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Understanding Climate Change Perspectives and Adaptive Measures among Farmers in Koppala District of Karnataka

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ABSTRACT

The present investigation to know farmer's perception on changing climate effect on agriculture and livestock, adaptions measures adopted by farmers to climate change in Koppala district of Karnataka state. The study examines the socio-demographic characteristics, farmers' perceptions, and climate change adaptation strategies in Koppala district, Karnataka, India. The district spans 5570 sq. km, with 594 inhabited villages and a population of 13,89,920 as per the 2011 census. The of respondents were male (98.51%), with most falling in the various age brackets of 35-54 years (50.37%) and above 54 years (41.48%). Illiteracy was prevalent, with 54.28% having no formal education. Farmers reported a decline in rainfall (90.37%) and increased temperatures (93.33%), leading to drought conditions every 3-4 years. The study highlights farmers' awareness of climate change (95.55%) and its impacts on agriculture, including water scarcity (81.48%), Decreased crop yields as a result of pest and disease infestations (87.40%), and changes in planting seasons. Factors influencing adaptation include lack of knowledge (77.77%), credit accessibility (81.48%), and water scarcity (77.77%). Most farmers employ crop rotation (87.40%) and improved seeds (77.77%) as adaptation strategies, while only 17.03 percent utilize farm ponds for irrigation. Kriging analysis indicated that exponential models were suitable and most effective in forecasting climate events including air temperature, as well as maximum and minimum temperatures, along with relative humidity. The findings underscore the need for tailored climate change adaptation policies, focusing on education, access to credit, and sustainable agricultural practices to mitigate the consequences of changing climate on livelihoods in Koppala district. Additionally, the study emphasizes the significance of continuous monitoring and predictive modeling to inform effective decision-making and resource allocation for climate resilience in agrarian communities.

Keywords: *Climate change, Farmers perception, Kriging, Koppala, Adaptation, Mitigation.*

Introduction

India has attained self-sufficiency in food grain production result of the green revolution [**1**] it brought a multitude of environmental challenges (e.g. Soil degradation results in a decrease in fertility level of soil for crop production, waterlogging, pollution of both ground and surface water and increased occurrences of insect pests and pathogens on plants have been intensified.) and socioeconomic problems (e.g., increased farm input prices and regional disparity) [**12**]. In addition to all these, climate change has added a new dimension to the existing problems by posing a significant threat to Indian agriculture in general and food security in particular [**32**]. Recent studies have identified India as a highly vulnerable country to changing climate situation, with findings showing a significant increase in temperature, frequent heatwaves, droughts, extreme precipitation events, and intense cyclonic activities [**34, 35, 39**]. [**20**] discovered that in the short run (2010–2039), climate change would lower yields by 4.5 to 9 per-cent, while in the long run (2070–2099), yields would be drastically reduced by at least 25 per-cent in the absence of adaptation. Additionally, crop water demand is expected to surge with prolonged warming, necessitating more irrigation [**48**]. However, irrigation and over-exploitation have already led to a substantial decrease in groundwater levels. Even areas experiencing increased precipitation due to changing climate would require excessive groundwater extraction if irrigated agriculture is expanded [**51**]. While changes in climate and agricultural production systems will impact food security, farmers are the first to bear the brunt [**42**]. Crop loss results in farmer distress, inflation, and consequently, far-reaching economic consequences and directly effects on nation's economy.

Adaptation decisions in farming are influenced by various factors, including farmers' perceptions, education, experience, available infrastructural support, and awareness activities. Factors such as low farmer's income, fragmentation of land, and less of education level can constrain adaptive capacity at the individual level [**41**]. The availability of education and information tends to increase the likelihood of adaptation, especially among young age farmers who are often more inclined to take risks [**22**]. Yet, the execution of adaptation strategies may face obstacles due to elevated expenses, alongside insufficient financial means and limited access to weather data, which impede adaptation efforts [**31**].

Institutional factors the availability of Kisan credit cards, soil health cards, and crop insurance pose significant challenges to the adoption of preferred strategies by farmers, as highlighted by Swami and Parthasarathy (2020). It is worth mentioning that institutions play a crucial role in influencing farmers' perceptions and choices concerning adaptation.

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They facilitate the adaptation process by providing necessary facilities and support, as emphasized by [**28**]. For instance, institutions offering technical and financial assistance can enhance farmers' ability to adapt, as suggested by [**11**]. Awareness of the cost-benefit analysis of adaptation, coupled with the use of extension activities, is also deemed essential, as pointed out by [**40**].

Both the government and the private sector play vital roles in enhancing adaptive capacity. Public-private partnerships have proven effective in bolstering adaptation efforts for drought, as demonstrated [**50**]. In terms of markets, climate change-induced reduced production, coupled with existing market imperfections in both domestic and international trade, exacerbates income losses for farmers [**26**]. Moreover, facilities such as irrigation availability can significantly influence farmers' perceptions, as noted by [**28**] and [**30**]. This underscores the importance of mainstreaming, which involves integrating adaptation with other policies, as emphasized by [**40**]. It is recognized that a singular or specific policy approach may not suffice; rather, an integrated approach is necessary. Recently collaborative action research has surfaced as a feasible choice to bolster the creation of localized adaptations [**21**].

During the investigation, we directed our attention toward a specific area., aiming to achieve the following objectives: (i) analyzing farmers' perception of ongoing climate change, its drivers, and its consistency with past climatic observations (ii) identifying the adaptation strategies implemented by farmers to adapt to changing climate condition and (iii) testing whether farmers' perception of changed climate impacted the implementation of adaptation strategies. By doing so, we explored hypotheses that (i) Farmers within the study area observe climate change through localized alterations in their immediate surroundings (ii) farmers' perception of changing climate aligns with historical weather data (iii) farmers who perceive changing climate are more likelihood to implement adaptation strategies and (iv) covariates like farmer age and farm resource endowment drive understanding of climate change and implementation of adaptation strategies. The study identified farmers' perspectives on climate change and adaptation options through focus group discussions, followed by individual farm-level surveys aimed at analyzing the correlation between perception and the strategies farmers use to adapt on their farms.

Materials and Methodology

General description of the study region

The research work was conducted in the Koppala district of Karnataka state from August to December 2023. Koppala district is situated between 15° 09′ 00″ to 16° 03′ 30″ north latitudes and 75° 47′ 30″ to 76° 48′ 10″ east longitudes, the district spans across a geographical area of 5559 square meters. District situated in the northern Maidan region of Karnataka state, Koppala district is renowned for its vulnerability to drought, falling within the arid tract of the country. The district's climate varies from mild to severe, featuring mild winters and hot summers. December marks the coldest temperatures, with an average daily minimum of 17.7 degrees Celsius, while daytime temperatures in May frequently soar to 45 degrees Celsius. During the monsoon period, it is common for relative humidity to surpass 75 percent, accompanied by wind speeds exceeding 15 km/hr., particularly in June and July. The recorded annual potential evaporation stands at approximately 1950 mm, with May experiencing over 220 mm and December around 120 mm.

The district typically receives an annual rainfall of 621 mm, distributed across approximately 49 rainy days each year. Approximately 67 percent of the rainfall happens during the southwest monsoon season June-Sept), with the northeast monsoon contributing about 24 percent during the post-monsoon period. The district is classified under the northern dry zone (Zone-2).

Study design, sampling procedure, and sample size

A cross-sectional survey design was employed in the research domain to evaluate farmers' perceptions of climate variability and their adaptation strategies within the surveyed Koppala district. A multi-stage sampling approach was employed to select participants, with 138 farmers interviewed from 11 distinct villages within the Koppala district.

Data collection Methods

A structured methodology survey was carried out to collect data using a single-visit, multiple-subject approach, conducting face-to-face interviews with a questionnaire to optimize the response rate. Preliminary Data was obtained from 1^0 and 2^0 sources within the Koppala district. 1^0 data were collected through the utilization of a pre-tested, semi-structured questionnaire, focus group discussions (FGDs), key informant interviews (KIIs) validated at the field level, and personal observations made during the period from August to December 2023. Secondary data, encompassing actual recorded weather information on yearly average rainfall, temperature (Minimum & Maximum), air temperature, percent relative humidity (RH), moisture percent in soil, wind speed, and temperature humidity index (THI) for the period of 2001 to 2033 (predicted), were collected to verify farmers' perceptions regarding rainfall and temperature trends.

While the questionnaire was originally designed in English, its implementation was conducted in the local language Kannada to guarantee reliable responses, utilizing appropriate local terms familiar to the people in the surveyed area. The questionnaire was designed to gather primary data regarding the socioeconomic attributes of the participants (including the age of the respondent farmer, level of education, number of people living in the individual household and landholding), farmers' perceptions of changing climate (trends in temperature, air temperature, rainfall, soil moisture, THI, relative humidity and wind speed) spanning the previous two decades, perceived reasons for changing climate of their place, its impacts on agriculture, livestock production, biodiversity, crop and livestock health and adaptation strategies.

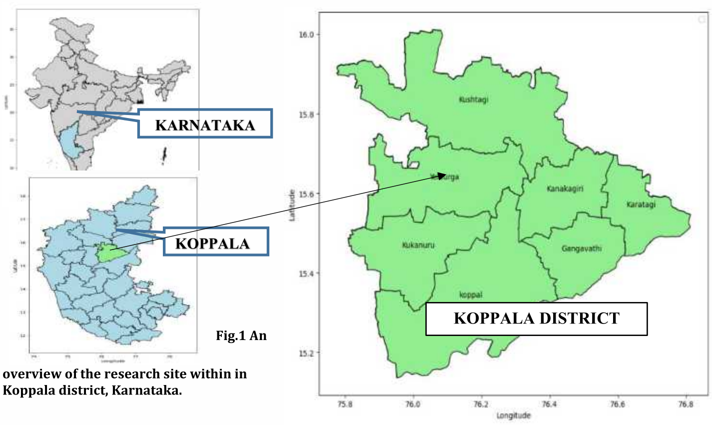


Fig.1 An overview of the research site within in Koppala district, Karnataka.

Data pre-processing and analysis

In our study, we utilized climate event datasets, including minimum and maximum temperature, air temperature, percent relative humidity (RH), moisture percent in soil, wind speed, and THI (Temperature Humidity Index), covering the period from 2001 to 2022. Min and Max temperature data downloaded from climatic research units (CRU) https://crudata.uea.ac.uk/cru/data/hrg/, moisture percent in soil, percent relative humidity (RH), air temperature, wind speed, and THI downloaded from National Oceanic and Atmospheric Administration (NOAA) https://www.noaa.gov/.

Kriging

Kriging, a spatial interpolation method, utilizes a set of sampled data points to predict variable values across a continuous spatial field. In the context of climate events ordinary kriging, the widely used method, assumes an unknown constant mean unless there's a scientific reason to reject it. The method entails establishing the spatial covariance structure to estimate values at points where samples have not been taken. Considering human impact, kriging proves valuable for assessing and predicting spatial patterns influenced by anthropogenic factors.

Variogram

A variogram, also known as a semivariogram, is a chart that plots the semi-variance or gamma value, which measures half the mean square difference against the distance or "lag" between each pair of sampled data points, representing the covariance between them. The "experimental" variogram is the plot of observed values, while the "theoretical" or "model" variogram represents the distribution model that most accurately corresponds to the data. Variogram models are derived from a select number of "approved" functions, such as Spherical, Exponential, and Gaussian models.

Spherical model:

$$\hat{y}(h) = C_0 + C\left[1.5\frac{h}{a} - \left(\frac{h}{a}\right)^3\right], if 0 \leq h \leq a. (1)$$

Exponential model:

$$\hat{y}(h) = C_0 + C\left[1 - exp\left\{-\frac{h}{a}\right\}\right] for\ h \geq 0\ (2)$$

Gaussian model:

$$\hat{y}(h) = C_0 + C\left[1 - exp\left\{-\frac{h^2}{a^2}\right\}\right] for\ h \geq 0\ (3)$$

Where "c" is sill, "a" is nugget, "h" is lag values

Although statistical tools can frequently assist in defining the best-fitting models using a variety of methodologies, such as root mean square error, least-squares, maximum likelihood, and Bayesian methods, the choice of a variogram model is user-defined. Based on the RMSE value, the most effective variogram model was chosen. RMSE values tells us how concentrated the data is around the line of best fit. Various variogram models were assessed for the values of climate events.

With the utilization of this model, the layers were distinctly delineated. After determining the variogram model that fit the data the best, the values were interpolated by ordinary kriging techniques. Before conducting kriging, the R software was utilized to generate grids and create the shape file for the study area. The derived climate change values for the research region were then visualized using the shape file after the grids were created and intersected with it using kriging in Python.

For the data processing, shape file generation, and spatial interpolations, various models and libraries were employed. Pandas, Numpy, Geo Pandas, Matplot, Ordinary kriging, ggmap, rgdal, rgeos, dplyr, tidyr and tmap were used.

Result and Discussions

Socio-demographic characteristics of respondent farmers of the study area.

The socio-demographic characteristics of the sample respondents of the Koppala district are summarized below. The district spans an area of 5570 sq. km, accounting for approximately 2.9 percent of Karnataka state's geographical expanse. It is delineated between 15° 09′ 00″ to 16° 03′ 30″ north latitudes and 75° 47′ 30″ to 76° 48′ 10″ east longitudes, with an average elevation of 529 meters above sea level. According to the 2011 census, the district comprises 594 inhabited villages and 35 uninhabited ones. Koppala district is situated within the central Karnataka plateau physiographic region and falls entirely within the northern dry agro-climatic zone of Karnataka. About (64 %) of the district area was under agriculture in 2021-22. A total of 549 inhabited villages with a total population of 13,89,920 and a literacy rate of 68.09 percent. The high proportion of male respondents likely stems from cultural factors, wherein men typically hold decision-making authority within households headed by males. Additionally, economic considerations may play a role, alongside the relatively lower number of female-headed households in the study region. The findings from the present investigation are consistent with the statement of [**46**] and [**4**] similarly found that (95.9 %) and (92.1%) of respondents were male in Illu Aba Bor Zone and Mana and Sekrou districts, respectively. The average age group of respondents is predominantly above 20 years, with the highest proportion falling within the 35-54 age bracket, accounting for 50.37 percent. Following this, the above 54 age group constitutes 41.48 percent, while 8.15 percent fall within the 15-34 age range. These statistics suggest that the majority of respondents in the research area are middle-aged or older, and people with more experience tend to lean towards and understand climate change and its impacts on agriculture and livestock production. The advanced age of the respondents may enhance their likelihood of adopting climate change measures, owing to their extensive experience in farming, social interactions, and familiarity with the physical environment, compared to younger farmers. The research revealed a limited participation of young individuals in agriculture and livestock production, potentially attributed to challenges such as limited access to agricultural inputs and the high capital demands of investing in agriculture. Furthermore, many young people might opt to migrate to metropolitan areas in pursuit of paid employment opportunities. The average age recorded in this study aligns with [**2**], findings of 45 years but surpasses that of [**45**], who reported an average age of 42.2 years. Concerning educational attainment, the majority of respondents (54.28%) are illiterate, indicating a lack of formal education. Additionally, 38.57 percent have received primary education and possess basic literacy skills, and 5.71 percent have attained a high school education. Notably, none of the respondents have pursued education beyond the high school level. The absence of educational institutions in the region was cited as the reason behind this, thereby indicating that limited access to education may impact the ability to adapt to climate change, characterized by declining rainfall and rising temperatures.

Present results are consistent with [**16**] research, which observed that 75 percent of households surveyed in the Dale district, Sidama zone, were illiterate. Nevertheless, they differ from the results of [**27**] who found higher illiteracy rates of approximately 82.22 percent and 80 percent among surveyed households in the Kersa and Tiro Afetea districts of the Jimma zone. Education helps farmers to be more knowledgeable or access information sources regarding improved technologies and enables them to realize climate change to sustain livestock productivity. As a result, those with lesser educational attainment are more apt to have increased awareness and a better grasp of extension messages concerning climate change and adaptation strategies. [**44**] Reported that education advances the farmers climate change perceptions as it helps to recall and forecast situations. [**5**] noted that personal characteristics like age, education, gender, and agricultural experience influence individual perceptions of climate change. The average family size of respondent farmers in the study area is (40.25%) 5 members in the family, highest family members are 15-20 persons which accounts for (12.50 %). This outcome aligns with the observations of [**23**] who documented an average family size of 6.9 individuals per household in the Horror and Guduru districts.

Table 1. Demographic and social attributes of respondent farmers from Koppala district.

1	**Total geographical area**	5570 sq kms
2	**Latitude**	15° 09′ 00″ to 16° 03′ 30″ North Latitude
3	**Longitude**	75° 47′ 30″ to 76° 48′ 10″ East Longitude
4	**Altitude**	529 mt
5	**Villages**	594 inhabited villages
6	**Population**	1,389,920
7	**Literacy rate**	68.09 per cent
8	**Age group (Year)**	**(%)**
	15-34	8.15
	35-54	50.37
	above 54	41.48
9	**Level of Education**	**(%)**
	Illiterate	40.74
	Primary school	55.55
	10th class	3.70
	PUC	0.74
	Degree	0.00
10	**Gender**	**(%)**
	Male	98.51
	Female	1.48
11	**Family size**	**(%)**
	1 to 5	47.41
	6 to 10	37.78
	11 to 15	10.37
	16 to 20	5.93
	> 20	0.74

Table 2. Ecological, soil type, cropping pattern and livestock population of Koppala district

1.Ave. annual temperature	29.5 °C
2.Ave. annual rainfall	587 mm
3.Ave. annual rainfall days	30-40 days
4.Ave. annual wind speed	5.67 mt/sec
5.Ave. annual pressure	1008-1010 mb
6. Cultivable area (rainfed + irrigated)	5.11 lakh ha
6. Soil type	Black cotton and red soil and red loamy soils
7. Irrigation type	both rains fed and irrigated (tube wells), canal irrigation
8. Major crops	maize, sugarcane, sorghum, Tur dal, black & green gram, cowpea, groundnut, vegetables, mulberry and oilseed crops.
9. Livestock Population (number)	
a. Cow	260408
b. Buffalo	77860
c. Sheep	547061
d. Goat	156509
e. Pigs	12657
Total	**1054495**
Poultry	3534459

Farmer's perception and causes of climate change over twenty years.

The results regarding the overall perception of changing climate knowledge revealed that 95.55 percent of farmers exhibited some level of awareness. Additionally, 87.40 percent of farmers acknowledged the presence of climate change patterns. A substantial majority, accounting for 92.59 percent, obtained their information on climate change from mass media and individuals in their immediate vicinity. Furthermore, they have noticed changes in their village's climate over the last twenty years, as depicted in (Figure. 2). This depicted that audio-visual aids mass media outlets such as television, newspapers, and radio play a vital role in enhancing farmers' awareness and access to information concerning climate change. Consequently, this enhances the probability of farmers adopting adaptation measures to alleviate the impacts of changing climate. These findings align with those of [**29**] who reported that farmers in rural Enugu state mainly depend on personal observations (98.1%), friends (83.8%), radio (57.1%), and television (26.6%) as their principal sources of climate change information. (Table.3) shows farmers' perceptions and causes of changing climate (temperature, rainfall, flood and drought). There existed a notable distinction in farmers' perceptions of changing climate and their views on temperature fluctuations, rainfall patterns, drought occurrences, and flood conditions based on their experiences spanning two decades. 93.33 percent of farmers experienced increased temperature levels in present condition as compared to twenty years back, 90.37 percent of farmers experienced there is a decrease in the quantity of rainfall in comparison to twenty years back to present day condition, there is no occurrence of flood condition in their area as shown 100 percent farmers did n't know the flood conditions in their area since last twenty years, 80 percent of the peasants in the district have noticed drought conditions every 3 to 4 years once because of uneven rainfall occurrences. This result agrees with the results of [**3**] who reported that 84 percent of respondents perceived an increase in temperature. The trend in rainfall is consistent with the findings of [**8**] who reported that 83.22 percent of farmers in the Wore Illu district perceived a reduction in rainfall over time.

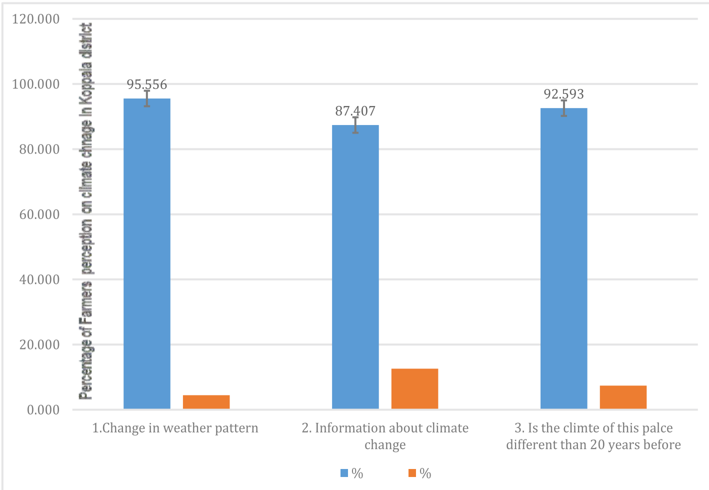


Fig. 2: General perception and knowledge of the changing climate situation in the district.

Table 3. Farmer's general awareness on changing climate events over twenty years.

Climate Variables	Increased (%)	Decreased (%)	No change (%)
1.Temperature	93.33	0.00	6.66
2.Rainfall	0	90.37	9.62
3.Flood	0	0	100
4.Drought	46.66	32.59	20.74

Evaluating the awareness and perceptions of farmers regarding climate change

Examining the current climate change situation requires a historical perspective and establishing a baseline climate data is essential to provide a reference point for assessing climate change. The findings from the farmers' perceptions regarding changes in the climate are depicted in Figure 3. The findings unveiled that farmers in the village have been engaged in farming for numerous years and have witnessed significant alterations in climate conditions. Notably, 80.74 percent of the farmers noted regular shifts in rainfall patterns, with a unanimous agreement regarding a decline in rainfall and prolonged dry spells throughout the cropping season, resulting in drought conditions. Due to reduced rainfall, flooding was not a concern in the village and almost all farmers shared the opinion of experiencing continued drought conditions in some years. With frequent changes in rainfall, there are frequent drought conditions 80 percent of farmers accepted continuous drought problems every three years once. 77.77 percent of farmers opinioned no occurrence of flood conditions because of very frequent changes in rainfall patterns which does not favor floods. Farmers observe other climate-related events like frequent thunderstorms and hailstorms (42.2 %), and very rare occurrences of windstorms (57.04 %). Frequent occurrence of heat waves (48.15 %), soil erosion (42.96 %), and loss of biodiversity (61.48 %) occurrence of pests and diseases to crops (67.41 %) was observed and experienced by the interviewed farmers of the study area. An increase in temperature, which they found unbearable, particularly during the summer months. Uneven rainfall and untimely occurrence of rains infrequent filling of water bodies (77.04 %), and frequent drying of water resources (70.37 per cent). Less forest area covered in the studied area less rare occurrence of forest fire (84.44 %), apart from that less and uneven occurrence of cyclones, hurricanes, and cold waves. This result is in agreement with [**3**], who found that 84 percent of respondents perceived an increase in temperature. Regarding rainfall, the majority (82.9%) perceived a decreasing trend over the past 20 years, while approximately 9.3% observed no change, 4.9% noticed an increase, and 2.9% were unsure of the rainfall trends. The outcomes of this study align with the conclusions drawn by [**5**], who observed farmers in the western part of Ghana perceived an increased temperature and a decline in rainfall. Similarly, farmers from Koppala district echoed these findings, confirming their perception of temperature increases and rainfall decreases over the past twenty years, alongside a reduction in precipitation and elevated temperatures. They noted the occurrence of inconsistent and unpredictable rainfall patterns, accompanied by a decrease in precipitation and an increase in temperatures over the past twenty years. They observed that temperatures have intensified, leading to hotter and drier conditions, along with a rise in the frequency of hot days and a decline in nighttime coldness. They also observed changes in the amount, distribution, timing, and duration of rainfall, noting less frequent, irregular patterns with an earlier start and end to the rainy season, as well as more sporadic and shorter periods of rain.

They also noted that the timing of crop planting has shifted in their area, with a delayed start to crop cultivation becoming more common due to climate variability, which has led to decreased crop yields and increased food insecurity. They also stated that rising temperatures and decreasing rainfall have impacted the growth, maturity, quality, and quantity of natural pasture, leading to a feed shortage, especially during the prolonged dry season They also suggested that human activities like deforestation, along with natural processes, could be potential causes of climate change. Overall, the findings suggested that the farmers interviewed in the current study area possessed a strong understanding of climate change, which serves as a fundamental requirement for adaptation.

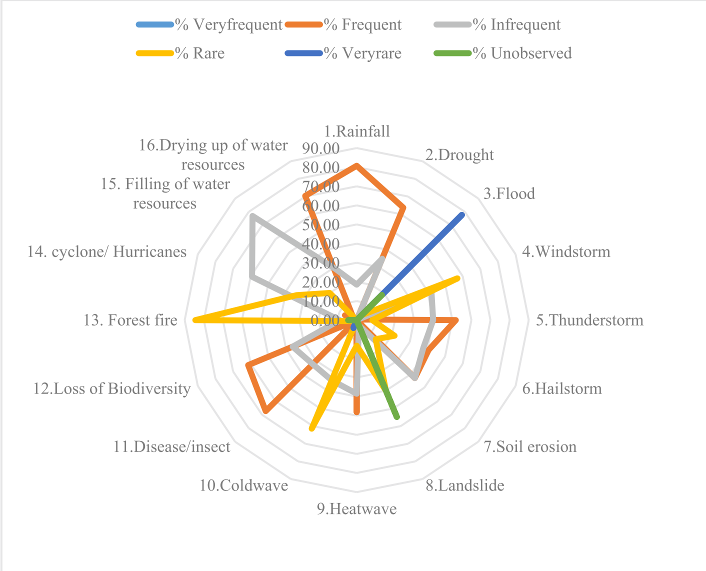


Fig. 3: Farmers' views on the effects of climate variability resulting from major weather related events in Koppala district.

Perception of farmers on climate change impacts on livelihood and agriculture

Concerning farmers' views on how changing climate affects their livelihoods and agriculture, various notable findings emerged. A substantial majority, comprising 81.48 percent of the farmers, noticed the scarcity of water in their village for the past 20 years. This concern was closely followed by worries about the deterioration of water quality. Additionally, 86.66 percent of the farmers acknowledged the drying up of water resources over time, with 68.88 percent identifying a lack of water as a hindrance to their agricultural activities. Furthermore, 77.14 percent of the farmers expressed their concerns about water scarcity, while 87.40 percent revealed that excessive crop losses due to moisture and an increase in fungal infections had been detrimental to their agriculture. As a result, these alterations have resulted in a rise in the occurrence of pests and diseases, impacting both crop and livestock populations. Farmers noticed these outcomes are attributed to notable changes in climatic events occurring over time. They have also encountered a new pest called the fall armyworm in maize (*Spodoptera frugiperda*), which has severely impacted maize production and wilt disease in pigeon pea, leading to substantial crop losses. Farmers mainly linked the prevalence of pests and diseases to the utilization of pesticides, hybrid crops, and intensive farming methods, which they perceive as contributing to the emergence of new pest and disease occurrences compared to those witnessed two decades ago. Additionally, farmers have been contending with erratic monsoon patterns during the sowing season and hailstorms during the harvest season, resulting in substantial yield losses. Consequently, 77.77 percent of farmers reported experiencing losses in farm earnings, as detailed in Table 4.

Table 4. Farmer's perception of climate change impacts on livelihood and agriculture.

Events	Yes (%) Respondents
1.Quality of water deterioration over the years	81.48
2.Drying of water bodies	86.66
3.Faced scarcity for water crop production	68.88
4.Due to climate change susceptibility of crops/ livestock to pest/ disease attacks has increased	87.40
5.Have you noticed new disease incidence in the crops	81.48
6.Have you noticed new insects in crops	81.48
7.Have you noticed new diseases or parasites in livestock	77.77
8.Have you noticed any shifts in the flowering and harvesting period of crops	76.29
9.Have you noticed any quality deterioration observed in farm products	74.07
10.Have you noticed any losses in farm earnings	77.77
11.Incidence of illness due to any disease increased in your family	59.25

3.6 Drivers of Climate Change Adaptation

The majority of farmers lack information and knowledge about climate change. additionally, they face challenges related to the timely non-availability of credit facilities for purchasing inputs and effective climate change mitigation strategies are absent. The combination of these three factors represents 80 percent of the issues raised by farmers. Furthermore, 77.77 percent of farmers agreed that the accessibility of credit significantly influences climate change adaptation. About 77.77 percent of farmers cited the scarcity of water during the dry season as a key driver prompting them to undertake adaptation measures. Furthermore, 77.77 percent of farmers highlighted that the emergence of new diseases or food shortages serves as a significant factor driving their adoption of climate change adaptation measures, as outlined in Table 5.

Table 5. Factors influencing adaptation to climate change.

Events	Yes (%) Respondents
1.Lack of information and knowledge on climate change acts as a barrier to climate change adoption	77.77
2.Credit accessibility influence take adaption measures	81.48
3.Using technology (like mobile, TV, radio, etc.) influence adopt adaptation measures	81.48
4.Government/NGO/others' support influences adopting adaptation strategies	82.96
5.Scarcity of water during the dry season influences to take adaptation measures	77.77
6.Outbreak of new diseases or food scarcity influence to take adaptation measures	77.77

Farmers' perspectives on strategies for adapting to and mitigating climate change.

In the district, a significant majority of farmers (80%) are not knowledgeable about strategies for mitigating climate change. Nevertheless, 87.40 percent have adopted practices such as intercropping and crop rotation. Water conservation methods, particularly those involving farm ponds, are less prevalent, with only 17.03 percent of farmers adopting them. On the other hand, 77.77 percent of farmers have embraced improved seeds for crop cultivation and 80.74 percent have adopted soil conservation technologies such as green manuring, construction of graded bunds, and contour bunding for control of soil erosion. Regarding their livestock, most farmers (48.14 percent) prefer desi cows over crossbreeds. However, only 43.70 percent utilize weather forewarning systems to monitor weather conditions, as indicated in Table 6. The strategies they have implemented include providing crucial irrigation during prolonged dry spells, typically by administering one or two rounds of irrigation to their crops. They rely on resources such as bore wells and lift irrigation facilities provided by the government. Additionally, they employ soil conservation techniques such as mulching, the construction of graded bunds, and the application of green manure. They have implemented an intercropping system involving maize and cowpea, alongside a cereal-pulse cropping system, to maintain soil fertility. Nonetheless, farmers frequently face challenges in accessing crop and livestock insurance to protect against climate change-induced disasters. Additionally, less participation in community-based initiatives for land and soil conservation.

Table 6. Climate change adaptation/ mitigation strategies

Events	Yes (%) Respondents
1.Received any skill development training program to cope with the impact of climate change	22.96
2.Changed in cropping pattern (crop rotation/intercropping/ new crop) over the past 20 years	87.40
3.Invested in farm ponds for irrigation purposes	17.03
4.Adopted improved seeds for cultivation	77.77
5.Intensified the application of farm inputs	77.77
6.Reared livestock of a different breed than the earlier one over the past 20 years	48.14
7.Measures have you taken to improve soil properties	80.74
8.Change in planting time to overcome pest and disease attacks	71.85
9.Using any forewarning systems to know about weather conditions	43.70

Kriging

The geospatial analysis uncovered valuable insights into the spatial and temporal dynamics of climate change events in the Koppala district. Utilizing variogram modeling, the spherical model emerged as the optimal fit, highlighting a distance range of spatial autocorrelation in the climatic events across different talukas of the Koppala district. The successful minimization of root means square error further validated the model's accuracy, enhancing the reliability of the findings. Over 20 years of climatic change events were recorded for the kriging studies. Beyond academic contributions, these results hold practical significance for crafting effective management strategies and policy interventions, offering a foundational understanding of the spatial intricacy of climate change events with farmers' experience in climate change events occurring in their area to kriging data.

In our study, we assessed three variogram models - Spherical, Gaussian, and Exponential - for climate change events such as air temperature, maximum and minimum temperature, relative humidity(RH), moisture percent in soil, wind speed, and THI (temperature humidity index). We used metrics including Partial Sill, Full Sill, Range, Nugget, RMSE, and MSE. For air temperature studies, the exponential model outperformed the others, with a partial and full sill of 0.2056, a range of 0.66040, and an exceptionally low Nugget of 5.10054, indicating its superior ability to capture spatial dependence. With the lowest RMSE (0.0212) and MSE (0.0004), the exponential model proved to be the most effective in modeling and predicting spatial variability. This makes it the preferred choice for air temperature analysis, as depicted in **Table 3.8.1a and Fig 4**.

In the study of maximum temperature, the exponential model outperformed other models, exhibiting a partial and full sill of 0.23630 and a range of 0.66040, along with an exceptionally low Nugget value of 8.46959. These results indicate its superior ability to capture spatial dependence. Additionally, with the lowest RMSE (0.1046) and MSE (0.0109), the exponential model proved to be the most effective in both modeling and predicting spatial variability. Consequently, it is the preferred choice for analyzing maximum temperature, as illustrated in **Table 3.8.1b and Fig 5.**

In the study of minimum temperature, the exponential model exhibited outstanding performance compared to other models, showing a partial and full sill of 0.2025 and a range of 0.6604, along with an exceptionally low Nugget value of 4.4499. These findings suggest its exceptional capability to capture spatial dependence. Furthermore, with the lowest RMSE (0.0711) and MSE (0.0051), the exponential model emerged as the most effective in both modeling and predicting spatial variability. Consequently, it is the preferred choice for analyzing minimum temperature, as presented in **Table 3.8.1c and Fig 6**.

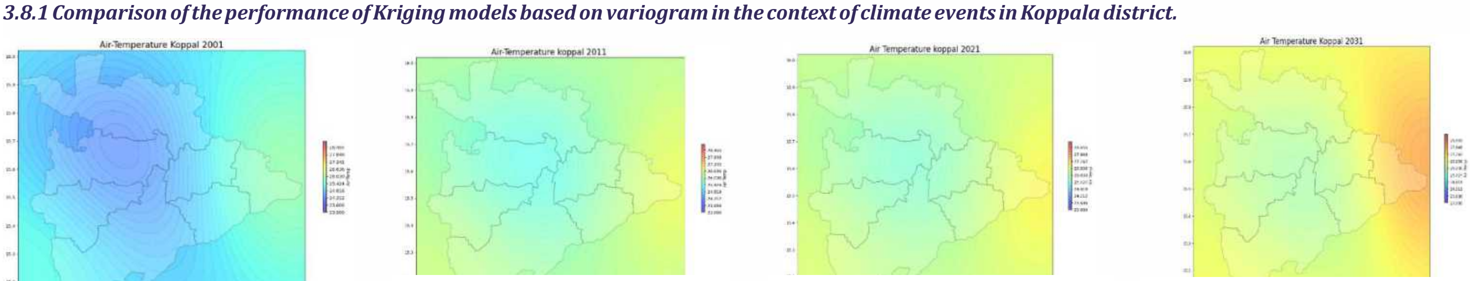
In the study of relative humidity, the spherical model outperformed other models, exhibiting a partial and full sill of 32.1468 and a range of 0.6604, along with an exceptionally low Nugget value of 5.4967. These findings indicate its enhanced capacity to capture spatial interdependence. However, with the lowest RMSE (11.1359) and MSE (124.0075), the exponential model proved to be the most effective in both modeling and predicting spatial variability. Consequently, the preferred choice for analyzing relative humidity, is depicted in **Table 3.8.1d and Fig 7.**

In the study of soil moisture, the exponential model outperformed other models, demonstrating a partial and full sill of 3.3525 and a range of 0.6604, along with an exceptionally low Nugget value of 5.8952. These results imply its superior capability to seize spatial dependence. Furthermore, with the lowest RMSE (0.5193) and MSE (0.2696), the exponential model proved to be the most effective in both modeling and predicting spatial variability. Consequently, it is the preferred choice for analyzing soil moisture, as presented in **Table 3.8.1e and Fig 8.**

For wind speed studies exponential model outperformed with compared to other models with a partial and full sill of 0.03754, a range of 0.66040, and an exceptionally low Nugget of 9.7959, indicating its superior ability to capture spatial dependence. With the lowest RMSE (0.0039) and MSE (0.0002), the exponential model proved to be the most effective in modeling and predicting spatial variability, making it the preferred choice of relative humidity analysis depicted in table **3.8.1f & fig 9**.

For THI studies exponential model outperformed with compared to other models with a partial and full sill of 0.04451, a range of 0.04451, and an exceptionally low Nugget of 8.26515, indicating its superior ability to capture spatial dependence. With the lowest RMSE (0.0711) and MSE (0.0108), the exponential model proved to be the most effective in modelling and predicting spatial variability, making it the preferred choice of relative humidity analysis depicted in Table **3.8.1g** & **fig 10.**

3.8.1 Comparison of the performance of Kriging models based on variogram in the context of climate events in Koppala district.



Air-temperature for Koppala 2001

Air-temperature for Koppala 2011

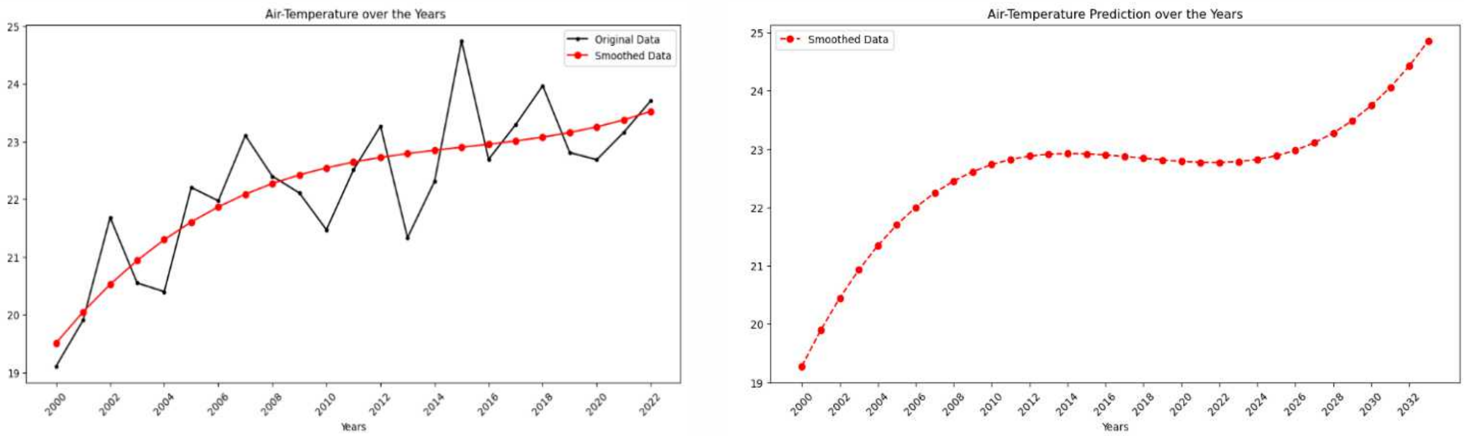
Air-temperature for Koppala 2021

Air-temperature for Koppala 2031(Predicted)

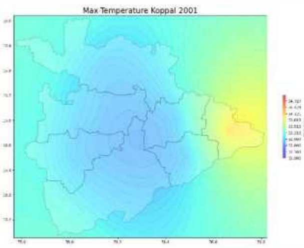
Fig.4 Air-Temperature for Koppala 2001-2033 (Predicted)

a. Air-Temperature

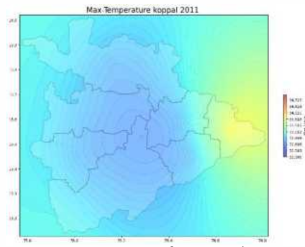
Variogram model	Partial Sill	Full Sill	Range	Nugget	RMSE	MSE
Spherical	0.2228	0.2228	0.66040	8.79855	0.0212	0.0004
Gaussian	0.2652	0.2652	0.66040	8.70148	0.0212	0.0004
Exponential	0.2056	0.2056	0.66040	5.10054	0.0212	0.0004



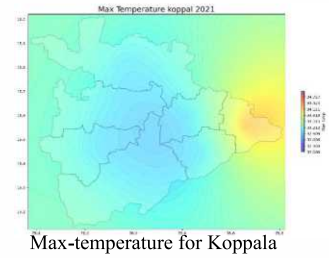
Analysis of climate trends for air temperature (2001-2031)



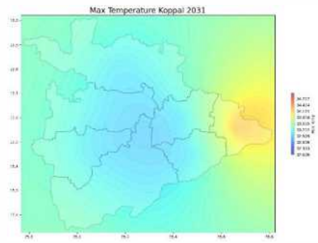
Max-temperature for Koppala



Max-temperature for Koppala 2011



Max-temperature for Koppala 2021

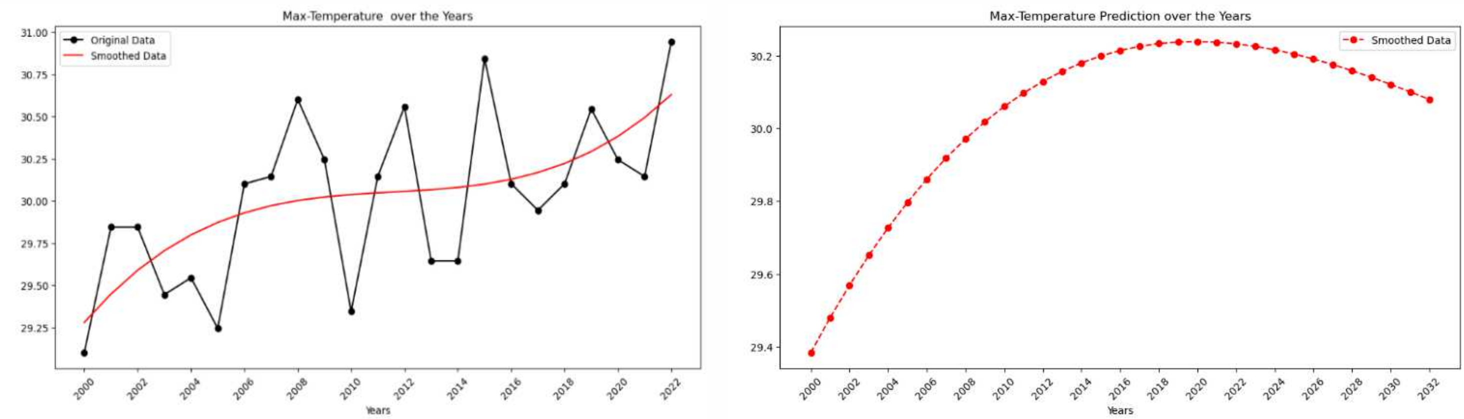


Max-temperature for Koppala 2031(Predicted)

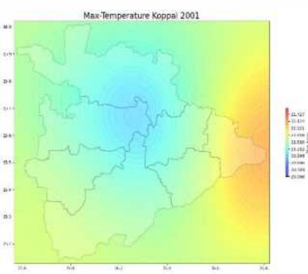
Fig. 5 Max-Temperature for Koppala 2001-2033 (Predicted)

b. Maximum Temperature

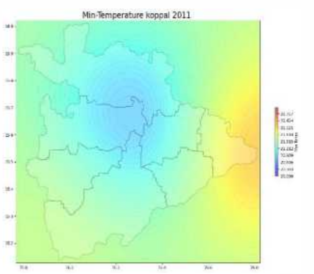
Variogram model	Partial Sill	Full Sill	Range	Nugget	RMSE	MSE
Spherical	0.25631	0.25631	0.66040	9.11838	0.1046	0.0109
Gaussian	0.30615	0.30615	0.66040	1.02095	0.1046	0.0109
Exponential	0.23630	0.23630	0.66040	8.46959	0.1046	0.0109



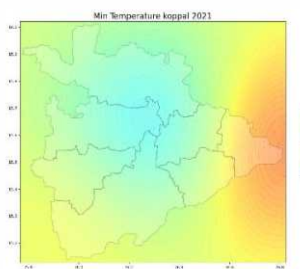
Analysis of climate trends for Max-Temperature (2001-2031)



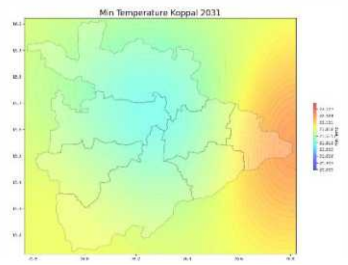
Min-temperature for Koppala 2001



Min-temperature for Koppala 2011



Min-temperature for Koppala 2021

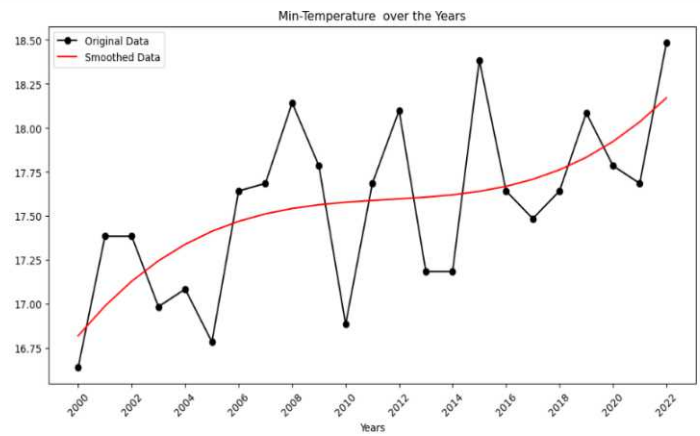


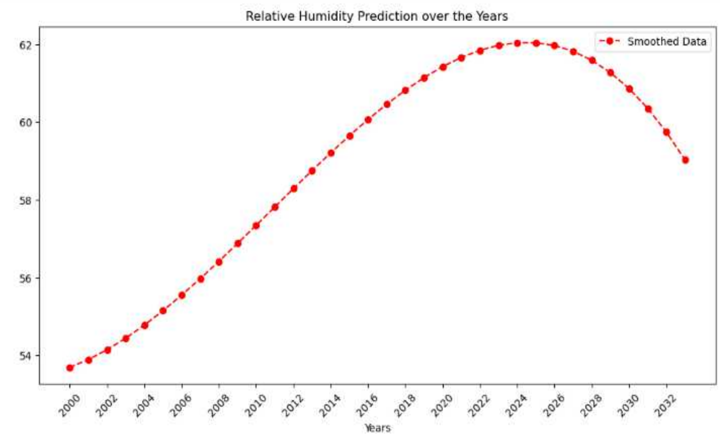
Min-temperature for Koppala 2031 (Predicted)

Fig.6 Min-Temperature for Koppala 2001-2033 (Predicted)

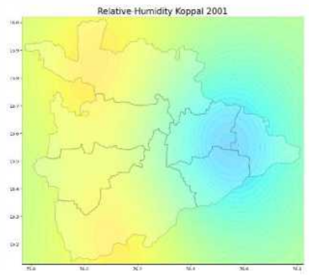
c. Minimum Temperature

Variogram model	Partial Sill	Full Sill	Range	Nugget	RMSE	MSE
Spherical	0.2137	0.2137	0.6604	1.5129	0.0711	0.0051
Gaussian	0.2086	0.2369	0.6604	0.0282	0.0711	0.0051
Exponential	0.2025	0.2025	0.6604	4.4499	0.0711	0.0051

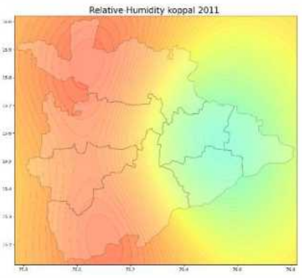




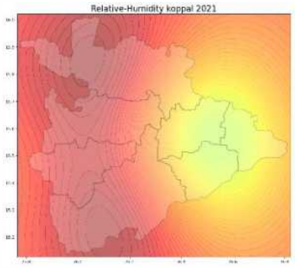
Analysis of climate trends for MIN-Temperature (2001-2031)



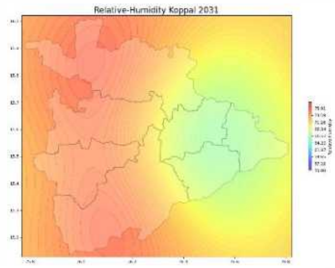
Relative Humidity for Koppala 2001



Relative Humidity for Koppala 2011



Relative Humidity for Koppala 2021

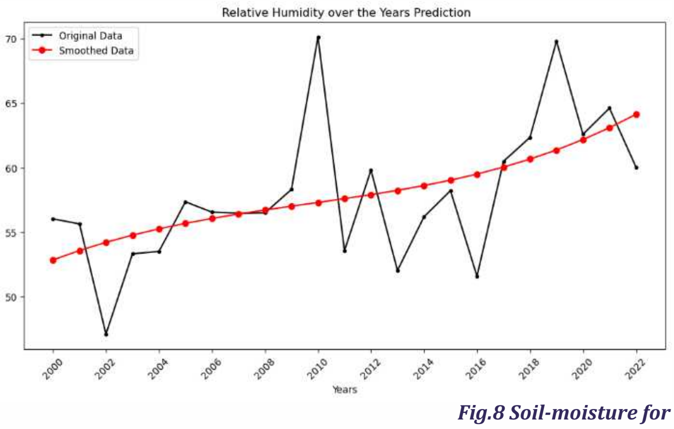


Relative Humidity for Koppala 2031(Predicted)

Fig.7 Relative Humidity for Koppala 2001-2033 (Predicted)

d. Relative Humidity

Variogram model	Partial Sill	Full Sill	Range	Nugget	RMSE	MSE
Spherical	32.1468	32.1468	0.6604	5.4967	11.1359	124.0075
Gaussian	34.8636	34.8636	0.6604	6.0328	11.1136	123.5124
Exponential	33.5018	33.5018	0.6604	9.31286	11.4305	130.6568



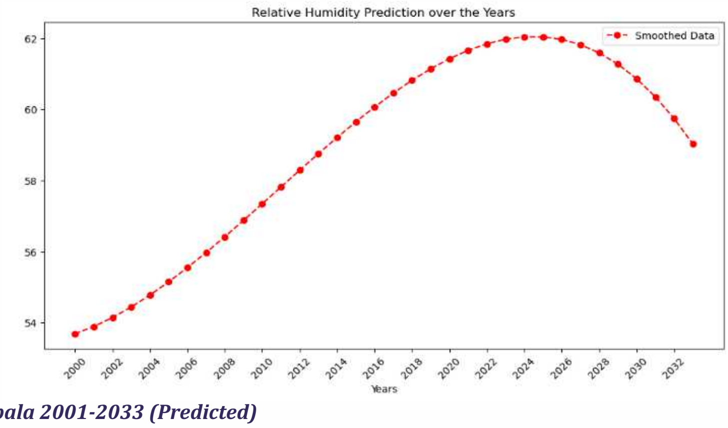
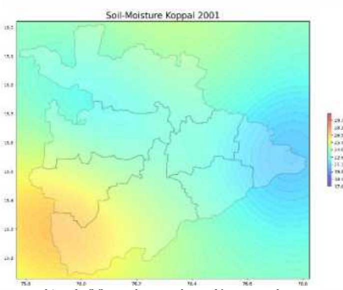
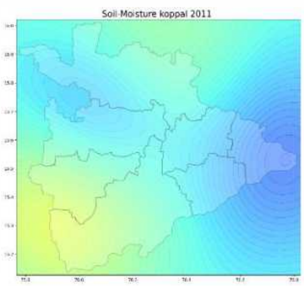


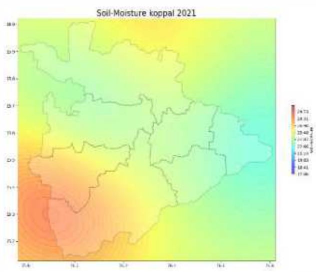
Fig.8 Soil-moisture for Koppala 2001-2033 (Predicted)



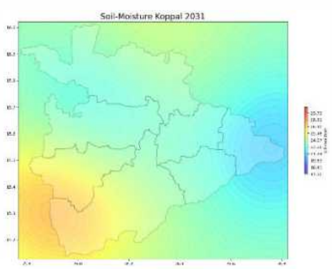
Soil-Moisture for Koppala 2001



Soil-Moisture for Koppala 2011



Soil-Moisture for Koppala

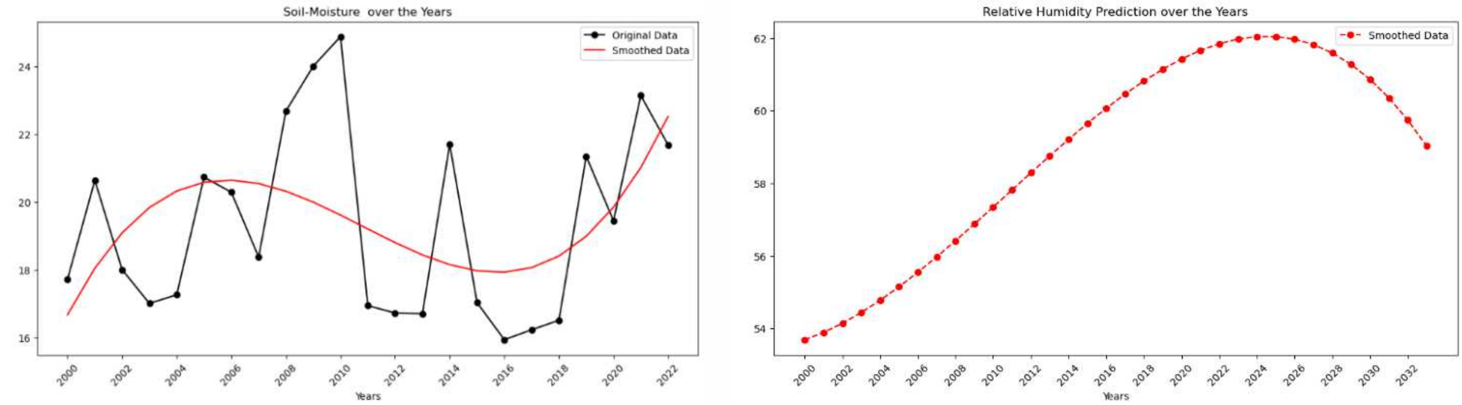


Soil-Moisture for Koppala 2031(Predicted)

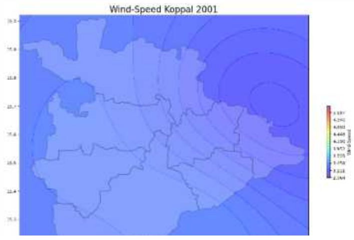
Analysis of climate trends for relative humidity (2001-2031)

e. Soil Moisture

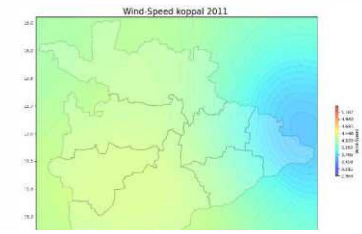
Variogram model	Partial Sill	Full Sill	Range	Nugget	RMSE	MSE
Spherical	3.7459	3.7453	0.6604	1.1527	0.4842	0.2345
Gaussian	4.6541	4.6541	0.6604	1.0776	0.4816	0.2320
Exponential	3.3525	3.3525	0.6604	5.8952	0.5193	0.2696



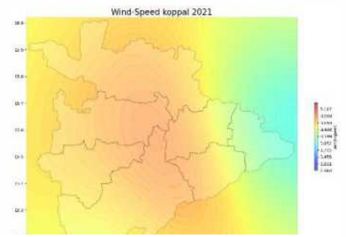
Analysis of climate trends for soil moisture (2001-2031)



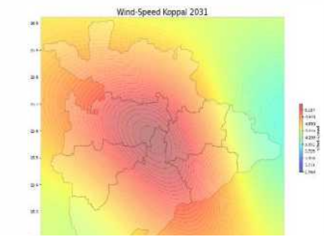
Wind-Speed for Koppala 2001



Wind-Speed for Koppala 2011



Wind-Speed for Koppala 2021

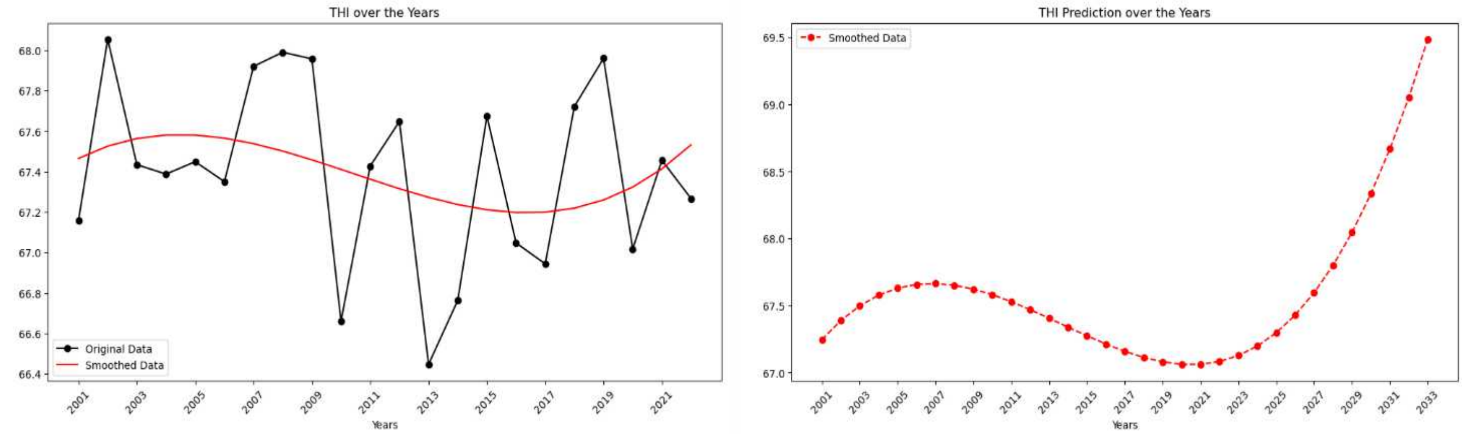


Wind-Speed for Koppala 2031(Predicted)

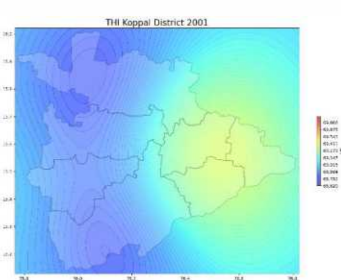
Fig.9 Wind Speed for Koppal 2001-2033(Predicted)

f. Wind Speed

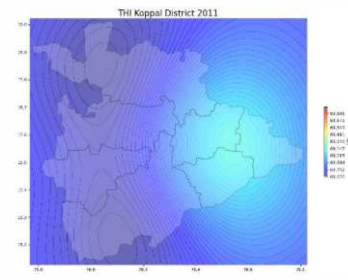
Variogram model	Partial Sill	Full Sill	Range	Nugget	RMSE	MSE
Spherical	0.04070	0.04070	0.66040	2.69089	0.0039	0.0002
Gaussian	0.04862	0.04862	0.66040	1.21209	0.0039	0.0002
Exponential	0.03754	0.03754	0.66040	9.7959	0.0039	0.0002



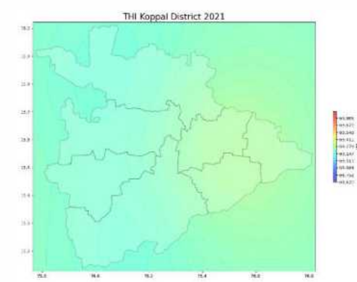
Analysis of climate trends for wind speed (2001-2031)



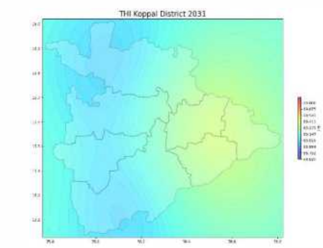
THI for Koppala 2001



THI for Koppala 2011



THI for Koppala 2021

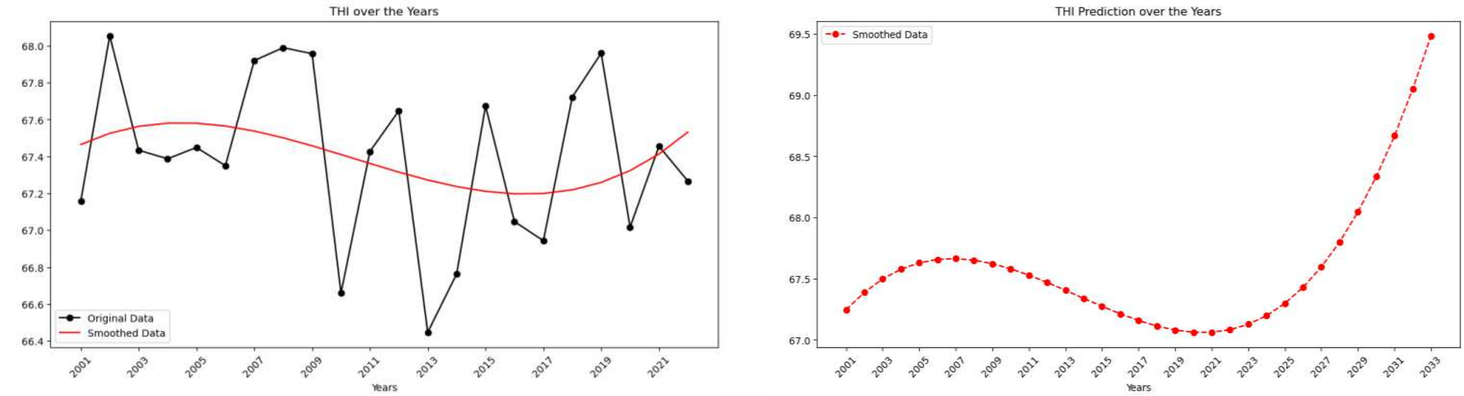


THI for Koppala 031(Predicted)

Fig.10 THI (Temperature humidity index) for Koppala 2001-2033 (Predicted)

g. THI (Temperature Humidity Index)

Variogram model	Partial Sill	Full Sill	Range	Nugget	RMSE	MSE
Spherical	0.04787	0.04787	0.66040	8.58047	0.1039	0.0108
Gaussian	0.05683	0.05683	0.66040	6.42048	0.1039	0.0108
Exponential	0.04451	0.04451	0.66040	8.26515	0.1039	0.0108



Analysis of climate trends for THI (2001-2031)

Adaptation strategies proposed by the farmers.

Farmers ought to be capable of adapting to mitigate the ill effects of changing climate. They have proposed specific adaptation measures. The majority have already initiated adaptation efforts by opting to cultivate short-duration, heat-tolerant crops like millets, pulses, maize, leafy vegetables, and flower crops. Mentioned crops can endure heat and water stress, thereby serving as a response to changing climate conditions. Analysis of farmers' adaptation needs has enlightened the importance of constructing small check dams, implementing canal irrigation, and creating ponds in their vicinity sourced from the Tungabhadra dam to meet their irrigation requirements. Farmers unanimously endorse the promotion of diverse livelihood options to protect their incomes, acknowledging risks such as failure of crops and outbreaks of diseases and pests linked to climate change. These four adaptation strategies should receive greater priority owing to their specific requirements. Moreover, additional adaptation options such as crop-based weather insurance and early weather predicting warning systems should be more extensively distributed, with programs customized to meet the specific requirements of individual farmers. The unpredictability surrounding the late occurrence of the monsoon, uneven rainfall distribution, seasonal alterations, variability in rainfall, and the necessity for novel adaptation approaches in addressing evolving climatic conditions are the principal factors contributing to farmers' hesitancy to participate in *Kharif* season cropping.

Focus group discussions (FGDs) have revealed that there is a frameshift in climate towards warmer and drier conditions, leading many farmers to adjust their cropping patterns to ensure the sustainability of their livelihoods. They have adopted the cultivation of short-duration crops such as millets, pulses, leafy vegetables, and flowers. Within cropping systems, adaptation practices involve practices initiated by farmers themselves, including changing cultivation types and timings or adjusting irrigation methods. Similarly, planned adaptation measures should be implemented. This involves the provision of new seed varieties to farmers that exhibit tolerance to salt, pests, and drought, facilitated by Krishi Vigyan Kendra (KVK). Additionally, information on new management strategies, such as revised cropping patterns and improved contingency crop calendars, should be disseminated to farmers to help them adapt to these changes. Promoting the use of modern micro-irrigation technologies, especially drip irrigation, through government subsidies, would serve this purpose effectively. Desilting farm ponds and expanding the storage capacity of water would help in conserving soil moisture in croplands. Crop weather-based insurance schemes need to be widely publicized to address individual crop failure issues since it is very important to the individual farmer level. Diversified livelihood options, such as integrating agroforestry, sericulture, and floriculture, should be considered as part of integrated farming systems need concern in present-day agriculture systems, without reducing the importance of ensuring food security. This approach could enhance farmers' prospects for sustainable agriculture and stable income, while also increasing environmental awareness. Enhancing farmers' access to weather-based forecasting information from mass media channels would aid in increasing their awareness and adaptability, especially amidst emerging climate change scenarios. According to this study, the changes perceived by farmers may not coincide with the analysis of weather data. This inconsistency was noted previously by [**38**], as their analysis of meteorological data did not corroborate farmers' perceptions of decreasing rainfall.

A growing literature indicates that farmers have noted phenological disturbances in crops, such as premature flowering, leaf growth, fruiting/maturity, and flower bud shedding in plants, attributed to elevated temperatures and moisture stress. These alterations are affecting both crop yields and farmers' means of living. Other researchers, such as [**10**] [**47**], and [**15**], have reported comparable findings. The process of adapting to a changing climate involves a two-step approach, farmers initially notice changing situations in climatic events and subsequently react to these changes through adaptation. African researchers, as indicated by [**14**], have highlighted that adaptation strategies are crafted from farmers' agricultural experiences. Nevertheless, the foreseeable impacts of present human activities on future climate, especially concerning crop production, are undeniable, necessitating collaborative endeavors to direct policies toward genuine sustainability [**9**]. To achieve this objective scientists, policymakers, and stakeholders should be closer collaborate with farmers and extension workers to grasp the evolving weather patterns, thereby enhancing the formulation and implementation of adaptation policies.

Strengthening capacity-building efforts at local, national, and regional levels is imperative for empowering developing countries like India to adapt to shifting climates as mentioned by [**38**].

Conclusion

The objective of this study was to gather both qualitative and quantitative information on farmers' awareness of climate change, assess their specific adaptation needs, and analyze meteorological parameters to determine the consistency between perceptions and actual observations. The majority of farmers demonstrate awareness of climate variability and change, with their perceptions aligning with analyzed climate data trends, except for rainfall. While local autonomous adaptation measures are widely practiced, such as cultivating short-duration pulses and growing fruits, flowers, and vegetables, they may not fully mitigate the increasing impacts of climate change. It is crucial to incorporate planned adaptation into state government developmental planning for long-term benefits. Future efforts should prioritize implementing a new agricultural development framework tailored to address farmers' site-specific adaptation needs, as suggested during focus group discussions (FGDs). Over the past twenty years, farmers have observed a rise in temperature and a decrease in precipitation, consistent with meteorological data trends from 2001 to 2022, which indicate increasing mean annual minimum and maximum temperatures, alongside decreasing rainfall trends. Farmers attribute climate change primarily to anthropogenic activities, natural processes, and natural occurrences. Furthermore, the study reveals that farmers exhibit knowledge of the effects of changing climate on agricultural production and productivity.

Declaration of Competing Interest

The authors state that they have no known financial conflicts of interest that could have influenced the research presented in this paper.

Consent from Farmer's

We have recorded videos of each farmer with their clear and transparent consent, signifying their willingness to participate in activities involving their land and data, all in adherence to agreements ensuring transparency and respecting their rights and interests.

Funding

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Declaration of Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

References

1. Abrol, I.P. and Sangar, S. (2006). Sustaining Indian agriculture–conservation agriculture the way forward. *Curr. Sci*. 91 (8), 1020–1025.

2. Adebabay, K. (2009). Characterization of milk production systems, marketing and on-farm evaluation of the effect of feed supplementation on milk yield and milk composition of cows at Bure District, Ethiopia. Department of Animal Science and Technology School of Graduate Studies Bahir Dar University. Master thesis of Science in Agriculture (Animal Production).

3. Adeoti, A.I., Coster, A.S., Akanni, T.A. (2016). Analysis of farmers vulnerability, perception and adaptation to in Kwara State, Nigeria. Int. J. Clim. Res. 1 (1), 1–16.

4. Adugna, E., Fikadu, M., Taye, T. (2019). Perception of small livestock keepers on the effect of climate related risks and household food security: the case of Mana and Sekoru districts, Jimma zone. *Ethiopia. J. Appl. Sci. Technol*. 10 (1), 49–70.

5. Akinyemi, F.O. (2017). Climate change and variability in semi-arid Palapye, Eastern 'Botswana: an assessment from smallholder farmers perspective. Wealth. Clim. Soc. 9 (3), 349–365

6. Alam, G.M., Alam, K. and Mushtaq, S. (2017). Climate change perceptions and local adaptation strategies of hazard-prone rural households in Bangladesh. *Clim. Risk. Manag*. 17, 52– 63.

7. Arkin, H. and Colton, R.R. (1963). Tables for Statisticians. Barnes and Noble, New York, pp. 136–137.

8. 'Bewuketu, M., (2017). Farmers Perception and Adaptation Strategies to Climate Change: the Case of Woreillu District of Amhara Region, Northeastern Ethiopia. Haramaya University, Haramaya. MSc thesis.

9. Blowers A., Boersema J, Martin A. (2012). Is sustainable development sustainable. *J. Integr. Environ. Sci*. 9(1): 1-8.

10. Brown ME. (2006). Evaluating the challenges of natural resource management in Senegal through the utilization of data obtained from participatory rural appraisals and remote sensing.

11. Chen, H., Wang, J., Huang, J. (2014). Policy support, social capital, and farmers' adaptation to drought in China. *Glob. Envirn. Chang*. 24, 193–202.

12. Cummings, R.W. and Paroda R. S. (2019). Reorienting Indian agriculture: challenges and opportunities.

13. Dawadi, B., Shrestha, A and Acharya, R. H. (2022). Regional Sustainability. 3:122–132.

14. Deressa T.T., Hassan R.M. and Ringler C. (2011). Perception of an adaptation to climate changes by farmers in the Nile basin of *Ethopia. J. Agric. Sci*. 149(1): 23-31.

15. Dieye A. M, Roy D. P. (2012). A study of rural Senegalese attitudes and perceptions of their behavior to the climate. *Environ. Manage*. 50(5): 929-941.

16. Endeshaw, A. (2007). Assessment of Production and Marketing System of Goats in Dale District, Sidama Zone. Hawassa University, Ethiopia, p. 178p. MSc Thesis Submitted to The School of Graduate Studies Department of Animal Production and Range Sciences.

17. FAO, (2006[a]): World reference base for soil resources, Food security. Food and Agriculture Organization Policy Brief, 4 pp.,

18. The Food and Agriculture Organization of the United Nations (FAO) published a report in (2019) titled "Agriculture and Climate Change: Challenges and Opportunities at the Global and Local Levels - Collaborating on Climate-Smart Agriculture," spanning 52 pages, based in Rome.

19. Ga, M. (2004). More intense, more frequent and longer lasting heat waves in the 21[st] century. *Science.* 305 (5686):994–997.

20. Guiteras, R. (2009). The Impact of Climate Change On Indian agriculture. Manuscript. Department of Economics, University of Maryland, College Park, Maryland.

21. Hochman, Z., Horan, H., Reddy, D.R., Sreenivas, G., Tallapragada, C., Adusumilli, R., and Roth, C.H. (2017) investigated the strategies of smallholder farmers in India for coping with climate variability in their study titled "Adapting to a Variable Climate." This research was published in the journal Agricultural Systems, Volume 150, pages 54–66.

22. Jha, C.K., Gupta, V. (2021). Farmer's perception and factors determining the adaptation decisions to cope with climate change: An evidence from rural India. *Environ. Sustain. Indic*. 10, 100112.

23. Kassahun, G. (2021). Management and utilization practices of natural pasture in Western Ethiopia*. J. Agri. Sci. Food. Technol*. 7 (1), 147–153.

24. Kirtman B, Power S, Adedoyin J, Boer G, Bojariu R, Camilloni I, Wang H (2013) Near-term climate change: projections and predictability. In: Stocker T et. al. (eds) Climate change 2013: the physical science basis. Cambridge University Press, Cambridge, pp 953–1044.

25. Masson-Delmotte, V., Zhai, A.P., and Pirani, S.L. (2021) contributed to the Intergovernmental Panel on Climate Change (IPCC) report titled "Climate Change: The Physical Science Basis," which constitutes Working Group I's contribution to the Sixth Assessment Report. This publication is released by Cambridge University Press, Cambridge.

26. Mendelsohn, R. (2000). Efficient adaptation to climate change. *Clim. Change*. 45: (3), 583–600.

27. Mohammed, H., Yisehak, K., Meseret, M. (2016). Characterization of livestock production system in three selected districts of Jimma Zone, southwest Ethiopia. J. Reprod.Infertil. 7 (2), 47–62.

28. Niles, M.T., Mueller, N.D. (2016). Farmer perceptions of climate change: Associations with observed temperature and precipitation trends, irrigation, and climate beliefs. Glob. Environ. Chang. 39, 133–142.

29. Okoro, J.C., Agwu, A.E., Anugwa, I.Q. (2016). Climate change information needs of rural farmers in Enugu state. *J. Agri. Exten*. 20 (2).

30. Patel, S., Mall, R.K., Jaiswal, R., Singh, R. and Chand, R. (2022). Vulnerability Assessment of Wheat Yield Under Warming Climate in Northern India Using Multi-Model Projections. *Int. J. Plant Prod*. 16, 611–626.

31. Pandey, R., Kumar, P., Archie, K.M., Gupta, A.K., Joshi, P.K., Valente, D., Petrosillo, I. (2018). Climate change adaptation in the Western-Himalayas: Household level perspectives on impacts and barriers. *Ecol. Ind*. 84, 27–37.

32. Rao, C.R., Raju, B.M.K., Rao, A.S., Rao, K.V., Rao, V.U.M., Ramachandran, K., Venkateswarlu, B., Sikka, A.K., Rao, M.S., Maheswari, M. and Rao, C.S. (2016). A district level assessment of vulnerability of Indian agriculture to climate change. *Curr. Sci*. 1939–1946.

33. Ravi Shankar, K., Nagasree, K., Maruthi Sankar, G.R., Prasad, M.S., Raju, B.M.K., Subba Rao, A.V.M., and Venkateswarlu, B., published in (2013), explored farmers' perceptions and adaptation strategies to climate change in South India, emphasizing the extension's role in climate adaptation and mitigation efforts. This research is documented in Extension Bulletin No. 03/2013 from the Central Research Institute for Dryland Agriculture, Hyderabad, Volume 28.

34. Ray, L.K., Goel, N.K. and Arora, M. (2019). Trend analysis and change point detection of temperature over parts of India. *Theor. Appl. Climatol*. 138(1–2),153–167.

35. Rohini, P., Rajeevan, M. and Srivastava, A.K., 2016. On the variability and increasing trends of heat waves over India. *Sci. Rep*. 6, 26153. doi:10.1038/srep26153.

36. Selvaraj KN. (2009). Risk Management Strategies for Drought-Prone Rice Cultivation: A Case Study of, India. *Asian J. Agric. Devel*. Vol. 6: No. 2 95:95-124.

37. Sen, P.K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Am. Stat. Assoc.* 63 (324), 1379–1389.

38. Simelton E; Quinn CH; Batisani N; Dougill AJ; Dyer J; Fraser E; Mkwambisi D; Sallu SM; Stringer, L. (2013). Is rainfall really changing? Farmers" perceptions, meteorological data, and policy implications, Climate and Development, 5, pp.123-138.

39. Sharma, S. and Mujumdar, P. (2017). Increasing frequency and spatial extent of concurrent meteorological droughts and heat waves in India. *Sci. Rep*. 7 (1), 1–9.

40. Singh, N.P., Anand, B., Khan, M.A. (2018). Micro-level perception to climate change and adaptation issues: A prelude to mainstreaming climate adaptation into developmental landscape in India. *Nat. Hazards* 92 (3), 1287–1304.

41. Singh, S. (2020). Farmers' perception of climate change and adaptation decisions: A micro-level evidence from Bundelkhand Region*, India. Ecol. Indic*. 116, 106475.

42. Soubry, B., Sherren, K., Thornton, T.F., (2020). Are we taking farmers seriously? A review of the literature on farmer perceptions and climate change, 2007–2018. *J. Rural Stud*. 74, 210–222.

43. Swami, D., Parthasarathy, D. (2020). A multidimensional perspective to farmers' decision making determines the adaptation of the farming community. *J. Environ. Manage.* 264, 110487.

44. Tagel, G., Van Der Veen, Anne (2013). Farm level adaptation to climate change: the case of farmer's in the Ethiopian Highlands. Environ. Manage. 52 (1), 29

45. 45. Tesfaye, A., Chairatanayuth, P. (2007). Management and feeding systems of crop residues: the experience of East Shoa Zone, *Ethiopia. Livest. Res. Rural. Dev*. 19 (3), 6–12.

46. Teshager, A., Belay, D., TayeTolemariam. (2013). Socioeconomic and farm characteristics of smallholder cattle producers in ilu Aba bora zone of Oromia regional state, south western Ethiopia. *Global. Vet*. 10 (5), 607–613.

47. Tschakert P. (2007). Views from the Vulnerable: Understanding climate and other stressors in the *Sahel. Global. Environ.Change*. 17:381-396.

48. Venkateswarlu, B. and Singh, A.K. (2015). Climate change adaptation and mitigation strategies in rainfed agriculture. In: Climate Change modelling, Planning and Policy for Agriculture. Springer, New Delhi, pp. 1–11.

49. Zhang, L., Hu, J., Li, Y., Pradhan, N.S. (2018). Public-private partnership in enhancing farmers' adaptation to drought: Insights from the Lujiang Flatland in the Nu River (Upper Salween) valley, China. Land Use Policy 71, 138–145.

50. Zhang, X., Vincent, L.A. and Hogg, W.D. (2000). Temperature and precipitation trends in Canada during the 20th century. *Atmos. Ocean*: 38 (3): 395–429.

51. Zaveri, E., Grogan, D.S., Fisher-Vanden, K., Frolking, S., Lammers, R.B., Wrenn, D.H., Prusevich, A. and Nicholas, R.E., 2016. Invisible water, visible impact: groundwater use and Indian agriculture under climate change. *Environ. Res. Lett.* 11(8)., 084005.

