

SPATIO-TEMPORAL ANALYSIS OF CROP YIELD TRENDS AND CLIMATE VARIABILITY IN INDIA

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SPATIO-TEMPORAL ANALYSIS OF CROP YIELD TRENDS AND CLIMATE VARIABILITY IN INDIA

by

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CERTIFICATE

This is to certify that thesis entitled “**Spatio-Temporal Analysis of Crop Yield Trends and Climate Variability in India**” being submitted by **Mr. Anand Madhukar** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by him. **Mr. Anand Madhukar** has worked under our guidance and supervision and has fulfilled the requirements for submitting this thesis, which to our knowledge, has reached the requisite standard.

The results contained in this thesis are original. They have not been submitted, in part or whole, to any other University or Institute for the award of any other degree or diploma.

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ABSTRACT

Agriculture provides food and livelihood to a large population contributing immensely to socio-economic growth. Wheat rice and maize are three major food crops grown worldwide. This thesis examines the spatial and temporal trends in the yields of these three food crops across India using four types of parsimonious regression models. The results suggest that crop yields for wheat, rice, and maize have improved substantially historically. However, the yields are stagnating recently in many states of India. The thesis identifies those states where yields are now leveling off. We observed that stagnation in wheat yield is more widespread than rice and maize in Indian states. It leads us to investigate wheat yields at a granular resolution, i.e., district level further. Investigation of wheat yield trends at the district level confirmed the findings of state level analysis of yield trends. It was observed that wheat yield is recently not improving in 69 major wheat-producing Indian districts corresponding to ~48% of wheat harvested area over 1966 to 2015.

Many researchers have investigated the climatic trends during four weather seasons in India. Nevertheless, there is scarce scientific literature on climatic trends during cropping seasons in India. Therefore, we also investigated the climate variability trends during major cropping seasons, i.e., *Rabi* and *Kharif* in India. Since most of the previous climate studies focus mainly on the temperature and precipitation trends only, we undertook a comprehensive analysis encompassing up to ten climatic variables. In addition, the uniqueness of our climate trend analysis also lies in the availability of results at national, state and district level, using parametric (i.e., linear regression), nonparametric (i.e., Mann Kendall, Sen's slope, modified Mann Kendall tests), and innovative trend analysis methods. Results of climate trend analysis revealed that temperature variables have increased significantly across India.

Changing climatic trends are impacting agricultural yields globally. Therefore, this thesis also investigated the statistical relationships between different climate variables and wheat yields in India using statistical modeling. Two types of approaches were broadly used: state level correlation analysis and district level regression modeling. Both time series modeling and panel data modeling methods were employed. We found that most of the climate variables are negatively associated with wheat yield across a large part of India. Our analysis identified such Indian states and Indian districts so that they can adapt state-level and district-level mitigation/adaptation measures to reduce the negative climatic impacts.

In this backdrop of stagnating yields and the negative impact of temperature and water variables, irrigation has been widely suggested as an adaptation strategy to improve crop yields and address the negative impact of temperature rise. So, we also investigated the effect of irrigation on wheat yields in India across 175 major wheat-producing Indian districts using statistical modeling. The results demonstrated that irrigation has affected wheat yield positively in 142 Indian districts historically. Irrigation also reduces the negative impact of temperatures on wheat yields. However, irrigation does not eliminate the negative temperature impact entirely. The negative impact of temperature is still present in the districts with more than 99% irrigation coverage. Therefore, additional and alternative adaptation measures are now needed to be adopted to improve wheat yields further.

The study paves the way for future empirical studies in India and other parts of the world with similar methodology. The thesis results will prove very helpful for identifying crop yield trends, climatic trends, and the association between the two across Indian states and districts, and can be employed for state-level and district-level planning. Also, this work will motivate future researchers in India to investigate the impact of other mitigation/adaptation measures (other than irrigation) on crop yields.

सारांश

कृषि एक बड़ी आबादी को भोजन और आजीविका प्रदान करके सामाजिक-आर्थिक विकास में काफी बड़ा योगदान देती है। गेहूं, चावल और मक्का तीन प्रमुख खाद्य फसलें दुनिया भर में उगाई जाती हैं। यह तीसरे चार प्रकार के मॉडलों का उपयोग करके भारत भर में इन तीन खाद्य फसलों की पैदावार में प्रवृत्तियों की जांच करती है। परिणाम बताते हैं कि गेहूं, चावल और मक्का की फसल की पैदावार में भारत में ऐतिहासिक रूप से काफी सुधार हुआ है। हालांकि हाल में कई राज्यों में इन फसलों की पैदावार में ठहराव आ रहा है। तीसरे ऐसे उन राज्यों की पहचान करती है जहां अब पैदावार लेवल हो रही है। हमने देखा कि भारत के राज्यों में गेहूं की उपज में ठहराव चावल और मक्का की तुलना में अधिक व्यापक है। यह खोज हमें गेहूं की उपज में प्रवृत्तियों की जांच और निचले स्तर (यानि जिला स्तर पर) करने के लिए प्रोत्साहित करती है। जब हम भारत के आठ प्रमुख गेहूं उत्पादक राज्यों में जिला स्तर पर गेहूं की उपज के रुझानों की जांच करते हैं, तो परिणाम राज्य स्तर पर उपज के रुझानों के निष्कर्षों की पुष्टि करते हैं। पता चलता है कि हाल में 69 प्रमुख गेहूं उत्पादक भारतीय जिलों में गेहूं की पैदावार में सुधार नहीं हो रहा है, जो 1966 से 2015 तक गेहूं की कटाई वाले क्षेत्र का ~48% है।

कई शोधार्थियों ने भारत में चार मौसमों (मानसून, पोस्ट मानसून, शरद और ग्रीष्म) के दौरान जलवायु प्रवृत्तियों की जांच की है। फिर भी, भारत में फसली मौसमों के दौरान जलवायु प्रवृत्तियों पर वैज्ञानिक साहित्य दुर्लभ है। इसलिए, हमने भारत में प्रमुख फसली मौसमों अर्थात् रबी और खरीफ के दौरान जलवायु परिवर्तनशीलता की प्रवृत्तियों की भी जांच की। चूंकि पिछले जलवायु अध्ययनों में से अधिकांश मुख्य रूप से तापमान और वर्षा के रुझानों पर ध्यान केंद्रित करते हैं, इसलिए हमने दस जलवायु चरों को शामिल करते हुए एक व्यापक विश्लेषण किया। इसके अलावा, हमारे जलवायु प्रवृत्ति संबंधी विश्लेषण की विशिष्टता एक साथ राष्ट्रीय, राज्य और जिला स्तर पर

परिणामों की उपलब्धता में भी निहित है; और पैरामेट्रिक (यानी रैखिक प्रतिगमन), नॉन पैरामेट्रिक (यानी मान केंडल, सेन स्लोप, मॉडिफाइड मान केंडल टेस्ट) और इनोवेटिव ट्रेंड एनालिसिस के तरीके के एक साथ उपयोग में भी। जलवायु प्रवृत्ति विश्लेषण के परिणामों से पता चलता है कि पूरे भारत में तापमान में काफी वृद्धि हुई है।

जलवायु के बदलते रुझानों से विश्व स्तर पर कृषि पैदावार प्रभावित हो रही है। इसलिए, हमने सांख्यिकीय मॉडलिंग का उपयोग करके भारत में विभिन्न जलवायु चरों और गेहूं की पैदावार के बीच सांख्यिकीय संबंधों की भी जांच की। इसके लिए दो प्रकार के दृष्टिकोणों का मोटे तौर पर उपयोग किया गया: राज्य स्तरीय सहसंबंध विश्लेषण और जिला स्तरीय प्रतिगमन मॉडलिंग। टाइम सीरीज मॉडलिंग और पैनेल डाटा मॉडलिंग दोनों तरीकों को नियोजित किया गया। हमने पाया कि अधिकांश जलवायु चर भारत के एक बड़े हिस्से में गेहूं की उपज को नकारात्मक रूप से प्रभावित कर रहे हैं। हमारे विश्लेषण में ऐसे भारतीय राज्यों और भारतीय जिलों की पहचान की गई है ताकि वे नकारात्मक जलवायु प्रभावों को कम करने के लिए राज्य स्तरीय और जिला स्तरीय मिटिगेशन/एडप्टेशन उपायों को अनुकूलित कर सकें ।

स्थिर पैदावार और तापमान व पानी के चरों के नकारात्मक प्रभाव की इस पृष्ठभूमि में, सिंचाई को फसल की पैदावार में सुधार और तापमान वृद्धि के नकारात्मक प्रभाव को दूर करने के लिए एक अनुकूलन रणनीति के रूप में व्यापक रूप से संदर्भित किया गया है । इसलिए, हमने सांख्यिकीय मॉडलिंग का उपयोग करते हुए 175 प्रमुख गेहूं उत्पादक भारतीय जिलों में गेहूं की पैदावार पर सिंचाई के प्रभाव की भी जांच की। परिणामों से पता चला है कि सिंचाई ने ऐतिहासिक रूप से 142 भारतीय जिलों में गेहूं की उपज को सकारात्मक रूप से प्रभावित किया है। सिंचाई से गेहूं की पैदावार पर तापमान का नकारात्मक प्रभाव भी कम होता है। हालांकि, सिंचाई नकारात्मक तापमान प्रभाव को पूरी तरह से खत्म नहीं कर पाती है। तापमान का नकारात्मक प्रभाव 99 फीसद

से अधिक सिंचाई कवरेज वाले जिलों में भी मौजूद है। इसलिए गेहूं की पैदावार को और बेहतर बनाने के लिए अतिरिक्त अनुकूलन उपायों की भी आवश्यकता है।

हमारा मानना है कि थीसिस के परिणाम भारत के राज्यों और जिलों में फसल उपज प्रवृत्तियों, जलवायु प्रवृत्तियों, और इन दोनों के बीच संबंधों की पहचान करने में बहुत उपयोगी साबित होंगे; और इनका उपयोग राज्य स्तरीय और जिला स्तरीय योजना में भी किया जा सकेगा। साथ ही, यह शोध कार्य भविष्य में ऐसी शोधों को भी प्रेरित करेगा जो भारत में सिंचाई के अलावा दूसरे अनुकूलन विकल्पों के फसल उपज प्रवृत्तियों पर प्रभावों का समग्र अध्ययन और मूल्यांकन करेंगी। यह थीसिस दुनिया के अन्य विकासशील देशों में इसी तरह की पद्धति का उपयोग कर अनुभवजन्य अध्ययनों (Empirical Studies) के लिए भी मार्ग प्रशस्त करती है ।

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LIST OF ABBREVIATIONS

Abbreviation	Full Form
AIC	Akaike Information Criterion
<i>Cld</i>	Cloud cover
CRU	Climate Research Unit
<i>CYV</i>	Crop yield variability
<i>Dtr</i>	Diurnal temperature range
<i>F_{IA}</i>	Irrigated area fractions
<i>HA</i>	Harvested area
<i>IA</i>	Irrigated area
<i>Pet</i>	Potential evapotranspiration
<i>Pre</i>	Precipitation
<i>T_{mn}</i>	Minimum temperature
<i>T_{mp}</i>	Mean temperature
<i>T_{mx}</i>	Maximum temperature
<i>Vap</i>	Vapor pressure
<i>Vpd</i>	Vapor pressure deficit
<i>Wet</i>	Wet days frequency