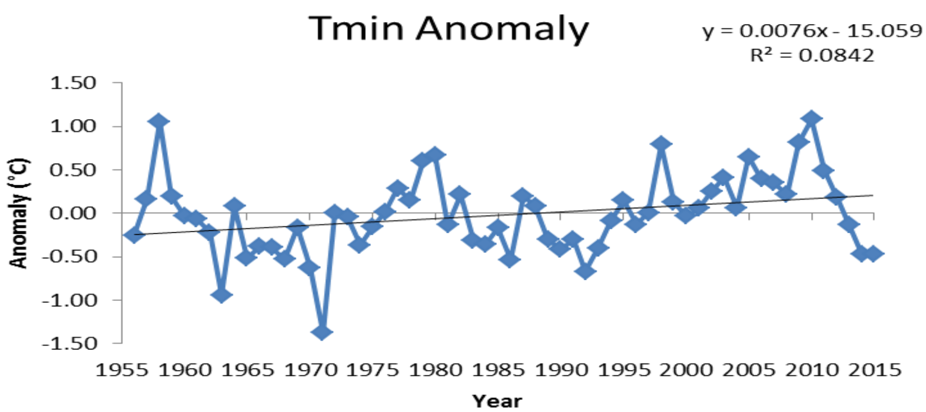


Figure 3. Linear temperature trends of Bhubaneswar City 1956-2015





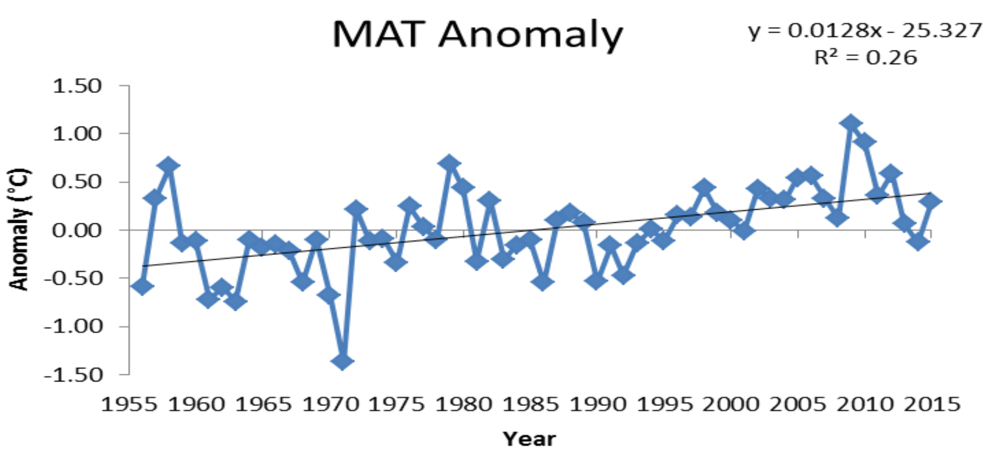
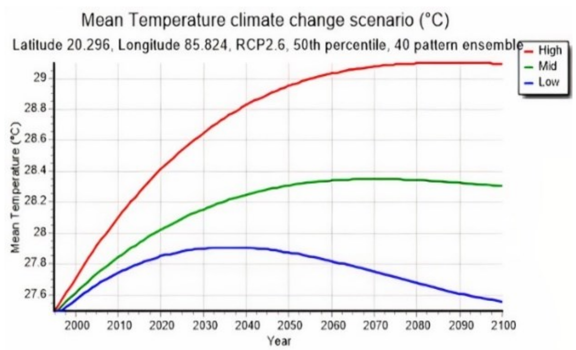


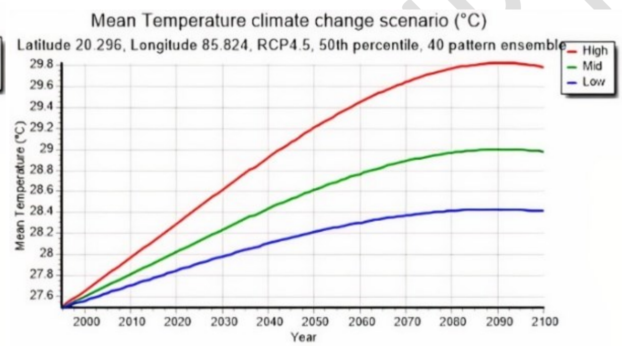
Figure 4. Maximum, minimum and mean annual temperature anomalies of Bhubaneswar during 1956–2015

Projection of mean temperature for 2050 and 2100

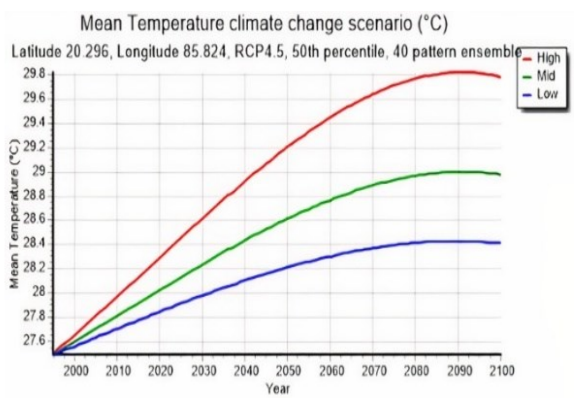
Validating the SimCLIM climate model with the observed data obtained from IMD have conferred that the model has shown a reasonable skill in simulating temperature patterns for Bhubaneswar city. The magnitudes and frequency characteristics of the surface temperature variability on annual time scales agreed. Hence, this study attempts to assess various aspects of future projections in Bhubaneswar city using SimCLIM. The mean temperature scenarios of climate change for Bhubaneswar city revealed positive trends for different RCPs for the time scale from 1995 to 2100 (Fig 5). The results obtained from SimCLIM show a temperature change of 0.81°C, 1.12°C, 1.03°C, and 1.54°C for RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 emission scenarios, respectively, under medium projection for the year 2050. Similarly, the results revealed a temperature change of 0.80°C, 1.48°C, 2.08°C, and 3.68°C for RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, respectively, under medium projection for the year 2100. Basha *et al.* (2017) project a temperature increase of 3.2°C in India by the end of the century. The findings also agree with an earlier study by Kumar *et al.* (2011), whose results projected a temperature increase of 1–4° C for the year 2050 and an increase of more than 4.5°C for the year 2100.



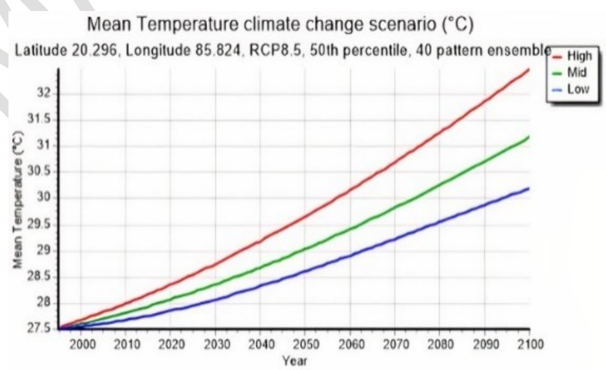
RCP2.6



RCP4.5



RCP6.0



RCP8.5

Figure 5. SimCLIM total trend of mean temperature projection at Lat. 20.296/Long. 85.824 for different RCPs.

Raghavan *et al.* (2020) also reported that under the RCP8.5 scenario, these temperatures are expected to rise by about 4.7°C and 5.5°C by the end of the twenty-first century, respectively, compared to recent temperatures (1976–2005 average). The percentage deviation in mean temperature from base temperature was 2.95% for RCP 2.6, 4.04% for RCP 4.5, 3.75% for RCP 6.0, and 5.56 % for RCP 8.5 emission scenarios for the projection year 2050, and 0.04% for RCP 2.6, 1.22% for RCP 4.5, 3.64% for RCP 6.0, and 7.26% for RCP 8.5 emission scenarios for the projection year 2100.

Farmer's perceptions of temperature change

Of the interviewees, 50.90% were in the 50+ age group, and 43.63% of the farmers had more than 21 years of farming experience. According to Amadou *et al.* (2015), the older the farmer is, the more experience they have with farming practices. Correct perception of climatic variability positively correlates with age and experience (Rapholo & Makia, 2020). Among them, 55.45% had received an education below the 10th standard. A maximum number of interviewees could be placed in the marginal farming category, and 67.27% practiced rain-fed farming. According to Sathyan *et al.* (2018), millions of rainfed smallholder farmers would face immediate hardship and hunger due to climate change. They will be less able to make appropriate decisions about when to sow, what to grow, and how to time inputs (NICI, 2009) and have a low ability to respond (Burnham & Ma, 2017). Almost 90% of the farmers work as daily laborers during the off-seasons (Table 2). Among those surveyed, 60% of the farmers have a landholding of 1–2.5 acres, and 90% have an annual income of < 10.8 Lakhs (2056 USD). Almost every interviewee opined that the temperature had increased in the last 20–30 years; 77.71% of respondents strongly agreed and 22.32% agreed that the temperature was rising.

Similarly, around 75% of the farmers strongly agreed on the rainfall pattern, and 25% agreed that the rainfall decreased. About 68.75% of the interviewees strongly agreed to a decrease in the number of cool days, 16.96% agreed, and 14.29% agreed moderately. Further, a majority of the interviewees believed that hot days are increasing; among them, 68.75% of the farmers strongly agreed, and 31.25% only agreed that the number of hot days is increasing during the summer and rainy seasons (Fig.6). Regarding their perception of climate change hazards, 50% of the farmers indicated that climate change is anthropogenic, 6.25% thought it was natural, and 43.75% believed that the temperature change is a result of both anthropogenic and natural factors (Fig. 7). The majority of the farmers (89%) indicated that the Super Cyclone (1999) was the most powerful tropical cyclone in the last two decades that significantly impacted their livelihoods. Atmospheric temperature, water vapor, and ice concentration influence the sea surface temperature (SST) (Carvalho & Wang, 2020). However, cyclonic events such as Phailin (2013), Hudhud (2014), and Fani (2019) have had considerably less impact on their agricultural production. Cyclones have had a physical, economic, and psychological effect on people due to the repeated loss of farms, livelihoods, and assets (Patel, 2018). Around 62.50% of the interviewees opined that urbanization, deforestation, and cyclones are the main reasons for uprooting and damaging trees, leading to temperature increase in the city.

In comparison, 18.75% said only tree loss due to the cyclone, 11.46% only deforestation and 7.29% said the city's rapid growth, mainly in the last ten years, was the temperature change. With the growing population and urbanization trend, deforestation has increased, disrupting natural atmospheric and climatic patterns and amplifying the destructive effects of natural disasters (Ali *et al.,* 2014). According to Sahoo *et al*. (2020), in Bhubaneswar, around 5% of trees were damaged entirely, 6% were uprooted, 31% had significant damage, and 57% had partial damage from storm Fani in 2019. Storms and cyclones have exacerbated the loss of current green cover (Sahoo & Bhaskaran, 2016, 2017). The city has experienced the uprooting of millions of trees due to cyclones. Hurricane damage can reduce a forest's ability to absorb carbon dioxide from the atmosphere, contributing to global warming (Tulane University, 2021). Around 66.66% of the interviewees opined that the drought was infrequent, whereas 33.34% indicated it was rare.

Table 2 Social and economic background of the interviewee in Bhubaneswar City

Variable	Interviewee (%)
Age of farmers(Years)	
Below 30	6.36%
Between 30-40	20.90%
Between 40-50	21.84%
Above 50	50.90%
Farming Experience(Years)	
1-5	1.81%
6-10	10%
11-15	12.72%
16-20	31.84%
21 and above	43.63%
Qualifications of farmers	
Below 10th	55.45%
10th	30.92%
+2	4.54%
Graduate	9.09%
Size of landholding under operation (Acres)	
Between 1-2.5	60%
Between 2.5-5	26.36%
Below 1 acre	7.29%
No land	0.90%
Between 5-10	5.45%
Annual income (Lakhs)	
Below 1.5 (1810.01 USD)	90%
1.5-3 (1810.01 USD- 3620.02 USD)	10%
Type of crop	
Rabi	76.36%
Rabi and Kharif	23.64%
Source of water	
Rainfed and Irrigated	32.73%
Rainfed	67.27%

According to most interviewees (71.88%), floods happen rarely, and 28.12% stated that floods occur very infrequently. According to Mishra *et al.* (2020), the city witnessed urban flooding in 2008, 2014, 2016, 2018, and 2019. Most interviewees (62.50%) felt that cyclones frequently occurred, whereas 37.50% thought it often.

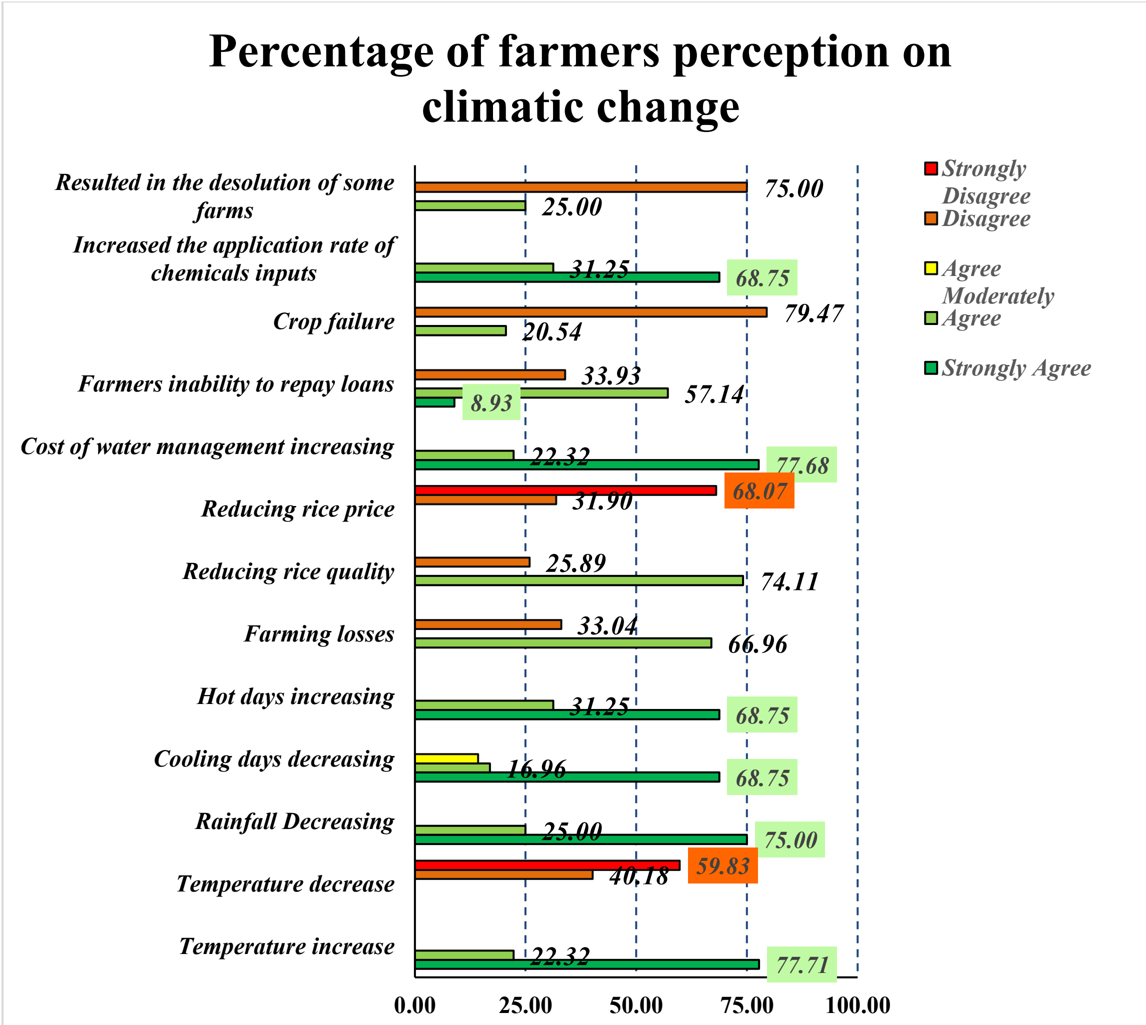


Figure 6. Farmers' perception of climate change and farming losses

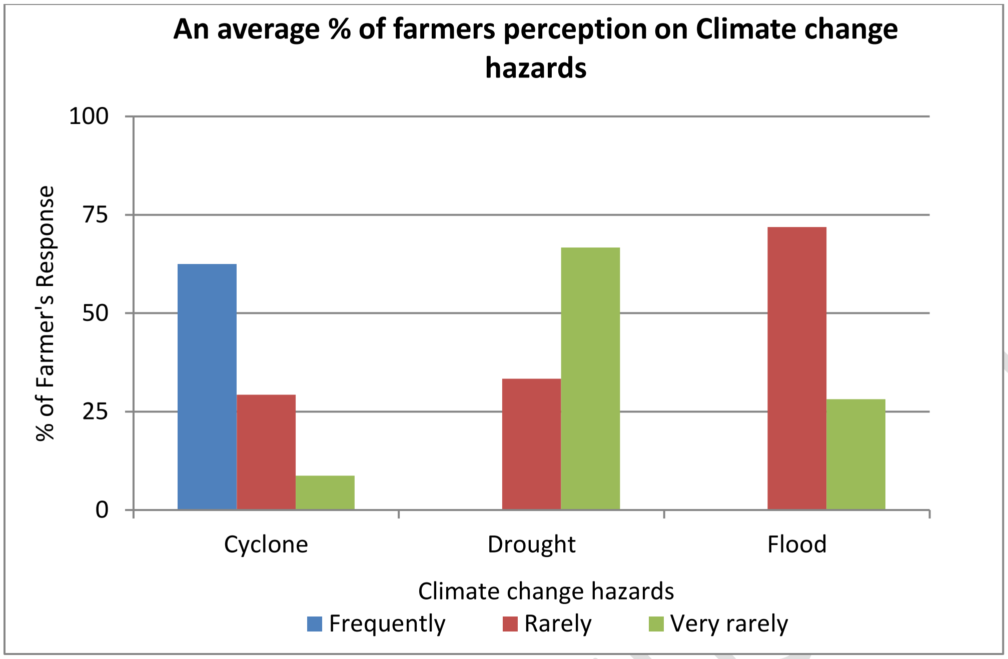


Figure 7. Farmer's perception of climate change hazards

Conclusions

The present study, the first of its kind, focused on Bhubaneswar city, India, and integrates the temperature trend projections using the SimCLIM model and farmers' perceptions. The Mann–Kendall and Sen's Slope estimator test results exhibited positive temperature trends. A notable conclusion from the farmers' perception study is that their responses regarding the temperature variations agree with the meteorological data, which is a testament to their experiential knowledge. These changes in the observed and projected temperature trends reveal that Bhubaneswar city may expose to significant climate change-induced risks of rising temperatures. The present study results will be an essential source of information for environmental managers and policymakers to frame adaptation strategies, particularly for Bhubaneswar city. To some extent, highly educated farmers had additional knowledge of good farming practices and coping and adaptation strategies for climate change-induced hazards like cyclones and floods. The government has to support the farmers in adaptation strategies such as efficient usage of water resources in agriculture since the rain has become more unpredictable and unseasonal. Through policymakers and intellectuals, the government needs to expedite the improvement and dissemination of agricultural technologies such as irrigation schemes and the usage of climate-resilient crops.

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Supplementary File

Questionnaire Survey Form

QUESTIONNAIRE FOR FARMERS IN BHUBANESWAR

A. General Information of the farmers

<table>
<tr><td>Name:</td><td>Address:</td><td>Occupation: Main: Secondary:</td></tr>
<tr><td>Gender:
☐ Male ☐ Female

Family Members:</td><td>Age: ☐ Below 30 years
☐ Between 30-40 years
☐ Between 40 -50 years
☐ Above 50 years</td><td>Qualification: ☐ Below Matric ☐ Matric
☐ Graduate ☐ Post Graduate
☐ Any other, (please specify)____________</td></tr>
<tr><td colspan="2">Size of land holding under operation?
☐ Below 1 acres
☐ Between 1- 2.5 acres
☐ Between 2.5 - 5 acres
☐ Between 5 - 10 acres
☐ Above 10 acres</td><td>Annual Household Income (Gross in Rs.)
☐ Below 1.5 lakhs (1810.01 USD)
☐ 1.5 - 3 lakh (1810.01-3620.02 USD)
☐ 3 - 5 lakhs (3620.02-6033.36 USD)
☐ 5- 10 lakhs (6033.36-12066.73 USD)
☐ Above 10 lakhs (12066.73 USD)</td></tr>
<tr><td colspan="3">Type of Crop farming: ☐ Rabi ☐ Kharif ☐ Other, Specify___________________________</td></tr>
</table>

Source of water for Agriculture: ☐ Irrigated ☐ Rainfed ☐ Other, Specify________________________

Questions on temperature change perceptions

1. Do you feel any change temperature in past few years?

   ☐ Yes ☐ No ☐ Don't Know Any other _________________

   ☐ If yes, whether it is ☐ Decreasing or ☐ Increasing

2. Are the number of hot days has increased?

   ☐ Yes ☐ No ☐ Can't say ☐ Any other________________

3. Are the number of cool days decreased?
   ☐ Yes ☐ No ☐ Can't say ☐ Any other ___________________

4. How rainfall quantity in the city has changed?

   ☐ Increased ☐ Decreased ☐ No change ☐ Any other ___________________

5. Erratic rainfall distributions
   ☐ Yes ☐ No ☐ Can't say ☐ Any other ___________________

6. Reasons for temperature change
   ☐ Deforestation ☐ Urbanization ☐ Cyclones ☐ Other

7. Do you believe global warming is due to natural or anthropogenic causes?

   ☐ Natural causes ☐ Anthropogenic causes

   ☐ Both natural and anthropogenic ☐ There is no global warming

8. Drought has occurred more frequently in recent years?
   ☐ Yes ☐ No ☐ Don't Know ☐ Any other ___________________

9. Temperature variation increases
   ☐ Farming losses ☐ Reduced rice quality ☐ Reduced rice yield

   ☐ Cost of water management ☐ Reduced rice price due to loss of the quality

   ☐ Resulted in farmer's inability to repay loans ☐ Crop failure

   ☐ Increased the application rate of chemical inputs
   ☐ Resulted in the desolation of some farms

10. Which of the climate change impacts you are facing in your area?

☐ Flood ☐ Cyclone ☐ Drought ☐ Heat Waves ☐ Other