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Impact of Climate Change on the Agricultural Productivity: A Case Study in Cooch Behar District of West Bengal, India

Ram Krishna Mandal[1]* and Riti Basak[2]

[1]Professor & HOD, Department of Economics, Cooch Behar Panchanan Barma University, Cooch Behar, West Bengal, India

[2]Ph. D. Scholar, Department of Economics, Cooch Behar Panchanan Barma University, Cooch Behar, West Bengal, India

ABSTRACT

Introduction: Agricultural systems worldwide are facing increasing challenges from climate change along with localized effects from changes in temperature, rainfall patterns and increases in extreme weather affecting crop productivity and livelihoods of farmers.

Objectives: The study has tried to explore the adverse impact of climate change on agricultural production in the Cooch Behar region of West Bengal and the response of local farmers to recent challenges.

Research Methodology: The study has tried to show how climate change affects agricultural output in Cooch Behar district, West Bengal through quantitative and qualitative data acquisition methods based on a micro-level case study approach. The study's area of interest includes in the Terai and the Eastern Himalaya agro-climatic region of Cooch Behar of West Bengal. Due to its high dependence upon agriculture, with many farmers being small and marginal producers using rain-fed agriculture practices, Cooch Behar is particularly vulnerable to variations in rainfall quantity and quality; flooding; and temperature extremes.

Results and Discussion: Adverse impacts of climate change on agricultural productivity and its mitigation especially in Cooch Behar district are sought.

Suggestions: Use & expand agricultural techniques that are climate resilient, water resource management improvement, supporting climate-smart agriculture, i.e., crop diversification and resilient varieties are suggested.

Conclusion: In West Bengal, Cooch Behar's agriculture is facing challenges from climate change; these include altered rainfall patterns, increased variation in temperatures, extreme weather events, and unstable yield. The area's farmers have identified increasing temperatures and changing rainfall as ongoing problems with regards to how they plant, grow, and harvest their crops, impacting food security and their livelihoods.

***Corresponding author**
Ram Krishna Mandal, Professor & HOD, Department of Economics, Cooch Behar Panchanan Barma University, Cooch Behar, West Bengal, India.

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Introduction

Agricultural systems worldwide are facing increasing challenges from climate change along with localized effects from changes in temperature, rainfall patterns and increases in extreme weather affecting crop productivity and livelihoods of farmers. In India, agriculture is responsible for generating considerable employment opportunities and maintaining food security for millions of people in rural areas. However, changing monsoon patterns and thermal regimes are disrupting farmers' planting schedules and yield of both staple and high value crops (Ghurake, n.d). The North Bengal plains, specifically Cooch Behar district located in the Terai and Eastern Himalayan agro-climatic zone, represents the impacts of changing climate conditions on smallholder farmer communities. Smallholder farmers in Cooch Behar district are highly reliant on rainfall for growing their crops which makes them very sensitive to weather fluctuations that impact soil moisture, crop growth cycles as well as insect and disease pressures [1]. Qualitative information collected in Cooch Behar Sadar subdivision shows that farmers are reporting increased temperatures and erratic rainfall patterns associated with climate change and variability [1]. The farmers in Cooch Behar clearly believe that climate change and climate variability has a negative impact on their crops resulting in unpredictable yields which requires planting at different times than normal, switching to shorter-duration cultivars, and implementing climate resilient agricultural practices in order to limit any negative effects on crop yield [1]. Furthermore, agricultural assessments conducted at the district level indicate that there are notable correlations between changing weather patterns and changes in crop maturity times, decrease in aroma and grain quality of rice, and significant concerns raised about reductions in yield of crops providing evidence of a variety of impacts from climate-related stressors on productivity metrics in Cooch Behar district.

The dual challenges of uncertainty in climate and socio-economic limitations highlight the necessity of specific adaptation and resilience strategies. The implementation of cutting-edge agricultural resilience methods (e.g., water harvesting, conservation farming, diversified crop systems) to help support productive capacity and protect farmer livelihood in response to current and projected climate changes has been identified as one of the most important areas of focus within the region of Cooch Behar [1].

Literature Review

I. The Relationship Between Climate Change and Agriculture on a Global Scale: The global impact of climate change on shifts in global agricultural productivity caused primarily by climate change is creating changes in agricultural productivity worldwide as temperature, rainfall, and extreme weather all change due to climate change [2]. India, as primarily an agricultural economy, is a country highly influenced by weather associated with warm season rainfall and limited irrigation. Because of this, India's agricultural economy is highly impacted by changes in temperature, rainfall, and extreme weather all associated with warm season rainfall [3]. Changes in rainfall patterns, average temperature increases, rising numbers of floods/droughts, have resulted in decreased yield stability, increased soil degradation, and decreased access to water, all of which affect agriculture and therefore food security [2]. These are general trends, so using these general trends provides a good starting place for understanding local impacts on the economic impact of climate change in Cooch Behar.

II. The Effect of Climate Change on Agricultural Productivity in Cooch Behar: There is a limited amount of climate data published in peer-reviewed journals for specific regions and therefore there is a limited amount of research on the specific impacts of climate change on the economy of the Cooch Behar district of West Bengal. As West Bengal deals with erratic rainfall patterns and temperature extremes within the state (West Bengal State Action Plan on Climate Change as cited in Climate Policy Snapshot), researchers have documented that these erratic patterns of rainfall and temperature extremes are associated with the following climate related stressors on crops: crop stress, cropping pattern changes, phenology changes (i.e., timing of planting and crop maturity), and irrigation-related issues (i.e., heavy rain and no rain) with respect to rain-fed agricultural systems that are most common in Cooch Behar have all increased over recent years and increasing significantly threaten agricultural viability. Therefore, the cumulative impact of all of the climate-related factors previously listed contribute to crop failures, unpredictable harvest outcomes and increased pressure on smallholder agricultural systems for increased productivity has increased in Cooch Behar.

III. Farmer Perceptions of Climate Change in Cooch Behar: In Cooch Behar Sadar, 2019 data shows there is a perception among farmers that climate change is having an impact on agriculture. Most farmers said they see an increase in temperature and fluctuations in rainfall, especially during pre-monsoon and monsoon seasons [1]. The data show that farmers believe this unpredictability leads to inconsistency in crop yield and agriculture planning. Similar results have been reported from other locations in West Bengal where reports on how climate has impacted farm productivity, as well as disruption to farm livelihoods, are available (coastal West Bengal reports). Das and Paul conducted KAI-based assessments of farmers in the study area on the knowledge and adoption of climate-related agricultural practices [1]. Findings indicate that farmers have a moderate level of adoption of adaptation strategies, indicating that, while the awareness of climate change is widespread among these farmers, the constraints of economics, limited landholdings and access to resources impact their ability to fully implement adaptive response strategies.

IV. Cultural Adaptation and Climate-Resilient Agricultural Practices: Adaptation strategies of farmers in the Cooch Behar District blend traditional practices and emerging concepts for achieving adaptation through Climate-Resilient Farming. In the study conducted by Das and Paul, farmers expressed a clear preference for adaptive farming practices aimed at enhancing both yield and resilience including changing sowing dates for better timing, planting early maturing varieties, utilizing multiple cropping systems, and combining organic and chemical inputs to combat pests and diseases [1]. The measures reflected by Cooch Behar farmers correspond closely to the climate-smart agricultural recommendations outlined in available agricultural science literature; the main adaptation activities are found to be (i) Diversifying the cropping system and producing different types of crops; (ii) Improved management of irrigation, using more efficient systems; (iii) Increasing use of climate-resilient cultivars. At the state level, policy frameworks support the continued use of these strategies. The West Bengal State Action Plan on Climate Change outlines several key strategies including crop and varietal diversification, developing new climate-resilient crop varieties, developing irrigation water storage techniques, improving seed storage and crop insurance, and developing resource-conserving agricultural technologies as part of a coherent adaptation strategy for increasing productivity in the face of growing climate change challenges.

V. Factors Influencing Adaptation Choices and Barriers: Socioeconomic and institutional factors shape the adaptation behavior of farmers of Cooch Behar, as well as others throughout similar agro-ecological contexts. According to Das & Paul educational status, size of landholding, and available economic resources are significant determinants of whether or not farmers choose to adopt different types of agricultural strategies; this finding is consistent across additional studies completed at the national and regional (West Bengal) level. Farmers who have greater access to information, extended networks, and the ability to obtain assistance from government programs, demonstrate a higher level of adaptive capacities. Smallholder farmers, however, tend to stick with their conventional practices due to the high costs and risks associated with adopting such strategies when they lack access to financial resources. It has been suggested that by enhancing extension services, access to climate-related information, and institutional support, adaptation is adopted more frequently. For example, studies conducted in other areas of West Bengal (e.g., Jhargram) show that, although there is a high degree of awareness about climate change, the government has not formally recognized any adaptation measures, leaving most farmers unable to implement them without receiving adequate support.

Research Gap

While the available literature contains important information about the effects of climate change on farmers in Cooch Behar District and West Bengal as a whole, there is still much more to be gained from additional research. For example, the majority of studies have relied on an analysis of farmers' perception of climate impacts and adaptation behavior as opposed to a systematic integration of long-term meteorological data with productivity trend data for blocks or villages within the Cooch Behar District. As a result, there are few empirical relationships established between temperature change, variability in rainfall, extreme climatic events, and the overall yield performance of crops (rice, jute, potato, maize) within the district. Furthermore, much of the research conducted to date has taken the form of cross-sectional surveys designed to capture only short-term perceptions of climate change; however, these studies do not examine the relationship between climate and agricultural production over time using time-series data. Additionally, there are no assessments of vulnerability specific to individual crops or to individual growing seasons (the kharif, rabi, and the current pre-kharif seasons) that have been conducted in order to quantify the impact of climate change on agricultural productivity within the Cooch Behar Agro-Ecological Zone using quantitative methods. Due to this lack of agricultural disaggregation, policy recommendations related to climate change impacts on agriculture continue to remain general, rather than location specific.

A significant gap lies in adaptation effectiveness. Although farmers adopt multiple adaptation strategies, there is little evidence on how effective these strategies are at increasing production, reducing risk, or stabilizing income during periods of changing climate. In Cooch Behar, very little work has been done to evaluate institutional issues (e.g., access to extension services, climate information systems, irrigation governance, crop insurance, and credit facilities) and their role in shaping adaptive capacity across various farm size and socio-economic groups.

As such, a clearly articulated need now exists for an integrated, micro-level, and statistically robust research project in the district of Cooch Behar that includes climatic data and crop productivity analysis, evaluates the effectiveness of adaptation strategies, and incorporates socio-economic, institutional, and gender dimensions. Addressing these gaps provide the district with the information it requires to develop a climate-resilient agricultural development plan that is evidence-based.

Objectives

The study has tried to explore:

a) The adverse impact of climate change on agricultural production in the Cooch Behar region of West Bengal and the response of local farmers to recent challenges.
b) The way crop variety, time of harvest and crop yield of important local crops (rice, jute and potato) are changing as a result of climate change.
c) The measures, farmers take to adapt or mitigate to the risks of agricultural production from climate change.
d) The suggestions on policy and planning for the promotion of climate-resilient agriculture in Cooch Behar.

Research Methodology

Research Design: The research methodology for assessing how climate change affects agricultural output in Cooch Behar district, West Bengal consists of quantitative and qualitative data acquisition methods. The analytical research method is beneficial in developing a comprehensive understanding of the relationship between climatic factors, agricultural output, and environmental adaptation behaviors through a micro-level case study approach.

Study Location: The study's area of interest includes Cooch Behar, which is situated in the Terai and the Eastern Himalaya agro-climatic region of West Bengal. Due to its high dependence upon agriculture, with many farmers being small and marginal producers using rain-fed agriculture practices, Cooch Behar is particularly vulnerable to variations in rainfall quantity and quality; flooding; and temperature extremes.

Data Sources: The primary focus of this investigation is a compilation of secondary data from a variety of sources. The source information is supplemented with results regarding climate change and its impact upon agriculture in Cooch Behar through data collected via prior empirical studies. Secondary data is primarily consisting of published research articles; government documents; climate change documents published by the IPCC; agro-meteorological research; agricultural census data; data from the West Bengal State Action Plan for Climate Change; and institutional publications such as book, journals and reports.

Variables Assess: The research incorporates both climate-related variables and agricultural outcome variables. Climate-related variables include amount of precipitation and variability of precipitation; average annual temperature; onset and duration of seasonal variability; both flooding and water logging; and extreme weather events. Agricultural outcome variables include yield and productivity of crops; changes in cropping pattern and calendar; soil moisture conditions; incidence of pests and disease; and levels of irrigation and water shortage.

Analytical Framework Based on Crop Type: The research employs a crop-specific analytical framework focusing on Cooch Behar district's principal crops of rice, jute and potato. Through agro-meteorology research and crop simulation study results, the impacts of heat stress, rainfall, flooding, and moisture shortages on these crops are reviewed.

Analytical Techniques: Descriptive and comparative analytical techniques are employed by the researcher to interpret associations between climate variables and production. Farmers' perception or adaptation behavior towards climate change is observed through content analyses of published field studies in Cooch Behar district. Climate-smart agriculture frameworks and State Level Climate Action Plans provide the analytical foundation for evaluating policy & institutional responses.

Case Study Assessment Approach: An assessment case study approach has been utilized to examine Cooch Behar District as a micro-level unit using climate change effects on Indian Agriculture as the rationale for study. This has enabled an in-depth reviewing of localized vulnerabilities and productivity factors from an adaptability perspective.

Adaptation Factor Assessment: Research assesses adaptation strategies employed by farmers, Climate-smart Agricultural practice methods, Water management interventions, Agricultural Extension Services, and Policy instruments including Crop insurance & Advisory systems regarding the linkages between climatic influences to socio-economic/institutional building blocks of Resilience.

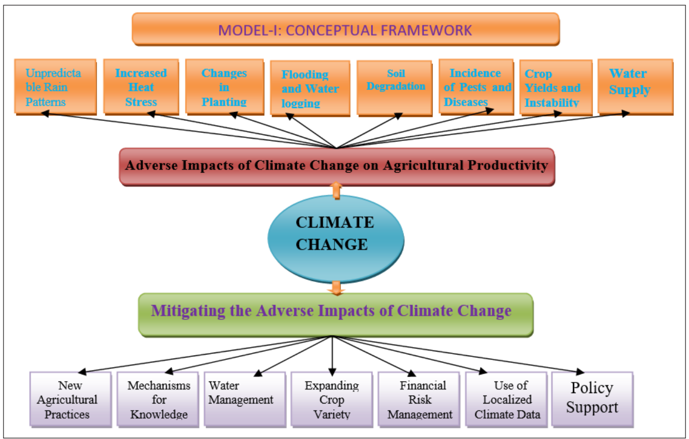
Interpreting Analysis: Through a properly integrated framework of climatic stressors, crop productivity outputs, farmer responses and systems of institutional support, the findings is interpreted as an overall picture of how climate change is impacting sustainable agricultural practices and thereby livelihood security in the study area.

Methodological scope: The methodological scope of this research refers to all facets of studying the effects of climate and agriculture on each other from a micro-analysis approach; the impact of climate change on crops together with their respective adaptation measures is evaluated at the level of Cooch Behar District (India). The study's objectives, analysis, and policy recommendations must also be consistent throughout the research.

Results and Discussion

Adverse Impacts of Climate Change on Agricultural Productivity in Cooch Behar District

The conventional patterns for Rainfall in Cooch Behar have been changed fundamentally by Climate Change. There have been unprecedented Monsoons and irregular Water Availability, which have had an adverse impact on Timeliness of Plantation and, in turn, Crop Yield. Farmers have also experienced increased Average Temperatures; erratic Rainfall during Growing Periods; and consequently, Agricultural Productivity Declines, as well as a greater risk to staple Crop Production from climate change. Additionally, the intensity of Climate Change through Extreme Weather Events (Floods; and Drought) has also created substantial challenges to Fertilizer and Irrigation Mgmt. on Farms, the potential to reduce output from their farms, and consequently the risk of Food Insecurity in the Region. The impacts of Climate Change and the need for Mitigation are summarized in Conceptual Framework (Model-I).



Interpretation of Model-I: Model-I Conceptual Framework for the Impact of Climate Change on agricultural productivity illustrates the effect of Climate Change as the primary driver (Core) of Agricultural Productivity through multiple Inter-connecting pathways. For example, when Farmers are stressed by increased Heat, Irrigation problems due to Weather (Unpredictable Rainfall); Flooding; and Water Logging; and increased Pest/Disease infestation during key Planting Times, this can lead to a Degree of Instability in Crop Yield. Thus, Biophysical Stresses (Soil Quality; and Water Availability) caused by Climate Change; further reduce the Resilience of Agricultural Systems. Additionally, the Framework also presents Mitigation as a response by illustrating how Farmers can Mitigate the effects of Climate Change (i.e. New Agricultural Practices; Improved Water Management Practice; and Crop Diversification) due to changing Climate. A significant component of these framework elements is captured in Knowledge Transfer Processes; Localized Climate Data; Financial Risk Management; and Policy Support Schemes to enable Farmers to adapt and build their Adaptive Capacity to Climate Change. Therefore, the Framework summarizes the capacity of Climate Change and Mitigation to create an Integrated Process that shapes Sustainable Agricultural Productivity.

1. Unpredictable Rain Patterns: Farmers in Cooch Behar are experiencing unpredictable rainfall patterns that are making it hard for them to predict the best times to plant crops, and how well crops germinate. The amount of moisture that crops get at critical points in their growth, especially during the pre-monsoon and monsoon growing seasons, have been greatly diminished by these changing precipitation patterns. Farmers in Cooch Behar Sadar subdivision have reported observing these variations in timing and intensity of precipitation, and have experienced the negative consequences of those changes on crop yield and production [1].

2. Increased Heat Stress: Increasing temperatures combined with drought-like conditions and erratic precipitation patterns make it increasingly difficult for farmers to provide adequate amounts of water for their crops and to keep the soil moist enough; both due to increased temperatures and due to the drying effects of increasing temperatures on crops. With the rise of atmospheric carbon dioxide levels in North Bengal, there has also been an increase in the amount of stress experienced by all varieties of crops grown in North Bengal, including rice, jute, and vegetables. Farmers in Cooch Behar have also noted rising temperatures and the associated effects on the growth and water needs of their crops [1]. Research has shown that warming temperatures have a negative effect on the productivity of all crops, especially in tropical and subtropical climates [4].

3. Changes in Planting and Growing Seasons: The overall climate change effects have caused the monsoons to start later and/or finish later than normal, causing disruptions in the traditional growing seasons of farmers in West Bengal resulting in a later than normal planting of their kharif crops. As a consequence of climate change, farmers in West Bengal have also started to experience an overall smaller length of growing seasons (i.e. the time between planting and harvest has decreased) than before climate change. As Haque has reported, and is corroborated by Das & Paul, the overall change in rainfall patterns and the frequency and timing of rainfall-producing weather events due to climate change has caused farmers in West Bengal to have greater difficulty than normal in planning timely cultivation, thereby negatively affecting their productivity [1,3]. Furthermore, many of the planting timetable disruptions that have affected the timing of cultivation have occurred in the Cooch Behar region due to changes in rainfall patterns resulting from climate change [1].

4. Flooding and Water logging Problems: In Cooch Behar, which is located in the Terai area known to have many floods, unusual rainfall events lead to a lot of flooding and waterlogging. When too much water sits in the ground for too long, it damages the crops, lower the amount of oxygen in the soil, and contribute to the development of root disease. According to the IPCC, more extreme rainfall could increase the likelihood of flooding in this part of South Asia and adversely impact agricultural output [5]. According to Das and Paul, increased instances of heavy rain in Cooch Behar have had an adverse impact on the crops and the condition of the soil as well [1].

5. Soil Degradation and Nutrient Loss: Unpredictable rainfall results in soil degradation through soil erosion, loss of nutrients, and reduced soil health. Soil erosion occurs when heavy rains wash away topsoil, while long periods without rain reduce the number of microbes present in the soil and the cycling of nutrients. According to Porter et al., climate variability accelerates the processes that cause the degradation of soil, and therefore, creates a reduction in productivity over the long term [6]. In the Terai region of North Bengal, the degradation of the soil is becoming more apparent in rain-fed farmland (such as the farmlands of Cooch Behar) [1].

6. Increased Incidence of Pests and Diseases: More humidity and higher temperatures favour insect, pathogen, and weed multiplication. As a result of climate change, the life cycles of pests and their geographic distribution evolve, thereby increasing the amount of crop damage associated with pests. The IPCC confirms that with increasing temperature and humidity, the biotic stress on crops is intensified [5]. The farmers in Cooch Behar reported an increase in pressure from pests and diseases due to changing climatic conditions [1].

7. Declining Crop Yields and Instability: Crop yield instability and decline are driven by the combined impacts of heat stress, uncertainty of rainfall, flooding and pest outbreaks. Lobell and Field show that yield variability in many staple crops can be attributed to climate trends already occurring [7]. Haque illustrates yield fluctuations are driven by climatic stressors in West Bengal and agrees with agricultural productivity challenges within Cooch Behar evidenced by Das & Paul [1,3].

8. Uncertainty of Water Supply from Irrigation: Although Cooch Behar experiences high levels of rain, there is a high variability in the distribution of rainfall resulting in limited access to water to support crop production through irrigation during the rabi and pre-kharif seasons. Reduced groundwater aquifer recharge and dry ponds diminish irrigation supplies. According to Schmidhuber & Tubiello climate change has resulted in significantly increasing levels of risk related to agricultural water insecurity in developing countries [8]. Das & Paul report farmer concerns related to insufficient water during periods of drought [1].

9. Economic Vulnerability for Farmers: Increased risk of income is placed on small and marginal farmers by reduced productivity. Crop loss caused by climate change limits household earnings and increases the reliance on wage labor and migration. According to Thornton et al., livelihoods of smallholder farmers are more vulnerable to climate change [9]. Das & Paul have reported that climatic stress negatively impacts the stability of farm income and ability to adapt within Cooch Behar [1].

Crop-Wise Adverse Impacts of Climate Change

1. Rice (Oryza sativa)

Temperature and Yield Decline: Climate change has affected the productivity of rice (Oryza sativa); for example, both increased temperature and variation in precipitation impact yields negatively. Unique to rice, increased temperatures affect productivity primarily at the floral initiation and grain-filling stages because they shorten the growing period. Models of rice production in India predict significant declines in yield under projected climate change, particularly due to increased heat stress and increased variability in precipitation [10].

Rainfall Variability and Crop Calendar Shift: Variability in rainfall patterns in West Bengal; models anticipate delayed onset of monsoon and irregular precipitation patterns due to climate change. These changes disrupt plantings of kharif rice causing reduced effective growing seasons resulting in yield reductions [11].

Water Stress and Flood Risks: The Terai region of Cooch Behar experiences considerable rainfall; however, climate change has contributed to an increase in the frequency of excessive rainfall events such as drought and very heavy rainfall, which can lead to both drought and flooding (Cooch Behar Studies). This is especially true in regions where latent irrigation systems do not exist.

Overall, the above-referenced climate changes have created downward pressure on productivity of rice production in West Bengal, including the greater area of Cooch Behar due to increased heat stress, impending rainfall patterns and variations of extreme weather events [10,11].

2. Jute (Corchorus spp.)

Temperature & Rain Variation (Climate Dynamics): The temperature and rainfall patterns, are both critical to jute production during the various stages of growth or phenology. Evidence based on spatiotemporal trend analysis of many major jute producing districts across West Bengal show significant variability for both rainfall (precipitation) and temperature trend data over the past several decades. The climate trend variability significantly impacts the sowing conditions and crop phenology of jute and rice [12].

Impact of Weather on Rice & Jute Yield: However, most studies do not actually analyze the impact of the weather on jute yield in Cooch Behar (Jute) although in southern West Bengal, weather yield correlation studies have shown that climatic variables (precipitation and temperature) have a significant impact on rice (kharif) and jute yield with temperature having a larger impact than precipitation for rice yield (the impact of jute yield due to climate variables is apparent) [13].

Many data sources exist for these respective climatic variable yield impacts across the jute grower districts (as noted above) although it shows that as the climate becomes warmer and precipitation variability increases, jute productivity reduces because of the impact on germination and crop phenological timing [12,13].

3. Potato (Solanum Tuberosum):

Projected Yield Reductions with Climate Change: Models are used to show that changing climate projections leads to decreasing yields for potatoes being grown in West Bengal in the future due to increasing temperature and moisture stress. Specifically, potatoes planted in 2050 are projected to produce 11% lower yield versus what would be anticipated today, while potatoes planted late could yield as much as 25% less than what would be anticipated under the influence of climate change [14].

Temperature Sensitivity in Simulations: Using models that simulate both temperature and rainfall impacts on potato crop development, we find that potatoes are very sensitive to high temperatures and require adequate moisture for optimal tuber filling. As a result, the changing patterns of temperature and rainfall negatively impacts overall potato crop growth and performance [14].

Regional Relevance to Cooch Behar: Most potato studies based off climate change projections at the state level have focused on the west Bengal region. However, considering the local climatic conditions (heat events and varying rain), we anticipate that potato yield in Cooch Behar experiences similar yield declines as predicted by other studies unless different adaptations to climate change are applied [14].

Mitigating the Adverse Impacts of Climate Change on Agricultural Productivity in Cooch Behar District

1. Strengthening Climate-Smart and Climate-Resilient Agricultural Practices: Climate-smart agriculture (CSA) and

Climate Resilient Agriculture (CRA) represent the foundation of any efforts to combat climate change and its negative effects. Climate-smart agricultural practices are also agronomically and environmentally appropriate in that they improve productivity while conserving natural resources for example, precision planting, integrated pest management, optimizing nutrient applications, and retaining residue on the ground [15]. Studies show that implementing these practices creates resilience to climatic stresses, such as droughts and floods, through improved soil health and moisture retention, resulting in reduced crop yields in areas that are reliant on rainfed agriculture like Cooch Behar [15]. Additionally, diversifying crops, using short-duration and stress-tolerant varieties, can help farmers in uncertain climate conditions by spreading risk over a larger area, thereby stabilizing their production, in accordance with CSA guidebooks [16].

2. Improving Institutions and Mechanisms for Knowledge Transfer: Improving institutional support to deliver agricultural extension services and Krishi Vigyan Kendras (KVK), whereby, the application of climate resilience technologies and techniques via KVK's has an important role to play for locally based farmers .KVKs in Cooch Behar can also act as knowledge centres with demonstrations of climate resilient techniques, local agronomic advice for climate risk, and training modules for local farmers. Providing effective extension services helps to scale up innovations from research to practice/management while improving the capacity of local farmers to interpret climate signals and adjust their management based on this information. Beyond physical demonstrations, the improvement of ICT-based advice and mobile services supports increased delivery and timeliness of climate information to farmers so that they can receive actionable guidance about when they should plant; schedule irrigation; and manage pests.

3. Improving Water Management and Water Supply Infrastructure: Due to the reliance of Cooch Behar on monsoon rains, as well as the limited coverage of irrigation, improving water resources management is necessary in order to reduce vulnerability to irregular precipitation events. Climate-smart water management involves using Micro-Irrigation systems (drip, and sprinkler irrigation), on-farm water harvesting structures, and conserving soil moisture through mulch and contour farming [3]. These methods increase water use efficiency and decrease the risk of farming during extended dry spells. Groundwater management strategies are also required to achieve a sustainable supply of water, taking into account the balance between withdrawal and recharge in light of climate change across West Bengal [17].

4. Expanding Crop Variety and Integrated Farming Systems: Diversifying crop production helps avoid climate risks by reducing farmer reliance on a small number of crops that are vulnerable to particular stresses like droughts and floods. By including pulses, vegetables, and other crops that are not as highly impacted by climate change along with their main staples (rice), farmers can create more resilient and stable incomes [16]. Using a combined approach to farm system design with crop, livestock and horticultural production allows for diversified sources of income and improved use of resources, which reduces the overall socio-economic impact of climate shocks on rural livelihoods.

5. Support for Financial Risk Management and Market Support Systems: Financial risk management strategies such as weather-indexed crop insurance programs and subsidized loans for purchasing climate-adapted technologies are necessary components in mitigating the impact of climate-induced crop failure [18]. By supporting smallholder's hesitations to take risks through the use of adaptive technology and to encourage investment into adoption of these technologies. In addition, strengthening market linkages helps ensure farmers are paid fair prices for their diverse crops and thus, helps to create an economically sustainable future with changing climate conditions.

6. Use of Localized Climate Data and Early Warning Systems: Access to timely and accurate localized weather forecasts and early warning systems assists farmers in making better decisions regarding when to conduct agricultural activities thereby reducing the impact of climate-induced losses. Integration of climate information services into agricultural extension programs facilitates improved decisions regarding sowing, crop selection, and pest control measures. If implemented properly, climate information services can improve the ability of farmers to respond in real-time to farmer determinants of whether a given area is dry or experience extreme temperature increases due to the effects of climate change in West Bengal.

7. Policy Support/Community Engagement: To successfully scale up and support climate-change adaptation in agriculture on a regional level, interventions concerning Policy Support and Community Engagement (CWC) must be made by district and state governments. Climate Action Plans, at the district and state level, which include climate-adaptation-focused objectives, provide resources for agricultural practices that have an effect on climate, and create an engagement plan for stakeholders relative to their respective participatory process creates a supportive environment for the ongoing development of a resilient community

Involving the local community in the planning, development, and implementation of these Policies (in terms of agricultural practices) as well as including and representing the needs of farmers in the policy decisions enhances community ownership.

Suggestions

1. Use & Expand Agricultural Techniques That Are Climate Resilient

a) **Climate Smart Agriculture (CSA) Implementation:** Increasing productivity through climate-smart measures (precision agriculture, integrated nutrient management, integrated water management, weather-smart agronomy, and resource-efficient technologies) can improve resilience to climate variability and decrease greenhouse gas emissions by making more sustainable use of natural resources [15].

b) **Conservation Agriculture:** Conservation Agriculture for Sustainable Intensification (CASI), through minimum tillage, residue retention, & crop rotation, have demonstrated that they build up organic matter in soils & help with water retention and that they are capable of being scaled up with infrastructure support at the local level [19].

c) **Organic & Regenerative Practices:** Organic and regenerative farming maintains soil health & resilience over the long term when compared to conventional industrial agricultural systems that are exposed to adverse climate conditions [20].

2. Water Resource Management Improvement

a) **2.1 Expanding Micro-Irrigation Systems:** By introducing various micro-irrigation technologies (drip systems, sprinkler systems, etc.), such irrigation technology reduces reliance on variable and unpredictable rainfall while increasing crop water-use efficiency under climatically stressful conditions [3].

b) **2.2 Construction of Water Conservation Structures:** Constructing farm-based water conservation structures (such as field bunds & farm ponds) and providing for soil moisture conservation are important for ensuring that crops can continue to grow during periods of extended drought. This is especially important in regions of rainfall variability (such as Cooch Behar) that often experience extended dry periods [3].

3. Supporting Climate-Smart Agriculture: Crop Diversification and Resilient Varieties:

a) **Promote varieties that have multiple functions:** Cereal crops grow quickly and will increase yield for more than one season (4); limiting resources (3) created by cereal (3) limits yield productivity. Beverley [3] identified regions where multiple types can be grown together.

b) **Promote crop varieties that can withstand extreme conditions:** Develop and encourage development of rice and other crop varieties (rice) developed for both drought and flooding conditions. Develop and promote varieties that have been developed specifically for the region's characteristic climate [3].

4. Strengthening Agricultural Extension and Institutions

a) Empower the Krishi Vigyan Kendra (KVK) Action Team: KVKs in Cooch Behar and surrounding areas have contributed greatly to disseminating technologies for adapting to climate, conducting demonstrations on technology applications and training farmers on how to implement climate-resilient agricultural practices [21].

b) Increase Knowledge Transferal: Increasing the number of farmer field schools, conducting participatory workshops, and using digital means of disseminating information via advisory services can increase a farmer's ability to utilize sound climate adaptation techniques and technology [3].

5. Strengthening Climate Smart Information/Warning Systems

a. **Localized Climate Forecast Service:** Localized weather forecasts/early warning systems give farmers/investors information relevant to make informed decisions about sowing, irrigation, harvest, and overall decision-making about farming; and (5) help to eliminate risk associated with immediate climate change event [15].

b. **Climate Risk Advisory Tools:** Using mobile technologies as ICT tools can support the development of real-time decision-making, especially in smallholder agricultural operations where there is limited access to resources [15].

6. Provide Greater Financial Instruments that Minimize Risk.

a) 6.1 Increase Coverage of Crop Insurance: Weather based crop insurance will help reduce income risk related to climate extremes [3,19]. As a result of reducing income risk from extreme weather events, farmers will have an additional incentive to adopt resilient farming/livelihood strategies.

b) 6.2 Credit Access for Adaptation Technologies: Financial assistance for climate-resilient inputs, irrigation infrastructure project financing and conservation technologies, through subsidized loans, will provide the necessary financial resources for small and marginal farmers to make investments in climate adaptation strategies [21].

7. Natural Resource Management at the Local Level

a) Participatory Community Based Water and Land Management: Local communities can engage in water conservation, soil enhancement and watershed management initiatives in order to sustainably manage shared resources under altered climate conditions [15].

b) Agroforestry and Integrated Farming Systems: The addition of trees within a farming system has the ability to improve the microclimate for farming, support carbon sequestration and diversify income streams for smallholder farmers [16].

8. Strengthening Policy and District Planning

a) Climate Action Plans at a District Level: Create climate action plans for Cooch Behar that are specific to the district's agro-ecological conditions. The District Climate Action Plan will be needed to perform a vulnerability assessment and to conjugate site-specific adaptive measures [3].

b) Public-Private Partnerships and Access to Markets: Rural infrastructure, storage facilities and market links must be established such that smallholder farmers have reliable opportunities to sell their diversified agricultural products in times of climate stress [21].

9. Foster Research and Innovation

a) Local Crop Research: Conduct research to identify site-specific options for adaptation (e.g. adjustments to planting calendars, resilience strategies for improved soil health and the dynamics of pests and disease under new climate patterns [3].

b) Development of Technologies for Small-Scale Farmers: Develop low-cost technologies (e.g. low-cost weather stations, soil moisture sensors and other sensor technologies) for smallholder farmers to utilize on their farming operations for the purpose of improving the overall resilience of the climate resilient smallholder farmers [15].

Limitations

1. The study is built upon secondary data and existing literature. This means that the author used published material instead of collecting data first-hand through a rigorous primary-field-level survey.
2. Because there is no long-term district-level climate data and crop yield data for Cooch Behar, the study is unable to analyze statistically or econometrically the relationship between climate change and crop yield.
3. Much of the evidence of farmers' perceptions has been taken from previous studies, which means the information may not be reflective of the most recent experience of climate change by farmers or farmers' adaptation processes to climate change.
4. The crop-wise analysis is limited to the three major crops (rice, jute, and potato) grown in the district; therefore, all other crops, livestock systems, and horticulture were not fully incorporated into the crop-wise assessment.
5. The district cannot be fully analyzed for its spatial differences within the district (i.e. identifying blocks or villages with higher or lower levels of vulnerability to climate change) because of problems with the data and the absence of geographic information system (GIS)-based micro-climate data within the district.

Conclusion

In West Bengal, Cooch Behar's agriculture is facing challenges from climate change; these include altered rainfall patterns, increased variation in temperatures, extreme weather events, and unstable yield. The area's farmers have identified increasing temperatures and changing rainfall as ongoing problems with regards to how they plant, grow, and harvest their crops, impacting food security and their livelihoods. The same patterns and climate changes have affected other areas of West Bengal. Erratic rainfall, variability in temperature, late arrivals of the monsoon season, flooding, and loss of agricultural productivity all correlate with this experience. Also, vulnerability assessments show that Cooch Behar is affected by both climate change and socioeconomic vulnerabilities and it is also one of the districts that has the greatest vulnerability related to climate. Therefore, unless there are targeted adaptation measures and institutions to assist farmers in the district, climate change will continue to create negative impacts on crop production and ultimately lead to reduced income levels or instability in rural economies in Cooch Behar. Climate-smart agricultural practices, the provision of resilient inputs, better water and risk management systems, and local forecasting and advisory systems are necessary for protecting agricultural production and rural livelihoods in Cooch Behar from further weather challenges.

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