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Climate Change and Its Regional Impacts on Agricultural Geography

Dr. Pijush Kanti Tripathi[1*], **Archana Salaskar**[2], **Nirmala Beng**[3], **Satish Kumar J**[4], **Arun Kumar**[5]
[1*]Associate Professor of Geography, Haldia Government College, Purba Medinipur, West Bengal Email id: pijushgeo1970@gmail.com, ORCID ID- 0009- 0008- 2817- 1668
[2]Asst Prof, Vasantdada Patil Prathishthan's College of Engineering and Visual Arts, Sion, Mumbai, Maharashtra, Mumbai University EMAIL ADDRESS: archana.salaskar@gmail.com
[3]Former Assistant Professor Department of Geography St. Joseph's College, Torpa Khunti, Jharkhand Ranchi University, Email: nirmalabeng7@gmail.com
[4]Assistant Professor, Department of Environmental Science, JSS AHER Mysore ORCID ID: 0000-0002-5338-0292, satishkumarj@jssuni.edu.in
[5]Assistant Professor, G G.M. Science College Jammu Email: drikenter2011@gmail.com, Orchid id:0000-0001-7994-865

Abstract
The challenge of climate change has been a dynamic menace to agricultural systems as it affects temperature, precipitation, and the occurrence of extreme weather events. As a climate-sensitive sector, agriculture is more vulnerable in one region compared to another; thus, it is imperative to analyse agriculture in terms of geography to be in a position to know its effects. The study explains the effects of climate change on agricultural geography by studying spatial variations of crop productivity, land-use processes, and adaptive capabilities among different agro-climatic regions. The study is based on the forms of a regionally comparative, mixed-methods design, followed by the analysis of data through time-series statistics and multivariate modelling. Climatic and agricultural signals were assessed, ranging from temperature patterns, rainfall abnormalities, harvest operations, and conversion of land-use, in arid, semi-arid, floodplain, and upland zones. The outcomes show a considerable geographical disparity: hot areas underwent the most climate pressure (e.g., temperature growth of 1.8 °C, loss of rain by 12%, and yield down by 22%), and floodplains showed improved yields (+10%) and adaptive infrastructure. Spatial indices proved that both arid and semi-arid areas suffer more vulnerability due to the unavailability of socio-economic and technological capabilities. On the contrary, irrigated plains were more resilient and institution-supported. The study indicates that region-based planning, investments in adaptive technologies, and geographically acceptable policies will help reduce the unequal effects of climate change on the agricultural sector and ensure resilient and sustainable land use.

Keywords: *Climate Change, Agricultural Geography, Regional Vulnerability, Adaptive Capacity*

1. INTRODUCTION

Climate change is one of the greatest threats to global ecological stability and human sustainability in the 21st century [1]. It is defined by long-term changes in temperatures, patterns of rainfalls and snowfalls, frequent appearance of extreme weather conditions, and augmented levels of greenhouse gases in the air, including CO_2, CH_4, and N_2O [2]. The changes have far-reaching impacts on the biophysical systems of the Earth, of which agriculture is particularly vulnerable [3]. Agriculture, a climate-sensitive industry, is one of the industries that is majorly dependent on stable climatic conditions to be efficient [4]. Changes in temperatures and precipitation, and also the rise of the frequency of droughts, floods, and heatwaves, have already started to interfere with the traditional agricultural calendar and diminish crops, as well as affecting the nutritional value of staple crops [5]. The empirical evidence presented by the Intergovernmental Panel on Climate Change (IPCC) and regional climate models shows that agricultural systems, especially in the low- and middle-income countries, are more exposed to stresses caused by climate change [6]. These alterations do not exclusively belong to the ecological pattern as they overlap the socio-economic layers, consequently reshaping the production, land usage, and rural livelihood patterns in space [7]. Agriculture is still one of the main pillars of national economies, especially in developing parts of the world, where it plays an important role in increasing domestic GDP, job creation, and food supplies [8]. Other than its economic responsibility, agriculture supports the livelihoods of millions of households through subsistence agriculture practices and acts as a risk buffer in terms of poverty and malnutrition [9]. Nonetheless, the industry is too dependent on climate-dependent parameters, thus subjecting it to the vagaries of global warming [10]. Climate change should be seen through the prism of geography as its effects are spatially heterogeneous, both at the level of climate variables (for example, precipitation) and agricultural systems [11, 12]. Geography as a field of study is very crucial in providing information on the interactions of physical landscapes and human systems in both space and time [13]. Agricultural geography, in particular, examines how crops, farming systems, and the socio-economic background influence agricultural decision-making and are spatially distributed [14]. Thus, a geographical perspective provides region-specific analysis of the climate-agriculture relationship, which reflects the intricacy of regional agro-ecological systems, access to resources, and responsiveness [15]. An important feature of climate change is that the effects are not evenly distributed across all geographic regions. The changes in the global average temperature may rise; all these changes are significant, timely, and have varied effects [16]. As examples, large areas of semi-arid regions might be under severe drought stress, whereas coastal areas will be more subject to salinization based on rising sea levels [17]. Similarly, the mountainous areas undergo a threat of glaciers receding and changes in hydrological systems, which makes irrigation-based farming downstream susceptible to these changes [18]. The differences are compounded by the divergent socio-economic capability to respond [19]. The areas of high income can afford climate-resilient infrastructure, crop insurance, and precision agriculture, but marginalized regions can even miss access to basic adaptation technology [20]. This unequal exposure and adaptive capacity lead to a structure of the agricultural sector which is massively fragmented, as with some areas there is decreasing productivity, and other areas of climatically favorable regions are increasing [21]. Therefore, the geographic variation of the natural and human systems implies the need to examine how such differential effects are transforming the agricultural geographies [22].

The objective of this study is to evaluate the impacts of climate change on the geography of agriculture by reviewing the regional changes. It addresses agro-climatic regional differences and effects on crop productivity and land-use dynamics, and farming systems in different regions. Other emerging trends that the study looks into include crop displacement, desertion of land, or development of land, and the changes in seasons. One of the focal areas is the determination of how socio-economic, technological, and policy aspects influence regional adaptive capacity or agricultural resilience.

2. METHODOLOGY

2.1 Study Design

The study uses a regionally comparative study design and combines climatic, agricultural, and socio-economic factors to assess how climate change is affecting the geography of agriculture. This was employed in a mixed-method study design where both time-series and spatial analysis were observed, as well as statistical modeling. It was meant to gather physical and human-made adaptations to the variance of climate. The statistical tools have been used to computerize the data quantitatively to judge the changes that occurred in crop patterns, land distribution, and productivity as time went by. The methodology that involves geospatial tools along with regression analysis enables the identification of climate-induced regional variance in agricultural choice as well as common trends.

2.2 Selection of Study Areas

The study takes into consideration a variety of agro-climatic regions, which have been chosen based on ecological vulnerability, agricultural intensity, and exposure to climate. The areas include arid lands, rain-fed plains, flood-prone areas, and highlands. Selection aimed to include spatial heterogeneity and different intensities of climate sensitivity. The soil type, hydrological systems, and crop systems also differed at the regional level; therefore, a geographic sampling was also taken into account. Having multifaceted zones allows making comparisons of the ways that different landscapes and farming systems adapt to similar pressures of climate, which can be used both to learn how certain areas of high vulnerability occur and to learn some generalizable adaptation trends.

2.3 Data Sources

This study uses data collected through international meteorological databases, remote sensing sites, agricultural census, and population records. Climatic parameters are mean and seasonal temperatures, rainfall, and extreme weather occurrences. The agricultural information includes crop productivity, land use, and crop cycling. Adaptive capacity was evaluated with the inclusion of socio-economic indicators like irrigation access, population density in rural areas, as well as the level of incomes. Spatial resolution, time scale, and all the coordinate systems were harmonized in all datasets. Data cleaning, reclassification, and interpolation were some of the preprocessing steps done to establish consistency and accuracy among all the regional datasets.

2.4 Climatic Trend Analysis

Statistical methods, including linear regression, moving averages, and Mann-Kendall trend tests, analyze the trends in temperature and precipitation. This analysis ascertained climatic long-term changes and seasonal variation in regions. The extreme weather events were measured, such as droughts, floods, and heatwaves, inside the index that used to quantify extreme weather, such as the Standardized Precipitation Index (SPI) and the Temperature Anomaly Index (TAI). Temporal anomalies were employed to envisage sharp climatic changes due to agricultural catastrophes. This was to identify both gradual climate changes as well as episodic stresses that disproportionately impact agricultural activities, planting calendars, and land productivity across the diverse agro-ecological contexts.

2.5 Agricultural Impact Assessment

Impacts on agriculture were evaluated in terms of variations of crop yield and variation in cropping patterns, as well as land use alterations. The sensitivity and vulnerability were determined by correlating crop performance with climatic anomalies. To obtain an assessment of vegetation health dynamics, changes, and detection of phenological shifts, NDVI (Normalized Difference Vegetation Index) satellite image data were utilized. The agricultural vulnerability indicators to such disasters were made by creating composite agricultural indices by using agricultural yield data, frequency of crop failure, and dependence on climate-sensitive crops.

2.6 Statistical Modelling

A multivariate statistical model was deployed to measure the correlation between climatic variables and the agricultural outputs in different regions. The result of the Ordinary Least Squares (OLS) regression model documented the derivation of the direct impact of temperature and rainfall on crop yields, and Principal Component Analysis (PCA) was useful in identifying key factors that contributed to the vulnerabilities of the region. The interaction terms were employed in measuring the effect of socio-economic attributes in moderating the climate. These statistical methods gave an empirical platform to the spatial analysis and allowed predictive results in the direction and magnitude of agricultural change.

3. RESULTS

3.1 Regional Climate Trends

Climatic data analysis over a long time shows that there is great regional variability in the increase in temperature as well as precipitation. The semi-arid zone led the pack at 2.1 °C, and the upland region was second with 1.9 °C, the arid zone had 1.8 °C, and the floodplain with 1.5 °C. The datasets of rainfall depicted a decrease in arid (12 %) and semi-arid (8 %), but also increased floodplain (15 %), probably owing to the strengthening of seasonal rainfall systems. Harsh weather episodes showed that the denser droughts occurred in dryland areas, and floods occurred mostly in floodplains. Table 1 shows that the lowest temperatures increased in semi-arid areas and that arid regions experience the greatest reduction in rainfall, and droughts and floods occurred most frequently in floodplains.

Table 1: Regional Climate Trends over time

Region	Avg. Temp Rise (°C)	Rainfall Change (%)	Drought Events	Flood Events
Arid Zone	1.8	−12	18	2
Semi-Arid Zone	2.1	−8	15	3
Floodplain	1.5	+15	4	12
Upland Region	1.9	+3	9	5

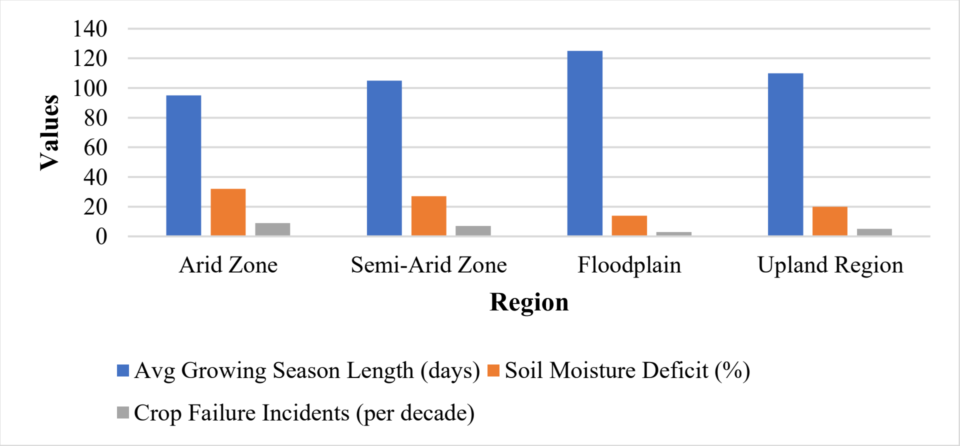

Figure 1: Climate-Agriculture Interaction by Region

Figure 1 shows the regional differences in the agricultural parameters. Floodplain has the least soil moisture deficit (15 %), the least crop failure cases (2 per decade), and the longest growing season (125 days). The Arid Zone, on the other hand, has a shorter growing season (95 days), increased soil moisture deficit (32 %), and crop failures (8 per decade), which show a higher climatic stress.

3.2 Agricultural Outcomes

Climatic stress has rendered a drastic alteration in land use and agricultural performance. The arid region witnessed a 22 % reduction in crop products, and the semi-arid region recorded a drop of 18%. By contrast, the floodplain experienced an improvement in yield of 10 % due to a good supply of water. Adaptive innovation was exhibited by the flood plain in the form of the highest new crop introduction (3 types). Irrigated land shrank dramatically in dry areas (a 15 % fall in arid and a 10 % decline in semi-arid terrain), whereas the floodplain experienced a small growth. Cultivable land shrank a great deal in dry areas 15 % in arid and 10 % in semi-arid regions, whereas the floodplain expanded more modestly. Table 2 indicates that yield decreases and the loss of cultivated land have been huge in arid and semi-arid regions, and that yield increases, diversified crops, and land encroachment are large in the floodplain, pointing to more agricultural bust conditions.

Table 2: Agricultural Outcomes by Region

Region	Crop Yield Change (%)	New Crop Types Introduced	Cultivation Area Change (%)
Arid Zone	−22	1	−15
Semi-Arid Zone	−18	2	−10
Floodplain	+10	3	+8
Upland Region	−5	1	−3

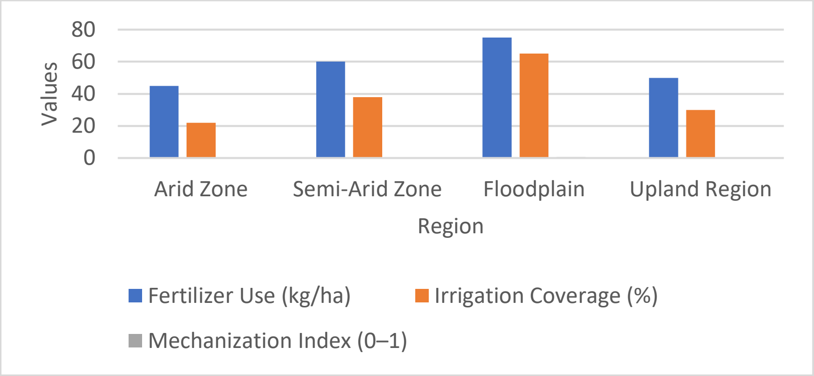

Figure 2: Agricultural Resource and Input Use by Region

Figure 2 shows the disparities of agricultural inputs regionally. Floodplain has the highest fertilizer application (75 kg/ha), irrigation area (65 %), and the lowest use of machinery (0.05). By contrast, the Arid Zone irrigation coverage is the lowest (23%) and use of fertilizer is the lowest in the region (45 kg/ha), which mean a lower input use and lower infrastructure.

3.3 Spatial Patterns

The spatial analysis indicated inequality in climate stress as well as adaptive capacity. In the arid zone, the Climate Stress Index was highest (0.85), and in the floodplain, it was lowest (0.45). On the other hand, the Adaptation Index was highest in the floodplain (0.65) compared to the arid zone (0.30). Table 3 shows that there is a stark contrast between vulnerability and resilience in different areas, with the arid and semi-arid zones showing high levels of stress and low adaptation capacities, thus showing high net impact scores, whereas the floodplain indicated favorable adaptation levels with minimal climate stress, which translated to a low net impact.

Table 3: Spatial Climate Impact Patterns

Region	Climate Stress Index (0–1)	Adaptation Index (0–1)	Net Impact Score
Arid Zone	0.85	0.30	+0.55
Semi-Arid Zone	0.75	0.40	+0.35
Floodplain	0.45	0.65	−0.20
Upland Region	0.60	0.50	+0.10

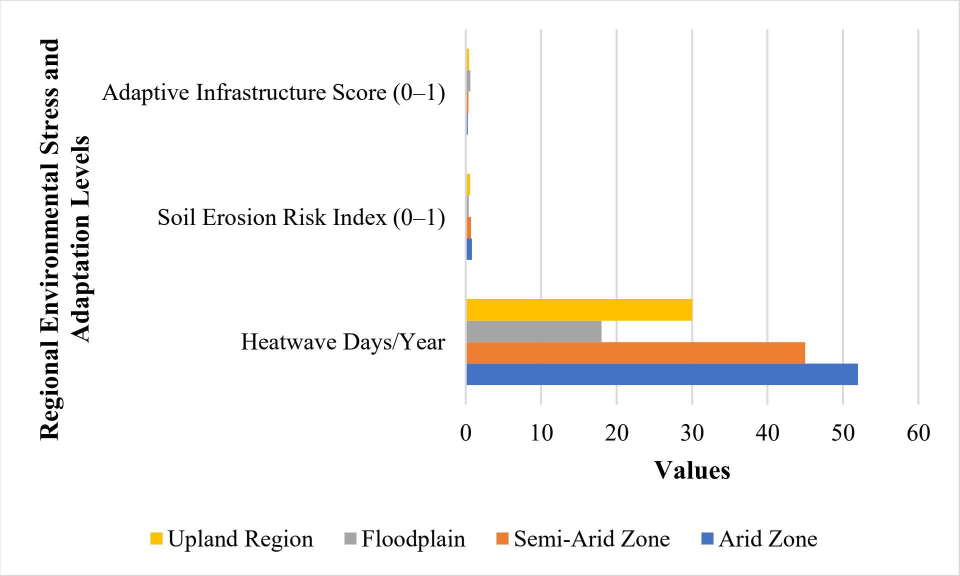

Figure 3: Environmental Exposure and Risk Factors by Region

Figure 3 shows the level of environmental stress and adaptation in the regions. Arid Zone is the area of the highest frequencies of heatwaves (52 days/year), which is scored low according to the adaptive infrastructure (~ 0.12) and high in soil erosion risk (~ 0.85). On the contrary, the Floodplain exhibits the lowest number of days under heat waves (18/year) and a greater adaptability score (~0.45), which is linked to better resistance to environmental changes.

3.4 Comparative Analysis

Comparative regional analysis indicates that rainfed systems had higher yield instabilities (33 %) as opposed to irrigated systems (25 %). The terrain comparison showed that the resilience score was higher in the plains (0.62) as compared to the highlands (0.45). Also, the plains recorded more adaptation practices (5 %) compared to highland as well as rainfed areas (3 practices each), which indicates superior institutional support or major investments in the lowlands. Table 4 compares terrain and irrigation systems, indicating that plains and irrigated systems display lower yields of variability, greater resilience scores, and develop more adaptation measures as compared to highlands and rainfed systems, giving the former more climate resilience.

Table 4: Comparative Regional Analysis

Comparison	Yield Variability (%)	Resilience Score (0–1)	Adaptation Measures Count
Plains vs Highlands	25	0.62	5
Irrigated vs Rainfed	33	0.45	3

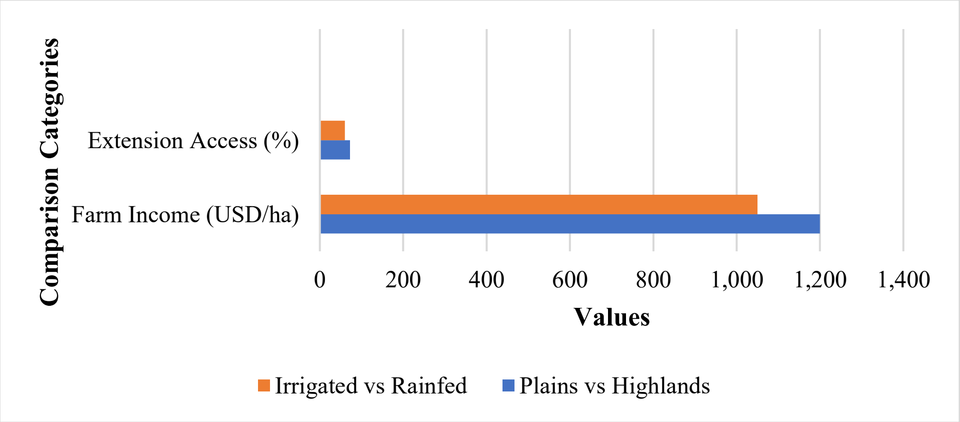

Figure 4: Socio-Economic and Technological Comparison

Figure 4 presents a comparison of the production system and the region of farm income and extension access. Irrigated farms get a yield of USD 1,100/ha in comparison to 1,200/ha in plains; moreover, access to extension is greater in irrigated zones (70%), than in plains, (55%). That implies that irrigation enhances income and the availability of advisory services.

4. DISCUSSION

The findings indicate that the effects of climate change on agriculture differ greatly. The arid zone had a temperature increase of 1.8 °C, a loss of rainfall of -12 % and 18 cases of drought (Table 1). This caused a decrease of 22 % in crop yields and 15 percent in land fraction (Table 2). It had a Climate Stress Index of 0.85 and an Adaptation Index of 0.30 to generate the highest net impact score (+0.55, Table 3). The floodplain, on the other hand, had +15% rainfall and more infrastructure, such that it experienced the +10% yield boost and "-0.20 final impulse." Comparative data (Table 4) demonstrate further that irrigated plains are more resilient (score 0.62) compared to rain-fed highlands (score 0.45). These patterns underscore the spatial inequality of climate stress and highlight the crucial role of adaptive capacity and regional planning in mitigating agricultural vulnerability.

The implications of such findings are vital for regional state agricultural planning and state policy-making. The varying exposure of the risk within zones sheds light on the insufficiency of universal policy solutions to climate pressure [23]. In the areas prone to high risks or risks, these include arid and upland parts, it is of paramount importance that investments be made in drought-hardy crops, soil moisture protection systems, and local and community resilient infrastructure. The areas with positive adaptation patterns, such as the floodplains, are to be assisted in scaling up the innovations, such as efficient water management practices, early warning systems, as well as climate-smart extension services [24]. In addition, these findings lend support to the need to incorporate aspects of geographic sensitivity in national climate action plans to achieve an all-inclusive type of sustainable agricultural resilience.

The results of this study line up most with the overall literature on climate-agriculture interaction. The extensive drought effects recorded in dryland areas in the world reveal yield losses by 15-30 % in continued drought years, and this is equivalent to the yield decrease and the high erosion danger that was recorded in the arid and semi-arid areas of this study [25]. On the same note of expressing the positive performance of the floodplain zone, deltas, where it is also reported that with greater rainfall and when it is well handled, improved, or rather stable yield is recorded. This study contrasts with other studies that present a homogeneous picture of flood-prone regions being defenseless, and adaptive infrastructure and crop planning projects seem to be absorbing climatic shocks well. Such disparities affirm the value of agricultural geography in the local analysis. In the long run, the study highlights the importance of future studies that interlink real-time weather prediction and regional agricultural planning. Better preparations can be made by enhancing remote sensing applications in early stress indicator identifications, such as vegetation decay and water shortage. Politically, the sharing of inter-regional learning platforms as well as farmer-led innovation tests would hasten the proliferation of winning adaptation practices. Also, longitudinal research is needed to track the changes in the adaptation capacity in response to the increased climatic stress. Since climate prediction models point toward an increase in uncertainty, the geography of the agricultural system must not only adapt to change as manifested through movement in the biophysical boundaries but also in the increment of investments in social, institutional, and technological responses that increase resilience to systemic change at a regional scale.

6. CONCLUSION

This study reports that the consequences of climate change in agriculture are disproportionate across geographical regions as they are influenced by variation in climatic exposure, resources, and adaptive capacity. The most vulnerable areas were areas of arid and semi-arid lands that faced high temperatures, reduced precipitation, droughts, and a drop in crop productivity. Conversely, floodplain areas were more resilient, as they were positively affected by higher rainfall, diversified cropping systems, and the dedication of adaptation measures. These are spatial differences in agricultural performance, which are validated by quantitative measures including Climate Stress and Adaptation Indices. The findings highlight the significance of the regional study in agricultural geography. Equal national or worldwide evaluations also tend to neglect localized weaknesses and adaptive advantages. Geographic disaggregation allows pinpointing high-risk zones and target adaptation options through a geographically disaggregated method. Future studies to increase predictive accuracy should incorporate data on finer resolution climate patterns, satellite-based remote sensing, and on-farm adaptation. The policymakers should make region-specific interventions, including irrigation assistance in water-stressed areas and water drainage solutions in flood-prone zones. An important ingredient of developing climate-resilient agriculture will be to increase the scale of effective practices and institutional support, especially in vulnerable areas. These facts are paramount to achieving food security and sustainable land exploitation in light of the rapid shift in climatic pressure.

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