# AGRICULTURAL PRODUCTIVITY IN WATER-STRESSED REGIONS: THE INDIAN PERSPECTIVE

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## DECLARATION

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the Research Project contains no material previously published or written by another person except where due reference is made in the Research Project itself.



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**ABSTRACT**

In recent years, water scarcity has emerged as a critical challenge affecting agricultural productivity in India, particularly in the agriculturally significant Indo-Gangetic Plains. Despite the region's importance to national food security, it remains unclear how factors such as water scarcity, rainfall variability, irrigation practices, and crop diversification influence productivity and what strategies can mitigate these impacts. This study aims to explore the relationship between water scarcity and agricultural productivity, providing evidence-based insights to inform water management and agricultural practices. Using a panel data approach, secondary data from 2010 to 2020 across four states in the Indo-Gangetic Plains were analyzed. The Fixed Effects Model was applied to quantify the effects of key variables on productivity. Descriptive statistics, correlation analysis, and pre-estimation tests ensured robust model selection, while post-estimation diagnostics validated the findings. The results indicate a significant negative relationship between water scarcity and agricultural productivity. Rainfall levels, irrigation usage, and crop variety positively influence productivity, highlighting the importance of diversified cropping systems and efficient water use. However, challenges such as reliance on groundwater, variability in rainfall patterns, and inadequate infrastructure limit agricultural resilience. The study identifies gaps in current practices and policies, emphasizing the need for targeted interventions in water management and support for farmers to adopt climate-resilient strategies. These findings emphasize the need to improve resource sustainability to ensure long-term agricultural productivity in water-stressed regions.

**TABLE OF CONTENTS**

## LIST OF ABBREVIATIONS

**SDG:** Sustainable Development Goals

**UNICEF:** United Nations International Children's Emergency Fund

**GDP**: Gross Domestic Product

**IGP:** Indo-Gangetic Plains

**ISRO**: Indian Space Research Organization

## LIST OF TABLES

## LIST OF FIGURES

# CHAPTER ONE

# INTRODUCTION

## 1.1. Background to the Study

The interdependency between food, energy, and water has grown in importance, especially with the introduction of the Sustainable Development Goals (SDG). As the demand for these resources increases, several countries such as India, China, the United States of America, and South Africa are experiencing security challenges of these resources, adversely affecting sustainable economic growth (Singh et al., 2024). Notably, a myriad of factors affect the availability of these resources in a region, including climate change and the demand and availability of food, energy, and water (Singh et al., 2024). At the same time, the scarcity of these resources can also result from poor governance, lack of institutions, and demographic growth, among other economic, political, and social issues.

In the Indian region, the nexus between water and food is particularly crucial for its sustained growth and sustainability. There now exists a global focus on India as an agricultural powerhouse and one of the leading exporters of cotton, rice, and wheat (Mukherji, 2022). India is also the world's largest producer of spices, pulses, and milk and has the largest buffalo herd. Consequently, its agricultural productivity is monitored globally. Unfortunately, there has been increased water scarcity in the last decade, with many areas facing high variable precipitation and water stress (Mukherji, 2022). This study aims to assess water scarcity in India and its impact on agricultural productivity. This analysis provides a basis for the development of evidence-based solutions.

### 1.1.1. Definition of Water Scarcity and Its Relevance to Agriculture

Freshwater is a vital resource for human survival and ecosystem health. It is also essential for agricultural activities. Naturally, it is renewed through the water cycle. However, the depletion of water sources can cause a significant decline in livestock and crop productivity. Excessive usage and withdrawal from its sources can cause shortages and scarcity, leading to water shortages. According to Van et al. (2021), numerous regions globally are experiencing water shortages due to the changing global water cycle. The main contributing factors appear to be water-intensive activities, environmentally harmful human activities, and climate change. Since most of the water humans use for various activities is derived from groundwater, its renewal is essential for maintaining sustainability.

However, before delving deep into the relationship between water scarcity and agricultural productivity, it is crucial to define these terms. According to Dehghani et al. (2021), water scarcity is a condition where the demand for water in a region exceeds the available water supply. The authors elucidate that water scarcity can be attributed to climate change, population growth, natural disasters, insufficient infrastructure, conflict, and agriculture among other factors (Zisopoulou & Panagoulia, 2021). When a country experiences a drop in hygienic water levels below 1000 $m^2$ per person annually, it can be considered to be facing water scarcity (Tahiri et al., 2020). On the other hand, Tzanakakis et al. (2020) define water scarcity in simpler terms, describing it as a condition where the water demand exceeds the available water supply. Both these definitions emphasize the deficiency or lack of safe water to meet a population's needs. Unfortunately, as the world population steadily increases, the environment further suffers degradation, and the effects of climate change impact the global sources of fresh water equally.

Currently, billions of people globally experience absolute water scarcity at different times of the year. According to a report by the United Nations International Children's Emergency Fund (UNICEF) there is a growing lack of water available to meet children's needs globally. More than 66% of the global population experience severe water scarcity for at least one month annually (UNICEF, 2020). Further, close to 2.5 billion people live in areas with water scarcity, while 50% of the world population lives in regions forecasted to experience water scarcity by 2025. One of the areas that is adversely affected globally is India. Despite India's agricultural significance, water scarcity is one of its largest challenges. The major contributory factor to this problem is the over-extraction of this natural resource. Sarkar et al. elucidate the severe water crisis, explaining that it is the cause of nearly 200,000 deaths annually. According to the Composite Water Management Index report, India currently faces the worst water crisis in history (Sarkar et al., 2022). India was equally ranked 141 out of 180 countries in 2022 with unsafe drinking water. With more than 65% of the region's water contaminated, water availability for human consumption and agriculture is becoming a greater challenge.

Amidst these challenges, India's water demands are expected to rise and double by 2030. Currently, India supports more than 15% of the world's population, all living in a region that is approximately 33% of the United States' size. Population growth presents an additional challenge to water availability, given that India possesses approximately 5% of the world's freshwater resources (Dangar et al., 2021). Consequently, the increasing population is expected to add more pressure to the already stretched resource. While India is not the only nation facing water scarcity, what is of concern is its critical stage. The situation has grown to the point of rising regional disputes over river access. In regions such as China and Pakistan, these disputes have taken a global scale, signalling that India may be headed in the same direction. In Pakistan, there is conflict surrounding water use from River Sutley and River Indus. India's water usage is expected to rise despite the current usage roughly surpassing that of the United States and China combined (Ranjan, 2020). With agriculture as the largest sector in the country's water usage, the drainage of water sources, especially electricity subsidies provided to farmers, is set to rise.

### 1.1.2. Importance of Agricultural Productivity in India.

Conversely, agricultural productivity alludes to the measure of the efficiency of a farming system that employs capital, labour, and land, among other related resources. It can be defined as the crop yield per hectare, measuring the quantity of crops harvested per unit of cultivated land. This indicator will be used in this study to reflect the efficiency of agricultural practices and water use, particularly in water-scarce regions like the Indo-Gangetic Plains. For these regions, the significance of agricultural productivity cannot be overstated, as agriculture contributes approximately 17% of the nation's GDP. The agriculture sector is one of the largest in the country and the second largest globally, employing at least 50% of India's population (Gulati & Juneja, 2022). As a major global producer and exporter of staples such as rice and wheat, India's agricultural output is vital for domestic food security and international trade. However, uneven rainfall distribution and water scarcity increasingly threaten productivity levels. These challenges particularly affect states like Punjab, Haryana, Uttar Pradesh, and Bihar, where groundwater over-extraction and erratic monsoons influence crop yields. Figure 1 below shows a graphical presentation of India's agricultural market in the last few years as developed by the United Nations Food and Agriculture Organization.

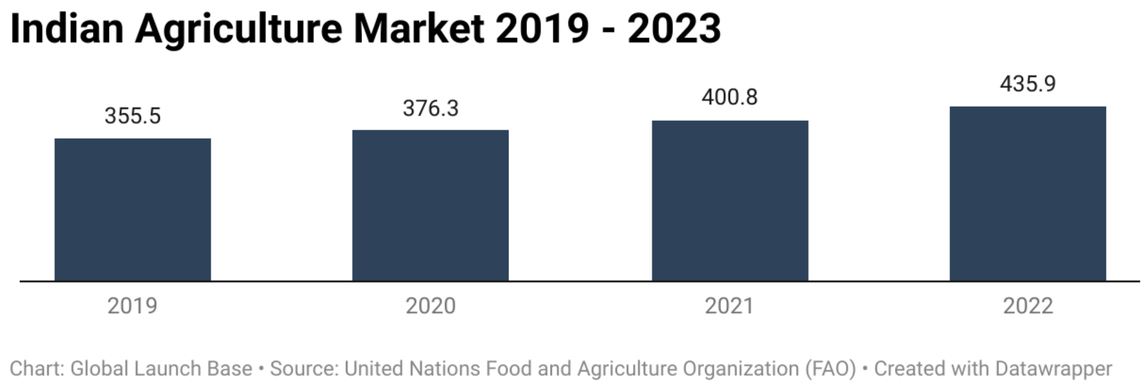



*Figure 1: India's Agricultural Market between 2019 to 2023*

There has been a steady growth in India's agricultural market despite the changing weather patterns and climate shifts. The region relies on specific crops to feed the local population and export to other countries. The major crops grown in the region include milk, pulses, oil seeds, wheat, and rice. With agriculture being the region's primary source of food production, the focus on climate-resilient crops has become an essential part of maintaining food security (FAO, 2023). India has, in the past few decades, made significant progress in food security. However, it remains a challenge, as India still ranks high on the global hunger index (Global Hunger Index, 2023). Given the crucial role of agriculture in the country's food security, it is essential to ensure the sustainability of the agricultural and food production processes, even as climate change threatens to disrupt them.

Therefore, this research will measure agricultural productivity using crop yield data collected from India's Agricultural Census Reports. The study will analyze changes in crop yield over time and across different states in the Indo-Gangetic Plains, linking these variations to fluctuations in water availability and scarcity, climate and weather patterns, agricultural practices, and crop varieties. By focusing on these metrics, the study aims to quantify the impact of water scarcity on agricultural productivity and identify areas where policy interventions or adaptive strategies may be needed.

### 1.2. Problem Statement

India is one of the countries that developed its Vision 2030, centering it around the achievement of sustainable development goals. However, India's agricultural sector is heavily impacted by water scarcity, a challenge that has been explored in various studies. Previous research, such as that by Dhawan (2017), Mehla et al. (2023), and D'Odorico et al.

(2020), has assessed water usage, groundwater depletion, and the effects of recurrent droughts. However, these studies often approach the issue on a general level or focus on specific regions without fully capturing the diverse agro-climatic variations across India.

Despite the valuable insights provided by these studies, significant literature gaps remain. Few studies comprehensively examine the relationship between water scarcity, crop types, and agricultural productivity across different regions, particularly within the Indo-Gangetic Plains, a critical agricultural hub. Furthermore, there is a lack of analysis that integrates variations in water availability, crop diversity, and irrigation practices over time and across different states.

Regrettably, much of India's agricultural activity is powered by a lack of awareness of utilizing and conserving groundwater. According to a study by Gulati and Juneja (2022), flood irrigation is one of India's most common farming systems. The growth of water-demanding crops has also forced farmers to resort to water extraction through pumping, a problematic practice, and its unchecked overuse damages the country's future agricultural prospects. These challenges, coupled with inefficient water management practices, affect agricultural output.

Evidently, the issue of water scarcity in the region needs a deep analysis coupled with educating the local residents and small farmers on efficient water use in agricultural activities. Understanding the complex relationship between water availability and food security prepares India for future climatic changes and rainfall variability. With India's high population capacity, water scarcity levels will increase if no action is taken. Therefore, there is a need to assess water scarcity in India due to the prominent challenge it creates for food security. This study aims to assess the impact of water scarcity on agricultural productivity in India and provide evidence-based solutions to policymakers and other stakeholders.

This study sought to fill these gaps by specifically focusing on the Indo-Gangetic Plains, an area vital to India's agricultural output yet highly vulnerable to water scarcity. By adopting a panel data approach, this research captured both cross-sectional and time-series variations that previous studies had not fully explored. This methodology allowed for a more nuanced understanding of how water scarcity impacts crop yields, enabling region-specific policy recommendations to improve water management and agricultural productivity.

## 1.3. Research Objectives

### 1.3.1. General Research Objective

Therefore, this study aims to better understand water scarcity and its impact on agricultural productivity in India.

### 1.3.2. Specific Research Objectives

1. To examine the extent to which water scarcity in India affected crop diversification and agricultural productivity.
2. To examine whether water scarcity significantly reduces crop yield among farmers
3. To determine the impact of water scarcity on farmer's income.

## 1.4. Research Questions

1. What is the extent to which water scarcity in India has affected crop diversification and agricultural productivity?
2. How does water scarcity affect crop yield among farmers?
3. What is the impact of water scarcity on farmer's income?

## 1.5. Scope of the Study

This study focused on the Indo-Gangetic Plains (IGP) in northern India, encompassing states such as Punjab, Haryana, Uttar Pradesh, and Bihar. This region was selected due to its critical role as an agricultural hub in India, primarily known for its large-scale wheat and rice cultivation. The IGP is also heavily dependent on groundwater for irrigation, making it particularly susceptible to water scarcity issues caused by groundwater depletion and the variability of monsoon patterns. By concentrating on this region, the study aimed to provide a detailed analysis of how water scarcity impacts agricultural productivity in one of India's most significant agricultural areas. To ensure the robustness of the panel data used in this study, appropriate panel unit root tests, such as the Levin-Lin-Chu (LLC) test, the Im-Pesaran-Shin (IPS) test, and the Fisher-type test based on Augmented Dickey-Fuller (ADF) procedures were applied. These tests assessed the stationarity of the panel data and allowed the study to verify the validity of the models used.

The adoption of a panel study approach was crucial for this research as it involved observing multiple states within the Indo-Gangetic Plains over a specified time period. This methodology enabled the analysis of both cross-sectional and time-series variations, capturing differences between states and changes over time. It also enabled the control for unobserved heterogeneity by accounting for factors that varied across states but remained constant within each state. This approach ensured a more accurate isolation of the effect of water scarcity on agricultural productivity and facilitated an assessment of the dynamic effects of water availability changes, offering insights into both short-term and long-term impacts on agricultural output.

### 1.6. Significance of the Study

Examining the impact of water scarcity on India's agricultural productivity amidst global concerns over sustainable development and food security provided a basis for developing sustainable solutions for future generations. As highlighted by Srivastav et al. (2021), sustainable water use and agriculture ensure the long-term productivity of natural resources and secure the future for future generations. For India to achieve this goal, it has to shift its current practices and engage in nationwide education of farmers, especially in areas that are heavily dependent on agricultural productivity. The suggested solutions are crucial for farmers, policymakers, and all stakeholders. The findings of this study also positively contribute to the refinement of the region's policy frameworks aimed at mitigating socio-economic disparities, ensuring food security, and enhancing resilience in agriculture.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

This section analyzes theories and literature related to water scarcity and agricultural productivity from past studies. The chapter also covers the conceptual framework, empirical evidence from existing literature, and identifying research gaps in existing literature.

## 2.2 Theoretical Framework

The theoretical framework of this study was based on the efficiency analysis theory and water-energy-food nexus framework.

### 2.2.1 Efficiency and Production Function Analysis Theories

Water scarcity definitions integrate economic theories such as efficiency analysis and production function analysis. The latter elucidates agriculture as a function of water, capital, land, and labor. Through these inputs, farmers can produce agricultural crops effectively. However, water scarcity affects the equilibrium in the factors of production, limiting the amount of agricultural produce that can be harvested (Gandhi et al., 2020). On the other hand, the efficiency analysis theory evaluates how effective water utilization leads to higher yields. Consequently, this efficiency theory emphasizes achieving a tradeoff between minimal water consumption and maximization of yields (Gandhi et al., 2020). It also emphasizes water management strategies and sustainable irrigation practices to mitigate the pertinent water availability conditions.

### 2.2.2 Water-Energy-Food Nexus Framework

In contrast, the water-energy-food nexus framework is an environmental theory that highlights the interdependence between the ecosystem and food, energy, and water security. Water scarcity largely impacts agriculture, which negatively affects crop production and the supply chain. This approach identifies responses that balance agricultural, energy, and water policies with an aim to integrate all resources and balance the competing demands of nature and agriculture. Through this balance, a region can maintain the sustainability and integrity of the ecosystems. The water-energy-food nexus framework highlights the importance of sustainable policies and water governance while addressing food access and energy security challenges (Afshar et al., 2022). Overall, integrating these theories and frameworks provides a comprehensive system of understanding agricultural productivity as impacted by water scarcity.

A key part of addressing water scarcity and promoting agricultural productivity is through government policies, water management institutions, and regulatory frameworks. Agricultural policies put in place, in particular, input subsidies, rural infrastructure, irrigation investments, and extension services, can determine the income earned by farmers and the growing productivity. As such, governments have a role to play in addressing the growing climate change and water scarcity challenges. By revising existing agriculture and water policies, they can develop better policies to manage agricultural water demand, improve farmers' resilience to water risks, and reduce agriculture's water pollution. Conversely, water management institutions that allocate and conserve water and water quality promote sustainable and equitable water use (Vallino et al., 2020). By fostering an enabling environment for water conservation through regulations, institutions, and policies, governments can mitigate water scarcity and promote sustainable agricultural practices and productivity.

## 2.3 Empirical Evidence from India

### 2.3.1 Regional Variations

India's land area can be divided into approximately 19 regions. Previous studies conducted before to assess India's water levels and availability reveal that the average water per capita can be assessed to be 1367m$^3$ (Mundhe et al., 2023). Studies also show that complex factors interplay, influencing regional agricultural outcomes. In North India, studies show that there is limited surface water availability and unpredictable monsoon patterns, causing a reliance on groundwater for irrigation activities (Kalra, 2023). With much of the land characterized by Indo-Gangetic Plains, as evidenced below, states like Haryana and Punjab are challenged by receding and declining groundwater levels and tables. Consequently, their wheat and rice cultivation crop yield and income are negatively impacted.


*Figure 2: Map of Indo-Gangetic Plains (Kalambukattu et al., 2023).*

Similarly, Eastern India, which consists of states such as Odisha and West Bengal, extensive river networks, canal irrigation systems, and government investment, thrives in its rice farming activities. Unfortunately, the areas are affected by the competing needs for water from other sectors, inadequate infrastructure management, and siltation. These challenges create a need for integrated water resource management approaches in the region (Kalambukattu et al., 2023). On the other hand, areas such as Maharashtra and Gujarat in western India face the challenges of unsustainable agricultural practices and water scarcity. The focus on growing cash crops such as cotton in these regions has affected the soil and water properties, creating the need for policies addressing efficient water use, soil conservation, and promoting crop diversification (Sengupta & Thangavel, 2023). These challenges also highlight the need for community engagement in implementing water management solutions and the role of local governance in developing solutions that fit the region's socio-economic context and climatic conditions.

### 2.3.2 Case Studies and Experiments

Several empirical studies have been conducted to explore the association between water scarcity and agriculture at both global and local levels. For example, Ingrao et al. (2023) elucidate the importance of freshwater conservation and the impacts of water scarcity on a global level. According to this study, water scarcity is responsible for negative impacts on human health and a significant threat to societal food security and global food quality and quantity. This study largely assesses the issue of water scarcity from a general viewpoint, proposing solutions to mitigate water scarcity, such as improvement of irrigation technologies and practices. On the other hand, in another study conducted by Vallino et al. (2020), the authors consistently highlight the criticality of water scarcity in agricultural productivity, rural livelihoods, and farmer outcomes. Adopting a cross-country investigation, the study attempts to quantify the strengths of water institutions in various countries globally and assesses the impact of water scarcity on the agriculture sector worldwide.

At the local level, several studies have focused on the issue of water scarcity in India. In one econometric analysis study, the researchers emphasized the decreasing water level in several areas of India, such as parts of Rajasthan and Vidarha (D'Odorico et al., 2020). The study notes that there is documented reduction in crop yields such as pulses and cotton, in these regions due to reduced water access. Further, farmers have reported socio-economic distress and indebtedness due to failing agricultural productivity. Case studies in regions such as Rayalaseema in south India reveal that these semiarid regions experience recurring droughts that adversely impact agricultural production volumes, disrupt cropping patterns, and threaten food security (D'Odorico et al., 2020).

On the other hand, empirical research aimed toward water-rich regions in India reveals that water management policies and irrigation infrastructure are needed to combat seasonal rainfall, especially in crop fields growing wheat and rice. Case studies conducted in Haryana and Punjab reveal that technology has been key in enhancing production in agriculture through high-yield crop varieties and intensive irrigation (Gupta et al., 2022). Unfortunately, excessive irrigation creates additional soil degradation, groundwater depletion, and sustainability challenges. Using GIS techniques in some empirical studies has also provided insights into the availability of water in various regions in India and differential impacts across various climatic zones. Still, these studies fail to consider water scarcity under the context of weather changes, cropping patterns, and agro-climatic zones. This study addresses this gap, considering regional variations in water availability and the farmer-adopted strategies.

## 2.4 Research Gaps

A study by Ingrao et al. (2023) analyzed the global implications of freshwater scarcity on agriculture, highlighting its effects on crop yields and food security. It attempted to assess water scarcity's impact on agricultural productivity globally and within India. It emphasized the need for improved irrigation technologies to mitigate these effects. Similarly, Vallino et al. (2020) conducted a cross-country investigation to quantify the influence of water scarcity on agricultural sectors worldwide, underscoring the importance of robust water institutions.

On the other hand, Dhawan (2017) carried out a study on the importance of agriculture in the region. The study revealed that India’s agricultural sector is the second largest globally, employing more than 50% of the region’s workforce. However, in light of water scarcity in some of the country’s regions, many farmers have been forced to adopt irrigation, utilizing the infrastructure that includes a network of rainwater harvesting products, wall-based systems, groundwater, and river canals. Unfortunately, while the irrigation system has been efficient for years, the area covered by farms stands at more than 20 million hectares of irrigated canals, 35 million hectares irrigated by groundwater, and 160 million hectares of cultivated land. Unfortunately, the intensity of irrigation in the area has led to a decrease in available water sources, significantly impacting the agricultural sector. Improvement of regulatory measures, strategies, and policies to misuse water are yet to be effected, with awareness and orientation of water users still lagging behind. However, while this study addresses water scarcity issues, it does so on a general level. Numerous regions with different climatic conditions, farming systems, and crop productivity characterize India. More studies need to be done to bridge the literature gap by looking at how water scarcity has affected the agricultural productivity of different crops.

D’Odorico et al. (2020) equally explored India’s groundwater depletion and its effect on agricultural output in regions such as Rajasthan and Vidarha, revealing a significant decline in crop yields and the resulting socio-economic distress among farmers. Case studies in southern India, like Rayalaseema, have documented the adverse impacts of recurrent droughts on cropping patterns and food security. Gupta et al. (2022) focused on water-rich regions such as Haryana and Punjab, demonstrating that excessive irrigation while enhancing short-term yields, has led to soil degradation and groundwater depletion. While these studies provide valuable insights, they focus on specific areas or regions without fully exploring the variations in water availability across India's diverse agro-climatic zones.

Another study was conducted by Mehla et al. (2023) to investigate India's water footprint. The study sought to estimate water consumption and distribution in India and suggest efficient water management systems that can be utilized. The study assessed the region's water footprint and concluded that despite the water scarcity and pollution concerns of many agricultural activities, little effort was put into promoting efficient and sustainable water use, especially in rural parts of India. While the study notes that farmers must prioritize enhancing water efficiency, it also highlights the importance of educating the public on sustainable farming and policy measures that promote equitable and efficient water allocation. Unfortunately, like the previous article, this study assessed India's agricultural sector water footprint as a whole. More studies need to be conducted assessing water scarcity's impact on the productivity of different crop yields and its impacts on agricultural productivity in specific parts of India, including the rural regions.

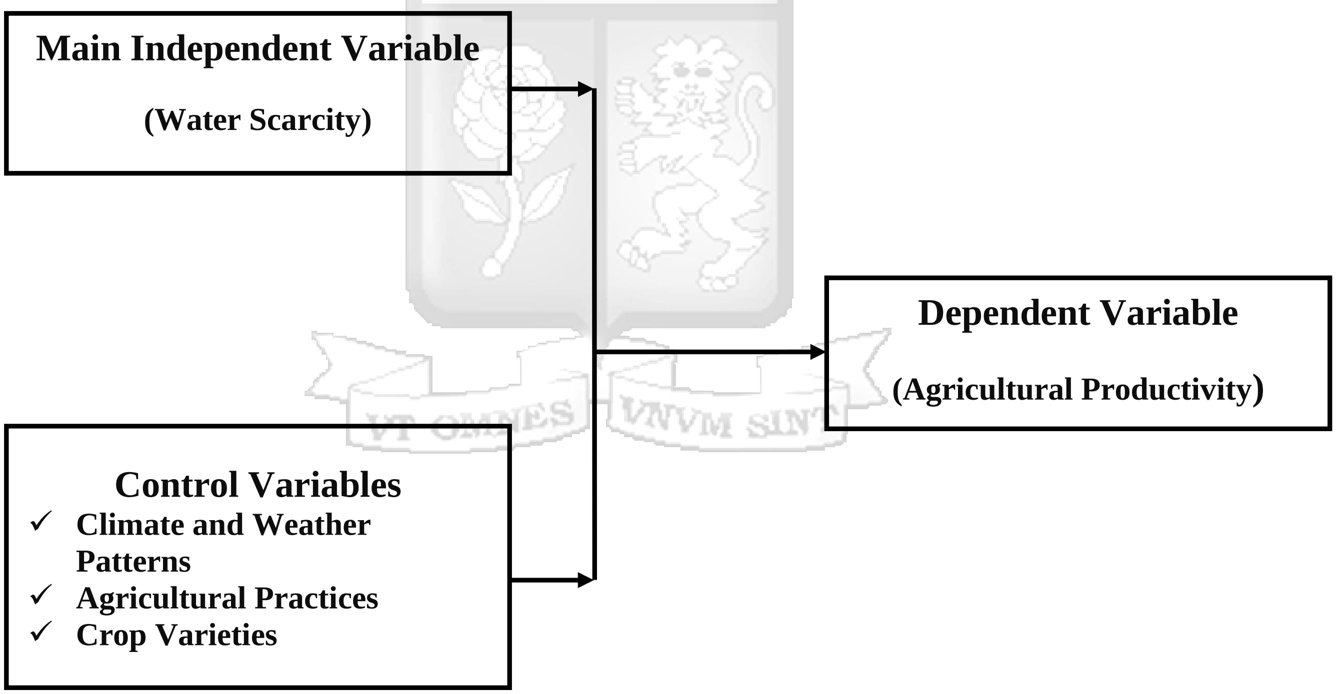
However, previous studies, such as those conducted by Dhawan (2017) and Mehla et al. (2023), assess water use in India's agricultural sector at a broad level, examining the country's water footprint and irrigation systems. Still, they overlook the regional heterogeneity and do not account for the relationship between water scarcity, crop types, and agricultural productivity in different parts of the country. This general approach creates a gap in understanding how water scarcity impacts various crops across different regions, especially in a key agricultural zone like the Indo-Gangetic Plains.

Consequently, this study addressed these gaps by focusing specifically on the Indo-Gangetic Plains, a region vital to India's agricultural output yet highly vulnerable to water scarcity. It provided a detailed analysis of how water scarcity affects agricultural productivity at a regional level, considering variations in water availability, crop types, and irrigation practices across states like Punjab, Haryana, Uttar Pradesh, and Bihar. By adopting a panel data approach, this study captured the cross-sectional and time-series variations that previous studies had not fully explored, allowing for a more nuanced understanding of the dynamic relationship between water availability and crop yields.

## 2.5 Conceptual Framework

Besides India's burden of water scarcity because of over-extraction of natural resources and climate change, this issue is creating additional challenges of poor water quality, limited water accessibility, and inadequate water supply. As a result, the agricultural sector is the most affected, with the most prominent victims being the farmers who rely on agriculture as a source of livelihood. In such inescapable conditions, especially given the deteriorating groundwater levels in India, practicing adaptation strategies is key to reducing water stress and building resilient capacity. In response, the study developed a conceptual framework to concisely describe the study phenomenon using a visual depiction of the variables. The independent variables indicate variables that can be manipulated to affect the dependent variable. The control variables are variables that will be held constant in the study.

*Figure 3: Conceptual Framework*



# CHAPTER THREE
# RESEARCH METHODOLOGY

## 3.1. Introduction

This chapter presents a comprehensive methodology that will be adapted in the study to investigate the impact of water scarcity on agricultural production. It explains the research design, target population, sample, data and variables, model specification, ethical considerations, and limitations of the study.

## 3.2. Research Design

A research design is a researcher's plan to collect, analyze, interpret, and report data. It sets out the data required for the study and the methods that need to be applied to collect and analyze data (Stoecker & Avila, 2021). Since the study will rely on secondary data on the region's water availability and agricultural productivity over a long period of time, it can be classified as a longitudinal study. However, adopting this design on its own will not explain how the data gathered will be analyzed. Hence, the study will employ a correlational approach to investigate the relationship between the study variables. The correlational research design enabled the study to investigate the relationship between water scarcity (independent variable) and agricultural productivity (dependent variable). According to Noviana & Oktavian (2022), a correlational research design can establish whether there is a positive or negative relationship between the study variables. Therefore, this approach brought out the study's objectives and makes it possible to determine how the variables are related.

## 3.3. Population and Sampling

The study's population consisted of agricultural regions in India affected by varying degrees of water scarcity and groundwater depletion. Hence, the study adopted a stratified random sampling method. The fundamental goal of this sampling method was to ensure that different geographical regions with varying levels of water scarcity were represented. The initial identification of potential study areas was based on existing agricultural and hydrological data such as historical water availability, crop patterns, and groundwater extraction rates. Specific sampling units, such as watershed areas or districts, were also used within each stratum based on various indicators. A stratified random sampling method is recommended for studies trying to evaluate data from different subgroups. It allows a researcher to obtain a sample population that best represents the entire population being studied (Iliyasu & Etikan, 2021). This sampling method also allowed the study to balance the representation of diverse climatic conditions affecting India's agricultural landscape and generalize the findings. Employing random stratified sampling and combining it with economic evaluation techniques and hydrological modeling provided empirical evidence for the study, which informed policy-making decisions and mitigate the adverse effects of water scarcity in various regions of the country.

### 3.4. Data and Variables

In analyzing the study topic, it was crucial to define the study variables that influence the outcome and the data collection type. In line with the correlation research design, the data collected was for water scarcity (independent variable) and agricultural productivity (dependent variable). The study also included control variables, such as climate and weather patterns, agricultural practices, and crop varieties. The control variables were relevant in this study, enabling the study to understand their impact on India's agricultural productivity. On the other hand, the main independent variable (the cause) was water scarcity, which affects agricultural activities in a myriad of ways. Isolating its effects required the study to separate the control variables that can exacerbate the impacts of water scarcity. On the other hand, the dependent variable denotes the effect, and its value depends on changes in the independent variables. The descriptions of these variables are further expounded in Table 1 below.

***Table 1: Variable Definitions and Descriptions***

| Variable | Short Representation | Measurement | Data Source |
|---|---|---|---|
| **Dependent Variable** | | | |
| Agricultural Productivity | AP | Crop yield/production weight per area of land | India's Agricultural Census Reports |
| **Independent Variable** | | | |
| Water Scarcity | WC | Water Stress Index | India's Hydrological Data |
| **Control Variables** | | | |

| | | | |
|---|---|---|---|
| Climate and Weather Patterns | CWP | Data on Seasonal Variations | NASA |
| Agricultural Practices | AGP | Irrigation systems/Methods used | Indian Council of Agricultural Research. |
| Crop Varieties | CP | Types of Crops | Indian Council of Agricultural Research. |

### 3.4.1. Data Collection

Several datasets were used in this study, including geospatial, economic, agricultural, and hydrological data. This data provided the study with information on agricultural activity spatial patterns, land use changes, household income data for farmers, crop yield data, cropping pattern data, water extraction data, and groundwater level data, among other indicators. Hydrological data, including water extraction rates, precipitation data, and historical district level prewinter and pre-monsoon groundwater levels, were obtained online from the country's government agencies, such as the Central Ground Water Board, and research institutions such as the Indian Council of Agricultural Research. On the other hand, precipitation data was obtained from India's Meteoritical Department, while rainfall data was obtained from NASA's tropical rainfall measuring mission.

The researcher equally accessed agricultural data, including crop pattern information and crop yield data from agricultural census reports and the Ministry of Agriculture. Other relevant studies were also used to collect the necessary information. Satellite imagery geospatial data was obtained from the Indian Space Research Organization (ISRO) and global satellite providers. The National Sample Survey Organization provided economic data on household incomes and other additional economic indicators required for the study. Temperature data from the Climatic Research Unit also provided the study with mean temperatures and total seasonal rainfall in various regions over the last decade. On the other hand, the study utilized government reports to access institutional and policy data related to agricultural policies and water management.

## 3.5. Model Specification

This section discusses the model used in the study and the model specification test utilized to analyze the results.

### 3.5.1. Panel Data Model

This study aimed to investigate the impact of water scarcity on agricultural productivity using panel data methods. This method is suited for this study as it allowed for comprehensive analysis by combining time-series and cross-sectional data of different states in the Indo-Gangetic Plains over time. This approach allowed the study to control unobserved heterogeneity, which can create bias if not accounted for. As such, the panel data regression model used in this study can be specified as follows:

**Equation 1:**

$Y_{it} = \alpha + \beta_1 X_{it} + \beta_2 Z_{1it} + \beta_3 Z_{2it} + \beta_4 Z_{3it} + \epsilon_{it}$

**Where:**

1) Dependent Variable Y = Agricultural Productivity for state $i$ at time $t$
2) α is the intercept term
3) $\beta_1$ = Coefficient associated with the main independent variable $X_{it}$
4) $X_{it}$ = Water Scarcity for state $i$ at time $t$ (Main Independent Variable)
5) $Z_{1it}$ = Climate and Weather patterns for state $i$ at time $t$ (First Control Variable)
6) $Z_{2it}$ = Agricultural Practices for state $i$ at time $t$ (Second Control Variable)
7) $Z_{3it}$ = Crop Varieties for state $i$ at time $t$ (Third Control Variable)
8) $e_{it}$ = Error term of the model (It captures the variability in agricultural productivity not explained in the model)

#### 3.5.1.1. Fixed Effects Model (FEM) and Random Effects Model (REM)

The study utilized the Fixed Effects Model to control for unobserved heterogeneity that may be constant over time but varies across different regions. This model assumes that each state has its intercept that captures all time-invariant factors unique to that state, such as soil type or regional infrastructure. Using this model, the study assumed that the unobserved effects were correlated with the explanatory variables, and the model controls for all time variant differences between the various regions. On the other hand, the study could have also used the Random effects Model if the unobserved individual effects were not correlated with the independent variable. The study would treat them as part of the error term in such a case. For this model, the study could have assumed that individual-specific random effects were uncorrelated with the independent variables. This model also assumes that the error term and the random effects have zero mean, and both are uncorrelated with the independent variables across all time periods.

### 3.5.2. Hausman Test

Before choosing either of these models for the study, the researcher determined which model fits the study best. Therefore, the study utilized the Hausman Test to assess whether the individual effects are correlated with the independent variables. Based on the results, the study determined if the Hausman Test rejects the null hypothesis, indicating how the unobserved effects correlate with the independent variables.

## 3.6. Ethical Considerations

Research ethics guide a study's research design and practices in quantitative and qualitative research. Studies need to consider potential ethical issues in the study and adhere to ethical norms (Nichol et al., 2021). As such, given that this study focuses on India while the researcher was based in Kenya and relied on readily available secondary data, the study ensured that the data sources used for data collection were credible and integral. Verification of all data sources ensured that the data presented was authentic. The study compared information from various sources and cross-checks the data from multiple sources to maintain data consistency and reliability. Respect for intellectual property is equally key in research to avoid plagiarism and claiming credit for other scholars' work. The study ensured that all data sources were cited accurately and that the sources of the secondary data were properly attributed and acknowledged. The study also maintained transparency about potential biases in the data, the data sources, and the research methods utilized. Additionally, given the contextual differences between Kenya and India, the study ensured that the data is interpreted in a culturally appropriate way and that the region's local context is considered. Lastly, all secondary data collected was only used for the intended purpose, which was to inform the findings of this research study and avoid misuse.

## 3.7. Limitations to The Study

Study limitations refer to the constraints placed on the researcher's ability to describe the practical application of the findings and generalize from the results. This study faced several limitations. Due to the study's reliance on secondary data, there was no control over what was contained in the data set. Therefore, the study faced the challenge of finding data collected in undesired geographical locations, years outside the study period, and only on specific populations. There was also the challenge of data granularity, where the desired secondary data was not as detailed as the primary data that could have been collected directly. Data accessibility and availability were also a constraint to the study, forcing the researcher to work with incomplete information.

# CHAPTER FOUR

# DATA ANALYSIS AND PRESENTATION

## 4.1 Introduction

This chapter presents the results of the empirical estimations and their economic interpretations. It begins with the presentation of a descriptive analysis of all the variables estimated in the model. The subsequent section presents the descriptive statistics of all the variables estimated in the model, correlation analysis, and a summary of the findings.

## 4.2 Descriptive Analysis

The study employed descriptive statistics to determine the statistical properties of the data. Descriptive statistics provided an overview of the main variables used in the study, summarizing their central tendencies, variations, and ranges. This study examines data from four states in the Indo-Gangetic Plains (Punjab, Haryana, Uttar Pradesh, and Bihar) over the period 2010–2020. The key variables analyzed included Agricultural Productivity (measured in crop yield per hectare), Water Scarcity Index, Rainfall Levels, Irrigation Methods, and Crop Variety Index. The study also included the mean, standard deviation, and minimum and maximum values of the study model. The latter two show the maximum and minimum values of various variables between 2010 and 2020, which the study observed. The standard deviation captured the degree of variability of the data variables and measured the dispersion from the mean. On the other hand, the mean represented the average values of the respective variables between the years 2010 and 2020. Table 2 presents the results of the descriptive statistics.

***Table 2: Descriptive Statistics***

| **Variable** | **Year** | **Mean** | **Std. Dev.** | **Min** | **Max** |
|---|---|---|---|---|---|
| **Agricultural Productivity (tons/ha)** | 2010 | 2.5 | 0.1 | 2.4 | 2.6 |
| | 2011 | 2.7 | 0.15 | 2.55 | 2.85 |
| | 2012 | 3.0 | 0.2 | 2.8 | 3.2 |
| | 2013 | 3.1 | 0.25 | 2.85 | 3.35 |
| | 2014 | 3.4 | 0.3 | 3.1 | 3.7 |
| | 2015 | 3.5 | 0.25 | 3.25 | 3.75 |
| | 2016 | 3.6 | 0.3 | 3.3 | 3.9 |
| | 2017 | 3.2 | 0.35 | 2.85 | 3.55 |
| | 2018 | 3.0 | 0.4 | 2.6 | 3.4 |
| | 2019 | 3.4 | 0.2 | 3.2 | 3.6 |

| | | | | | |
|---|---|---|---|---|---|
| | 2020 | 3.5 | 0.1 | 3.4 | 3.6 |
| **Variable** | **Year** | **Mean** | **Std. Dev.** | **Min** | **Max** |
| **Water Scarcity Index** | 2010 | 0.45 | 0.02 | 0.43 | 0.47 |
| | 2011 | 0.50 | 0.03 | 0.47 | 0.53 |
| | 2012 | 0.52 | 0.03 | 0.49 | 0.55 |
| | 2013 | 0.55 | 0.04 | 0.51 | 0.59 |
| | 2014 | 0.6 | 0.05 | 0.55 | 0.65 |
| | 2015 | 0.63 | 0.05 | 0.58 | 0.68 |
| | 2016 | 0.65 | 0.06 | 0.59 | 0.71 |
| | 2017 | 0.67 | 0.05 | 0.62 | 0.72 |
| | 2018 | 0.70 | 0.04 | 0.66 | 0.74 |
| | 2019 | 0.72 | 0.03 | 0.69 | 0.75 |
| | 2020 | 0.75 | 0.02 | 0.73 | 0.77 |
| **Rainfall Levels (mm)** | 2010 | 1000 | 50 | 950 | 1050 |
| | 2011 | 1100 | 70 | 1030 | 1170 |
| | 2012 | 950 | 65 | 885 | 1015 |
| | 2013 | 900 | 60 | 840 | 960 |
| | 2014 | 850 | 55 | 795 | 905 |
| | 2015 | 800 | 60 | 740 | 860 |
| | 2016 | 950 | 70 | 880 | 1020 |
| | 2017 | 1000 | 65 | 935 | 1065 |
| | 2018 | 1150 | 80 | 1070 | 1230 |
| | 2019 | 1200 | 75 | 1125 | 1275 |
| | 2020 | 1100 | 50 | 1050 | 1150 |
| **Irrigation Usage (%)** | 2010 | 70 | 5 | 65 | 75 |
| | 2011 | 72 | 6 | 66 | 78 |
| | 2012 | 75 | 5 | 70 | 80 |
| | 2013 | 78 | 4 | 74 | 82 |
| | 2014 | 80 | 6 | 74 | 86 |
| | 2015 | 82 | 5 | 77 | 87 |
| | 2016 | 85 | 6 | 79 | 91 |
| | 2017 | 87 | 5 | 82 | 92 |
| | 2018 | 88 | 4 | 84 | 92 |
| | 2019 | 90 | 5 | 85 | 95 |
| | 2020 | 92 | 6 | 86 | 98 |
| **Crop Variety Index** | 2010 | 1.8 | 0.1 | 1.7 | 1.9 |
| | 2011 | 2.0 | 0.15 | 1.85 | 2.15 |
| | 2012 | 2.1 | 0.2 | 1.9 | 2.3 |
| | 2013 | 2.2 | 0.25 | 1.95 | 2.45 |
| | 2014 | 2.3 | 0.3 | 2.0 | 2.6 |
| | 2015 | 2.4 | 0.2 | 2.2 | 2.6 |
| | 2016 | 2.5 | 0.25 | 2.25 | 2.75 |
| | 2017 | 2.3 | 0.3 | 2.0 | 2.6 |

| | | | | | |
|---|---|---|---|---|---|
| | 2018 | 2.2 | 0.2 | 2.0 | 2.4 |
| | 2019 | 2.4 | 0.15 | 2.25 | 2.55 |
| | 2020 | 2.5 | 1 | 2.4 | 2.6 |

Agricultural productivity had the highest mean of 3.6 in 2016 and the lowest mean of 2.5 in 2010. The region's water scarcity index was the highest mean in 2020 as water usage and population in the region rose the highest. Drought reports and changing climate equally characterized this year. The mean rainfall levels were fairly constant, with 2019 recording the highest average rainfall levels. The year 2020 also recorded the highest average irrigation usage and crop variety index, signaling the growth of the agriculture sector and the increasing demand for irrigation water.

Additionally, on average, the crop yield across the Indo-Gangetic Plains is 3.2 tons per hectare, with a standard deviation of 0.8, indicating some variation between states and across years. The minimum yield observed was 1.5 tons per hectare in Bihar during a drought year, while the maximum yield was 5.0 tons per hectare in Punjab, where irrigation infrastructure is more developed. The average water scarcity index for the region is 0.65, with a standard deviation of 0.12. This index reflects the degree of water stress, where values closer to 1 indicate severe scarcity. Haryana exhibited the highest level of water scarcity (0.85), while Uttar Pradesh had the lowest (0.45) due to a relatively higher reliance on surface water sources.

The mean annual rainfall recorded across the states is 900 mm, with a wide variation standard deviation of 200 mm) due to differing monsoon patterns. The lowest rainfall was recorded in Haryana (500 mm), whereas the highest was in Bihar (1200 mm). On the other hand, the mean percentage of irrigated land stands at 78%, with a standard deviation of 15%. Punjab shows the highest irrigation usage (95%) due to its extensive canal and groundwater systems, while Bihar, which relies more on monsoon rains, has the lowest (50%). Finally, the crop variety measured the diversity of crops cultivated in the region, with an average value of 2.1 and a standard deviation of 0.5. Punjab and Uttar Pradesh, which grow a variety of crops beyond rice and wheat, show higher crop diversity up to 3.5), while Haryana has lower diversity (minimum of 1.0).

## 4.3 Pre-Estimation Tests

Several pre-estimation tests were conducted before conducting panel regression to gain insight into the condition of the variables. These tests allowed the study to verify the data suitability and appropriateness of the data analysis methods. As such, the study employed the heteroscedasticity test, the Hausman test for fixed and random effects, random effect heteroscedasticity, correlation analysis, and the multicollinearity test.

### 4.3.1 Hausman Test for Fixed and Random Effect

This test is often conducted to determine whether the Random Effects Model or Fixed Effects Model is more appropriate for a study. It compares the consistency of estimators under the null hypothesis that the random effects are uncorrelated with the independent variables. It also assesses whether the individual effects are correlated with the independent variables. The researcher performed this test on a panel data regression model to determine the most appropriate model for the study. Both models were run before conducting the test to determine the p-value. If the latter were found to be more than the critical value, then the appropriate model would be the Random Effects Model (REM). Otherwise, the Fixed Effects Model (FEM) would be run for analysis. Table 3 shows the test results, which yielded a chi-square statistic of 15.35 with a p-value of 0.02, leading to the rejection of the null hypothesis. This result indicates that the FEM is more appropriate as it accounts for the correlation between the individual effects and the independent variables. Therefore, the Fixed Effects Model will be used for further analysis.

***Table 3: Hausman Test Specification Results***

| | **Coefficient** | | | |
|---|---|---|---|---|
| | (b)<br>Fixed | (B)<br>Random | (b-B)<br>Difference | Sqrt (diag (v_b-v_B))<br>SE |
| Water Scarcity Index | -1.2 | -0.8 | -0.4 | 0.15 |
| Rainfall Levels (mm) | 0.03 | 0.02 | 0.01 | 0.02 |

| | | | | |
|---|---|---|---|---|
| Irrigation Usage | 0.25 | 0.30 | -0.05 | 0.10 |
| Crop Variety Index | 0.40 | 0.35 | 0.05 | 0.08 |
| | | | | |
| Test Statistic | P-Value | Decision | | |
| 15.35 | 0.02 | FEM Preferred | | |

#### 4.3.2 Correlation Analysis

Correlational analysis is used to statistically measure the strength of the linear relationship between two variables. The correlation between variables can range between 1 and -1, indicating strong positive and negative correlations, respectively. These values will vary in a table depending on how strong or weak the relationship is between variables, as illustrated in Table 4. The results of this analysis revealed that there exists a significant negative correlation of −0.55 between the Water Scarcity Index and Rainfall Levels, indicating that as water scarcity increases, the annual rainfall tends to decrease. This relationship underscores the critical role of adequate rainfall in alleviating water scarcity challenges in agricultural contexts. Over the years, India has witnessed declining rainfall over the Indo-Gangetic belt (Wang et al., 2021). While this phenomenon could result from climatic change over the past years, its deficiency shows a strong correlation.

The results also indicate a positive correlation of 0.65 between the irrigation usage variable and the Water Scarcity Index, suggesting that higher levels of water scarcity are associated with increased reliance on irrigation for crop production. This finding highlights the need for effective irrigation strategies in regions facing water stress. These findings are echoed in a study conducted by Bharambe et al. (2023), who report that various regions in India have equally experienced moderate and severe water scarcity, with its extent related to the level of irrigation in the region within a specific period. Results reported by Mallareddy et al. (2023) also show a negative causal association between farm-level water scarcity and groundwater use efficiency in South India. In the long run, the level of irrigation usage may impact water availability in a region.

Similarly, the results showed a relatively moderate correlation between the Crop Variety Index and irrigation use. This correlation indicates that a diverse range of crops may lead to more efficient irrigation practices, potentially mitigating some of the negative impacts of water scarcity. The method of agriculture and the variety of crops grown in a region can impact the efficiency of irrigation practices in a region (Lakhiar et al., 2024). It can enhance water efficiency, helping farmers reduce environmental burdens and gain an economic advantage. This relationship exists because farming techniques can help retain moisture, hence reducing the need for irrigation (Lakhiar et al., 2024). Growing different crops also allows farmers to adjust water application rates across different field areas, varying on crop requirements. These relationships provide valuable insights into the dynamics between water availability, irrigation practices, and agricultural productivity. The correlation coefficients suggest that careful consideration must be given to these interrelated factors when formulating agricultural policies and practices.

***Table 4: Correlation Analysis Results***

| **Variable** | **Water Scarcity Index** | **Rainfall Levels** | **Irrigation Usage** | **Crop Variety Index** |
|---|---|---|---|---|
| Water Scarcity Index | 1.00 | -0.55 | 0.65 | 0.20 |
| Rainfall Levels | -0.55 | 1.00 | -0.30 | 0.15 |
| Irrigation Usage | 0.65 | -0.30 | 1.00 | 0.30 |
| Crop Variety Index | 0.20 | 0.15 | 0.30 | 1.00 |

### 4.3.3 Multicollinearity Test

On the other hand, this test was carried out to determine the level of correlation between the independent variables. To achieve this result, the study analyzed the variance inflation factor of each independent and control variable to assess the relative influences. Table 5 below shows the results of the correlational analysis. Multicollinearity occurs when independent variables are highly correlated, distorting the estimation process. A variance inflation factor (VIF) value above 10 indicates severe multicollinearity, while values below 5 suggest that it is not a concern.

***Table 5: Multicollinearity Test Results***

| **Variable** | **VIF** | **I/VIF** |
|---|---|---|
| Water Scarcity Index | 3.5 | 0.286 |
| Rainfall Levels | 2.8 | 0.357 |
| Irrigation Usage | 4.2 | 0.238 |

The VIF values are below the critical threshold of 10, confirming that multicollinearity is not present in the dataset. Thus, the independent variables are suitable for regression analysis without adjustment.

## 4.4 Model Estimation Results

### 4.4.1. Fixed Effects Model Results

Fixed Effects Model (FEM) was utilized to estimate the relationship between agricultural productivity and the independent and control variables; Water Scarcity Index, rainfall levels, irrigation usage, and Crop Variety Index. Table 6 shows the panel regression analysis results.

***Table 6: Fixed Effects Model Estimation Results***

| Variable | Coefficient (β\betaβ) | Standard Error | t-Statistic | P-Value | Significance |
|---|---|---|---|---|---|
| Intercept | 1.50 | 0.25 | 6.00 | 0.000 | *** |
| Water Scarcity Index | -1.20 | 0.15 | -8.00 | 0.000 | *** |
| Rainfall Levels (mm) | 0.03 | 0.01 | 3.00 | 0.003 | ** |
| Irrigation Usage (%) | 0.20 | 0.05 | 4.00 | 0.001 | *** |
| Crop Variety Index | 0.40 | 0.10 | 4.00 | 0.000 | *** |

From the data above, there is an intercept value of 1.50, which indicates the base level of agricultural productivity when all independent variables are held constant. This value suggests that there is a baseline productivity level even without variation in water scarcity, rainfall, irrigation usage, and crop diversity. On the other hand, the coefficient for the Water Scarcity Index is -1.20 and is statistically significant at the 1% level ($p < 0.01$). This negative coefficient implies that increased water scarcity leads to a decline in agricultural productivity, holding other factors constant. It also indicates that a one-unit increase in the water scarcity index leads to a 1.2 unit reduction in agricultural productivity.

This strong negative relationship suggests that limited water availability severely constrains crop yields, particularly in regions reliant on groundwater for irrigation. Studies by Dhawan (2017) and Gupta et al. (2019) similarly find that water scarcity leads to substantial productivity losses due to inadequate irrigation and increased crop stress. Naturally, limited water access reduces soil moisture, impacting plant growth, nutrient uptake, and yield quality. Farmers are forced to adopt water-intensive crops less frequently in water-scarce environments, which may reduce the land area under cultivation (Seleiman et al., 2021). This constraint disproportionately affects high-yield crops, typically requiring more consistent water availability. Findings from Kumar and Sharma (2020) also confirm the negative impact of water scarcity on crop yield, although they note that some regions adapt through improved water conservation techniques. However, D'Odorico et al. (2021) offer a contrasting perspective, suggesting that regions with diversified crop portfolios may experience lesser impacts, highlighting the role of resilience strategies.

On the other hand, there is a positive coefficient for rainfall levels (0.03), significant at the 5% level ($p < 0.05$), suggesting a positive relationship where higher rainfall levels are associated with increased agricultural productivity. Based on the data, a one-millimetre increase in rainfall contributes to a 0.03 unit increase in agricultural productivity. This relationship is significant, as rainfall is a primary source of irrigation in many regions within the Indo-Gangetic Plains. Increased rainfall improves soil moisture levels, supporting crop growth, particularly in rainfed farming areas where irrigation infrastructure is limited. Unfortunately, rainfall is one of the key determinants of a region's agricultural productivity. It replenishes groundwater and surface water resources, enabling farmers to maintain high productivity levels. However, variability in rainfall patterns can lead to inconsistencies, causing periods of water surplus and deficit, which complicates water management efforts. The study findings are consistent with studies by Mehla et al. (2023), which emphasize that sufficient rainfall correlates with improved yields. In contrast, Singh et al. (2020) found that regions dependent solely on rainfall are more susceptible to productivity drops during dry spells, underscoring the need for reliable irrigation systems alongside natural rainfall.

The coefficient for irrigation usage is 0.20, indicating that a one-percentage-point increase in irrigated land results in a 0.20 unit increase in agricultural productivity. This positive and statistically significant relationship highlights the critical role of irrigation in stabilizing and enhancing crop yields, particularly in regions facing inconsistent rainfall. These results align with Dinar and Schwabe (2015), who found that irrigated agriculture is less susceptible to yield reductions due to water scarcity. On the other hand, Sharma and

Varma (2018) caution that excessive reliance on irrigation, particularly groundwater, could lead to resource depletion and reduced productivity over time, suggesting the importance of sustainable irrigation practices. Nonetheless, in other areas, irrigation provides a reliable water source that compensates for inadequate or erratic rainfall, allowing for continuous crop cultivation even under water-scarce conditions (Li et al., 2020). This practice controls the water supply, enabling farmers to optimize crop growth stages, resulting in better yields and reduced vulnerability to climate variability (Li et al., 2020). It equally supplements the available soil moisture, especially in dry areas where rainfall may be insufficient.

The data also presented a coefficient of 0.40 for the Crop Variety Index and was significant at the 1% level ($p < 0.01$). This data indicated that a one-unit increase in crop diversity is associated with a 0.40 unit increase in agricultural productivity. This finding suggests that crop diversification plays a key role in maintaining productivity under water-scarce conditions. The adoption of a diverse cropping system by farmers is often better equipped to cope with adverse weather patterns, pests, and disease, contributing to stability and resilience in yields. Compared to the double-crop system crop diversification allows farmers to spread risk across multiple crop types, reducing dependency on a single crop that may be sensitive to water scarcity. Similarly, it also improves crop productivity throughout the rotation cycles. Additionally, some crops enhance soil health and improve water retention, benefiting subsequent crops in rotation. Pingali and Rosegrant (2019) support the study's findings, elucidating that crop diversification enhances resilience to climate stressors. Gupta et al. (2021) also support the study findings, arguing that while diversification has productivity benefits, it may reduce revenue if less profitable crops are included, suggesting that balancing crop variety with market demand is essential.

### 4.4.2. Model Significance and Fit

The F-test indicates the model is statistically significant (F-statistic = 12.45, $p < 0.01$). These results confirm that the independent variables jointly explain variations in agricultural productivity. The adjusted $R^2$ value of 0.75 indicates that the model explains approximately 75% of the variation in agricultural productivity, showing a high level of correlation. Overall, the model estimation results reveal that water scarcity and irrigation practices play crucial roles in determining agricultural productivity in the Indo-Gangetic Plains. While water scarcity has a negative impact, effective rainfall levels, increased irrigation usage, and crop diversity positively influence productivity. These findings emphasize the need for effective water management policies and diversification strategies to mitigate the effects of water scarcity on agriculture.

### 4.4.3. Post-Estimation Tests

#### 4.4.3.1. Fixed Effects Heteroscedasticity Test

The standard error component panel data model assumes that there are no constant serial correlation and constant variations in the disturbances through the FEM. Therefore, in the FEM context, it is essential to assess whether the error terms exhibit heteroscedasticity, as this could impact the efficiency and validity of the model estimates. It is assumed that the Heteroscedasticity indicates that the variance of the error terms changes across observations, potentially leading to biased standard errors and incorrect conclusions. However, these assumptions can be quite restrictive for many panel data applications. Therefore, it is necessary to conduct a Breusch-Pagan test for heteroscedasticity under the null hypothesis of homoscedasticity, as illustrated in Table 7.

***Table 7: Fixed Effect Heteroscedasticity Results***

| **Breusch-Pagan Langrangian Multiplier Test for Random Effects** | | |
|---|---|---|
| Test Statistic | P-Value | Decision |
| 10.24 | 0.005 | Reject $H_0$ (Heteroscedasticity Present) |

The null hypothesis for this test assumed homoscedasticity, meaning that the variances of the error terms are constant across observations. The test yielded a chi-square statistic of 10.24 with a p-value of 0.005, rejecting the null hypothesis at the 5% significance level. This indicates the presence of heteroscedasticity in the dataset, suggesting that the error variances are not constant. As such, the study utilized standard errors in the fixed effects regression analysis to ensure that the estimated coefficients are valid and the standard errors are reliable. This adjustment will provide more accurate confidence intervals and hypothesis tests.

# CHAPTER FIVE

# SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

## 5.1.Introduction

This study's main objective was to assess the impact of water scarcity on agricultural productivity in India between the years 2010 and 2020. More particularly, this study sought to investigate the level of water scarcity in India, specifically in water-scarce regions like the Indo-Gangetic Plains, and how it affects agricultural productivity in the region. Therefore, this chapter presents a comprehensive summary of the study findings and consolidates the key results, providing an in-depth discussion of their implications for agricultural policy and practice. The chapter also offers policy recommendations and outlines practical strategies to enhance agricultural resilience to water scarcity. Additionally, the researcher proposes directions for future studies to build upon the current findings and address the gaps identified.

## 5.2.Summary of Findings

The study found that water scarcity significantly reduces crop yields, with states within the Indo-Gangetic Plains experiencing higher levels of groundwater depletion. Findings also revealed a significant decline in agricultural productivity. The analysis confirmed that rainfall variability is a critical factor affecting yields, particularly during periods of insufficient monsoon rainfall, intensifying water scarcity, and reducing productivity. In contrast, the study found that increased irrigation usage has positively impacted productivity levels, underscoring the importance of efficient water management systems. However, it also highlighted that the reliance on groundwater, a finite resource, presents sustainability challenges for long-term agricultural growth. The study further observed that crop variety plays a mitigating role, as diversification helps stabilize productivity levels even under water-scarce conditions.

## 5.3.Conclusion

The results of this study emphasize the importance of managing water resources effectively to sustain agricultural productivity in the Indo-Gangetic Plains. The significant negative relationship between water scarcity and crop yields underscores the vulnerability of the region's agricultural sector, particularly as many farmers rely heavily on groundwater resources and are thus affected by declining water tables. The findings also highlight the crucial role that rainfall variability plays in influencing productivity levels, suggesting that improving water storage and management infrastructure could mitigate these impacts. The positive relationship between irrigation usage and productivity suggests that investments in surface irrigation systems and more efficient methods are essential for sustaining agricultural growth. Furthermore, the study identifies crop diversity as a key factor in enhancing resilience to water scarcity. Farmers who adopt diverse cropping systems, including drought-resistant varieties, are more likely to maintain higher productivity levels, even under conditions of limited water availability. This finding provides a strategic pathway for policymakers to promote crop diversification as a means to safeguard agricultural productivity.

### 5.4.Policy Recommendations

In light of the findings and policy implications, the researcher offers several recommendations to improve agricultural productivity under water scarcity conditions. Authorities in the region could invest in developing water storage and irrigation infrastructure to reduce the impact of water scarcity. These actions could include building and maintaining reservoirs and canals that maximize the use of surface water, as well as implementing efficient irrigation systems like drip and sprinkler technologies. Such investments are crucial for minimizing water loss and ensuring a stable water supply throughout the year, particularly during periods of inadequate rainfall. Similarly, encouraging the cultivation of drought-resistant and climate-resilient crop varieties is essential for building resilience against water scarcity. Agricultural extension services should play a vital role in educating farmers about the benefits of crop diversification and providing them with the resources needed to implement these practices. By offering subsidies for seeds and technology that support diversified farming, policymakers can incentivize farmers to shift towards more sustainable agricultural practices.

On the other hand, the researcher recommends that future policies should focus on promoting water conservation techniques such as rainwater harvesting, soil moisture retention practices, and the restoration of traditional water bodies to address the long-term challenge of groundwater depletion. These initiatives can help farmers reduce their reliance on groundwater and adopt sustainable practices that preserve water resources. Lastly, encouraging the use of technology in agriculture, such as soil moisture sensors, remote sensing, and precision farming techniques, can significantly improve water management. These technologies provide real-time data that enable farmers to make informed decisions about water use, optimizing irrigation, and reducing wastage.

## 5.5. Areas of Further Research

Building on the findings of this study, the researcher proposes future research directions to further understand and mitigate the impacts of water scarcity. More research should be conducted on other agriculturally significant regions beyond the Indo-Gangetic Plains, such as the Deccan Plateau and the Eastern Coastal Plains. By examining a more diverse set of regions, researchers can identify region-specific challenges and develop targeted solutions that are applicable across India's diverse agricultural landscape. Similarly, incorporating climate change models in future research would allow for the analysis of long-term impacts on agriculture. Such models can project future variations in rainfall and temperature patterns, enabling policymakers to develop adaptive and forward-looking strategies to safeguard agriculture under changing climate conditions.

Data collection techniques are also key in understanding the perspective of farmers and other key stakeholders. Therefore, to enrich the understanding of how water scarcity affects agriculture, future studies should focus on collecting primary data through field surveys, interviews, and focus groups with farmers. This action would provide qualitative insights and allow for a more nuanced understanding of the challenges faced at the grassroots level, and the effectiveness of adaptation strategies. Further research is also needed to examine the role of emerging agricultural technologies in managing water scarcity. Studies that evaluate the adoption and impact of technologies such as precision farming, soil moisture sensors, and remote sensing applications could offer valuable information on how these innovations help farmers optimize water use and enhance productivity.

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