Groundwater Use and its Productivity in Crop Production: An Economic Study in Balasore District of Odisha

A THESIS

Submitted in fulfillment of the

requirements for the award of the degree

of

Master of Science (Research)

By

Arpita Das

SCHOOL OF HUMANITIES AND SOCIAL SCIENCES

INDIAN INSTITUTE OF TECHNOLOGY INDORE

June, 2023

INDIAN INSTITUTE OF TECHNOLOGY INDORE

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"Groundwater Use and its Productivity in Crop Production: An Economic Study in Balasore District of Odisha"** in the fulfillment of the requirements for the award of the degree of **MASTER OF SCIENCE (RESEARCH)** and submitted in the **School of Humanities and Social Sciences, Indian Institute of Technology Indore**, is an authentic record of my own work carried out during the time period from August 2021 to June 2023 under the supervision of Dr. Mohanasundari Thangavel, Assistant Professor, School of Humanities and Social Sciences, IIT Indore.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

Arpita Das 08/06/2023

Signature of the student with date

ARPITA DAS

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

T.MO 08/06/2023

Signature of the Supervisor of MS (Research) thesis with date
Dr. MOHANASUNDARI THANGAVEL

Arpita Das has successfully given her MS (Research) Oral Examination held on **July 5, 2024.**

05/07/24
Signature of Chairperson (OEB) with date

T.MO 05/07/2024
Signature of Thesis Supervisor with date

Kedar. 5/7/2024
Signature of Convener, DPGC with date

Ruchi Sharma 5/7/24
Signature of Head of Discipline with date

ACKNOWLEDGEMENTS

Writing this report has been fascinating and extremely rewarding. I am grateful to a number of people who have contributed to the final result in many different ways. Each of them has provided extensive personal and professional guidance and taught me a great deal about both scientific, and systematic study and life in general.

To commence with, I am obliged to the Indian Institute of Technology Indore and the School of Humanities and Social Sciences for providing an opportunity to carry out this detailed research and study, which can help a long way in better exposure to the problems and issues related to the state and the country.

I take this opportunity to express my deep sense of gratitude and respectful regard to my supervisor Dr. Mohanasundari Thangavel without whose involvement my study would not have started. The door to her office chamber was always open whenever I ran into a trouble spot or had a question about my research or writing. She consistently allowed this report to be my own work but steered me in the right direction whenever she thought I needed it. Her invaluable guidance, constant encouragement, affectionate attitude, understanding, patience, and healthy criticism added considerably to my experience.

I owe my special thanks to Prof. Ruchi Sharma (HoD-SHSS), Dr. Kalandi Charan Pradhan (DPGC-SHSS) and my PSPC members Prof. Pritee Sharma and Prof. Nirmala Menon, who have been extending their constructive suggestions, unstinted support, and timely motivation during the entire course.

I am highly thankful to the experts who were involved in the survey for this report: Mr. Jagajyoti Panda, JE (OAIC) and the Department of OAIC of the surveyed district. Without their passionate participation and input, the survey could not have been successfully conducted. I am also extremely grateful to the respondent farmers, who wholeheartedly explained the actual scenario and provided all the information required for this study.

I would like to acknowledge my indebtedness and render my warmest thanks to Er. S.K. Pattanaik, (Asst. Executive Engineer (Civil), GWS&I) and the Department of CGWB, Bhubaneswar for sharing their time, resources, and knowledge that has been utilized for the comprehensive and systematic preparation of this report.

In spite of his unavoidable academic schedule, I sincerely admire the contribution of my senior Dr. Bidur Paria for inspiring, enlightening me the glance of this study and stimulating discussions on this report. I would also like to thank my friends Snehalata Sahu, Shibani Das, and my other friends for always dropping everything at a moment's notice which helped me improve my work.

Finally, I must express my very profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my period of study and through the process of researching and writing this report. This accomplishment would not have been possible without them.

Thank you all!

DEDICATION

Dedicated to my Family

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMNS

1	BCM	Billion Cubic Meters
2	CGWB	Central Ground Water Board
3	CWC	Central Water Commission
4	DDWS	Department of Drinking Water Supply
5	DGWR	Dynamics of Groundwater Resources
6	DoWR	Department of Water Resources
7	DTW	Deep Tube Well
8	DW	Dug Well
9	EWP	Economic Water Productivity
10	FAO	Food and Agriculture Organisation
11	GDP	Gross Domestic Product
12	GOI	Government of India
13	GWS&I	Groundwater Survey and Investigation
14	ha. m	Hectare meter
15	HYV	High Yielding Varieties
16	IWMI	Integrated Water Management Institute
17	IWMP	Integrated Watershed Management Programme
18	IWP	Irrigation Water Productivity
19	Kms	kilometres
20	Lph	Litre per hour
21	Lpm	Litre per minute
22	Lps	Litre per second
23	m	Meter
24	Mha. m	Million Hectare meters
25	mbgl	Meter Below Ground Level
26	MCM	Million Cubic Meters
27	MDTW	Medium Deep Tubewell
28	Mha	Million hectares
29	mm	Millimetre
30	MoWR	Ministry of Water Resources
31	MSPs	Minimum Support Prices
32	NABARD	National Bank for Agriculture and Rural Development
33	OAIC	Odisha Agro Industries Corporation
34	OLIC	Odisha Lift Irrigation Corporation
35	PWP	Physical Water Productivity
36	QGIS	Quantum Geographic Information System
37	RD&GR	River Development and Ganga Rejuvenation
38	RRHS	Rooftop Rainwater Harvesting Systems
39	SDGs	Sustainable Development Goals
40	SOGWE	Stage of GroundWater Extraction
41	Sq. m	Square meters
42	SRI	System of Rice Intensification
43	STW	Shallow Tube Well
44	ULBs	Urban Local Bodies
45	VIF	Variance Inflation Factor
46	WP	Water Productivity

ABSTRACT

Water, an essential element for sustaining life, is relied upon by the entire human population, who depend on both surface water and groundwater. Groundwater is favored over surface water due to its accessibility and quality. It plays a crucial ecological role by supporting rivers, wetlands, lakes, and subterranean ecosystems within alluvial aquifers. However, in recent decades, the excessive extraction of groundwater has led to a decline in the water table. This has had varied impacts, with both positive and negative consequences. On one hand, groundwater use has provided socioeconomic benefits in the short and medium term, improving human well-being, enhancing agricultural and industrial production, supporting urban and rural development, improving health, and reducing poverty. On the other hand, the high extraction rates have put many aquifers and their associated ecosystems at risk, resulting in long-term environmental impacts. India's groundwater extraction rate, as assessed by the DGWR in 2017, stands at 63.33 percent. Agricultural irrigation is the primary cause of groundwater extraction, consuming nearly 90 percent of the country's groundwater potential. The rapidly increasing population has led to a higher demand for food and fiber, leading to unsustainable groundwater use through the extensive use of high-yielding variety (HYV) seeds. This has resulted in the conversion of previously safe areas into over-exploited zones. To address this issue, it is necessary to realign the cropping pattern with water resource availability in the country. Water productivity mapping can help achieve this goal.

Odisha, an agriculturally dependent state, faces diverse challenges such as recurring droughts in the western regions, pockets of saline water along the coast, and acute water scarcity in other parts. Consequently, the extraction of groundwater is necessary to address these issues. However, the increasing reliance on groundwater resources to meet the growing water demands of various sectors is exerting stress on the groundwater system. According to the estimation by the Directorate of Ground Water Resources (DGWR) compared to 2013, there was a 13.58 percent increase in the stage of groundwater extraction (SOGWE) in 2020 in Odisha. This increase is primarily attributed to higher extraction for irrigation purposes and a decrease in recharge. As a result, five previously classified safe blocks have now become semi-critical, with four of them located in coastal areas.

Keeping in view of this alarming situation, the scope of this study is restricted to the utilization of groundwater for irrigation purposes. The study adopts primary as well as

secondary data analysis to examine the groundwater situation in the state and in the district of Balasore. From the secondary data analysis (a pictorial presentation of Odisha using QGIS and a graph of Balasore district) of the state (2009-2017), it is found that there has been a decrease in rainfall and an increase in irrigation intensity across the state. The deficit rainwater is adjusted through groundwater irrigation for irrigation. In spite of an increase in easily accessible groundwater irrigation, the cropping intensity has declined in the state, and no such significant change in crop diversification in Balasore, which can be attributed due to poor quality input uses, monoculture specifically paddy, and inappropriate irrigation. The primary data collected from the two villages of Balasore district namely Gopimohanpur and Armala were selected for the study following a multi-stage sampling procedure. A total of 100 respondents were interviewed to assess the determinants of groundwater use for irrigation, calculate its productivity, and also find the determinants of this water productivity. It is observed that paddy cultivation is carried out in a major proportion of land in both villages. The OLS regression analysis found that the age of the farmer, soil testing, crop diversification, land size, per-capita food consumption, and source of finance significantly determine groundwater extraction; age of the farmer, share of agricultural income, land size, fertilizer use intensity, and soil testing significantly affect irrigation water productivity, whereas the age of the farmer, share of agricultural income, crop diversification, total input cost, and soil testing affects economic water productivity. The irrigation water productivity is 0.66 kg/m^3 for Gopimohanpur village, and earned them Rs 11.42 per m^3 of water after self-consumption, whereas irrigation water productivity and economic water productivity (of marketed crops) of Armala village are 0.67 kg/m^3 and Rs 10.60/m^3, respectively. The t-test also shows no significant difference in means of water productivity between the villages but exhibits a difference in means between the land holding sizes.

As most of the farmers are small and marginal, the input-output production and management are based on previous experience and observations. Also, crop diversification is not much favourable and is water intensive in nature. In this regard, proper training including soil testing provisions, and awareness about the market and hydro-geological conditions of the place, is of utmost importance. Additionally, crops like millets, pulses, and oilseeds can be encouraged to cultivate with a proper water management system.

Chapter- 1

INTRODUCTION

1.1 Global Scenario of Groundwater Use and Agriculture

Globally, the oceans comprise 97 percent of the planet's water while covering around 71 percent of its surface. Freshwater resources account for only 3 percent of the total water on Earth, with glaciers and ice sheets holding 75 percent of all freshwater, while the remaining 25 percent is stored as groundwater (IWMI, 2015). In recent decades, groundwater has emerged as a crucial natural resource in many countries worldwide.

As a source of water supply, groundwater has various advantages over surface water, including higher quality, better protection against pollution and infection, reduced susceptibility to annual and seasonal fluctuations, and more uniform distribution across large territories. Groundwater is often accessible in areas where surface water is scarce. For countries like Saudi Arabia, Malta, and, Denmark, groundwater is the only source of water supply. In semiarid and arid regions, groundwater is extensively utilized for irrigating approximately about one-third of the land area. In most European countries, groundwater plays a significant role in providing drinking, domestic, and, municipal water supply (Todd & Mays, 2004).

Agriculture is the largest consumer of water globally, accounting for an average of 70 percent of total freshwater withdrawals, which can rise to 95 percent in certain developing countries. While global freshwater resources are projected to be sufficient to meet agricultural demand by 2050 with appropriate investments and technologies, significant water availability discrepancies are anticipated between and within countries. However, water scarcity will persist in regions such as the Near East, North Africa, South Asia, and others where the usage and depletion is high. Cities and industries compete with agriculture for water usage, leading to increasing water stress levels in many countries or regions. Some river basins facing water scarcity align with major cereal-producing areas worldwide.

The 2030 Agenda for Sustainable Development, the Sustainable Development Goals (SDGs), and the Paris Agreement are global frameworks that aim to promote sustainable livelihoods and inclusive growth. Within these frameworks, agriculture holds a crucial role due to its connections to rural development, health, nutrition, food security, and the environment. However, agriculture faces a triple challenge in the current landscape. Firstly, it must increase safe and nutritious food production in order to fulfil the increasing demand caused by population expansion. Secondly, it needs to generate employment, income, and contributing to rural economic growth and poverty eradication. Lastly, agriculture plays a vital role in the sustainable management of natural resources as well as adaptation and mitigation of climate change, which has affected the livelihoods of the most vulnerable populations (FAO, 2017).

1.2 Status of Groundwater Utilization in India

In ancient India, rivers, canals and tanks were the main surface water resources. Many Years of neglect and lack of maintenance and management had reduced the usage, productivity and efficiency of tanks. So tanks have lost 30–35 percent of their water storage capacity which was further supported by groundwater. Groundwater support has come in hand to supplement the tanks and bridge the gap (Palanisami & Thangavel, 2021). Groundwater has been utilized in India for over 6,000 years, dating back to the Vedic times. References to dug wells and guidelines for locating well sites based on certain types of trees, anthills, and soil characteristics can be found in the Holy Scriptures. However, these guidelines were primarily applicable to the Indo-Gangetic alluvial terrain, and their relevance is limited in the hard rock areas. Presently, India faces the challenge of sustaining 15 percent of the world's population with only 6 percent of the world's water resources and 2.5 percent of the world's land (IWMI, 2018). Therefore, both land and water resources need to be carefully managed in a sustainable manner. Approximately two-thirds of India's land is composed of hard rocks, while the remaining portion consists of unconsolidated and semi-consolidated sediments. The average annual precipitation in India is around 4,000 Billion Cubic Meters (bcm). Out of this, the estimated average surface water resources amount to 690 bcm per year, and only 447 bcm can be stored as groundwater (Figure 1.2) (CWC, 2017).

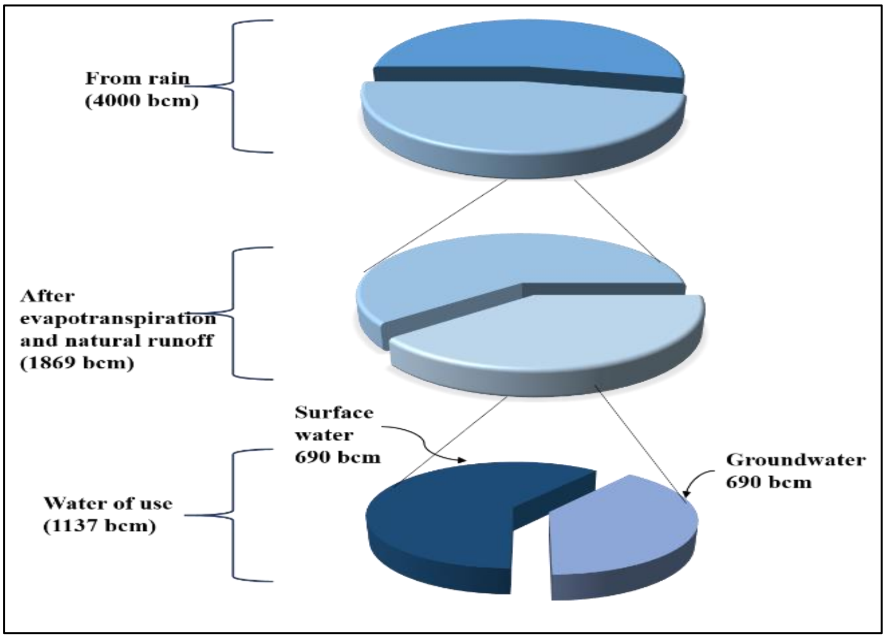

Figure 1.1: Estimated average water resources stored as groundwater in the country

Source- CWC, 2017

As of March 2017, the overall groundwater extraction rate in the country was 63.33 percent. States with the highest groundwater extraction rates include Punjab (165.77 percent), Rajasthan (139.88 percent), Haryana (136.91 percent), and Delhi (119.61 percent). On the other hand, states with the lowest groundwater extraction rates, below 3 percent, are Meghalaya, Mizoram, Nagaland, Manipur, Arunachal Pradesh, and Sikkim (DGWR, 2017). The assessment units are classified into different categories based on their extraction rates.The stage of Groundwater Extraction is to be computed as given below,

Stage of Ground Water extraction = (Existing gross extraction for all uses)/(Annual extractable groundwater resource) × 100

The existing gross groundwater extraction for all uses refers to the total of existing gross groundwater extraction for irrigation, domestic and industrial purposes. The categorization of assessment units for groundwater development is based on two criteria: a) the stage of groundwater extraction, and b) the long-term trend of pre and post-monsoon water levels.

Table 1.1: Stage of Groundwater Extraction in India

Category	No. of Assessed Units (Blocks/ Mandals/ Talukas/Firkas)
Total Assessment Units	6881
Over Exploited (> 100%)	1186 (17%)
Critical (90-100%)	313 (5%)
Semi-critical (70 – 90%)	972 (14%)
Safe	4310 (63%)
Saline	100 (1%)

Source: DGWR, 2017

The long-term trend of groundwater levels is typically calculated over a period of 10 years, considering local hydrogeological conditions. A significant rate of water level decline, ranging from 10 to 20 cm per year, is used as an indicator. The assessment units are classified into four categories: 'Safe,' 'Semi-critical,' 'Critical,' and 'Over-exploited' areas. The specific criteria for categorization can be found in table 1.2.

Table 1.2: Criteria for Groundwater level categorization

Stage of GroundWater Extraction	Category
≤70%	Safe
> 70% and ≤90%	Semi-Critical
> 90% and ≤100%	Critical
>100%	Over-Exploited

Source: DGWR of India, 2017

Apart from the four categories mentioned above, blocks, where the entire assessment area having poor-quality groundwater, are demarcated as ‘Saline’

India possesses some of the largest river basins globally, covering over 32 lakh square kilometers of land with the capacity to capture rainfall. In terms of renewable internal freshwater resources per capita, India holds the ninth rank in the world. Certain projections have been made regarding India's groundwater resource availability, which are presented in Table 1.3. The table shows that the country has been experiencing water stress since 2011[1](where the per-capita water availability was 1544 m^3/year), with per capita water availability steadily declining in the upcoming years. With the increase in population the country would soon become water scare.

Table 1.3: Water availability projections of the country

Year	Population (in billions)	Per capita water availability (in cubic meters per year)
2001	1.03	1820
2011	1.21	1544
2015	1.33	1441
2021	1.35	1421
2031	1.46	1306
2041	1.56	1225
2051	1.63	1174

Source: CWC "Reassessment of Water Availability in India Using Space Inputs," Oct 2017

1.3 Water Productivity in India

Increasing water demands have placed continuous stress on groundwater resources. The number of groundwater extraction structures has significantly increased over the years, from four million in 1951 to 17 million in 1997. As a result, the irrigation potential derived from groundwater has also grown from six million hectares (Mha) to 36 Mha during the same period. However, this has led to various problems, including sea-water intrusion, declining groundwater levels, and water quality deterioration, particularly in certain watersheds covering an area of about 0.2 million square kilometres (Zektser & Everett, 2004). In India, the National Water Policy of 2012 prioritizes drinking water supply, followed by irrigation and industrial use. Out of the total groundwater potential of 432 billion cubic meters (bcm), approximately 71 bcm is allocated for drinking water and industrial purposes, leaving around 361 bcm available for irrigation, which is the most consumptive use (Ministry of Jal Shakti, DoWR RD&GR, 2020). After meeting the aforementioned needs, the remaining water should be allocated to promote conservation and efficient utilization, as advocated by the National Water Policy of 2012. To address the growing water demands, the policy also emphasizes the direct use

[1] Water stress is defined as, per capita water availability below 1700 cubic meters, while water scarcity is defined as, per capita water availability below 1000 cubic meters.

of rainfall, desalination, and reducing inadvertent evapotranspiration to augment available water resources.

India ranks among the nations with the lowest economic water productivity ($3/m^3) when compared to Singapore ($1493/m^3), Australia ($65/m^3), China ($604/m^3), etc. In terms of agricultural crops, India is the world's largest consumer of water for rice, utilizing approximately 2020 m^3 per ton. However, within the country, the highest land productivity for rice is reported in Punjab at 4 tons/ha. Physical Water Productivity (PWP) in Punjab and Haryana is also high, with 0.57 kg/m^3 and 0.4 kg/ m^3, respectively. However, the Irrigation Water Productivity (IWP) in these states is comparatively low at only 0.22 kg/ m^3 (Sharma et al., 2018). Conversely, states with high irrigation water productivity, such as Jharkhand and Chhattisgarh, have poor irrigation coverage (3 percent and 32 percent, respectively), which lowers land productivity. For sugarcane, Tamil Nadu has the highest land productivity (105.3 tonnes per ha) and PWP (14.01 kg per m^3) (Sharma et al., 2018).

The varied water productivity throughout the country in agriculture is fundamental to water demand management in India. Due to inadequate access to water for crop water needs, almost 50 percent of the nation's agricultural land is currently unused for half of its productive period. Due to physical and economic water constraints, water availability is insufficient year-round, even in irrigated areas. In the north-west, central, and southern regions, the alternative groundwater supply has already been over-exploited, and the eastern region experiences uneven extraction. As agriculture uses roughly 78 percent of the freshwater resources available, mapping and enhancing the water productivity of important agricultural crops is one of the important solutions. Instead of merely depending on land productivity, this strategy will help realign the cropping pattern based on hydrological suitability.

1.4 Status of Groundwater Utilization in Odisha

Odisha, a state located on the eastern coast of India, has a geographical area of 155,707 km^2. It is endowed with vast groundwater resources that are largely untapped. The state is divided into 30 administrative districts, comprising 58 subdivisions and 314 blocks. As of the Census in 2011, the population of the state is 4.94 crores with a decadal growth rate of 13.97 percent. The rural population constitutes approximately 83.32

percent. Odisha exhibits five physiographic units, including coastal plains, northern uplands, and erosional plains of the Mahanadi valley, south western hilly region, and subdued plateaus. The state is home to 11 river basins, with most rivers flowing in an easterly and south-easterly direction. Odisha experiences a humid tropical climate, with the normal rainfall in the state recorded at 1502 mm (Agricultural Census, 2015).

The groundwater resources in the state of Odisha have been assessed on a block-wise basis. According to the 2017 groundwater report, the annual extractable groundwater resource in the state is estimated to be 15.57 billion cubic meters (bcm), while the net groundwater availability for future use is 8.85 bcm. The annual groundwater extraction for all purposes is 6.57 bcm, resulting in a stage of groundwater extraction of 42.18 percent. Out of the total of 314 blocks in the state, 308 have been categorized as 'Safe,' indicating favorable groundwater conditions, while the remaining six blocks are classified as 'Saline.' A comparison with the 2013 estimates reveals a 12.11 percent increase in groundwater extraction in 2017. This increase can be attributed to a significant rise of 27.45 percent in groundwater extraction for irrigation purposes within the state, as estimated in 2017 compared to 2013 (Figure 1.2, Table 1.4) (DGWR of Odisha, 2017).

In the state, out of 314 assessment units (blocks), 303 are considered safe in terms of groundwater availability. There are five semi-critical blocks and six saline blocks. The semi-critical blocks include Bahanaga and Baliapal in Balasore district, Bologarh in Khurda district, Garadpur in Kendrapada district and Korei in Jajpur district. The six saline blocks are Ersama in Jagatsinghpur district, Chandbali in Bhadrak district, Marshaghai, Mahakalpada, Rajnagar and Rajkanika in Kendrapada district.

Additionally, about 14 percent (44 blocks) of the total assessment units in the state have a groundwater extraction stage ranging from 60 percent to 70 percent.

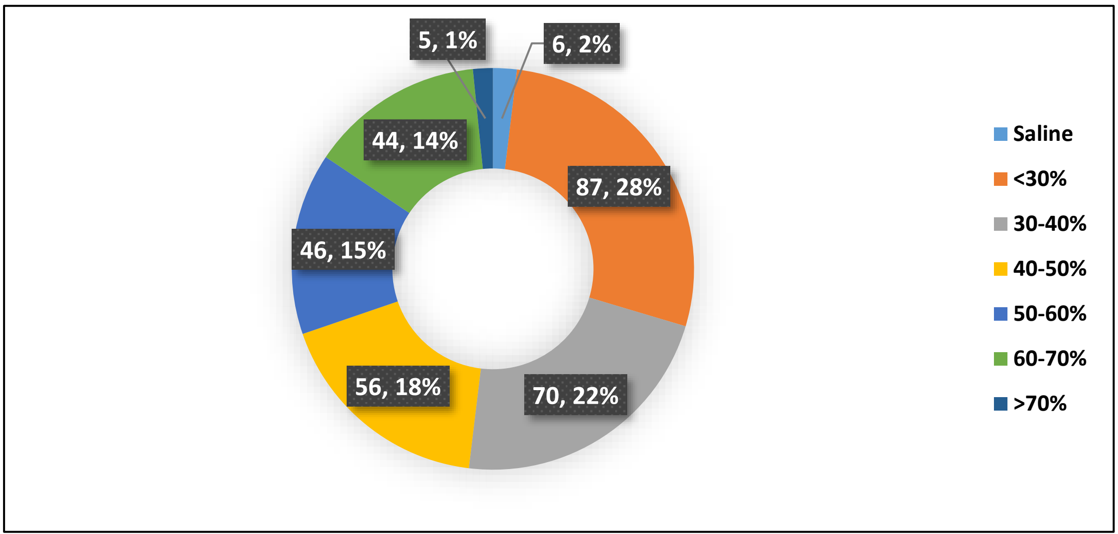

Figure 1.2: Block-wise stage of groundwater extraction of assessment units in Odisha

Source- DGWR of Odisha, 2017

Table 1.4- Groundwater situation of the state

Year	Annual extractable groundwater resource (ha. m)	Gross annual groundwater extraction for all uses (MCM)	Stage of groundwater extraction (percent)	Annual extractable groundwater resource (ha. m)
1992	20001	1431	7.15	20001
1999	21011	3107	14.79	21011
2004	21009	3848	18.31	21009
2009	16689	4362	26.14	16689
2011	16689	4729	28.33	16689
2013	16689	5018	30.07	16689
2017	15571	6568	42.18	15571
2017	15571	6568	42.18	15571

Source- DGWR of Odisha, 2017

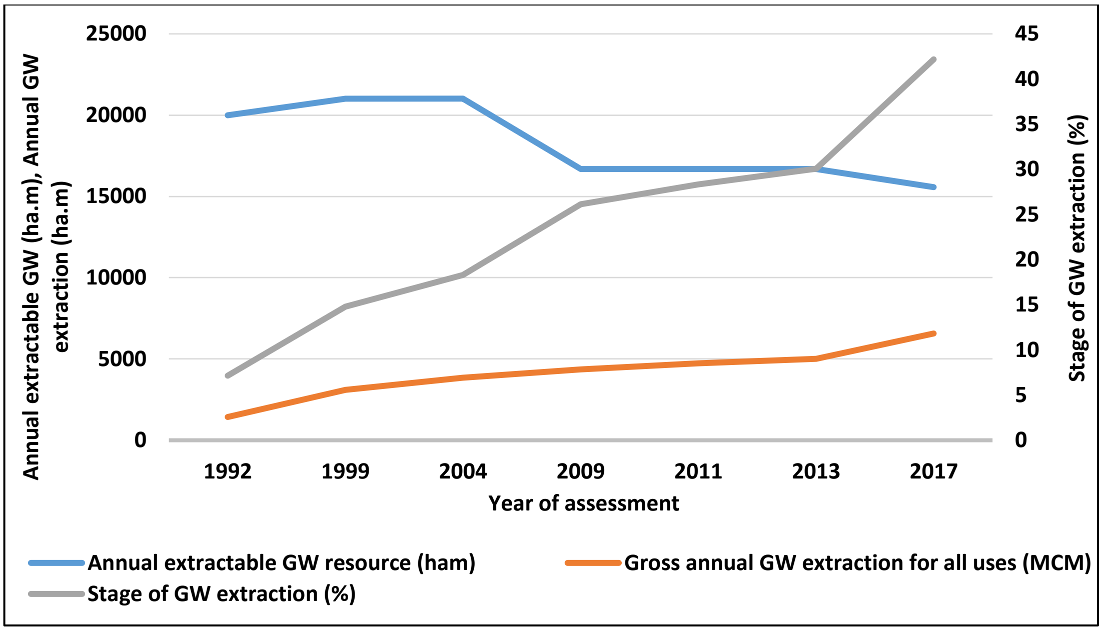

Figure1.3: Groundwater situation of Odisha

Source- DGWR of Odisha, 2017

A comparison of resource figures for the years 2017 and 2013, as shown in Table 1.4, reveals an increase in the Stage of GroundWater Extraction (SOGWE) in 2017 for both individual districts and the state as a whole compared to 2013. The primary reasons for this increase in SOGWE during 2017 are either an increase in groundwater extraction for irrigation purposes or a decrease in recharge. The table clearly indicates that most districts that experienced an increase in SOGWE in 2017 also had higher extraction for irrigation. However, there are a few exceptions, such as Rayagada, Kandhamal, Gajapati, and Ganjam districts, where SOGWE increased despite a decrease in extraction for irrigation. This can be attributed to a decrease in the recharge-worthy area in these districts, leading to a reduction in annual groundwater recharge and an increase in SOGWE. Over the past five to seven years, thousands of private and State Government bore wells and tube wells have been drilled in many districts to expand the areas under assured irrigation (Sixth Minor Irrigation Census, 2017). This has resulted in increased groundwater extraction in many districts, primarily for irrigation purposes, leading to five previously classified safe blocks becoming semi-critical.

1.5 Irrigation in Odisha

Irrigation plays a crucial role in agriculture as it reduces farmers' vulnerability to monsoon variability while increasing productivity and income through multiple crops.

By the year 2013-14, the gross irrigation potential created from all sources in Odisha was 5.005 m.ha (3.353 m.ha during Kharif and 1.652 m.ha during Rabi), and the gross irrigated area during the same year was 3.521 m.ha (2.254 m.ha during Kharif and 1.267 m.ha during Rabi), which accounted for 70.35 percent of the irrigation potential created. For crops like rice, other cereals, sugarcane, and spices, 100 percent of the crop area is irrigated during Rabi season (Economic Survey, 2013-14).

In Odisha, numerous irrigation schemes and projects have been introduced to enhance agricultural productivity. The government initiated the "Deep Borewell Secha Karyakrama" program in 2010-11 to exploit groundwater resources in the state's hard rock areas. The objective is to provide irrigation facilities to blocks with less than 35 percent irrigation coverage. The program was implemented in 256 blocks across 26 districts. Under the Jalanidhi program, individual tube wells and bore wells are promoted with a maximum subsidy of up to 75 percent of the project cost. Large-scale community lift irrigation projects executed by OLIC (Odisha Lift Irrigation Corporation) / OAIC (Odisha Agro Industries Corporation) are eligible for a 90 percent subsidy (DoWR of Odisha, 2020).

In certain Gram Panchayats (GPs) of coastal districts in Odisha (Balasore, Bhadrak, Cuttack, Ganjam, Jagatsingpur, Jajpur, Kendrapara, and Puri), the digging of shallow tube wells (STWs) has been restricted due to their classification as saline and semi-critical areas. The Assistant Agriculture Officer responsible for these areas will not issue permits for STWs, as their execution in saline-affected areas may disturb the delicate balance between saline and fresh water zones, leading to irreversible damage and affecting drinking water sources. Despite these restrictions, unauthorized groundwater extraction continues in these areas, adversely impacting groundwater and agricultural productivity, as well as posing a threat to future groundwater extraction.

While the planning for agricultural development in Odisha seems promising, the effective implementation and monitoring of ongoing and future schemes and projects are crucial. With a large population heavily dependent on agriculture for their livelihoods, ensuring water availability and its efficient utilization is vital for the success of agricultural operations and the overall agrarian economy. To achieve this, it is important to establish a reliable groundwater database and implement an efficient resource management system that includes a robust monitoring system. These measures are essential for planning the judicious and optimal use of groundwater resources in the state.

1.6 Policy Measures and Groundwater Management Initiated by Government of Odisha

i. **Policy Framework State Water Policy-** In 1994, the state of Odisha formulated its first State Water Policy, aligning with the principles outlined in the National Water Policy of 1987. However, over time, new developments, knowledge, issues, and challenges have emerged in water resources development and management. Recognizing the need for a review, the State Government has prepared a revised water policy called the "Odisha State Water Policy-2007." The policy establishes a prioritized order for water allocation, with drinking water and domestic use as the highest priority, followed by ecology, irrigation, agriculture, fisheries, hydropower, and industries, including agro-industries, navigation, and other uses such as tourism.

ii. **Odisha Irrigation Act and Rule**- The Odisha Irrigation Act was enacted in 1959, followed by the Odisha Irrigation Rules in 1961. This legislation addresses the legal aspects concerning the construction and upkeep of irrigation infrastructure. It also specifies the water rates applicable to different categories of irrigation systems that receive water supply. In 1998, the act was amended to include provisions for regulating the use, diversion, and consumption of water for industrial and commercial purposes beyond agriculture.

iii. **Odisha Pani Panchayat Act & Rule**- The Act mentioned was put into effect in 2002 with the main aim of facilitating efficient water utilization by farmers to enhance agricultural production. It also emphasizes the involvement of farmers' organizations in irrigation system management and maintenance to ensure reliable water supply and distribution. The Pani Panchayat Rule further outlines guidelines for the formation, membership, duties, and responsibilities of Water Users' Associations.

iv. **Rooftop Rainwater Harvesting and Groundwater Recharge-** In 2014-15, the Department of Water Resources (DoWR), Government of Odisha, introduced a new State Sector Scheme aimed at rainwater conservation and groundwater recharge. The scheme focuses on the adoption of Rooftop

Rainwater Harvesting Systems (RRHS) in both private and government buildings across all Urban Local Bodies (ULBs) in the state. The scheme includes a provision for providing subsidies to building owners. This eco-friendly initiative does not require any land acquisition or displacement of people. Initially, water-stressed towns such as Bhubaneswar, Behrampur, Bolangir, Jharsuguda, Titlagarh, Puri, Cuttack, Angul, Talcher, Sambalpur, and Rourkela were included in the scheme. In subsequent phases, other cities will be incorporated accordingly.

1.7 Significance of the Study

In his book "An Essay on the Principle of Population," Thomas Robert Malthus highlighted the exponential growth of population and its dependence on agriculture for survival. Groundwater extraction plays a crucial role in irrigation for agriculture. Odisha has abundant groundwater resources, but data from the Directorate of Ground Water Resources (DGWR) of Odisha indicates a depletion in groundwater levels, potentially caused by overdraft or reduced recharge. Almost 90 percent of groundwater extracted is used for irrigation, raising concerns about the sustainability of current groundwater practices as water levels continue to drop.

The cropping pattern in the state is highly skewed towards water-intensive crops, mainly concentrated in coastal districts, which only have crossed 50 percent of groundwater extraction, indicating inefficient groundwater management and uneven distribution within the state.

The Sustainable Development Goals (SDGs) aim to achieve zero hunger and food security. In agrarian regions, food security is heavily dependent on agricultural income, and water is an essential input for agriculture. Meeting these goals requires effective water management, policies, and investments to address the challenges posed by a growing global population, rising incomes, urbanization, and increased competition for water across agricultural, domestic, and industrial uses. Therefore, there is a need to study proper groundwater use and its productivity which impacts on agricultural productivity and food security to contribute decisively to ending hunger. Keeping in view of these concerns, importance of the study are mentioned below:

i. The agricultural sector is by far the largest user of freshwater and water use in agriculture tends to have lower net returns as compared to other competing uses such as in industrial purposes, because of the productivity.
ii. To increase irrigated farmland in the state, private irrigation projects as well as community irrigation projects are highly essential which requires a thorough study of the groundwater potential of different districts of the state in order to restrict over-extraction.
iii. In order to achieve Zero Hunger in an increasingly water-scarce world, it is required for a proper and systematic study of the accessibility and affordability and reliability of irrigation infrastructure and water productivity in particular.

It is important to note that sustainable groundwater management practices are crucial to ensure the long-term availability and productivity of groundwater resources in agriculture. Over-extraction and improper use can lead to groundwater depletion, land subsidence, and deterioration of water quality, highlighting the need for responsible and efficient groundwater management strategies.

1.8 Research Questions

i. What are the determinants that impact groundwater extraction for irrigation?

ii. How is the performance of irrigation water productivity and economic water productivity from the extracted groundwater?

1.9 Objectives of the Study

i. To calculate the amount of groundwater extracted and to find the determinants that impact its extraction.
ii. To measure irrigation water productivity and economic water productivity of extracted groundwater.

1.10 Limitations of the Study

Limitations of the present study are as follows:

i. The study takes only two villages of one coastal district of the state. Further expanding the study areas would enhance the robustness of the results.

ii. The study is confined only to groundwater utilization for irrigation purposes. The other uses of Groundwater drafting are not considered.
iii. Only 100 respondents are taken for the study due to time and resource constraints.
iv. For the secondary analysis, years from 2009 to 2017 are taken into consideration.
v. The interpretation of the data and the conclusion drawn rests on our own knowledge and observations, so the findings of the study are suggestive, not conclusive.

1.11 Organization of the Thesis

The study is presented in the following chapters.

i. **Chapter 1- Introduction:** In this introductory chapter, the status of groundwater, its use and its productivity in agriculture, and various policies implemented by the government to utilize groundwater optimally have been elaborated. Along with it, the significance of the study, the research questions, the objectives and limitations are pointed out on which the study is based on.
ii. **Chapter 2- Review of literature:** It deals with the review of the relevant concepts, reports, and past studies useful for the present study. Based on the reviews, research gaps are drawn accordingly.
iii. **Chapter 3- Data, sampling design and study area description:** This chapter describes the study area selection, the sources of primary and secondary data sets used in the analysis, and the secondary data analysis of the state of Odisha and the district of Balasore.
iv. **Chapter 4- Determinants of groundwater use in irrigation:** This chapter constitutes methodology, observation, and result analysis of objective 1.
v. **Chapter 5- Groundwater productivity in agriculture:** This chapter comprises the methodology, observation, and result analysis of objective 2.
vi. **Chapter 6- Conclusion, policy recommendations and future scope of the research-** This chapter concludes the study by proposing policy recommendations and the future scope of the research.
vii. **References:** Referred books, journals, reports, websites, and documents from websites are listed in this section.

Chapter 2

REVIEW OF LITERATURE

In this chapter, the concepts used in the earlier studies have been reviewed, and those relevant to the present study with reference to the objectives are specified. A review of the past studies has also been done for a better understanding of the subject and to identify the research gaps. This has helped in conceptualization, forming research questions, and determining appropriate analysis tools in arriving at meaningful conclusions. The review has been arranged under the following sub-headings.

2.1 Review of Concepts

- 2.1.1 Groundwater
- 2.1.2 Water Productivity

2.2 Review of Past Studies

- 2.2.1 Groundwater Use in Agriculture
- 2.2.2 Water Productivity in Agriculture
- 2.2.3 Groundwater Management

2.1 Review of Concepts

2.1.1 Groundwater

Water that percolates through rocks and soil and is kept beneath the ground is referred to as groundwater. Aquifers are the rocks that hold groundwater and are often made of gravel, sand, sandstone, or limestone. Water flows through these rocks due to their interconnected spaces, making them permeable. The saturated zone is the area where water fills the aquifer, whereas the aeration zone is made up of areas that are partially occupied by water and partially by air. Groundwater descends until it merges into a zone of dense rock at a certain depth. The depth at which groundwater is found from the surface is referred to as the water table. The water table might be as shallow as one foot below ground or as deep as several hundred metres. Heavy rainfall can cause the water table to rise, while continual groundwater exploitation might lead it to fall.

Extensive research has been conducted on groundwater due to its elusive nature. The study of the occurrence, distribution, and movement of water beneath the Earth's surface is known as groundwater hydrology (U.S. Geological Survey, 2019). The accompanying figure 2.1 illustrates the occurrence of groundwater and related terms.

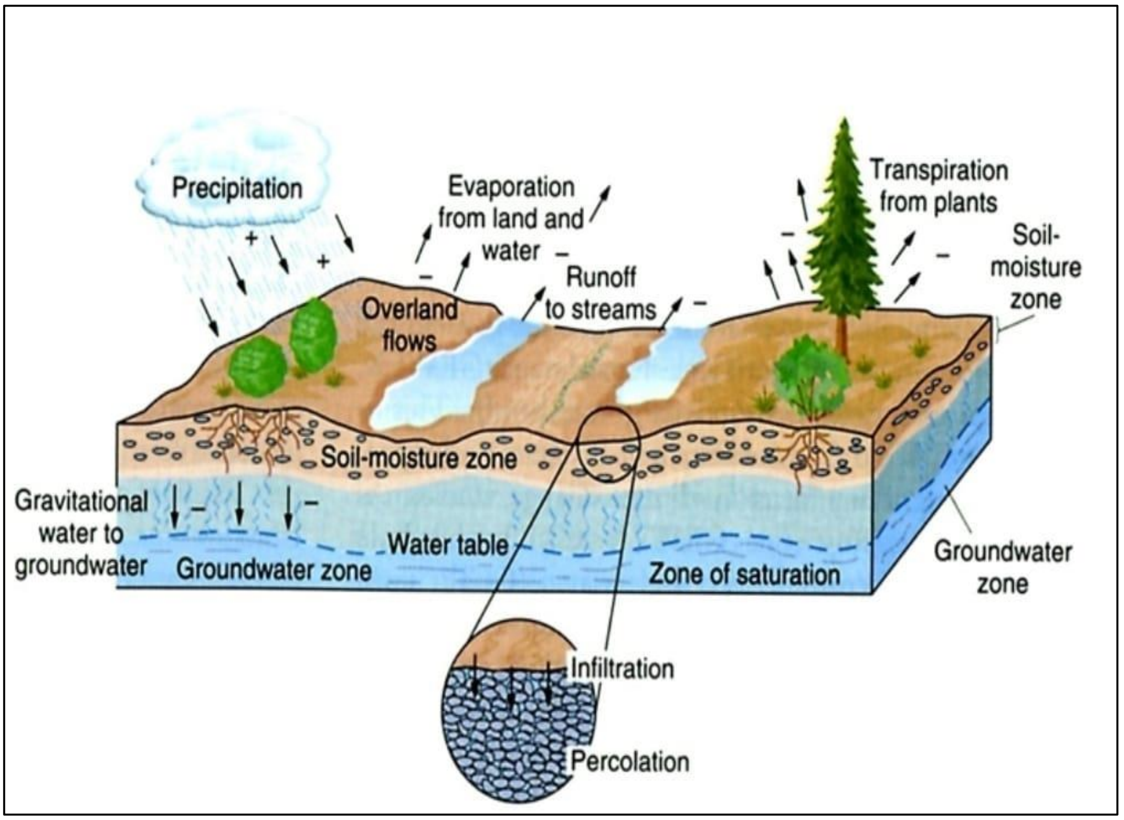

Figure 2.1: Representation of groundwater and associated terms

Source: Illustration by Wijayawardhana, 1998

2.1.2 Water Productivity

To ensure optimal utilization of water resources, accurate physical accounting is necessary. The commonly employed concept in this context is irrigation efficiency, which represents the dimensionless ratio of water utilized by crops to the total amount of water applied (Israelsen, 1950). This fundamental approach to irrigation accounting remained largely unchanged for over four decades. The term water use efficiency (WUE) was first used by Viets (1966) and has since gained widespread usage to describe the yield (photosynthesis, biomass, or economic) per unit of water (transpiration, evapotranspiration, or applied water). This perspective focuses on agronomic and crop production aspects, differing from the engineering definition of irrigation efficiency. Nevertheless, the terminology "water use efficiency" deviates from the conventional concept of "efficiency," which typically employs the same units for input and output. In 1997, Molden introduced the broader term water productivity (WP) for analyzing water usage across various levels of aggregation. In a broader context, "water productivity" concerns to the value or benefits obtained from water utilization. Hence, the concept of water productivity in agricultural production systems aims to achieve "producing more food with the same water resources" or "producing the same amount of food with fewer water resources." In simple words, water productivity is defined as the "crop production" per unit of "water used" (Molden, 1997).

Water productivity can be defined in various ways, depending on the purpose, scale, and domain of analysis (Molden et al., 2001; Bastiaanssen et al., 2003). From the perspective of plant physiologists and agronomists, it represents the ratio of dry matter or grain produced per unit of transpiration or evapotranspiration. For irrigation engineers, it is based on crop yields in relation to the water supplied through canals. Farmers evaluate water productivity by considering the total yield relative to the total irrigation water applied. Economists assess water productivity in economic terms, measuring the value of crop output per unit of water utilized (Singh, 2005). These economic values serve as a useful tool for comparing different crops and evaluating the net benefits derived from specific crops. Moreover, the economic definition of water productivity provides policymakers with a more informed basis for deciding on the allocation of water resources between agricultural and non-agricultural uses (Kijne et al., 2003).

However, while land and labour productivity have long been recognized, the concept of Water Productivity (WP) gained prominence only recently, particularly in developing countries. The current focus of water productivity has expanded to encompass the benefits and costs of water used in agriculture within terrestrial and aquatic ecosystems. In its broadest sense, water productivity aims to achieve increased food production, income generation, livelihoods, and ecological benefits while minimizing social and environmental costs per unit of water consumed (Sharma et. al., 2018).

In simpler and more calculative terms, water productivity is categorized into three broad perspectives:

a) Physical Water Productivity (PWP) is defined as the ratio of agricultural output to the total amount of water consumed by the crops from various sources, including irrigation and rainfall (expressed as kg of produce per cubic meter of water consumed during crop growth, kg/m^3).

$$PWP\ (kg/m^3) = \frac{Agricultural\ output}{Amount\ of\ water\ consumed\ from\ rainfall\ and\ irrigation}$$

b) Irrigation Water Productivity (IWP) is defined as the ratio of crop output to the irrigation water applied by farmers or the irrigation system, such as surface canals, tanks, ponds, wells, or tube wells (expressed as kg/m^3).

$$IWP\ (kg/m^3) = \frac{Agricultural\ output}{Amount\ of\ water\ consumed\ from\ irrigation}$$

c) Economic Water Productivity (EWP) is defined as the ratio of the value of crop output to the amount of water consumed or the amount of irrigation water applied by farmers (expressed as Rs/m^3).

$$EWP\ (Rs/m^3) = \frac{Value\ of\ crop\ output}{Amount\ of\ water\ consumed/Amount\ of\ irriation\ water\ applied}$$

2.2 Review of Past Studies

2.2.1 Groundwater Use in Agriculture

Agriculture plays a vital role in the Indian economy, employing a significant percentage of the population directly and indirectly (Census, 2011). Over time, the cropping pattern in the country has undergone notable changes during different phases. Prior to the Green Revolution, a majority of the land was devoted to food crops, with limited crop diversification. The Green Revolution introduced the Minimum Support Price (MSP) system, which incentivized the cultivation of specific crops like wheat and paddy, leading to intensive agricultural production. This resulted in India achieving self-sufficiency in food grains by the late 1980s. The Economic Reform phase that began in 1991 brought further changes, with globalization creating opportunities for agricultural exports and a more diverse cropping pattern. Additionally, the National Food Security Act (NFSA) promoted monoculture by subsidizing rice and wheat production to ensure food security (Gulati & Juneja, 2022).

The success of the Green Revolution in transforming agriculture towards the cultivation of rice, wheat, and sugarcane can be attributed to effective procurement procedures and government policies aimed at achieving self-sufficiency (Tansale & Jha, 2015). However, various factors influencing agricultural transformation differ among states and regions. Factors such as the family dynamics of the farmer (Bowman & Zilberman, 2013; Thanh et al., 2021), cultural and social values (Pinnawala & Herath, 2014), land-holding size (Gandhi, 2014), financial state (Inwood, 2013); and natural conditions (World Bank Group, 2016). On a broader scale, infrastructure development, information technology advancements, commercialization of agriculture, changes in patterns of food consumption also contribute to agricultural transformation (World Bank Group, 2016; Gandhi, 2014). Additionally, national-level policies associated with irrigation, market conditions (Renaud et al., 2015), and political influences (Archer et al., 2008) also play significant roles in shaping the overall agricultural transformation.

In India, agriculture traditionally relied solely on rainfall. However, due to changing cropping patterns and diverse agro-climatic conditions, the need for irrigation became crucial. The irrigation infrastructure in the country includes a comprehensive network of canals sourced from rivers, groundwater, well-based systems, tanks, and other rainwater harvesting structures. Approximately 160 million hectares (ha) of cultivated land in India is under irrigation, with 39 million ha being irrigated through groundwater, 22 million ha through canals, and about two-thirds of cultivation still reliant on the monsoon (Dhawan, 2017). Among the various sources of irrigation, groundwater plays a vital role in agricultural development, primarily due to its accessibility and quality. It significantly enhances the productivity of other agricultural inputs by providing reliable irrigation, particularly in drought-prone areas. Currently, the importance of groundwater has increased significantly due to technological advancements in extraction methods, financial assistance in the form of soft loans for installing groundwater extraction mechanisms, and a favourable price ratio that encourages water-intensive, commercial, and horticultural crops (Srivastava et al., 2013).

However, there exists a significant variation both between and within regions regarding the extraction of groundwater. Out of the total 6,881 assessment units (Blocks/Mandals/Talukas/Firkas) in the country, approximately 1,186 units (17 percent) in different states have been classified as 'over-exploited,' indicating excessive extraction. Additionally, 313 units (5 percent) are categorized as 'critical,' 972 units (14 percent) as semi-critical, and 4,310 assessment units (63 percent) as 'safe.' Furthermore, there are 100 assessment units (1 percent) classified as 'saline' due to the brackish or saline nature of the groundwater, rendering it unsuitable for domestic or agricultural purposes. The overall average groundwater extraction level for the entire country stands at 63 percent (DGWR of India, 2017). The areas experiencing over-exploitation are predominantly concentrated in the northwestern part of the country, encompassing portions of Punjab, Haryana, Delhi, and Western Uttar Pradesh (DGWR of India, 2017). Despite the presence of abundant replenishable resources in these regions, indiscriminate withdrawals of groundwater, particularly for irrigation purposes, have led to over-exploitation.

Our research focuses on Odisha, an agricultural state in eastern India, characterized by diverse conditions in different regions. The western regions experience recurrent droughts, the coastal areas have pockets of salty water, and many other regions face severe water shortages. According to estimates from the Directorate of Ground Water Resources of Odisha in 2017, there is an increase of 12.11 percent of groundwater extraction from 2013 to 2017 because of irrigation demands and a reduction in recharge rate. As a result, five previously safe blocks have now become semi-critical, with four of them located in coastal regions. The extraction of groundwater from these areas, despite their salt-affected nature, has the potential to disturb the delicate balance between saline and freshwater zones, causing irreparable harm to the drinking water supply. In regions where continuous groundwater extraction is prevalent, there have been negative impacts on agricultural productivity, groundwater productivity, and food security. The coastal districts of Bhadrak, Balasore, Kendrapara, Jagatsinghpur, and Ganjam heavily rely on groundwater irrigation, especially for rice cultivation.

However, the agricultural productivity in these areas remains moderate to low because of traditional farming practices, inefficient resource utilization, and limited water conservation measures. This highlights the need for improved farming techniques, efficient resource management, and enhanced water conservation measures to enhance agricultural productivity in these regions (Pattanayak & Mallick, 2018). The combination of groundwater irrigation and the Minimum Support Price (MSP) for rice has led to a shift from crop diversity to specialization in these coastal areas (Nayak, 2016; Nayak & Kumar, 2018). Since rice is a water-demanding crop, a significant number of blocks in these districts have experienced a rise in salinity (Rejani et al., 2008).

2.2.2 Water Productivity in Agriculture

Irrigated agriculture currently accounts for approximately 40 percent of global food production, utilizing around 20 percent of the world's cropland areas (FAO, 2020). The increasing scarcity of water and land for food production necessitates a focus on enhancing crop water productivity (CWP). Wheat and rice, two major crops cultivated on 21.3 percent of the world's total land area, require substantial amounts of water. On a global scale, average CWP values range from 0.50-1.68 kg/m^3 for wheat and 0.65-3.09 kg/m^3 for rice (Foley et al., 2020). A study conducted by Sharma et al. (2018) assesses the water productivity of ten major Indian crops, including paddy, wheat, maize, tur, chickpea, sugarcane, cotton, groundnut, rapeseed, mustard, and potato. The results reveal that water-intensive crops such as paddy, wheat, and sugarcane are predominantly cultivated in water-scarce regions in north-west India (Punjab, Haryana, and Maharashtra). A significant misalignment between cropping patterns and available water resources is observed when comparing the water productivity water productivity of these crops with their corresponding land productivity. Punjab, Haryana, and Maharashtra exhibit high land productivity but low irrigation water productivity. The existing electricity policy in agriculture in these states has resulted in indiscriminate groundwater exploitation and inefficient water use in agriculture. Conversely, relatively water-abundant states in the eastern region (Bihar, Jharkhand, Assam) lag behind in the production of these crops due to the absence of suitable procurement structures for rice or the presence of sugar mills in their areas. Consequently, there is inequitable water extraction nationwide, with excessive pressure concentrated in specific regions.

As a result of the uneven distribution and extraction of water, particularly groundwater resources, water markets have emerged in the agricultural sector, primarily in critical and over-exploited regions (Singh & Singh, 2006). The term "water markets" refers to localized, village-level informal arrangements where owners of modern water extraction mechanisms (WEMs) sell water to other farmers at a negotiated price (Saleth, 1998). Numerous studies have been conducted to assess the optimality and efficiency of groundwater extraction in these areas.

Singh & Singh (2006) conducted a study in the Meerut district of Western Uttar Pradesh to examine the structure, determinants, and efficiency of groundwater markets. The study utilized a logit model, revealing that the buying and selling of groundwater primarily depended on farm fragmentation and the non-availability of canal water. Furthermore, increased irrigation use would enhance productivity for buyers but result in overutilization of groundwater for sellers. Similarly, Sharma & Sharma (2006) investigated the factors influencing farmers' decisions to buy groundwater in critical and overexploited regions of Rajasthan. The results of the logistic regression analysis indicated that the size of farm holdings and the extent of farm fragmentation were the most significant factors affecting farmers' groundwater buying decisions. Larger land holdings were inversely related to the probability of buying groundwater, while higher levels of fragmentation increased the probability of buying groundwater. Lack of clear groundwater assessment rights and legal regulations regarding its trade allowed farmers with larger holdings to engage in profitable practices by charging higher rates to small and marginal farmers. Srivastava et al. (2009) examined groundwater extraction and water-use efficiency under different water market regimes in the Central Plain Zone (CPZ) of Uttar Pradesh. The study found that paddy, wheat, and sugarcane cultivation were contributing to the depletion of groundwater levels in the region. Estimates from Data Envelopment Analysis (DEA) revealed that both buyers and owners of water markets exhibited technical inefficiencies in water use, with actual irrigation water use exceeding the optimum level. Similarly, Haryana faced a declining water table situation due to low and uncertain annual rainfall, necessitating supplemental irrigation to meet crop water requirements (Singh & Amrita, 2016). Manjunathaa et al. (2011) conducted a study in the Eastern Dry Zone (EDZ) of Karnataka. Using DEA analysis, the study showed that water sellers and control farmers (those who use their own irrigation sources and are not involved in buying or selling groundwater) had higher reduction potential in input use compared to water buyers. Water buyers exhibited higher average technical efficiency, while water sellers demonstrated higher allocative efficiency and cost efficiency. When comparing resource utilization, water sellers were found to be more efficient than control farmers.

Odisha is an agrarian state, whose population largely depends on agriculture. The total population of the state as per 2011 census is 4.19 crores, out of which the rural population is 3.49 crores and the urban population is 0.70 crore. The rural population depends largely on agriculture for their livelihood, and the success of agriculture is closely tied to the availability of water and its efficient utilization (Groundwater Year Book, 2017). But unlike other states of the country, the irrigation facilities are not evenly developed throughout the state rather it is concentrated mainly in the coastal areas. The continuous groundwater extractions without any restrictions in these areas have resulted in salinity problems. Many such studies are carried out in support of these problems.

Pattanayak & Mallick (2018) employed Kendall's Ranking Coefficient method and Skewed distribution to analyze the impact of irrigation on agricultural productivity in Odisha. The study revealed that Balasore and Bhadrak districts exhibited high intensity of irrigation but moderately low agricultural productivity due to traditional farming practices, lack of input efficiency (such as fertilizers, seeds, etc.), and inadequate water conservation practices. Conversely, Jagatsingpur and Kendrapara districts had high intensity of irrigation but low agricultural productivity, while Ganjam district had moderately high intensity of irrigation but moderately low agricultural productivity. Rejani et al. (2008) conducted a study indicating that Balasore district's groundwater basin faced a severe threat of overdraft and seawater intrusion. They observed that the drawdown exceeded the permissible and optimal limits in order to meet water demand during the dry and non-monsoon periods, resulting in saltwater intrusion in both saline and non-saline areas. A study by Panda & Kumar (2011) highlighted the "vertical" competition among farmers in Balasore district, where the rate of bore well failures increased due to unrestricted groundwater extraction. Wealthier farmers owned deeper bore wells located further away from residential areas, as they could afford the electricity costs associated with pumping water from those locations. The presence of these deep bore wells owned by affluent farmers reduced the water yield capacity of shallower wells owned by poorer farmers. Consequently, poorer farmers had to either purchase groundwater or lease their land to wealthier farmers. Empirical relationships derived from pumping test results indicated that well depth and aquifer thickness significantly influenced aquifer discharge. Therefore, when designing a monitoring network, it is important to consider the depth of the exploited aquifer. Implementing a uniform borehole depth policy is necessary to protect the aquifer.

2.2.3 Groundwater Management

Groundwater is an invaluable resource that often goes unnoticed. Regardless of where we live on Earth, there is water beneath our feet. Similar to surface water, groundwater originates from precipitation and continues to move through the ground, sometimes at a slow pace and other times more rapidly. Eventually, it resurfaces and contributes to the global water cycle. Many of us have easy access to water, whether we grew up in cities with public water supplies or in small towns or farms with well water. However, for some people, finding a new water source is crucial. The current trend of groundwater exploitation raises concerns about its sustainability. One major issue in India is water scarcity, which needs immediate attention. The per capita water availability in the country has decreased from 1820 cubic meters in 2001 to 1421 cubic meters in 2021, placing India among the water-stressed nations globally (CWC, 2017). In the state of Odisha, excessive groundwater extraction and frequent dry spells have led to a 6.71 percent decline in groundwater levels between 2009 and 2017 (Water Resource Department, 2017). It is feared that if groundwater continues to be depleted and a region experiences consecutive droughts for two to three years, the state will face significant challenges, including a potential drinking water crisis.

There are multiple factors that contribute to the unsustainable extraction of groundwater. Large-scale deforestation, soil erosion, and excessive pumping have led to a permanent decline in the groundwater table. As the water table continues to lower, pumping becomes more challenging, discharge decreases, costs rise, and ultimately, the utilization of groundwater becomes uneconomical (Pant, 1987). Groundwater is often undervalued, especially in situations where its exploitation is unregulated. In such cases, the exploiter benefits from groundwater use but bears only a portion of the costs, typically the recurring pumping costs and well construction expenses, while ignoring external and opportunity costs. This undervaluation frequently leads to inefficient resource use from an economic standpoint (Das, 2015). There is a lack of systematic information regarding the groundwater economy, particularly regarding the impacts of groundwater depletion on agriculture. Overexploitation of groundwater resources can result in increased power consumption, ecological degradation, and unsustainable agricultural production (Wang et al., 2007). Additionally, climatic stresses such as droughts and rising temperatures contribute to groundwater depletion (Loaiciga, 2003; Panda & Kumar, 2011).

Certain regions, such as the Middle East and North Africa (MENA), face severe water scarcity and rely on other countries to meet their basic water needs, particularly in agriculture. These regions heavily depend on imports to fulfill their domestic food demand. These imports compensate for the water scarcity by utilizing the water resources of other countries through the concept of virtual water transfer. Coined by John Anthony Allan in 1993, virtual water refers to the amount of water used to produce a good or service, representing the water volume embedded in that particular product or service. When goods and services are traded, the embedded water and all the factors involved in their production phases virtually move across countries and regions. This movement of embedded water is known as virtual water trade. The alarming global rates of groundwater depletion can be attributed primarily to water withdrawals for irrigation in support of global food consumption. Approximately eleven percent of non-renewable groundwater used for irrigation is embedded in international food trade. Interestingly, the top three largest virtual groundwater exporters, namely Pakistan (first), the USA (second), and India (third), are paradoxically water-stressed countries. These exporters contribute to two-thirds of the total virtual groundwater exports (Dalin et al., 2017). The excessive extraction of groundwater for irrigation purposes is causing rapid depletion of aquifers in these crucial food-producing regions. This depletion not only poses a threat to the sustainability of water and food production locally but also globally through international food trade (Dalin et al., 2017).

Another controversial factor contributing to groundwater depletion is the Minimum Support Prices (MSPs). The government, driven by political and social objectives to enhance farmers' well-being, consistently increases the MSPs, particularly for water-intensive crops like paddy and wheat. Farmers do respond to price signals, and prices play a significant role in influencing their choices regarding acreage (Bhalla, 2007).

Agriculture experts and some farmers argue that a combination of guaranteed procurement, free power, and input subsidies has resulted in a detrimental paddy-wheat cycle. This cycle has depleted groundwater resources in the northwestern and northern states, deteriorated soil quality, and trapped farmers in a cycle of debt (Shah & Vijayashankar, 2021).

Given that irrigation significantly contributes to groundwater extraction, effective groundwater management becomes crucial. As the economy diversifies away from agriculture towards other sectors, there will be an increase in inter-sectoral competition for water. Consequently, agriculture's share of freshwater supplies is likely to decrease relative to other sectors. However, with a growing population, rising per capita income, and urbanization, the demand for food, feed, and fiber will increase. This presents a challenge: how to sustainably increase agricultural production with limited water resources.

The Economic Survey 2018-19 of India suggests a shift in focus from "land productivity" to "irrigation water productivity." The Department of Agriculture Cooperation & Farmers' Welfare has implemented the "Per Drop More Crop" component of the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY-PDMC). PMKSY-PDMC aims to enhance water use efficiency at the farm level through micro-irrigation technologies such as drip and sprinkler irrigation systems. Drip micro-irrigation not only conserves water but also reduces fertilizer usage, labor expenses, and other input costs. The objective of agricultural development should be to increase productivity per unit of water, particularly irrigation water, rather than focusing solely on land productivity. Given the current water stress in the country, it is necessary to adjust cropping patterns according to their irrigation water productivity, especially for water-intensive crops like rice and sugarcane, to avoid unsustainable agriculture and promote equitable use of scarce water resources (Sharma et al., 2018).

Addressing these challenges requires a multi-pronged strategy. This includes improving productivity and prices of alternative crops (such as oilseeds and pulses), strengthening market infrastructure, adopting the system of rice intensification (SRI), conducting aquifer mapping with comprehensive groundwater flow system data, controlling well depth and spacing, regulating pump capacity and efficiency, and implementing mitigation strategies like delaying paddy transplantation, laser leveling, zero tillage technology, bio-drainage, and rainwater harvesting for artificial groundwater recharge (Singh & Amrita, 2017). Additionally, it is important to recognize the strong interaction between tank irrigation (surface water) and groundwater table, and to use both tank and well irrigation complementarily rather than as substitutes in order to maintain hydrological balance and achieve sustainable water resource management in the long run (Chowdhury & Behera, 2018). In this regard, Pani Panchayat plays a crucial role in the sustainable and efficient management and use of irrigation structures in Indian states. The Orissa Pani Panchayat Act (2002) facilitates a democratic decision-making process, effectively managing irrigation projects. It addresses important aspects such as distribution and pricing of irrigation water, its expansion and, maintenance. Consequently, this approach promotes sustainable agricultural intensification and social inclusion (Behera & Mishra, 2018).

Groundwater management policies worldwide lack the necessary sustainability and efficiency for agricultural groundwater management. Incentive-based groundwater conservation programs serve as a prominent example of well-intentioned policies that can have contradictory consequences. These programs may inadvertently lead to increased groundwater extraction by reducing the marginal cost of irrigation (Sears et al., 2018). Therefore, policymakers must consider the comprehensive implications of their policies, including any potential contradictory consequences when designing regulations.

2.3 Research Gaps

i. The review of past studies revealed the inadequate research on regional and national level in assessing the productivity of water resources particularly in agricultural system. The easy access to groundwater in the coastal districts of Odisha has acted as a double-edged sword. On one hand, it favours agricultural production and on the other side it increases the risk of long-term environmental impacts due to high extraction rates and salt-water intrusion. Some of the coastal blocks of the state have already crossed 60 percent of groundwater extraction, which are facing salt-water intrusion. As groundwater irrigation comprises a major part of extraction in these blocks so the key question is whether it is productive. Only a few studies have been carried out in Odisha to measure groundwater productivity in agriculture. This study will try to enhance the existing literature.

ii. Secondly, a handful of studies have focused on the micro-level effects that influence groundwater extraction and its productivity for irrigation purposes. This study aims to address this knowledge gap by examining the various factors that impact groundwater extraction and productivity for irrigation.

By exploring these influencing factors, the study intends to shed light on the dynamics and determinants of groundwater extraction and its productivity for agriculture in the coastal zone, providing valuable insights for proper water management in irrigation practices.

Chapter 3

DATA, SAMPLING DESIGN, AND STUDY AREA DESCRIPTION

In this chapter, the description of the study area is discussed to enable an effective assessment of the objectives. The chapter also describes the choice of sampling methods and data collection considered for the study. An assessment of secondary data analysis of the Odisha state and the Balasore district has been discussed in the last section. In the last section, the conceptual framework of the two objectives of the study has be explained. It explains the process under the following headings.

3.1 Sampling Design

3.2 Selection of Study Area

3.3 Sources of Data

3.4 Secondary Data Analysis

3.5 Conceptual Framework

3.1 Sampling Design

The study uses the multi-stage sampling technique, by following various sampling methods at each stage. In the first stage, the Balasore district is selected purposively which extracts the highest groundwater for irrigation (DGWR of Odisha, 2017). The district consists of 12 blocks. We have randomly selected two blocks in the second stage which are Jaleswar block and Remuna block with 63.87 percent and 66.78 percent of groundwater extraction respectively (DGWR of Odisha, 2017). One village from each block is further chosen (third stage) at random for purpose of the study. We have selected the village of Goimohanpur from Jaleswar block and Armala from Remuna block. Finally in the fourth stage, a total of 100 respondents, 50 respondents each from the two villages are chosen by the simple random sampling method. With the help of Schedule method, only those farmers have been interviewed who are using groundwater for irrigation. Table 3.1 gives the sampling methods, study area/ respondent identification, and selection details.

Table 3.1: Sampling design

Stage	Sampling Methods	Study Area / Respondents	Selection Details
I	Purposive	District-Balasore	Based on maximum groundwater usage for irrigation
II	Random	Blocks-Jaleswar, Remuna	2 blocks from the Balasore district
III	Random	Village-Gopimohanpur, Armala	One village from each block
IV	Random	Respondents	50 from each village make up the total of 100 respondents

Source: Author's own compilation

3.2 Selection of Study Area

Odisha, an eastern state of India with a geographical area of 1,55,707 sq. km. It is bordered by the longitudes 81°24' to 87°29' in the east and the latitudes 17°49' to 22°34' in the north is endowed with vast groundwater resources. The State is divided into 30 administrative districts, which are further divided into 314 blocks and 58 sub-divisions. With a population of 4.19 crores (Census, 2011) and a density of 269 people per sq. km., around 83.32 percent of the total population resides in rural areas. Odisha has three main morphological units, which include coastal lowlands along the eastern boundary, river basin erosional plains, and northern and southern hilly regions with uplands. The normal annual rainfall of the state is 1451 mm (CGWB, 2017).

Geological setting, topography, and climate play a crucial role in the presence and movement of groundwater. The state can be divided into three distinct units based on its hydrogeological setup: (i) Consolidated formation (Hard rocks), (ii) Semi-consolidated formation, and (iii) Unconsolidated formation. These formations exhibit significant variations in lithological, textural, and structural compositions, resulting in distinct hydrogeological characteristics. Figure 3.1 shows the aquifer map of the state.

The consolidated formations consist of hard crystalline and compact metamorphic rock formations from the Archaeans and Pre-Cambrian ages. These formations lack primary porosity but become porous through weathering and fracturing. Groundwater extraction in this region is feasible through open wells and bore wells. Prominent districts with such formations include Koraput, Kalahandi, Bolangir, Bargarh, Keonjhar, and Mayurbhanj.

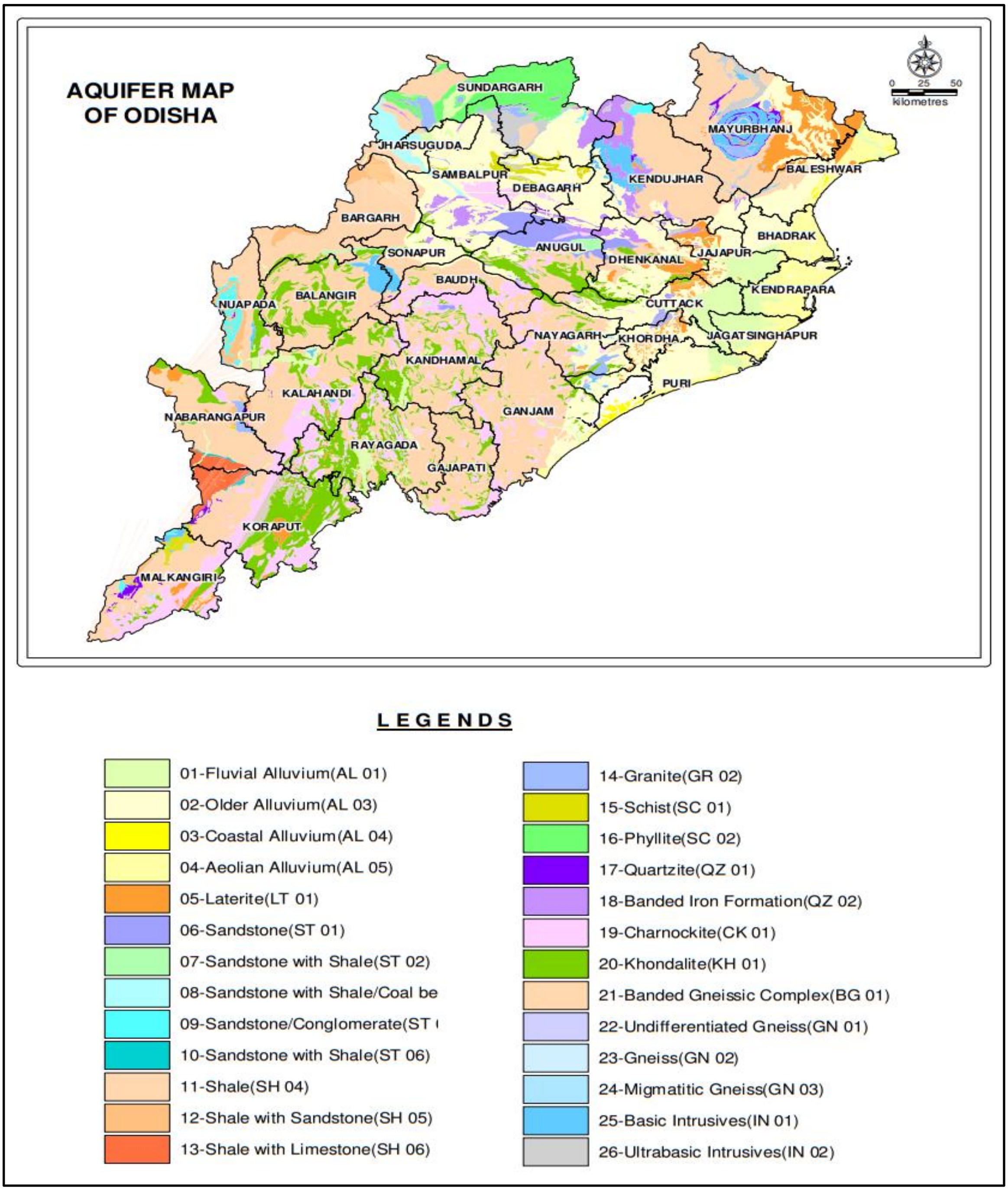

Figure 3.1: Aquifer map of the state of Odisha

Source: CGWB, 2017

The semi-consolidated formations comprise weathered and friable Gondwana sedimentary beds and loosely cemented beds from the Mio-Pliocene age. Coarse-grained, weathered, fractured, and friable sandstone constitutes aquifers with moderate potential. Groundwater occurs under water table conditions in near-surface aquifers and under confined to semi-confined conditions in deeper horizons. Baripada, Dhenkanal, Athgarh, and Bhubaneswar city are partially located in this category. The unconsolidated formations consist of Pleistocene laterites and Recent to sub-Recent alluvium. Groundwater occurs under water table conditions in shallow zones and is accessed through open wells. The coastal areas of the state, including the delta of the Mahanadi river basin, fall under this category.

For the purpose of our study, we have selected one district of the state, that is, Balasore, which extracts the maximum groundwater for irrigation among all the districts (DGWR, 2017). The district is located in northern Odisha, along the coastline of the Bay of Bengal, covering a total geographical area of 3634 sq. km. The district's geography can be divided into three parts: the north-western hills, the inner alluvial plain, and the coastal belt. The north-western hills consist mostly of hilly terrain covered with tropical semi-evergreen forests. The deltaic alluvial plain is highly fertile and serves as irrigated land. The third region, the coastal belt is primarily affected by brackish water from estuarine rivers, making it unsuitable for cultivation (District Statistical Handbook, 2018). Groundwater in the district is found in confined, unconfined, and semi-confined conditions. Unconfined aquifers are commonly accessed through dug wells with depths ranging from 5 to 12 meters. Hard rock formations are tapped using medium-deep bore wells, while alluvial formations are tapped using medium-deep to deep tube wells, depending on the characteristics of the sub-surface aquifers. The district experiences an average rainfall of 1568.4 mm and has a forest cover of 6.9 percent (District Irrigation Plan, 2016). Further from the district, two villages, 50 respondents each from two blocks respectively are chosen randomly which is explained in section 3.1 and presented in figure 3.2.

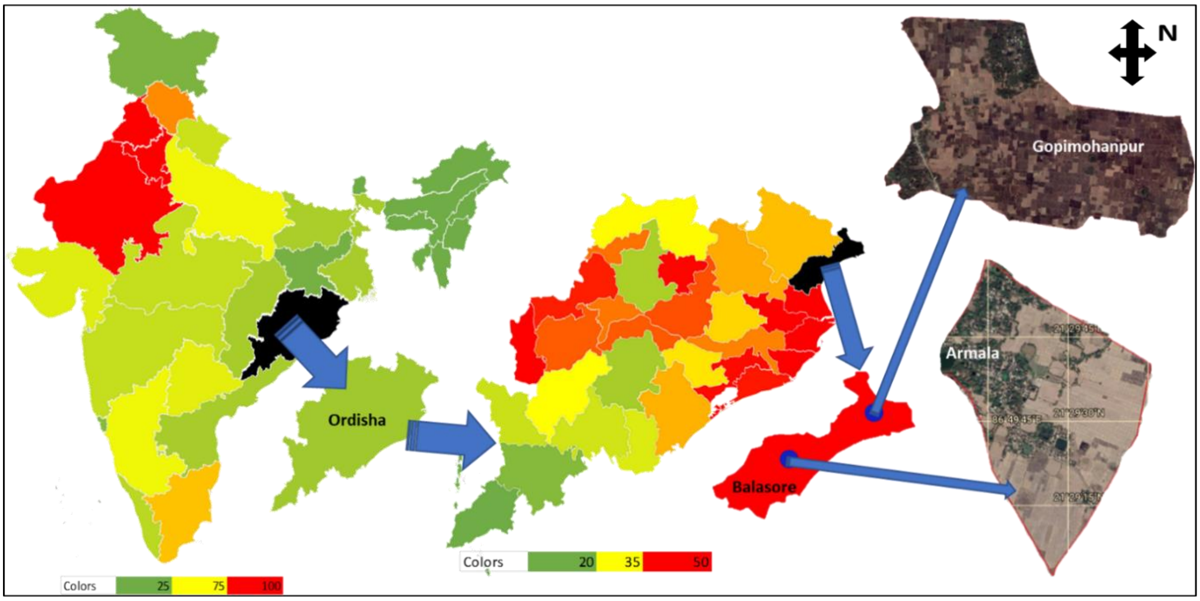

Figure 3.2: Selection of study area.

Source: By Authors' creation using MS Excel and Google Earth

Note - The colours indicate the stage of groundwater extraction of India and Odisha in 2017. For India, the colours are divided as 25 percent, 75 percent, and 100 percent of groundwater extraction, and for Odisha, it is divided as 20 percent, 35 percent, and 50 percent for proper visualization and differentiation.

3.3 Sources of Data

The study relies on both primary as well as secondary data sources. Based on the records of the department of OAIC (Odisha Agro-Industries Corporation), Balasore, the primary data is collected. The sample units, which are the respondent farmers in the study villages exhibit diverse socio-economic conditions. A comprehensive process was followed to identify the study area for this research. Scientists and engineers from CGWB (Central Ground Water Board) and GWS&I (Ground Water Survey & Investigation) in Bhubaneswar were consulted to gather ground-level information. The study district was selected based on their suggestions and information. Additionally, the engineer from the OAIC department of the Balasore district was contacted to obtain a priori information, including demographic details, irrigation sources, cropping patterns, water productivity, and groundwater conditions in the sample villages. Finally, two villages were chosen randomly following the department's recommendations. Interviews were conducted with farmers who solely rely on groundwater for irrigation.

The interviews covered various aspects, such as demographic details, household information, cropping patterns, amount of groundwater extractions, input usage, input costs, market conditions, soil testing facilities, groundwater quality, water conservation practices, and sources of finance, among others.

In the present study, tube wells were considered as the irrigation source for extracting groundwater in the sampled study villages. A total of seven units of tube wells were taken into account, specifically three from Gopimohanpur village and four from Armala village. These units are under the management of the Pani Panchayat, which oversees the water supply system for irrigation. All the tube wells installed by the OAIC department in both villages are designed to draw 84960 litres per hour (lph). Using this water discharge rate, we estimated the total groundwater extracted by farmers in the study villages. This estimation was based on the concept that each crop has specific critical stages requiring irrigation during certain phases of its lifespan. The number of times irrigation is required indicates the critical stages of each crop. The tubewells are designed to discharge a certain amount of groundwater, below which they are considered dysfunctional. The time interval between water discharges varies for different crops based on their requirements and the size of the landholding. To calculate the total water requirement for a single crop in its lifespan in the study villages, the following formula was used: time of water discharged once (in hours) × number of times irrigated (in hours) × discharge of the tubewell (lph) (DGWR, 2017). If a farmer practices multiple or mixed cropping, the amount of groundwater extracted for each individual crop is calculated using the same method and then added up to determine the total groundwater extracted by the farmer over a year.

The primary data for this study was collected from two sample villages from March 2022 to September 2022. The demographic details of the respondents can be found in Table 3.2. The table indicates that the majority of farmers in both villages were small and marginal. All households are involved in farming activities as primary occupation. However, due to insufficient income from agriculture alone, they are also engaged in other income-generating sources to sustain their livelihoods. When it comes to water conservation practices, the farmers do not implement many except for the System of Rice Intensification (SRI). They also mix a small amount of organic fertilizer and compost with chemical fertilizers as using only organic fertilizers does not result in the desired yield, leading to reduced profits. During the interviews, it was revealed that the farmers are willing to adopt water conservation practices. However, they face challenges such as lack of financing and limited access to information, preventing them from implementing these practices effectively.

Table 3.2. Socio-demographic details of household's information

Aspects		Gopimohanpur	Armala
Population	Male	145(52.5%)	129(49.4%)
	Female	131(47.5%)	132(50.6%
	Total	276(100%)	261(100%)
	Earner	127(46%)	125(47.8%)
	Dependent	149(54%)	136(52.2%)
	Total	276 (100%)	261(100%)
Occupation	Agriculture	50(100%)	50(100%)
	SHG	42(84%)	45(90%)
	Regular Employed	6(12%)	18(38%)
	Self Employed	27(54%)	50(100%)
	Casual Labours	12(24%)	16(32%)
	Total household	50(100%)	50(100%)
Land Holding Size	Marginal	33(66%)	9(18%)
	Small	15(30%)	26(52%)
	Semi-Medium	0(0%)	12(24%)
	Medium	2(4 percent)	3(6%)
	Total household	50(100%)	50(100%)
Water Conservation Methods Practiced	Compost	35(70%)	27(54%)
	SRI/SCI	36(72%)	38(76%)
	Mixed Organic and Fertilizer Farming	36(72%)	20(40%)
	Total	50(100%)	50(100%)

Source: Primary Data

Secondary data for this study were obtained from multiple sources, including the departments of CGWB, GWS&I, and Agriculture Statistics of Odisha. The data covers the years 2009, 2011, 2013, and 2017. Detailed information about the variables, their sources, and measurements can be found in Table 3.3. These variables were examined in the graphical analysis, employing QGIS spatial analysis tool and MS Excel.

Table 3.3: Sources of Secondary Data

Variables	Definition	Source
Rainfall Variations (RIN)	Coefficient of variation of rainfall (CV)	Agriculture Statistics of Odisha
Irrigation Intensity (IRI)	percentage share of gross irrigated area in gross cropped area	
Cropping Intensity (CI)	percentage share of gross cropped area in net cropped area	
Yield (YILD)	Index	Author's calculation
Diversification Index	Simpson diversification index	Author's calculation
Stage of Groundwater use	$\frac{Existing\ gross\ extraction\ for\ all\ uses}{Annual\ extractable\ groundwater\ resource} * 100$	Central Ground Water Board (CGWB), Government of India
Groundwater extraction for irrigation	Amount of groundwater extraction for irrigation in ha. m (hectare meter)	
Net groundwater availability for future use	Amount of groundwater available for future use in ha. m (hectare meter)	

Note – Simpson Diversification Index, where $DI_{jt} = 1 - \sum_{i=1}^{m} s_{ijt}^2$, where DI_{jt} - refers to the crop diversification index for district j in the year t, s_{ijt} - represents the share of the ith crop in district j's gross cropped area in the year t. Yield Index = $\sum(a1 * \frac{y1}{y0}) / \sum a1$, Where, y_1 is the given yield, y_0 is the base year yield, a_1 is the given acreage base year is taken as 2013-2014 (Hirsch, 1943).

3.4 Secondary Data Analysis

3.4.1 Changes in the Rainfall and Irrigation Intensity of Odisha

Figure 3.3 presents the actual deviation of rainfall from normal along with irrigation intensity for the years 2009 and 2017. In 2009, Fig. 3.3(a) indicates that the western parts of Odisha, including Jharsuguda, Sambalpur, Deogarh, Keonjhar, as well as some southern parts such as Malkangiri, Koraput, and Gajapati, experienced negative deviations in rainfall ranging from -37 percent to -10 percent compared to the normal rainfall. Coastal areas like Balasore, Kendrapara, Jagatsinghpur, Puri, and Ganjam received rainfall between -10 percent and 10 percent of the normal range. In contrast, central parts of the state such as Bolangir, Kalahandi, Nayagarh, Cuttack, and Bhadrak received more rain than usual. Comparing the rainfall amounts to the water used for irrigation in that year, it becomes evident that the western parts, which received less rain than normal, had lower irrigation intensity (Figure 3.3 (c)).

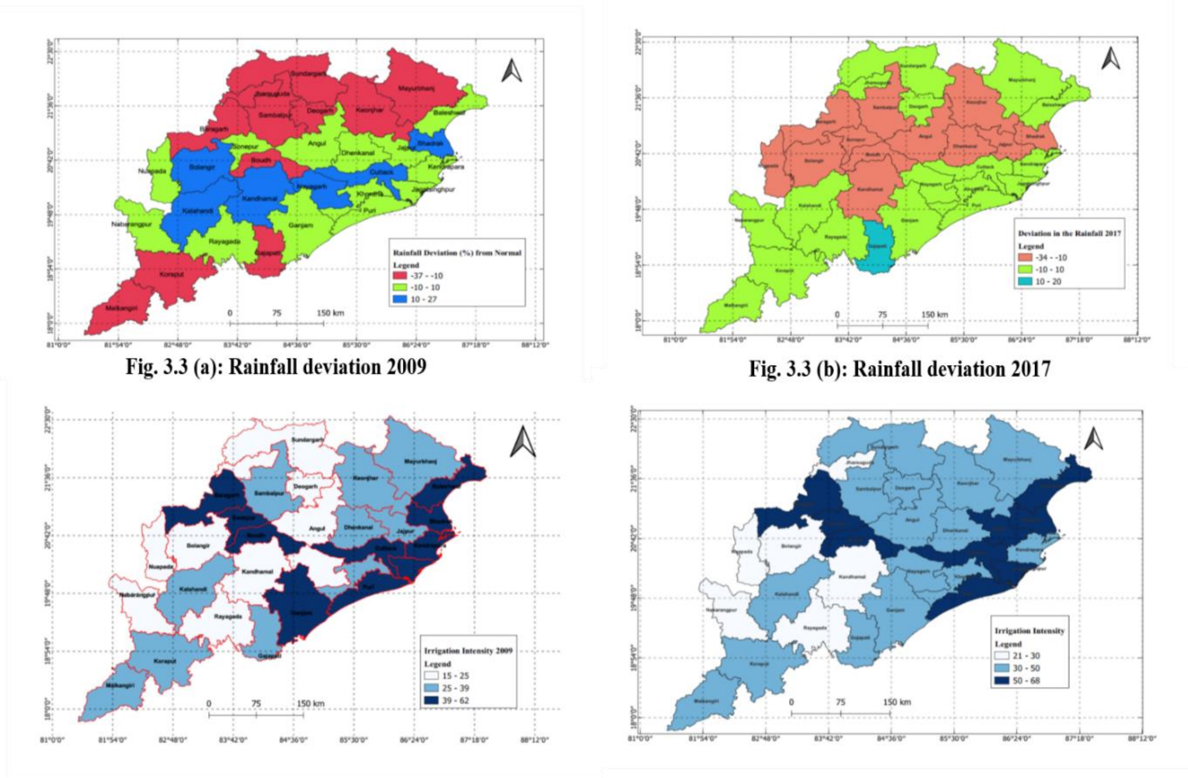

Fig. 3.3 (a): Rainfall deviation 2009

Fig. 3.3 (b): Rainfall deviation 2017

Fig. 3.3 (c): Irrigation Intensity 2009

Fig. 3.3 (d): Irrigation Intensity 2017

Figure 3.3: (a) and (b) Rainfall deviation in 2009 and 2017 respectively, (c) and (d) Irrigation Intensity in 2009 and 2017 respectively

Source- Odisha Agriculture Statistics and Authors using QGIS

Thus, in 2009, the western districts relied entirely on rainwater for irrigation. The coastal areas, with rainfall between -10 percent and 10 percent, exhibited high irrigation intensity, indicating a greater dependence on groundwater for irrigation. Analyzing the rainfall in the state for 2009 and 2017, it can be observed that the overall rainfall decreased, with only Gajapati district receiving more rain than usual, ranging between 10 percent and 20 percent (Figure 3.3 (b)). Additionally, an examination of irrigation intensity reveals that most districts had an intensity ranging from 30 percent to 50 percent, while coastal districts showed high irrigation intensity (Figure 3.3 (d)) (Nayak & Kumar, 2018). Over the years from 2009 to 2017, there has been an increase in negative rainfall deviations, possibly due to climatic changes, while irrigation intensity has simultaneously increased. This illustrates the increasing dependence on groundwater irrigation.

3.4.2 Changes in the cropping intensity and groundwater dynamics of Odisha

Fig. 3.4 illustrates the cropping intensity and groundwater scenario within the state for the years 2009 and 2017. In 2009, cropping intensities were predominantly between 150 percent and 200 percent in most districts, indicating that farmers in these districts cultivated nearly twice a year. Only two districts, Puri and Nayagarh, had cropping intensities exceeding twice a year (Figure 3.4 (a)).

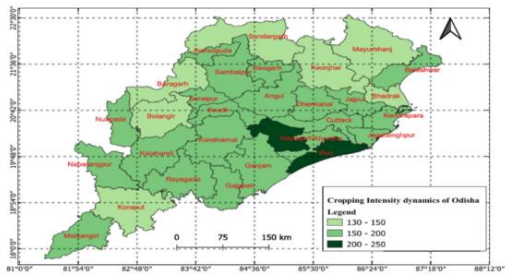

Fig. 3.4 (a): Cropping Intensity 2009

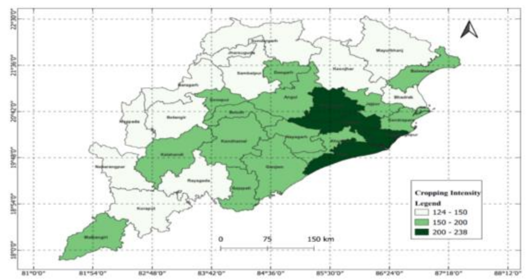

Fig. 3.4 (b): Cropping Intensity 2017

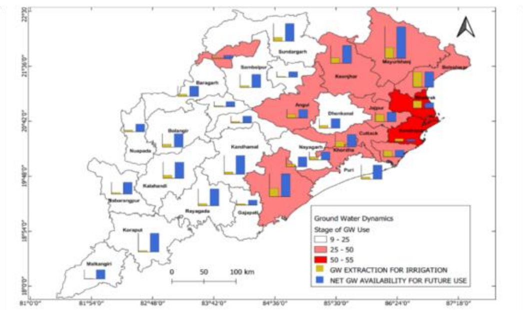

Fig. 3.4 (c): Groundwater Dynamics 2009

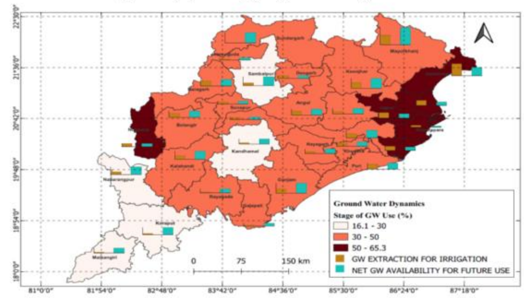

Fig. 3.4 (d): Groundwater Dynamics 2017

Figure 3.4: (a) and (b) Cropping Intensity in 2009 and 2017 respectively, (c) and (d) Groundwater Dynamics in 2009 and 2017 respectively

Source- Odisha Agriculture Statistics and Authors using QGIS

In that year, the groundwater extraction stage is not far along, with most districts ranging from 9 percent to 25 percent, indicating low cropping intensity and limited groundwater irrigation (Figure 3.4 (c)). In districts with higher groundwater extraction, such as Kendrapara and Bhadrak (50 percent to 55 percent), cropping is carried out less than twice a year. Out of the 314 blocks in the state, 236 are located in the hard rock area, covering approximately 90 percent of the geographical area. In these areas, groundwater extraction for irrigation is minimal due to physiographic structures, socioeconomic conditions, poor hydrogeological conditions, lack of extraction infrastructure, and dysfunctional bore wells. As a result, agricultural dependence in the state relies on the remaining 10 percent of the area, which falls under the alluvial soil region, ideal for crop production.

Most coastal blocks are situated in these regions, where irrigation infrastructure is well-developed. However, the tube wells, originally constructed to address groundwater issues and enable uninterrupted extraction, have unfortunately become the primary cause of saltwater intrusion in these areas. The monoculture practice of cultivating paddy, a water-intensive crop, has led to soil nutrient depletion, excessive groundwater use, and seawater intrusion. Comparing these districts with Fig. 3.3, it is evident that they exhibit high irrigation intensity, indicating inefficient groundwater management. In 2017, cropping intensity decreased (Figure 3.4 (b)) compared to 2013, while groundwater use for irrigation increased (Figure 3.4 (d)), resulting in declining net groundwater availability for future use. Districts such as Balasore, Bhadrak, Kendrapara, Jagatsinghpur, and Jajpur on the coast extracted 50 percent to 63.3 percent of groundwater for irrigation (Figure 3.4 (d)). These locations exhibit low cropping intensity, high irrigation intensity, and rainfall deviations ranging from -34 percent to 10 percent. Figures 3.3 and 3.4 demonstrate a significant correlation between irrigation intensity and groundwater extraction in the state. Although irrigation intensity is high, the cropping intensity is not desirable, as noted by Nayak (2016). Negative deviations from normal rainfall over the years indicate the potential depletion of groundwater, as recharge primarily depends on rainfall. Therefore, a realignment of crops and the consideration of groundwater recharge and conservation are necessary in these areas.

3.4.3 Relationship between Irrigation Intensity, Cropping Intensity, Crop Diversification and Groundwater Extraction in Balasore District

Figure 3.5 presents the data on irrigation intensity, cropping intensity, crop diversification, yield index, and stage of groundwater extraction in the Balasore district from 2009 to 2017. The cropping intensity in the district is observed to be below 200 percent, indicating that farmers grow less than two crops per year. It increased from 2009 to 2013 but declined thereafter. Crop diversification, on the other hand, remained relatively stable over the years. Paddy cultivation dominates the district, and farmers tend to avoid risk by sticking to the same crops over time. The yield index exhibits a significant change throughout the period. Initially, it increased until 2011, followed by a decline until 2013, and then showed a positive trend. Interestingly, despite relatively low crop diversification and cropping intensity, irrigation intensity and groundwater extraction have increased over the years. This suggests that farmers are extracting groundwater in an unsustainable manner, lacking awareness of crop water requirements. The excessive groundwater extraction has resulted in saltwater intrusion, particularly since the district is located in a coastal area (Panda & Kumar, 2011). As a consequence, two blocks have become semi-critical and six blocks have experienced partial salinity (DGWR, 2017). Over the span of ten years, the stage of groundwater extraction has increased by nearly 20 percent. Therefore, raising awareness among farmers about the groundwater situation and appropriate cropping patterns has become crucial. The injudicious extraction of groundwater by farmers has led to overexploitation and an improper drawdown of groundwater. Smallholder farmers, relying on their perceptions, have depleted natural resources (Pattanayak & Mallick, 2018).

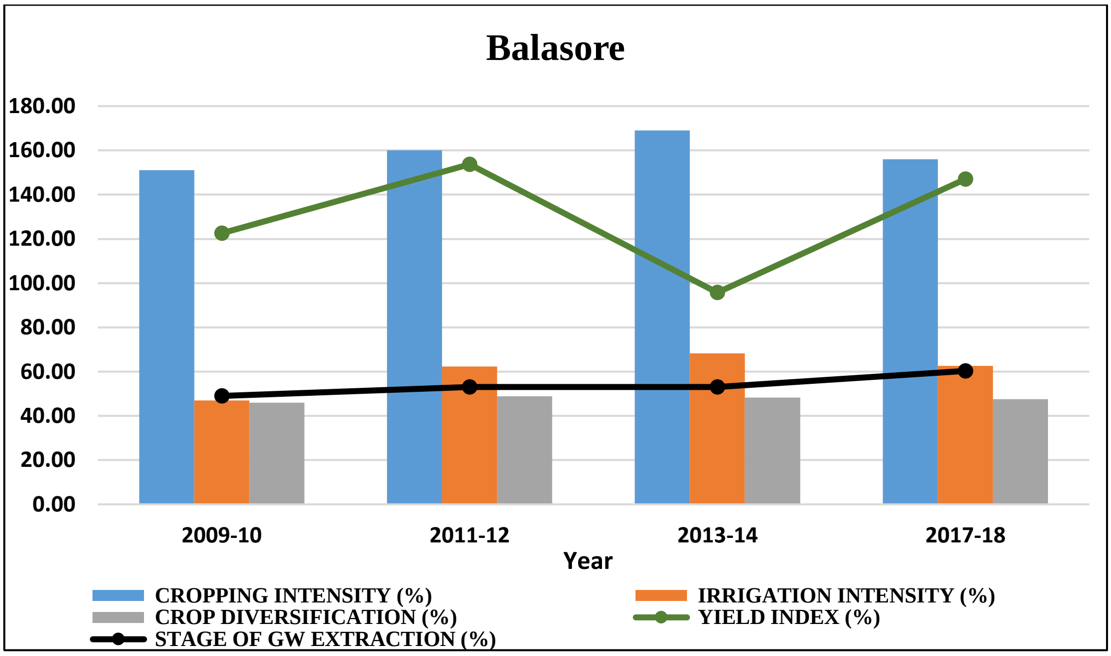

Figure 3.5: Relationship between irrigation intensity, cropping intensity, crop diversification, and groundwater extraction in Balasore district

Source- Odisha Agriculture Statistics and authors' compilation using MS Excel

3.5 Conceptual Framework for Primary Data Analysis

The study's overall conceptual framework for the two objectives based on primary data is presented in Figure 3.6. For Objective 1, the study calculates the total amount of groundwater extracted by respondent farmers and clarifies the factors that determine the extraction. Regarding the second objective, suitable econometric tools are used to calculate irrigation water and economic water productivity, as well as their determinants. Each objective is discussed in separate chapters, covering specific methodologies, conceptual frameworks, and analyses.

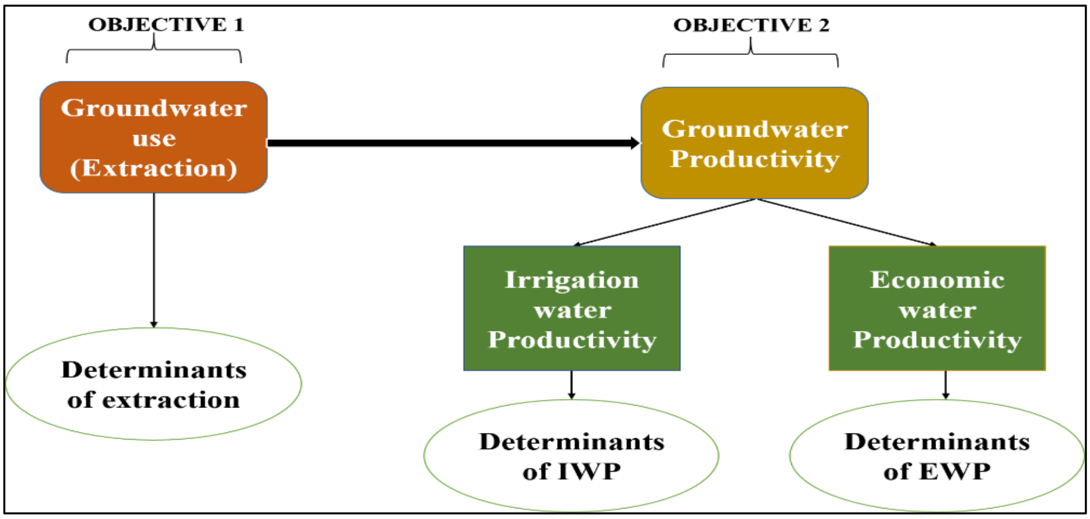

Figure 3.6: Conceptual framework of the objectives

Source: Author’s compilation

Chapter 4

DETERMINANTS OF GROUNDWATER USE IN IRRIGATION

4.1 Introduction

Globally, 70 percent of groundwater withdrawals are contributed towards agricultural production. North America uses 59 percent of its land area for groundwater irrigation, whereas South Asia and North Africa irrigate 57 percent and 35 percent respectively (UN World water Development Report, 2022). India, where agriculture employs more than half of the labour population and produces around 18 percent of GDP (Paria et al., 2021), predominantly uses groundwater for irrigation. Since the Green Revolution, there have been substantial modifications to the country's cropping pattern. The Green Revolution succeeded the agricultural transformation towards rice, wheat, and sugarcane due to well-managed procurement procedures and government policies in order to attain self-sufficiency (Tansale & Jha, 2015). However, there are other drivers that affect the agricultural transformation that differs between states or even regions within a state. Farmers' family dynamics, such as family size, age, education, and knowledge (Bowman & Zilberman, 2013; Thanh et al., 2021)), socio-cultural values, such as relationships, behaviours, attitudes, and beliefs (Pinnawala & Herath, 2014), land size (Gandhi, 2014), economic conditions (Inwood, 2013), and natural conditions, such as weather, climate, and soil (Saravanakumar et al., 2022; World Bank Group, 2016), can all contribute to transformation at the smallholder level.

In the state of Odisha, which is predominantly agricultural, different regions face diverse conditions, including recurrent droughts in western areas, pockets of salty water along the coast, and severe water shortages in many other regions. According to the estimates provided by the Directorate of Ground Water Resources (DGWR) of Odisha in 2017, groundwater extraction in the state increased by 12.11 percent between 2013 and 2017 due to irrigation demands and a decrease in recharge. As a consequence, five safe blocks have transitioned into semi-critical, with four of them located in coastal regions. The intrusion of saltwater into freshwater zones poses a significant risk, as the delicate balance between these two can be disrupted, resulting in irreparable damage to the drinking water supply. Despite these concerns, groundwater continues to be extracted from these regions, negatively impacting groundwater productivity, agricultural output, and food security, and posing a threat to future groundwater availability. The coastal district Balasore, one of the paddy-cultivated districts is facing a threat of groundwater over-extraction. The extraction of groundwater for irrigation in most of the blocks is more than 95 percent of the total extraction. SOGWE of the district is estimated at 60.31 percent (DGWR of Odisha, 2017).

Hence, groundwater extraction for irrigation is a significant issue as it is being done in an unsustainable manner. To address this problem, it is important to analyze the specific factors that contribute to groundwater extraction. These factors can vary depending on the location's hydro-geological conditions, agro-climatic conditions, and socio-economic conditions. While some studies have explored the effects of certain variables on groundwater extraction, such as soil testing, seed replacement, source of financing, household food intake per capita, and type of fertilizer, there is still a knowledge gap at the micro-level. This study aims to fill this gap by examining the influence of these factors, along with crop diversity and land holding size, on groundwater extraction. By understanding the specific factors that contribute to groundwater extraction, appropriate actions can be planned to address the issue effectively.

4.2 Conceptual Framework

Figure 4.1 illustrates the factors that influence the quantity of groundwater used for irrigation based on field experience. These factors can be categorized into farmer characteristics, farm characteristics, the market for agricultural inputs, and access to finance and institutional support for soil testing. These factors interact with each other, either directly or indirectly, and can act as constraints or opportunities for groundwater extraction.

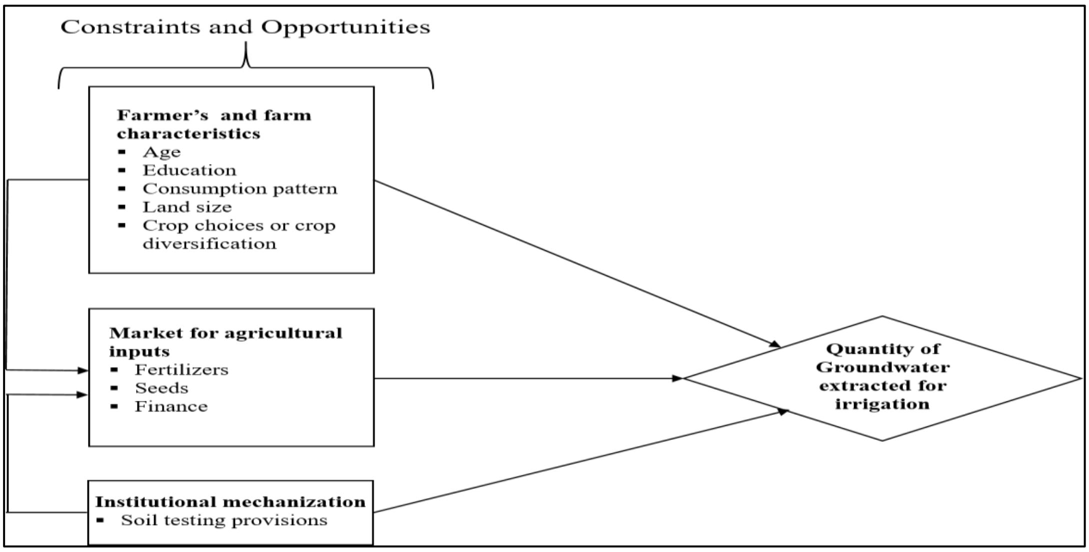

Figure 4.1: Conceptual framework of the factors influencing the quantity of groundwater use for irrigation

Source- Authors' compilation from field experience

The age and education of farmers play a significant role in encouraging soil testing to determine soil nutrient requirements. This knowledge informs fertilizer application, helping farmers decide the type (organic or chemical) and amount of fertilizer to use. Additionally, farmers' previous experiences, understanding of seed quality, and yield rates influence their choice of using certified purchased seeds or farm-saved seeds (Shivaswamy et al., 2022). Age and education can also have a positive or negative correlation with crop diversification. Younger farmers may be more innovative and willing to take risks, while older farmers may have a better understanding of soil texture and weather conditions, leading to diversified crops (FAO, 2014). Educated farmers are likely to have a better grasp of market conditions and can navigate uncertain events, facilitating crop diversification. However, educated farmers may also consider the opportunity cost of diversification compared to other income sources. Landholding size directly impacts crop diversification, considering factors such as input availability, soil suitability, climatic conditions, and irrigation facilities. A larger land holding provides more opportunities for cultivating different crop varieties. Access to finance, both self-financing and borrowing from formal and informal sources, significantly influences farmers' investment decisions and production choices. Lack of appropriate risk mitigation products or financial instruments that align with farmers' needs can discourage them from adopting better technologies, purchasing inputs, or making decisions that could improve farm efficiency and diversify crops. The consumption pattern of farming households, including food and non-food consumption, is influenced by land holding size and income sources.

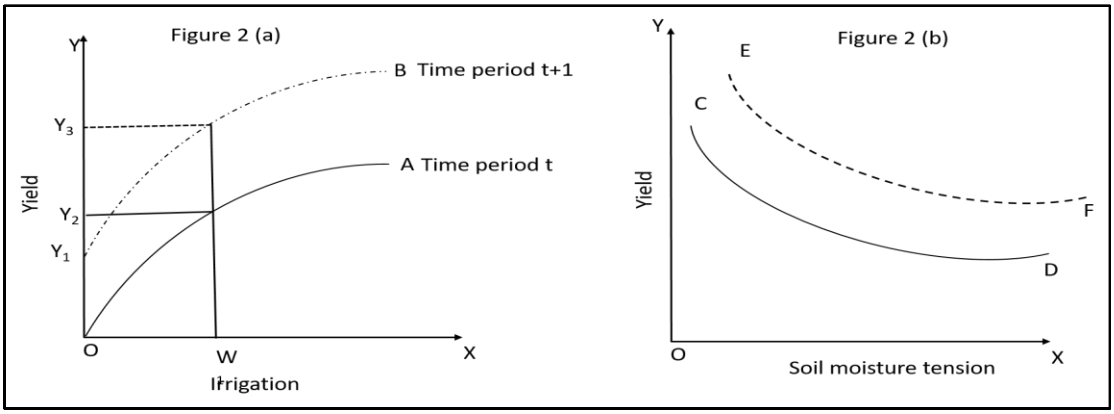

Figure 4.2: (a) Relationship between irrigation and yield, (b) Relationship between soil moisture tension and yield and its impact on fertilizer use

Source- Hexem and Heady, 1978, pp. 30, 32

Rural households primarily consume food grains cultivated on their own farms, and larger land holdings allow for a higher proportion of food consumption within the household, ensuring food security. Income volatility, both from farm and non-farm sources, and agricultural investments also impact the consumption pattern of farming households. The outcomes and extent of the relationship between these independent variables and groundwater usage are detailed in Section 4.4, based on field experience.

Apart from this, our study has also focused on the impact of soil testing and fertilizer usage on groundwater irrigation. This is explained with the help of figure 4.2. The yield response to water availability is influenced by the soil's texture and water-holding capacity. Soil water can be categorized into three types: gravity water, capillary water, and hygroscopic water. Capillary water, also known as soil moisture, is the water available in the soil pores that plant roots can access through osmotic pressure (Zhai et al., 2019). According to Moore's equal availability theory, irrigation should be applied when the soil moisture is slightly above the wilting point of the plant. Soils with higher water-holding capacity require less frequent irrigation compared to soils with lower water-holding capacity (Schwankl & Prichard, 2009). In addition to soil water content, nutrient availability is crucial for plant growth and productivity. Water and fertilizer both contain essential nutrients for plants. In situations with lower water-holding capacity or deficit irrigation, fertilization can help mitigate the negative effects of water scarcity by providing concentrated nutrients, thereby promoting plant growth and increasing yield (Dong et al., 2011). However, excessive water and fertilizer application beyond the optimal requirements can lead to problems such as excessive water utilization, increased costs, groundwater contamination, and reduced yield and quality of plants (Sylvester-Bradley & Kindred, 2009). Overuse of chemical fertilizers can also decrease the soil's organic matter, affecting its physical, chemical, biological, and ecological properties, including water-holding capacity. Therefore, it is crucial to apply water and fertilizer appropriately in terms of timing, type, and amount to enhance efficiency and maximize yield (Lal, 2012; Subhani et al., 2012). Soil testing plays a vital role in determining the nutrient requirements of plants, helping farmers make informed decisions about water and fertilizer management. Figure 4.2 (a) illustrates the relationship between irrigation and yield. It shows that even without irrigation, there can be a certain level of yield (OY_1). By conducting soil testing and understanding plant and soil nutrient requirements, water can be saved as the soil's water retention capacity can contribute to yield (OY_2 and OY_3) with less irrigation. The figure 4.2 (b) demonstrates the inverse relationship between soil moisture tension and yield. As soil moisture tension increases, the plant roots face difficulties in extracting water, resulting in lower yield (curve CD). Increasing fertilization can help increase yield (curve EF) by compensating for the water deficit. The appropriate input levels for achieving desired yield can be determined by considering the substitution between water and fertilizer. To ensure fertilizer efficiency, it is important to consider the time, type, and amount of fertilizer application (Abid et al., 2012). Soil testing prior to cultivation can provide valuable information about soil characteristics and nutrient requirements, facilitating optimal land preparation and management decisions.

4.3 Methodological Approach

The determinants of groundwater used for irrigation were identified through a comprehensive review of the literature and field visits. These determinants were then analyzed using Ordinary Least Square (OLS) estimation. The key determinants identified include the age of the farmer, level of education, landholding size, whether soil testing has been conducted, the type of fertilizers used (solely chemical or a combination of organic and chemical), the seed replacement rate for the Rabi season, crop diversification, per capita food consumption, and whether the household has invested in agriculture using its own source of finance. By examining these determinants, we aim to understand their respective impacts on groundwater usage and irrigation practices. The OLS estimation allows us to statistically analyze the relationships between these variables and provide insights into their significance and magnitude of influence. The functional form can be expressed as:

Groundwater use = f (Age, Education, Land holding, Soil-testing, Type of fertilizer, Seed Replacement Rate for Rabi, Crop diversification, Per-capita Food Consumption, Self-financing)

The study recognizes that the extraction of groundwater for irrigation is influenced by several factors, including soil texture, water-holding capacity, seed replacement rate, and the type of fertilizer used. Regular soil testing by farmers can help address these factors by providing insights into soil characteristics. In the analysis, we specifically considered the seed replacement rate for the Rabi season. During this season, farmers focus on maximizing profits and adjust their inputs, including irrigation, accordingly. Compared to the Kharif season, farmers have better control over irrigation in the Rabi season. Regarding fertilizer usage, none of the farmers in the study relied solely on organic fertilizer. Thus, we categorized farmers into two groups: those using only chemical fertilizers and those using a combination of organic and chemical fertilizers. The size of the landholding and the variety of crops cultivated also impact groundwater usage. These factors were given due attention in the analysis. Financing is a crucial determinant in agricultural investments and expenditures. Self-financing, which is considered a reliable source of finance, was included as an independent variable in this study. Lastly, in rural areas, household food consumption largely depends on crops produced on their own farms. Therefore, this factor was taken into consideration to examine the interconnections between fertilizer usage and groundwater usage. Hence, the model thus formed is

$$\ln GW\ Use = \beta_0 + \beta_1 lnAge + \beta_2 lnEdu + \beta_3 lnLH + \beta_4 ST + \beta_5 TF + \beta_6 SRRR + \beta_7 CD + \beta_8 lnPFC + \beta_9 SF + \epsilon$$

Where, $GW\ Use$ is the groundwater use for irrigation, Age is the age of the farmer, Edu is the education of the farmer, LH is the land-holding size of the farmer, ST is the soil testing, TF is the type of fertilizer used, $SRRR$ is the seed replacement rate in the rabi season, CD is the crop diversification, PFC is the per capita food consumption and SF is the self-financing[2]. $\beta_1, \dots, \beta_9$ are the respective slopes of the independent variables, β_0 is the intercept term. The error term ϵ, follows all the properties of the OLS regression method (Gujarati & Sangeetha, 2007). Since the dependent variable is a continuous variable and the independent variables include both continuous and categorical variables, the literatures also support an OLS regression for efficient estimations (Birthal et al., 2015; Mango et al., 2018). A step-wise methodology is adopted using STATA software following the appropriate procedure. In addition, statistical tests like VIF (Variance Inflation Factor) and Breusch-Pagan/Cook-Weisberg have been used to test the presence of multicollinearity and heteroscedasticity in the model.

[2] The units of all the variables are presented in table 4.3

4.4 Primary Data Analysis

4.4.1 Groundwater Extraction, Cropping Pattern of the Respondent Farmers

In our sample blocks, seven units of tube wells are taken into consideration i.e., three from Gopimohanpur of Jaleswar block and four from Armala village of Remuna block. These units come under Pani Panchayat, which manages and maintains the water supply system for irrigation. All the tube wells are designed to draft 84960 lph (liters per hour) in both villages which are installed by the OAIC department.

Table 4.1 and 4.2 indicates the crop cultivated and total volume of groundwater discharged during Kharif, Rabi, and Summer seasons for the cultivation of Paddy, and non-Paddy which includes Maize and Vegetables in the sample villages of the two blocks under study.

The respondent farmers of Gopimohanpur village of Jaleswar block practice multiple cropping by producing only paddy twice a year in Kharif and Rabi seasons. There is no crop diversification in this study village and this practice has been continuing for a long. Even though the soil, climate, and irrigation facilities have encouraged them to practice only paddy but the crop choice decision are mainly based on demonstration effect, lack of awareness, and generation farming. This means that, as per the respondents, even if they are aware and concerned about the soil health and depleting groundwater level, they are unaware of how to grow other alternative crops profitably by the efficient use of inputs, and also none of the farmers are taking any initiative in this regard. So they are practicing the same pattern over and over again.

On the other hand, the farmers of Armala village of Remuna block practice multiple and mixed cropping under which they grow paddy, maize, and different kinds of vegetables in all three seasons. The irrigation facilities along with the soil and climatic conditions of the place have encouraged them to practice varieties of crops. But as the block is partly saline and there is no awareness among the farmers like that of the earlier village, the respondents do not adopt any water conservation methods to harvest water efficiently. The respondent farmers of both villages do not grow Paddy at all in the summer season.

Farmers of Gopimohanpur village cultivate only paddy in a total of 128 acres of land each in the Kharif and Rabi seasons. For irrigating the land they extract 1,91,075.040 m^3 of water in the Kharif season and 7,14,768.480 m^3 in the Rabi season. Hence, for the total 258 acres of gross cultivated land, the total groundwater extraction for Paddy cultivation in a year by the farmers is 9,05,843.520 m^3.

As table 4.1 and 4.2 shows that the farmers of village Armala cultivate Paddy on 151.5 acres of land each in two seasons. Maize is cultivated on 16.5 acres of land and Vegetables on 37 acres each in all three seasons. The total extraction of groundwater for paddy cultivation in Kharif is 1,30,583.520 m^3 and in Rabi, it is 6,64,047.360 m^3. Thus, for the gross cropped area of 303 acres (151.5 × 2 acres), the total amount of groundwater exacted for paddy cultivation is 7,94,630.88 m^3 (1,30,583.520 m^3 + 6,64,047.360 m^3) in a year. In the said village, the groundwater extracted for maize is 37637.28 m^3 (Kharif), 138824.64 m^3 (Rabi), and 1,63,463.04 m^3 (Summer). The total amount of groundwater extracted during all the seasons for maize is 3,39,924.96 m^3 (37,637.28 m^3 + 1,38,824.64 m^3 + 1,63,463.04 m^3) for irrigating 49.5 acres (16.5 × 3) of gross cropped area in a year.

Table 4.1: Gross cropped area and cropping pattern practiced by the respondent farmers

Village name			Gopimohanpur	Armala	Total	
					acres	hectares
Number of households			50	50		
Crops cultivated (acres)	Kharif	Paddy	128	151.5	279.5	113.1
		Maize	0	16.5	16.5	6.7
		Vegetables	0	37	37	15
	Rabi	Paddy	128	151.5	279.5	113.1
		Maize	0	16.5	16.5	6.7
		Vegetables	0	37	37	15
	Summer	Maize	0	16.5	16.5	6.7
		Vegetables	0	37	37	15
		Gross cultivated area	256	463.5	719.5	291.2

Source: Authors observation from primary data

The total area cultivated for vegetables in Kharif (37 acres), Rabi (37 acres), and Summer (37 acres) and the respective groundwater extraction during the three seasons are 43,584.48 m3, 1,48,000.32 m3, 2,21,660.64 m3. Thus the total extraction of groundwater for vegetable cultivation comes to 4,13,245.44 m3 in the total of 111 acres (37 × 3) gross cropped area.

Table 4.2: Amount of groundwater extracted by the respondent farmers

Village name			Gopi-mohanpur	Armala	Total		
Number of households			50	50	million liters	ha. m	m3
Total volume of groundwater discharged (in million liters)	Kharif	Paddy	191.1	130.6	321.7	32.2	321658.6
		Maize	0.0	37.6	37.6	3.8	37637.3
		Vegetables	0.0	43.6	43.6	4.4	43584.5
	Rabi	Paddy	714.8	664.1	1378.8	13.8	1378816
		Maize	0.0	138.8	138.8	13.8	138824.6
		Vegetables	0.0	14.8	14.8	14.8	14800.3
	Summer	Maize	0.0	163.5	163.5	16.3	163463
		Vegetables	0.0	221.7	221.7	22.2	221660.6
Gross groundwater extracted			905.8	1414.6	905.8	1414.6	2320.4

Source: Authors observation from primary data

4.4.2 Factors Affecting Groundwater Extraction

Table 4.3 presents the variables used in the study, including both dependent and independent variables. The following variables are considered: groundwater use, age, education, landholding size, per capita food consumption (logged), self-financed, type of fertilizer used, crop diversification (binary), and seed replacement rate (ratio). The table provides information on the mean, standard deviation, maximum value, minimum value, partial correlation, and relevant literature support for the expected impact.

Table 4.3: Description of variables

Variables (type)	Definition/Measurement	Mean	SD	Min	Max	Partial correlation	Expected Sign
Dependent Variable							
Groundwater use (continuous)	Amount of groundwater extracted for irrigation (in liters) (in logarithmic scale)	17.02	13.89	16.16	17.81	-	-
Independent Variables							
Age (continuous)	Measures in years (in logarithmic scale)	53.15	7.31	35	65	-0.16*	Negative
Education (continuous)	Measures in years of education (in logarithmic scale)	9.89	2.83	5	17	-0.12	Negative
Land holding (LH) (continuous)	Measured in acres (in logarithmic scale)	3.33	2.96	0.5	20	0.81***	Positive
Soil testing (ST) (categorical)	Households tested soil = 1; 0 otherwise	0.43	0.5	0	1	-0.19*	Negative
Fertilizer consumption (TF) (categorical)	Households using chemical fertilizers = 0; both organic and chemical = 1	0.83	0.37	0	1	-0.05	Negative
Seed Replacement for Rabi Season (SRRR) (continuous)	Measured in Ratio (Purchased seeds (kg)/Total seeds (kg))	0.84	0.2	0.3	1	-0.04	Negative
Crop diversification (CD) (categorical)	Households cultivating diverse crops = 1; 0 otherwise	0.5	0.5	0	1	0.44***	Negative
Per capita Food Consumption (PFC) (continuous)	Measures in Rupees (in logarithmic scale)	767.79	220.23	407.14	1547.1	-0.18*	Negative
Self-finance (SF) (categorical)	Source of finance self = 1; 0 otherwise	0.19	0.39	0	1	-0.19*	Negative

Source: Authors' calculation using primary data

Note: SD- Standard Deviation, Min- Minimum, Max- Maximum, *Significant at 10 percent, ** Significant at 5 percent

Table 4.3 provides information on the correlation between groundwater usage and various independent variables. There is a positive correlation observed between groundwater usage and landholding size, as well as crop diversification. Conversely, the remaining variables show a negative correlation with groundwater usage. The age of the farmers was ranged from 35 to 65 years with an average of 53 years. While, the farmers have a mean of nine years of education, indicating that most farmers have completed less than matriculation. The average landholding size is 3.33 acres, suggesting that the majority of farmers are categorized as marginal or small landholders. Only 43 farmers conduct soil testing, while 83 farmers use a combination of chemical and organic fertilizers. The seed replacement rate indicates an average of 0.84, indicating that a significant percentage (57 farmers) of farmers use purchased seeds. In the Gopimohanpur village, farmers cultivate rice twice a year, specifically during the Kharif and Rabi seasons. Conversely, the farmers in Armala village cultivate vegetables, maize, and paddy throughout the year, indicating a diversified crop pattern. Out of the total 100 farmers, only 19 rely on self-finance for agricultural investments, while the remaining farmers depend on formal and informal sources of credit. The extent of the relationship between independent variables and groundwater usage is further analyzed in table 4.4 through regression analysis.

The regression analysis in Table 4.4 reveals a high degree of dependency between the independent variables and the dependent variable, as evidenced by the R-square (Coefficient of Determination) value of 0.82. This indicates that the independent variables effectively describe the dependent variable. The overall model demonstrates statistical significance at a one percent level of significance, with a low level of multicollinearity indicated by the VIF (Variance Inflation Factor) of 1.24. The age of the farmer exhibits a significant negative association with the amount of groundwater used. This suggests that more experienced farmers possess a greater understanding of when and how much irrigation should be applied, leading to more efficient groundwater usage. The results of the regression further shows that, there is a negative relationship between the education level of the farmer and groundwater usage (though not statistically significant). This implies that farmers with higher education are better equipped to make informed decisions regarding inputs, market conditions, and water-saving practices (Shahbaz et al., 2017).

In addition to the factors previously discussed, there are several other determinants that contribute to the over-extraction of groundwater for irrigation purposes. The choice of crops, as well as knowledge of soil quality, play crucial roles in determining the extent of groundwater extraction. The regression analysis reveals that the coefficient of crop diversification is positive and significantly associated with groundwater use. This implies that farmers in the study village cultivate water-intensive crops such as paddy, maize, and water-consuming vegetables, which require higher levels of groundwater extraction. While diversification has been linked to more efficient input use in recent studies (Paria et al., 2021), if the diversification is focused on water-intensive crops, it raises concerns about the sustainability of groundwater resources. Furthermore, landholding size is positively correlated with groundwater use. This indicates that as the size of the farm increases, there is a significant rise in groundwater extraction. This suggests an inefficient land-use practice that may negatively impact groundwater recharge rates and lead to degradation in groundwater quality (Foster & Cherlet, 2014).

Table 4.4: Results of OLS regression (robust)

Dependent variable - Ground Water use	Coefficient	t-statistic
Age	-0.207*	-1.96
Education	-0.073	-1.14
Land holding	0.400***	16.07
Soil testing	-0.077*	-1.77
Fertilizer consumption	-0.027	-0.58
Seed Replacement for Rabi Season	-0.004	-0.04
Crop diversification	0.233***	4.70
Per capita Food Consumption	-0.125*	-1.84
Self-finance	-0.093*	-1.95
Constant	18.327	28.88
Number of observation	100	
F (9, 90)	69.75***	
Prob > F	0.0000	
R-squared	0.8254	
Adjusted R-squared	0.8079	
VIF	1.24	

Source: Authors' calculation using primary data

Note: *Significant at 10%, ***Significant at 1% level

Self-financing through personal savings and other income sources emerges as a significant source of financing in the study area. The coefficient indicates a significant negative relationship between self-financing and groundwater usage, as self-financed farmers make efforts in water minimizing practices. Additionally, During the Rabi season, farmers have limited alternatives to groundwater irrigation. However, in the Kharif season, self-financed farmers make efforts to minimize irrigation costs through water harvesting techniques. They utilize information about rainfall timing and, even during rain, drain excess water from their fields and collect rainwater for future use. Consequently, throughout the Kharif season, they require only three to four irrigations, significantly reducing the reliance on groundwater for irrigation purposes and decreasing associated costs. In the sample village, farmers have access to various sources of finance for agricultural investments. Formal sources include government and cooperative banks, while informal sources encompass borrowing from friends, relatives, and landlords. Repayment of loans in formal sources follows established norms, including interest payments, whereas informal sources rely on personal and professional relationships for repayment terms. But the self-financing source is found to be reliable for less groundwater extraction.

The study identifies soil testing as another significant determinant. The coefficient reveals a negative and significant relationship between soil testing and groundwater usage. Soil testing plays a crucial role in providing information about soil characteristics, including nutrient content and water-holding capacity. Armed with this knowledge, farmers can optimize fertilizer use, select quality seeds, and apply irrigation water more efficiently (Dong et al., 2011; Shah et al., 2021). Similarly, the type of fertilizer used demonstrates a negative impact on groundwater usage, although it is not statistically significant. This implies that farmers who utilize a combination of organic and chemical fertilizers extract a lower amount of groundwater. Organic fertilizers increase the soil's organic matter, thereby enhancing its water-holding capacity and nutrient content (Lal, 2012; Subhani et al., 2012). This, in turn, reduces the need for excessive chemical fertilizer application. The results indicate that farmers who conduct soil testing tend to use less groundwater for irrigation and opt for a combination of organic and chemical fertilizers, as they are now aware of their soil's nutrient properties. During interviews, farmers expressed their lack of confidence and reported lower yields, which led to their reluctance to rely solely on organic fertilizers in their fields.

The study also examines the seed replacement rate as a determinant of groundwater usage during the Rabi season. The coefficient associated with this variable reveals that an increase in seed purchases leads to a decrease in groundwater usage. This suggests that farmers are opting for certified, high-quality seeds that are recommended for cultivation. The use of such seeds indirectly affects fertilizer usage and directly impacts groundwater usage. Farmers in the study villages acquire seeds from the Bargarh district (a western district of Odisha). According to information provided by the farmers, these seeds are cultivated using pure organic fertilizer. The application of these seeds results in higher yields, lower water consumption, and a reduced need for chemical fertilizers. Also, the genetically pure, physiologically sound (germination, vigour), free from physical impurities and seed-borne diseases, good quality seeds increase rate of germination, seedling emergence, reduces plant stress, and optimise nutrient uptake consequently leading to controlled irrigation (Kumar et al., 2023). Furthermore, per capita food consumption in the rural farming village influences groundwater usage. Since most of the food crops grown are consumed by the farmers themselves, an increase in food share (self-consumption) prompts a shift away from chemical fertilizers. Instead, farmers opt for organic fertilizers due to health concerns. This reduced reliance on chemical fertilizers leads to a decrease in groundwater extraction. Thus, there is a significant negative relationship between per capita food consumption and groundwater usage (Jambo et al., 2021).

Chapter 5

GROUNDWATER PRODUCTIVITY IN AGRICULTURE

5.1 Introduction

Land, labour, and water are significant resources in agricultural production. While land and labor productivity have long been recognized, the concept of Water Productivity (WP) has gained prominence only recently, particularly in developing countries. By estimating WP, demand-side policy initiatives can be developed to address the mismatch between cropping patterns and water availability in the country (Sharma et al., 2018). WP can be evaluated with irrigation water productivity and economic water productivity (Molden et al., 2003). The factors that can effect water productivity are agronomic factors such as crop selection and management, irrigation scheduling, soil management (Li et. al., 2016); hydrological factors such as water availability, and water distribution efficiency (Molden et. al., 2010); technological factors such as irrigation methods and irrigation technology (Cetin et, al., 2019); institutional factors such as water governance and access to financial resources and support (Eshete et. al., 2020); and market conditions and prices (Raza et. al., 2021).

Odisha has varied agro-climatic as well as varied hydro-geologic conditions zones. The coastal areas are agriculturally productive to well access to irrigation facilities but are prone to salt-water intrusion. On the other hand, the western zones are drought prone which also lack proper irrigation infrastructures. Pattanayak & Mallick, (2018) showed that the coastal district of Odisha has high intensity of irrigation but low agricultural productivity because of improper crop choices, traditional ways of farming, lack of input efficiency like fertilizers, seeds etc and fewer water conservation practices. These districts are also under a serious threat of overdraft and seawater intrusion (Rejani et al., 2008). As a remedial measures the literatures suggests the replacement of non-monsoon rice must be substituted with more profitable and less water consuming crops like chilli, green gram, and mustard with proper water conservation practices (Panda & Kumar, 2011, Paria et al., 2021).

Various studies have examined that, irrigation, use of fertilizers, rainfall, size of operational holdings, infrastructure and institutional factors, such as road density and access to institutional finance, tenancy, mechanization, livestock holdings, non-farm income opportunities, and distance from nearest town are some of the factors that determine the farmers' decision for land use pattern and its productivity for agriculture (Pandey & Ranganathan, 2018). Now there is an emerging demand for a focus on water productivity rather than land productivity. Few studies have worked on the determinants of water productivity in agriculture. This study deals with the calculation of water productivity in the study area and finds its determinants.

5.2 Methodological Approach

The study applies three methodologies as given below:

- To find correlations between variables- Pearson Correlation Coefficient
- To find any significant difference between the means of the group for water productivity- t-test
- To find the factors affecting water productivity (in this case groundwater productivity) for irrigation- OLS regression

5.3.1 Water Productivity

Water productivity in the case of agriculture, is calculated in the following ways:

i. Irrigation water productivity (kg/m^3) = $\frac{\text{Total amount of crop production (kg)}}{\text{Amount of groundwater extracted (m3)}}$[3]

ii. Economic groundwater productivity can be calculated in two ways,

Economic groundwater productivity (Rs/m^3)

a) Marketable = $\frac{\text{Selling price of crop output produced (Rs)}}{\text{Amount of groundwater extracted (m3)}}$

b) Marketed = $\frac{\text{Selling price of crop output sold (Rs)}}{\text{Amount of groundwater extracted (m3)}}$

[3] Calculated from the total groundwater required by the crop in its life span

5.3.2 t-test

Based on the equality of variances across the samples, an appropriate t-test was applied. So, in order to test for the equality of the variances, Levene's test is applied to check for the equality of the variances. The following hypothesis is formulated for the test:

$$H_0 : s_1^2 = s_2^2 \ (equal\ variances), \qquad H_1 : s_1^2 \neq s_2^2 (unequal\ variances)$$

Where, H_0 and H_1 are the null and alternative hypothesis respectively, and s_1^2 and s_2^2 are the sample variances. If calculated Levene's significance value is found to be less than the level of significance (here we have taken a 5 percent level of significance), then we reject the null hypothesis and conclude that unequal variances exist (Carroll & Schneider, 1985).

Next, in order to determine the difference in the means, a t-test has been conducted using STATA. t-test is a parametric test that compares the means of two independent groups in order to determine whether there is statistical evidence that the associated population means are significantly different. In our study, our samples have different variances. So, for unequal variances, the equation of the test is be presented in the following equation:

$$t = \frac{\mu_1 - \mu_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

The hypothesis thus formed would be,

$$H_0 : \mu_1 = \mu_2 (equal\ means), \qquad H_1 : \mu_1 \neq \mu_2 (unequal\ means)$$

Where μ_1 and μ_2 are the sample means of two groups, s_1^2 and s_2^2 are the sample variances and $n_1$and n_2 are the sample observations, and H_0 and H_1 are the null and alternative hypothesis respectively (Ruxton, 2006). If the calculated value is found to be greater than the tabulated value, then we reject the null hypothesis and conclude there is a difference in the means of the samples.

5.3.3 Pearson Correlation Coefficient

The Pearson Correlation Coefficient (PCC), is used to evaluate the linear correlation between the variables (X, Y). It is expressed in the equation

$$\rho_{X,Y} = \frac{COV(X,Y)}{s_X s_Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{s_X s_Y}$$

Where, $\rho_{X,Y}$ is the PCC between X and Y, $COV(X,Y)$ is the covariance of X and Y, s_X, s_Y are the standard deviations of X and Y, respectively. μ_X and μ_Y are the respective means of X and Y. $\rho_{X,Y}$ ranges from +1 to −1. A value of +1 implies that X is completely positively linearly correlated to Y. On the other hand, a value of 0 indicates that X is not linearly correlated to Y at all. Finally, a value of −1 implies that X is completely negatively linearly correlated to Y (Liu et. al., 2020).

5.3.4 OLS Regression

To find the factors that impact water productivity, the OLS estimation technique has been applied. The major determinants which are considered for irrigation water productivity are identified as the age of the farmer, education, the ratio of agricultural income to total income, land holding size, quantity of fertilizers used per acre (fertilizer use intensity), types of water conservation practices and whether the farmer has carried out soil testing. The functional form can be expressed as:

Irrigation Water Productivity = f (Age, Education, Ratio of agricultural income to total income, Land Holding, Fertilizer use intensity, Water conservation, Soil-testing,)

Hence, the model thus formed is

$$\ln IWP = \beta_0 + \beta_1 lnAge + \beta_2 lnEdu + \beta_3 AITI + \beta_4 lnLH + \beta_5 lnFUI + \beta_6 lnWC + \beta_7 ST + \epsilon$$

Where IWP is the groundwater irrigation productivity, Age is the age of the farmer, Edu is the education of the farmer, $ATIT$ is share of agricultural income to total income, LH is the land size, FUI is the fertilizer use intensity, WC are the types of water conservation practices and ST is the soil testing[4]. $\beta_1, \dots, \beta_7$ are the respective slopes of the independent variables, β_0 is the intercept term.

Similarly, the factors affecting the economic water productivity, which is the value of crops produced, are found to be the age of the farmer, his education, the ratio of his agricultural income to total income, crop diversification, total input costs (cost of fertilizer, seed, labour and irrigation), and the soil testing. For the regression analysis, we have considered only the marketed value, which is the product the farmers sell after self-consumption. The functional form can be expressed as:

$$\ln EWP = \beta_0 + \beta_1 lnAge + \beta_2 lnEdu + \beta_3 AITI + \beta_4 CD + \beta_5 lnTIC + \beta_6 ST + \epsilon$$

Where EWP is the economic groundwater productivity of the marked output, Age is the age of the farmer, Edu is the education of the farmer, $ATIT$ is share of agricultural income to total income, CD is the crop diversification, TC is the total input cost and ST is the soil testing. $\beta_1, \dots, \beta_6$ are the respective slopes of the independent variables, β_0 is the intercept term.

The error term ϵ, in the above regression equations follows all the properties of the OLS regression method (Gujarati & Sangeetha, 2007). A step-wise methodology is adopted using STATA software following the appropriate procedure. In addition, statistical tests like J-B test (Jarque–Bera test), VIF (Variance Inflation Factor), and Breusch-Pagan/Cook-Weisberg have been used to test the normality, multicollinearity, and heteroscedasticity in the model.

[4] Units of variables are presented in table 5.11

5.3 Conceptual Framework

Figure 5.1 demonstrates the factors that can influence water productivity. These factors are observed from the field experiences. Demographic details of the farmers, such as age and education, can influence water productivity positively. As water productivity is related to quality and monetary aspects, years of experience and knowledge will develop the technical know-how, soil-crop suitability, input use efficiency, market condition information, etc., which will increase productivity. As agriculture is the main source of income in rural areas, its share in total income will encourage farmers to invest in quality inputs and develop skills (training, precision farming, etc.), which will further improve productivity.

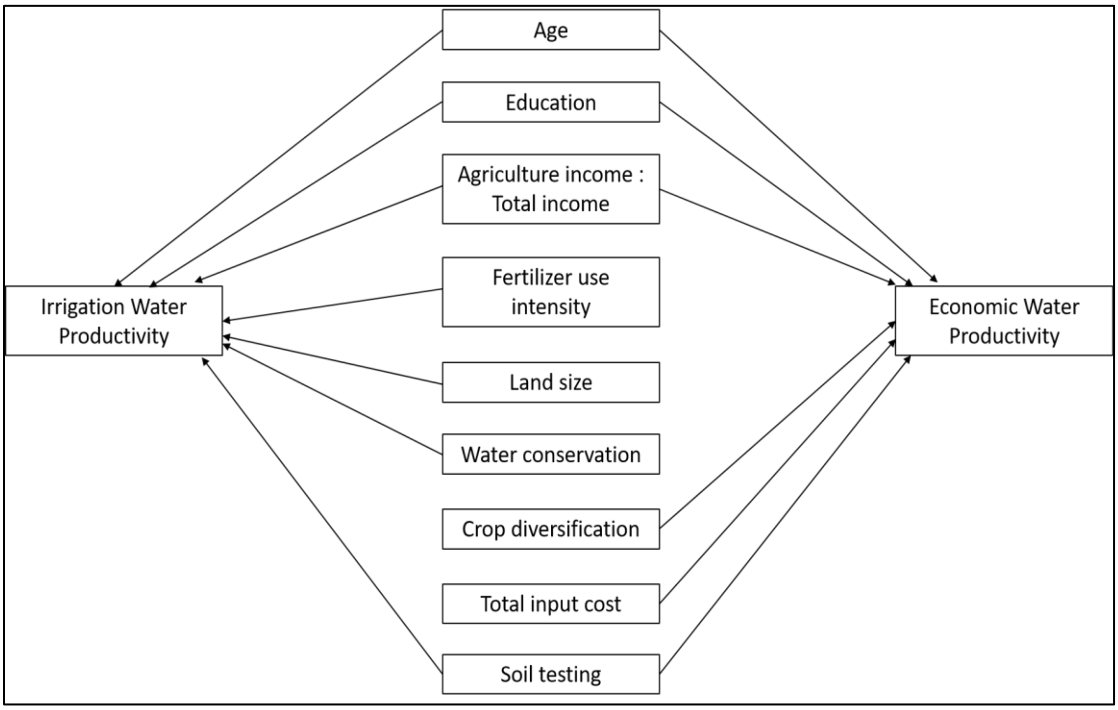

Figure 5.1: Conceptual framework of the factors influencing water productivity in agriculture

Source- Authors' compilation from field experience

Similarly, soil testing will let farmers know the nutrient requirements of the soil and suitable crops to grow, which will increase the yield as well as income based on the monetary value of the crop choices. Even though the benefits of organic farming are well known, due to uncertainty on crop yield, the farmers prefer chemical fertilizers, where sometimes they mix some quantity of organic fertilizers. But the heavy use of chemical fertilizers will reduce the water-holding capacity of the soil (as discussed in Chapter 4) as well as yield which will decline the irrigation water productivity. Land size and irrigation water productivity can have a positive relationship between them. As the land size increases, the farmers can equip themselves with efficient technological and management aspects. Similarly, farmers spend less water for irrigation as they practice water conservation methods. Crop diversification is carried out to minimize the risk of crop failure as well as to increase net agricultural returns. So a positive relationship is expected between crop diversification and economic water productivity. Generally, in the case of output, it can be increasing, decreasing, and constant with respect to input costs. Initially, with an increase in input costs output increases, then it becomes constant. Even after that if input costs further increase, then the output starts to decline which are due to the marginal productivity of the inputs.

5.4 Primary Data Analysis

5.4.1 Gross Cropped Area and Amount of Groundwater Extracted by the Farmers

Table 5.1 represents the gross cropped area[5] and the amount of groundwater extracted by the farmers in the study village. We have differentiated the crops into paddy and other crops (including maize and vegetables). The table shows that, in the case of paddy, the farmers of Gopimohanpur village cultivates 256 acres of land where as the farmers of Armala village cultivates around 303 acres of land and extracts 905.8 million litres and 794.6 million litres of groundwater respectively over the year. It shows that Gopimohanpur village has 15 percent less gross cropped area than Armala village but extracts 12 percent more groundwater than the later village. While the Armala village farmers cultivate other crops apart from paddy. In the case of per acre of water extracted, it is observed that Gopimohanpur village farmers extract 3.5 million litres per acre of land whereas the second village farmers extract 3.3 million liters of water per acre. This implies that the former village extracts 6 percent more groundwater than the later village.

[5] Gross cropped represented as total area sown once and/or more than once in a particular year

Table 5.1: Gross cropped area and amount of groundwater extracted by the farmers

Village	Obs	Gross Cropped Area (acres)		Total	Gross Groundwater Extracted (liters)		Total
		Paddy	Other crops		Paddy	Other crops	
Gopimohanpur	50	256	0	256	9.06E+08	0	9.06E+08
Armala	50	303	160.5	463.5	7.95E+08	7.53E+08	1.55E+09
Total	100	559	160.5	719.5	1.7E+09	7.53E+08	2.45E+09

Source: Author's own calculation from primary survey

Note: 'E+' means10 to the power

5.4.2 Irrigation and Economic Water Productivity of the Villages

Table 5.2 shows that, for the village Gopimohanpur, the irrigation water productivity for paddy which is grown in two seasons in a year is found to be 0.66 kg/m^3. It means from one unit (m^3) of groundwater extracted, the farmers could grow 0.66 kgs of paddy from their farm.

For the village Armala, the irrigation water productivity for paddy which also is grown in two seasons in a year is found to be 0.97 kg/m^3, which means for one unit (m^3) of groundwater extracted, the farmers could grow 0.97 kgs of paddy from their farm. The irrigation water productivity for non-paddy (Maize and Vegetables) which is produced in all the three seasons in all the yearlong is found to be as 0.32 kg/m^3.

Table 5.2 Irrigation water productivity of the sample villages

Village name	Groundwater irrigation productivity (kg/m^3)		
	Paddy	Other crops	Average
Gopimohanpur	0.66	0	0.66
Armala	0.97	0.32	0.67
Average	0.81	0.32	0.665

Source: Authors' calculation using primary data

For the village Gopimohanpur, the Economic water productivity for paddy produced (marketable) is found to be Rs 13.45/m^3. It means for one unit (m^3) of groundwater extracted, the farmers could earn Rs 13.45 for paddy from their farm whereas economic productivity for total paddy sold after self-consumption (marketed) is Rs 11.42/m^3.

For the village Armala, the Economic water productivity for paddy produced (marketable) is found to be 17.07 kg/m^3, which means for one unit (m^3) of groundwater extracted, the farmers could earn Rs 17.07 for paddy from their farm and productivity for total paddy sold after self-consumption (marketed) is Rs 16.08/m^3. The Economic water productivity for other crops (Maize and Vegetables) which is produced in all the three seasons in all the yearlong is Rs 4.33 /m^3 and for marketed (sold) productivity it is Rs 4.15 (Table 5.3).

Table 5.3: Economic water productivity of the sample villages

Village name	Economic groundwater productivity (Rs/m^3)					
	$\frac{\text{Selling price of crop output produced (Rs)}}{\text{Amount of groundwater extracted (m3)}}$			$\frac{\text{Selling price of crop output sold (Rs)}}{\text{Amount of groundwater extracted (m3)}}$		
	Paddy	Other crops	Average	Paddy	Other crops	Average
Gopimohanpur	13.45	0	13.45	11.42	0	11.42
Armala	17.07	4.33	11.2	16.08	4.15	10.60
Average	15.28	4.33	12.32	13.75	4.15	11.01

Source: Authors' calculation using primary data

5.4.3 t-test for Water Productivity

In order to find whether there is significant difference between the mean irrigation productivity and mean economic productivity in between the villages and between different land holding groups the following t-tests are carried out.

i. t-test for Irrigation Water Productivity between Villages

The table 5.4 shows the table for t-test to check whether there exists any difference in the means of irrigation water productivity between the two villages.

Table 5.4: t-test for irrigation water productivity

Village	Obs	Mean	Standard Error	Standard Deviation	95 percent confidence interval	
Gopimohanpur	50	0.673	0.053	0.381	0.565	0.782
Armala	50	0.670	0.034	0.243	0.601	0.739
combined	100	0.672	0.031	0.318	0.608	0.735
Diff		0.0031	0.063		-0.124	0.130
Levene Statistic	0.016			Pr(|T|>|t|)	0.961	
Unequal variance				Accept Ho There is no difference in means		

Source: Authors' calculation using primary data

From the table, the p-value for difference in means is greater than 0.05, so we accept the null hypothesis of equal means. This indicates that there is no statistical difference between the irrigation productivity in between the villages. Since the two villages do not follow any such water conservation practices nor there exist any variability in farming procedure for cultivation also there is similarity of agro-ecological conditions, so the test is found to have equal means.

ii. t-test for Economic Water Productivity of Crops Produced between Villages

Table 5.5 shows the t-test to check whether there exists any difference in the means of economic water productivity which is actually produced by the farmers of the two villages.

Table 5.5: t-test for economic water productivity actually produced

<table>
<tr><td>Village</td><td>Obs</td><td>Mean</td><td>Standard Error</td><td>Standard Deviation</td><td colspan="2">95 percent confidence interval</td></tr>
<tr><td>Gopimohanpur</td><td>50</td><td>13.458</td><td>0.876</td><td>6.200</td><td>11.696</td><td>15.220</td></tr>
<tr><td>Armala</td><td>50</td><td>11.200</td><td>0.466</td><td>3.300</td><td>10.263</td><td>12.138</td></tr>
<tr><td>combined</td><td>100</td><td>12.329</td><td>0.506</td><td>5.069</td><td>11.323</td><td>13.335</td></tr>
<tr><td>Diff</td><td></td><td>2.257</td><td>0.993</td><td></td><td>0.279</td><td>4.236</td></tr>
<tr><td>Levene Statistic</td><td>0.002</td><td colspan="2" rowspan="2"></td><td>Pr(|T|>|t|)</td><td colspan="2">0.025</td></tr>
<tr><td colspan="2">Unequal variance</td><td colspan="3">Reject Ho
There is difference in means</td></tr>
</table>

Source: Authors' calculation using primary data

From the table 5.5 it is evident that there is difference in means of the marketable produce that is actually harvested or produced, since the p-value is less than the significant value (0.05). Which shows that there is statistical difference between the economic productivity actually produced (before self-consumption) between the villages. Economic water productivity depends on the selling prices of the output. But the respondents are not satisfied with the government procurement in case of paddy as there is a limitation of quantities of produce to be sold in mandis. Hence, they are forced to sell their produce below the MSPs except some portion which are procured in the mandis. The farmers of Gopimohanpur village sell at Rs1200/quintal to Rs1400/quintal and the farmers of Armala village sell their produce at the prices Rs1100/quintal to Rs1300/quintal in the open market. Along with it, the farmers of Armala village grow vegetables and maize along with paddy. Due to these reason the means in the test results are found to be significantly different between the two villages.

iii. t-test for Economic Water Productivity Sold between Villages

Table 5.6 shows whether there exists any difference in the means of economic water productivity of the crops which are sold by the farmers of the two villages.

Table 5.6: t-test for Economic Water Productivity sold

Village	Obs	Mean	Standard Error	Standard Deviation	95 percent confidence interval	
Gopimohanpur	50	11.428	0.781	5.529	9.857	13.000
Armala	50	10.602	0.460	3.256	9.677	11.528
combined	100	11.015	0.453	4.533	10.116	11.915
Diff		0.826	0.907		-0.979	2.631
Levene Statistic	0.003			Pr(|T|>|t|)	0.365	
Unequal variance				Accept Ho There is no difference in means		

Source: Authors' calculation using primary data

Unlike that of the value in table 5.5, the table 5.6 reflects that there is no statistical difference between the economic productivity (sold/marketed) in between the villages as the p-value is greater than the significant value (0.05). This value of economic productivity depicts the produce that are sold after self-consumption. The major portion of food consumption in rural households are from own farm produce. Also the crop diversification in Gopimohanpur village is comparatively less than that of Armala village which leads to difference in variances of the crop output sold and consumed. Due to this reason the resultant means of crop output sold are found to be statistically same.

iv. Relationship between and t-test between Land Holdings and Water Productivity

The respondent farmers are marginal, small, semi-medium and medium (Table 3.3). None of the respondents have large farm size. Figure 5.2 shows that there is a direct relationship of irrigation water productivity and economic water productivity (produced and sold) with the land holding size. It is verified in the correlation matrix table 5.7. The correlation matrix shows that all the variables are significantly positively related with each other. The figure and the table explains that as the land size increases, water productivity also increases.

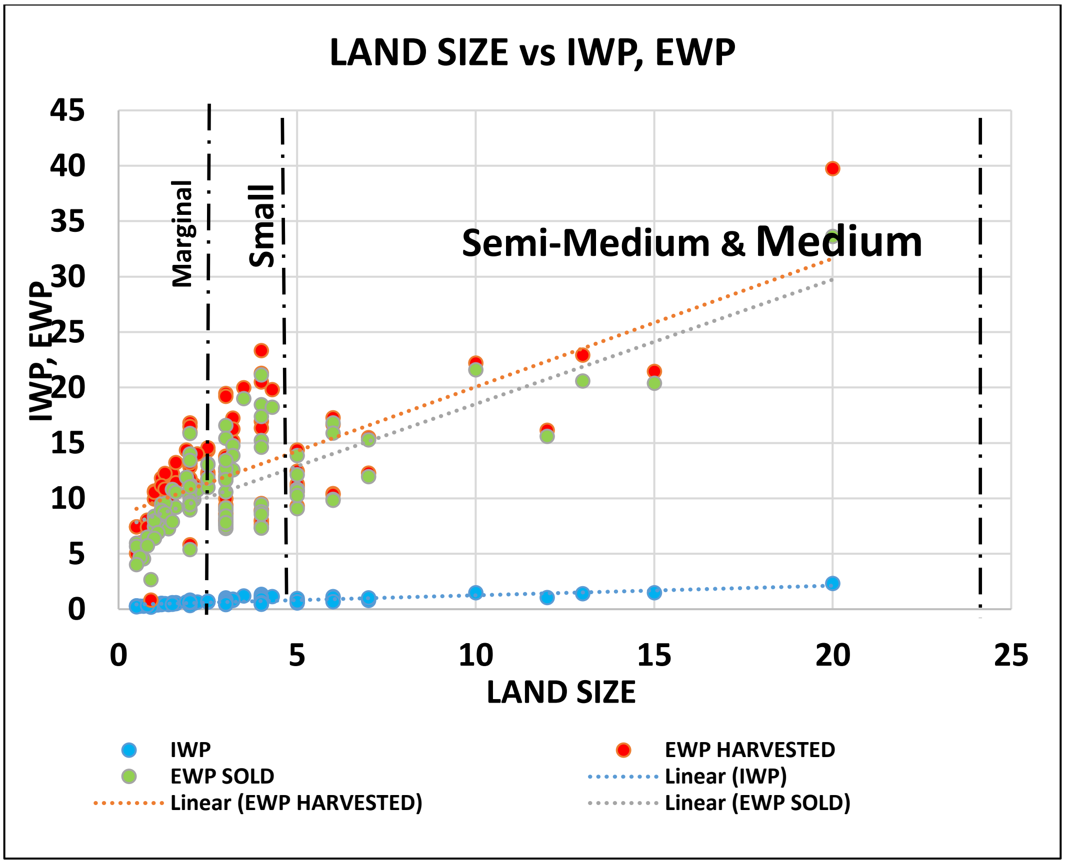

Figure 5.2: Relationship between land size, IWP, EWP harvested, EWP sold

Source: Authors' calculation using primary data

Table 5.7: Correlation between Land Size, IWP and EWP

	Land size	IWP	EWP produced (marketable)	EWP sold (marketed)
Land size	1			
IWP	0.809 (0.000)***	1		
EWP (marketable)	0.676 (0.000)***	0.957 (0.000)***	1	
EWP (marketed)	0.734 (0.000)***	0.985 (0.000)***	0.982 (0.000)***	1

Source: Authors' calculation using primary data

Note: ***Significant at 1% level

In order to test-the significance in the means of the land-holding groups t-test is carried out. Since the number of marginal farmers are comparatively more than rest of the land-holding groups, so we have differentiate the total respondent farmers with marginal and other groups (comprising of small, semi-medium and medium).

Table 5.8: t-test for Groundwater Irrigation Productivity

Group	Obs	Mean	Standard Error	Standard Deviation	95 percent confidence interval	
Marginal	42	0.491	0.022	0.147	0.445	0.537
Others	58	0.802	0.045	0.345	0.711	0.893
combined	100	0.672	0.031	0.318	0.608	0.735
diff		-0.310	0.050		-0.411	-0.209
Levene Statistic	0.001			Pr(|T|>|t|)	0.000	
Unequal variance				Reject Ho There is difference in means		

Source: Authors' calculation using primary data

Table 5.9: t-test for Economic Groundwater Productivity harvested

Group	Obs	Mean	Standard Error	Standard Deviation	95 percent confidence interval	
Marginal	42	10.319	0.483	3.135	9.342	11.296
Others	58	13.785	0.747	5.695	12.287	15.282
combined	100	12.329	0.506	5.069	11.323	13.335
diff		-3.465	0.890		-5.234	-1.697
Levene Statistic	0.002			Pr(|T|>|t|)	0.000	
Unequal variance				Reject Ho There is difference in means		

Source: Authors' calculation using primary data

Table 5.10: t-test for Economic Groundwater Productivity sold

Group	Obs	Mean	Standard Error	Standard Deviation	95 percent confidence interval	
Marginal	42	8.695	0.415	2.695	7.855	9.535
Others	58	12.696	0.638	4.861	11.417	13.974
combined	100	11.015	0.453	4.533	10.116	11.915
diff		-4.0007	0.761		-5.513	-2.488
Levene Statistic	0.004			Pr(|T|>|t|)	0.000	
Unequal variance				Reject Ho There is difference in means		

Source: Authors' calculation using primary data

Table 5.8, 5.9 and 5.10 shows that there is significant difference between the productivities between the different land holding groups as the p-value of all the water productivities are less than the significant value (0.05). This explains that as the land size increases, farmers can employ different methods and techniques to increase yield and productivity of land as well as water. Along with it, the consumption pattern is also influenced as they can diversify their crops for self-consumption which will change the economic productivity as well.

5.4.4 OLS Regression Analysis

Table 5.11 describes the dependent and independent variables used for the study. Irrigation water productivity, economic water productivity, age, education, land holding size, fertilizer use intensity, and total input costs are taken in logarithmic form. Share of agricultural income in total income is measured in ratio form. Water conservation methods, crop diversification and soil-testing are presented in categorical form. The table shows mean, standard deviation (SD), minimum value (Min) and maximum value (Max). Table 5.12 presents partial correlation of the independent variables with the dependent variable (IWP, EWP) and their expected sign. Here, the economic water productivity is considered for the actual output sold rather than considering the hypothetical EWP of harvested produce. Actually 100 farmers were interviewed, but due to the violation of normality distribution of dependent variables (IWP, EWP) two samples were removed from the analysis. The analysis in this section is based on 98 observations.

Table 5.11: Description of variables

Variables (type)	Definition/Measurement	Mean	SD	Min	Max
Dependent variables					
Irrigation water productivity (continuous)	Total amount of crops produced/Amount of groundwater extracted (kg/m^3) (in logarithmic scale)	0.64	0.26	0.17	1.48
Economic water productivity (continuous)	Selling price of crop output sold/ Amount of groundwater extracted (Rs/m^3) (in logarithmic scale)	10.68	3.82	2.65	21.58
Independent variables					
Age (continuous)	Measures in years (in logarithmic scale)	53.16	7.3	35	65
Education (continuous)	Measures in years of education (in logarithmic scale)	9.78	2.77	5	17
Agriculture income : Total income (continuous)	Measured in Ratio (Total agricultural income(Rs)/Total family income (Rs)	0.54	0.23	0.11	1
Land holding (continuous)	Measured in acres (in logarithmic scale)	3.06	2.25	0.5	15
Fertilizer Use Intensity (continuous)	Measured in ratio (Total amount of fertilizers applied (kg)/ Total land holding (in acres)) (in logarithmic scale)	733.87	287.15	280	1350
Water conservation (categorical)	Households practicing no conservation method = 0; One method = 1 Two methods = 2 Three methods = 3	1.92	0.87	0	3
Crop diversification (categorical)	Households cultivating diverse crops = 1; 0 otherwise	0.51	0.5	0	1
Total input cost (continuous)	Measures in Rupees (in logarithmic scale)	155464.1	114990.4	36885	758668
Soil testing (categorical)	Households tested soil = 1; 0 otherwise	0.42	0.49	0	1

Source: Authors' calculation using primary data

Table 5.12: Partial correlation matrix of independent variables w.r.t IWP and EWP

Independent variables	IWP	Expected sign with IWP	EWP	Expected sign with EWP
Age	0.24**	+	0.24**	+
Education	-0.01	+	-0.01	+
Agriculture income : Total income	0.42***	+	0.40***	+
Land holding	0.75***	+	-	
Fertilizer used per acre	-0.32***	-	-	
Water conservation	0.07	+	-	
Crop diversification	-		-0.28***	+
Total input cost	-		0.66***	+
Soil testing	0.17*	+	0.23**	+

Source: Authors' calculation using primary data

The average farmer's age is around 53 years with 9.78 years of education. It means that that most of the farmers are under-matriculate. The mean contribution of agricultural income to the total income is around 55 percent. It means that the farmers are still dependent on agriculture but are diversifying their income sources for risk minimisation of income loss. The mean of land holding size is 3 acres which show that most of the farmers are small and marginal. The mean fertilizer application is 730 kgs per acre. On the other, the farmers are practicing on average 2 water conservation methods. Here water conservation implies SRI/SCI cultivation method, mixing organic fertilizer, and using compost in farming. Half of the farmer household in the study area is growing only paddy and half of the population is diversifying their crops. But when it comes to soil testing practices, less than half test their soil which results in inefficient input uses. The average total input costs stands at Rs 155464.1.

The extent to which these impendent variables impact the dependent variables is discussed below separately for IWP and EWP.

Table 5.13 presents the OLS regression analysis of the factors affecting IWP. The R^2 is 0.76 which depicts that the independent variables could explain 76 percent of the variation of IWP. The overall model is significant with the low degree of multi-collinearity, VIF of 1.60. The age of the farmer positively significantly relates to the dependent variable. With age and experience the farmer could decide on the application of inputs, when and what to cultivate which increases the water productivity also from table 4.3 it is evident that as age increases groundwater extraction decreases. Since the groundwater extraction is in the denominator part, so age is positively related with irrigation water productivity.

Table 5.13: Results of OLS regression for Irrigation Water Productivity

Dependent variable - Irrigation water productivity	Coefficient (Robust)	t-statistic
Age	0.381**	2.01
Education	-0.004	-0.07
Agriculture income : Total income	0.309***	3.23
Land holding	0.618***	13.99
Fertilizer use intensity	-0.384***	-3.95
Water conservation	0.011	0.44
Soil testing	0.106**	2.03
Constant	-0.306***	-0.24
Number of observation	98	
F (7, 90)	62.08***	
Prob > F	0.0000	
R-squared	0.7686	
VIF	1.60	

Source: Authors' calculation using primary data

Note: *Significant at 10%, ** Significant at 5%, ***Significant at 1% level

On the other hand, education, though insignificant and negatively related impacts the dependent variable. Since the average education of the farmers are under matriculation so, they do not have enough knowledge to gather information as to how to increase productivity and to adopt new techniques of production. But if the share of agricultural income increases they can be motivated to engage and invest more in agriculture by applying inputs efficiently which will increase productivity. Hence the ratio of agriculture income to total income has a positive and significant relationship with the IWP. Similarly, the fertilizer use intensity, which is the amount of fertilizer applied per acre of land has a significant and a negative relationship with the IWP. As the proportion of chemical fertilizers is comparatively much more than the use of organic fertilizer, hence as the fertilizer intensity increases, the soil losses its fertility and water-holding capacity which will result in more groundwater extraction and a decrease in water productivity.

Water conservation methods though insignificant have a positive impact on irrigation water productivity. The farmers who are following different types of water conservation practices save water and extract comparatively less water. The System of Rice Intensification (SRI) or System of Crop Intensification (SCI) cultivation methods, practiced by most farmers, are considered among the most input-efficient planting methods, saving a significant amount of water (Zhao et al., 2010; Thakur et al., 2014). Additionally, the use of compost and organic manure further reduces the water demand for irrigation. Soil testing also has a significant positive impact on water productivity (Li et al., 2019). Crop yield is affected by soil characteristics and irrigation. Soil testing enables farmers to understand the nutrient requirements of their soil, allowing them to apply fertilizers appropriately and reduce water use. Since fertilizers cannot be absorbed in dry soil without water, soil testing helps avoid over-fertilization, thereby enhancing the effective use of water. Land size has a positive a significant relationship with the IWP. As land size increases, agriculture income increases, farmers would be motivated to use quality inputs to increase yield. Along with it, they also will have space to practice water conservation methods such as building lined canals to harvest rain water, channelizing water etc.Table 5.14 shows the regression results of the variables that impact EWP, which is actually sold.

Table 5.14: Results of OLS regression for Economic Water Productivity (sold/marketed)

Dependent variable - Economic water productivity (sold)	Coefficient (Robust)	t-statistic
Age	0.429**	2.02
Education	-0.035	-0.45
Agriculture income : Total income	0.31***	2.84
Crop diversification	-0.253***	-3.98
Total input cost	0.451***	10.49
Soil testing	0.135**	2.23
Constant	-4.716***	-4.74
Number of observation	98	
F (6, 91)	31.22***	
Prob > F	0.0000	
R-squared	0.6431	
VIF	1.45	

Source: Authors' calculation using primary data

Note: *Significant at 10 percent, ** Significant at 5 percent, ***Significant at 1 percent level

The value of R square is 0.64 with overall model significance. There is lesser degree of multi-collinearity as the VIF stands at 1.45. The coefficients are robust with homoscedasticity.

Age is positively and significantly related to the dependent variable. With increase in the age the farmers can be aware of when and how much to irrigate, this results in managed groundwater extraction (table 4.3). Additionally with more experiences, farmers can bargain for better value of the crops which leads to increase in economic water productivity. Education on the other hand, has a negative although insignificant impact on EWP. As the average education years is 9.7, the farmers are unaware about the cultivation and marketing of the high valued crops which leads to inappropriate crop-choice decisions.

With the increase in agricultural income, as explained in case of IWP (table 5.13), investment on quality inputs would lead to increase in production and yield, hence would result in increase of EWP. This is the reason for positive and significant relationship between shares of agriculture income with the EWP. But the crop diversification is showing a negative and significant impact on economic productivity. The farmers are producing more water-consuming crops like maize, cabbage, cauliflower, etc and also the price of the produce is not much valued. Crop diversification is carried out to minimize risk of crop-failure and to increase income. But in this case as the farmers are not much educated, mostly have marginal and small land holdings and the crop choices are based on perceptions and demonstrations from other farmers, so this has resulted to injudicious extraction of groundwater. The total cost is positively and significantly related to economic productivity which implies that crop production, in this case, is of increasing cost, that is with an increase in cost the revenue also increases. Here total input cost includes the cost of seeds, fertilizers, labour and irrigation. Quality inputs requires more investment on input, thus it raises total input cost. Similarly, soil testing also positively impacts economic water productivity. Soil testing will enhance water productivity by reducing the amount of groundwater extraction. Since it is in the denominator part, ultimately the ratio of economic water productivity increases.

Chapter 6

CONCLUSION AND POLICY RECOMMENDATIONS AND FUTURE SCOPE OF RESEARCH

This chapter provides conclusions and policy options along with the future scope of work.

6.1 Conclusion

The agricultural sector is by far the largest user of freshwater and water use in particular the groundwater. It is important to note that sustainable groundwater management practices are crucial to ensure the long-term availability and productivity of groundwater resources in agriculture. Over-extraction and improper use can lead to groundwater depletion, land subsidence, and deterioration of water quality, highlighting the need for responsible and efficient groundwater management strategies. Therefore, this study has carried out with the aim to assess groundwater productivity and their determinants in the Balasore district of Odisha.

The figures of secondary data for the state of Odisha for 2009 and 2017 elucidate three aspects. Firstly, despite a decrease in rainfall, irrigation intensity has increased in most districts over the years, so as the groundwater irrigation, illustrating that the water demand for irrigation is met through groundwater use. Second, in spite of an increase in irrigation intensity and more dependence on groundwater for irrigation, cropping intensity decreased from 2009 to 2017. This could be attributed to poor agroecological conditions (reduced rainfall), the impact of farm inputs such as the use of chemical fertilizers, poor quality seeds and inappropriate irrigation, and a lack of awareness about crop water and soil nutrient requirements. This shows that the farmers use the inputs including irrigation on a perception basis. Lastly, the well-developed irrigation infrastructure in the coastal districts has fuelled groundwater irrigation over the years leading to salinity problems. In the village-level primary analysis of the coastal district Balasore, which extracts the most groundwater for irrigation, the OLS regression model reveals that factors such as the age of the farmer, soil testing, crop diversification, land size, per-capita food consumption, and source of finance significantly impact groundwater extraction. The study also finds a significant positive correlation between groundwater utilization and soil testing. Further, findings suggest that more groundwater is extracted by farmers using only chemical fertilizers without testing the soil nutrient requirements. Soil testing provides nutrient requirements of the soil, thereby avoiding over-fertilization and consequently, less water use. The theory also supports that appropriate applications of water and fertilizer (time, type, and amount) are critical for increasing water and fertilizer use and yield. The secondary data analysis of the district also shows a marginal change in cropping intensity, and no significant crop diversification but has high irrigation intensity, especially groundwater, since the water-guzzling paddy is the dominant crop grown by the farmers over the year.

In water productive analysis, it is found that, Gopimohanpur village has 15 percent less gross cropped area than Armala village but extracts 12 percent more groundwater than the later village. It is because the former village cultivates only paddy three times over the year, which is a water-guzzling crop, whereas the later village diversifies towards other crops. The irrigation water productivity is found to be 0.67 kg/m^3 for Gopimohanpur village, which earned them Rs 11.42 per m^3 of water, whereas irrigation water productivity and economic water productivity of Armala village are 0.67 kg/m^3 and Rs 10.60 per m^3, respectively. The t-test also shows no significant difference in means of water productivity between the villages but exhibits difference in means between the land holding sizes. The OLS regression analysis also supports that as the land holding size increases, irrigation water productivity also increases. The regression analysis reveals that the age of the farmers, the share of agricultural income, and soil testing have a positive relationship with water productivity. Fertilizer use intensity negatively influences irrigation water productivity as it reduces the water-holding capacity of the soil and negatively impact soil health. Similarly crop diversification is no longer profitable as it has a negative relationship with economic productivity. The farmers grow water intensive crops such as paddy which compromises with the profit as well as efficient groundwater uses.

6.2 Policy Recommendations

Since the majority of the farmers in our study village are small and marginal, they are less inclined to invest in personal training and awareness regarding the quantity and quality of inputs to be utilized. Consequently, their input choices are primarily influenced by perception rather than informed decision-making. As a result, the overexploitation of natural resources is evident. It is crucial to conduct a comprehensive soil health management program by creating awareness among farmers and helping them understand the requirement for soil nutrients to enhance agricultural output while simultaneously preventing groundwater over-exploitation. Based on the results of the analysis the following policy implications are advocated.

(i) There should be regular training regarding proper accounting of inputs like fertilizers, seeds, and water specific to the soil type, topography, and climatic conditions through administrative channels and extension activities.

(ii) To understand the soil condition and provide the appropriate input level, the soil testing facilities must be established at panchayat levels, so that site-specific agriculture is possible and profitable for sustainable production.

(iii) Crop rotation and diversification, along with better resource management have to be promoted among all the farmers through agricultural departments which will reduce the dependence on water guzzling single crop choice such as paddy.

These objectives can be successful if there are proper institutional and management policies, such as proper functioning of water user associations which can benefit the farmer as well as the community as a whole.

6.3 Future Scope of Research

The procedure, observations and findings of the study can be extended and generalised to non-coastal, critical and over-exploited areas apart from the coastal area. It can further be advanced by confronting the existing understanding with new evidence. Groundwater efficacy in irrigation is also an importance aspect to utilize the resource optimally, which can further be taken into consideration for future work. The impact of water user groups in proper allocation of groundwater can also be studied for future aspects.

REFERENCES

Abid, M., Scheffran, J., Schneider, U. A., & Ashfaq, M. J. E. S. D. (2015). Farmers' perceptions of and adaptation strategies to climate change and their determinants: the case of Punjab province, Pakistan. *Earth System Dynamics*, *6*(1), 225-243.

Agriculture Census. (2015-16). India.

Archer, D. W., Dawson, J., Kreuter, U. P., Hendrickson, M., & Halloran, J. M. (2008). Social and political influences on agricultural systems. *Renewable Agriculture and Food Systems*, *23*(4), 272-284. doi:10.1017/S174217050700169

Bastiaanssen, W.G.M., J.C. van Dam and P. Droogers, 2003. Introduction. In Dam, J.C. van, and R.S. Malik (Eds.), 2003. Water productivity of irrigated crops in Sirsa district, India. Integration of remote sensing, crop and soil models and geographical information systems. WATPRO final report, including CD-ROM. ISBN 90-6464864-6: 11-19.

Behera, B., Pulak Mishra, P. (2018). Democratic Local Institutions for Sustainable Management and Use of Minor Irrigation Systems: Experience of Pani Panchayats in Odisha, India. Water Economics and Policy, doi:10.1142/S2382624X18500108

Bhalla, P. (2007). Impact of declining groundwater levels on acreage allocation in Haryana. *Economic and Political Weekly*, 2701-2707.

Birthal, P. S., Roy, D., & Negi, D. S. (2015). Assessing the impact of crop diversification on farm poverty in India. *World Development*, *72*, 70-92. http://dx.doi.org/10.1016/j.worlddev.2015.02.015

Bowman, M. S., & Zilberman, D. (2013). Economic factors affecting diversified farming systems. *Ecology and society*, *18*(1). http://www.jstor.org/stable/26269286

Central Water Commission. (2017). Reassessment of water availability in India using space inputs. *Basin Planning and Management Organisation, Central Water Commission, New Delhi*.

Carroll, R. J., & Schneider, H. (1985). A note on Levene's tests for equality of variances. *Statistics & probability letters*, *3*(4), 191-194.

Çetin, O., & Kara, A. (2019). Assesment of water productivity using different drip irrigation systems for cotton. *Agricultural Water Management*, *223*, 105693.

Chowdhury, C., and Behera, B., (2018). Is depletion of groundwater table linked with disappearance of traditional water harvesting systems (tank irrigation)? Empirical evidence from West Bengal, India. Groundwater for Sustainable Development. doi:https://doi.org/10.1016/j.gsd.2018.05.007.

Dalin, C., Wada, Y., Kastner, T. *et al.* Groundwater depletion embedded in international food trade. *Nature* **543**, 700–704 (2017). https://doi.org/10.1038/nature21403

Das, S. K. (2015). The economics of groundwater resource management. *International Journal of Ecosystem*, *5*(3), 65-68.

Department of Water Resources. (2017-18). Odisha.

Department of Water Resources. (2020-21). Odisha.

Dhawan, V. (2017). Water and Agriculture in India, Report prepared for the South Asia expert panel during the Global Forum for Food and Agriculture.

District Irrigation Plan. (2016). Balasore.

District Statistical Handbook. (2018). Balasore

Dong, W., Qin, J., Li, J., Zhao, Y., Nie, L., & Zhang, Z. (2011). Interactions between soil water content and fertilizer on growth characteristics and biomass yield of Chinese white poplar (Populus tomentosa Carr.) seedlings. *Soil Science and Plant Nutrition*, *57*(2), 303-312. doi:10.1080/00380768.2010.549445

Dynamic Ground Water Resources of Odisha. (2017). Odisha

Dynamics of Groundwater Resource. (2017), Government of India.

Economic Survey. (2013-14). India.

Economic Survey. (2018-19). India

Eshete, D. G., Sinshaw, B. G., & Legese, K. G. (2020). Critical review on improving irrigation water use efficiency: Advances, challenges, and opportunities in the Ethiopia context. *Water-Energy Nexus*, *3*, 143-154.

FAO. (2014). *Youth and agriculture: key challenges and concrete solutions*. Rome.

FAO. (2020). *The State of Food and Agriculture 2020. Overcoming water challenges in agriculture*. Rome. https://doi.org/10.4060/cb1447en

FAO. 2017. *The future of food and agriculture – Trends and challenges*. Rome.

Foley, D. J., Thenkabail, P. S., Aneece, I. P., Teluguntla, P. G., & Oliphant, A. J. (2020). A meta-analysis of global crop water productivity of three leading world crops (wheat, corn, and rice) in the irrigated areas over three decades. *International Journal of Digital Earth*, *13*(8), 939-975.

Foster, S., & Cherlet, J. (2014). The links between land use and groundwater—Governance provisions and management strategies to secure a 'sustainable harvest'. *The global water partnership. Available at the GWP ToolBox: www. gwptoolbox. org*

Gandhi, V. P. (2014). Presidential Address: Growth and Transformation of the Agribusiness Sector: Drivers, Models and Challenges. *Indian Journal of agricultural economics, 69*(1), 44-74. doi:10.22004/ag.econ.206364

Groundwater Year Book. (2017-18). India.

Gujarati, D. N., & Sangeetha, N. (2007). Basic econometrics. 4/e Tata McGraw-Hill.

Gulati, A., & Juneja, R. (2022). Transforming Indian Agriculture. In *Indian Agriculture Towards 2030: Pathways for Enhancing Farmers' Income, Nutritional Security and Sustainable Food and Farm Systems* (pp. 9-37). Singapore: Springer Singapore.

Hexem, R. W., & Heady, E. O. (1978). *Water Production Functions for Irrigated Agriculture*. Iowa State University Press, pp. 30, 32.

Inwood, S. (2013). Social forces and cultural factors influencing farm transition. *Choices: The Magazine of Food, Farm, and Resource Issues,* *Agricultural and Applied Economics Association*, *28*(2), 1-5. doi:10.22004/ag.econ.154994

Israelsen OW. 1950. Irrigation Principles and Practices. Wiley: New York; 471 pp

IWMI. (2015). *A water-secure world.* Colombo.

IWMI. (2015). *The connecting role of water management.* Colombo.

Jambo, Y., Alemu, A., & Tasew, W. (2021). Impact of small-scale irrigation on household food security: evidence from Ethiopia. *Agriculture & Food Security*, *10*(21), 1-16. https://doi.org/10.1186/s40066-021-00294-w

Kijne, J. W., Barker, R., & Molden, D. J. (Eds.). (2003). *Water productivity in agriculture: limits and opportunities for improvement* (Vol. 1). Cabi.

Kumar, S., Sripathy, K.V., Udaya Bhaskar, K., Vinesh, B. (2023). Principles of Quality Seed Production. In: Dadlani, M., Yadava, D.K. (eds) *Seed Science and Technology*. Springer, Singapore. https://doi.org/10.1007/978-981-19-5888-5_6

Lal, R., & Stewart, B.A. (Eds.). (2012). Soil Water and Agronomic Productivity (1st ed.). CRC Press. https://doi.org/10.1201/b12214

Li, X., Zhang, X., Niu, J., Tong, L., Kang, S., Du, T., ... & Ding, R. (2016). Irrigation water productivity is more influenced by agronomic practice factors than by climatic factors in Hexi Corridor, Northwest China. *Scientific Reports*, *6*(1), 37971.

Li, D., Du, T., Sun, Q., & Cao, Y. (2019). The key driving factors of irrigation water productivity based on soil spatio-temporal characteristics. *Agricultural Water Management*, *216*, 351-360.

Liu, Y., Mu, Y., Chen, K., Li, Y., & Guo, J. (2020). Daily activity feature selection in smart homes based on pearson correlation coefficient. *Neural Processing Letters*, *51*(2), 1771-1787.

Loáiciga, H. A. (2010). Sustainable Ground-Water Exploitation. *International Geology Review,* 1115-1121. doi:10.2747/0020-6814.44.12.1115

Mango, N., Makate, C., Mapemba, L., & Sopo, M. (2018). The role of crop diversification in improving household food security in central Malawi. *Agriculture & Food Security*, *7*. https://doi.org/10.1186/s40066-018-0160-x

Manjunathaa, A. V., Speelmanb, S., Chandrakanthc, M. G., Nuppenau, E., Huylenbroeck, V. (2011). Can Groundwater Markets Promote Efficiency in Agricultural Production? Report prepared for the 13th Biennial Conference of the International Association for the Study of the Commons (IASC), Hyderabad, India.

Molden, D., 1997. Accounting for water use and productivity. SWIM Paper 1. International Irrigation Management Institute, Colombo, Sri Lanka

Molden, D., H. Murray-Rust, R. Sakthivadivel and I. Makin, 2001. A water productivity framework for understanding and action. Workshop on Water productivity. Wadduwa, Sri Lanka, November 12 and 13, 2001.

Molden, D., Murray-Rust, H., Sakthivadivel, R., & Makin, I. (2003). A water-productivity framework for understanding and action. In *Water productivity in agriculture: Limits and opportunities for improvement* (pp. 1-18). Wallingford UK: Cabi Publishing.

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M. A., & Kijne, J. (2010). Improving agricultural water productivity: Between optimism and caution. *Agricultural water management*, *97*(4), 528-535.

Nayak, C., & Kumar, C. R. (2018). Crop Diversification in Odisha: An Empirical Assessment.

Nayak, D. K. (2016). Changing Cropping Pattern, Agricultural Diversification and Productivity in Odisha- A District-wise Study. *Agricultural Economics Research Review*, *29*(1). 93-104, http://dx.doi.org/10.5958/0974-0279.2016.00022.7

Palanisami, K., & Thangavel, M. (2021). Sustaining tank irrigation in south India through time-tested measures. In *Sustainable Development in India:*

Groundwater Irrigation, Energy Use, and Food Production (pp. 88-108). Routledge.

Panda, D. K., Kumar, A., (2011). Evaluation of an over-used coastal aquifer(Orissa, India) using statistical approaches, Hydrological Sciences Journal, 56:3, 486-497, doi:10.1080/02626667.2011.563741.

Pandey, G., & Ranganathan, T. (2018). Changing land-use pattern in India: has there been an expansion of fallow lands?. *Agricultural Economics Research Review*, *31*(347-2018-3195), 113-122.

Pant, N. (1987). Ground Water Depletion. Economic and Political Weekly, 219-220.

Paria, B., Pani, A., Mishra, P., & Behera, B. (2021). Irrigation-based agricultural intensification and future groundwater potentiality: experience of Indian states. *SN Applied Sciences*, *3*. https://doi.org/10.1007/s42452-021-04417-7

Paria, B., Pani, A., Mishra, P., & Behera, B. (2021). Irrigation-based agricultural intensification and future groundwater potentiality: experience of Indian states. *SN Applied Sciences*, *3*. https://doi.org/10.1007/s42452-021-04417-7

Pattanayak, U., & Mallick, M. (2018). A Study on Irrigation and Agricultural Productivity in Odisha. *Economic Affairs*, *63*(2), 317-323. doi:10.30954/0424-2513.2.2018.4

Pinnawala, S., & Herath, H. M. W. A. (2014). September Social factors influencing agricultural productivity in the non-plantation agriculture in Sri Lanka: A farm centered analysis. In *Proceedings of the 27th Annual Conference of the Organization of Professional Associations of Sri Lanka, Colombo, Sri Lanka* (pp. 27-28).

Raza, M. A., Gul, H., Wang, J., Yasin, H. S., Qin, R., Khalid, M. H. B., ... & Yang, W. (2021). Land productivity and water use efficiency of maize-soybean strip intercropping systems in semi-arid areas: A case study in Punjab Province, Pakistan. *Journal of Cleaner Production*, *308*, 127282.

Rejani, R., Jha, M. K., & Panda, S. N. (2008). Simulation-Optimization Modelling for Sustainable Groundwater Management in a Coastal Basin of Orissa, India. *Water Resource Management*, *23*, 235-263. doi:10.1007/s11269-008-9273-5

Renaud, F. G., Le, T. T. H., Lindener, C., Guong, V. T., & Sebesvari, Z. (2015). Resilience and shifts in agro-ecosystems facing increasing sea-level rise and salinity intrusion in Ben Tre Province, Mekong Delta. *Climatic Change, 133*(1), 69-84. https://doi.org/10.1007/s10584-014-1113-4

Ruxton, G. D. (2006). The unequal variance t-test is an underused alternative to Student's t-test and the Mann–Whitney U test. *Behavioral Ecology*, *17*(4), 688-690.

Saleth, R. M. (1998). Water markets in India: Economic and institutional aspects. *Markets for water: Potential and performance*, 187-205.

Saravanakumar, V., Lohano, H. D., & Balasubramanian, R. (2022). A district-level analysis for measuring the effects of climate change on production of rice: evidence from Southern India. *Theoretical and Applied Climatology*, *150*(3-4), 941-953.

Schwankl, L. J., & Prichard, T. L. (2009). Soil-based irrigation monitoring. UC ANR Drought Management website. Division of Agriculture and Natural Resources, University of California.

Sears, L., Lim, D., & Lawell, C. Y. C. L. (2018). The economics of agricultural groundwater management institutions: The case of California. *Water Economics and Policy*, *4*(03), 1850003.

Shah, M., Vijayshankar, P. S., & Harris, F. (2021). Water and Agricultural Transformation in India: A Symbiotic Relationship-I. *Economic and Political Weekly, 56*(29).

Shahbaz, P., Boz, I., & Haq, S. U. (2017). Determinants of crop diversification in mixed cropping zone of Punjab Pakistan. *Direct Research Journal Agricultural Food Science, 5*(11), 360-366. http://dx.doi.org/10.26765/DRJAFS.2017.2257

Sharma, B. R., Gulati, A., Mohan, G., Manchanda, S., Ray, I., &Manasinghe, U. Water Productivity Mapping of Major Indian Crops, Water Productivity Mapping of Major Indian Crops (2018).

Sharma, P., & Sharma, R. C. (2006). Factors Determining Farmers' Decision for Buying Irrigation Water: Study of Groundwater Markets in Rajasthan. Agricultural Economics Research Review, 19, 39-56.

Shivaswamy, G. P., Kishore, A., Joshi, K., Anuja, A. R., & Singh, K. N. (2022, January). Impact evaluation of seed replacement on pulses productivity in India. ICAR.

Singh, R. (2005). *Water productivity analysis from field to regional scale*. Wageningen University.

Singh, D. R., & Singh, R. P. (2003). Groundwater Markets and the Issues of Equty and Reliability to Water Access: A Case of Western Uttar Pradesh. *Indian Journal of Agricultural Economics*, *58*(1), 115-127.

Singh, D. R., & Singh, R. P. (2006). Structure, Determinants and Efficiency of Groundwater Markets in Western Uttar Pradesh. Agricultural Economics Research Review, 19, 129-144.

Singh, O., & Amrita. (2017). Management of Groundwater Resources for Sustainable Agriculture in Haryana. *Transactions of the Institute of Indian Geographers, 39*(1).

Singh, R. (2005). *Water productivity analysis from field to regional scale*. Ranvir Singh.

Srivastava, S. K., Ghosh, S., Kumar, A., Anand, P. S. B., & Raju, S. S. (2013). Trends in Irrigation Development and its Impact on Agricultural Productivity in India: A Time Series Analysis.

Srivastava, S. K., Kumar, R., & Singh, R. P. (2009). Extent of groundwater extraction and irrigation efficiency on farms under different water-market regimes in Central Uttar Pradesh. *Agricultural Economics Research Review*, *22*(1), 87-97.

Subhani, A., Tariq, M.A., Jafar, M.S., Latif, R., Khan, M., Iqbal, M.S., & Iqbal, M.S. (2012). Role of Soil Moisture in Fertilizer Use Efficiency for Rainfed Areas-A Review. *Journal of Biology, Agriculture and Healthcare, 2(11)*, 1-9.

Sylvester-Bradley, R., & Kindred, D. R. (2009). Analysing nitrogen responses of cereals to prioritize routes to the improvement of nitrogen use efficiency. *Journal of experimental botany*, *60*(7), 1939-1951. https://doi.org/10.1093/jxb/erp116

Tanksale, A., & Jha, J. K. (2015). Implementing national food security act in India: issues and challenges. *British Food Journal*, *117*(4), 1315-1335. https://doi.org/10.1108/BFJ-07-2014-0239

Thakur, A. K., Mohanty, R. K., Patil, D. U., & Kumar, A. (2014). Impact of water management on yield and water productivity with system of rice intensification (SRI) and conventional transplanting system in rice. *Paddy and Water Environment*, *12*(4), 413-424. https://doi.org/10.1007/s10333-013-0397-8

Thanh, H. T., Tschakert, P., & Hipsey, M. R. (2021). Moving up or going under? Differential livelihood trajectories in coastal communities in Vietnam. *World Development*, *138*, https://doi.org/10.1016/j.worlddev.2020.105219

Todd, D. K., & Mays, L. W. (2004). *Groundwater hydrology*. John Wiley & Sons.U.S. Geological Survey. (2019). U.S.A.

United Nations World Water Development Report. (2022). *Groundwater: Making the invisible visible.*

Viets Jr, F. G. (1966). Increasing water use efficiency by soil management. *Plant environment and efficient water use*, 259-274.

Wang, J., Huang, J., Rozelle, S., Huang, Q., & Blanke, A. (2007). Agriculture and groundwater development in northern China: trends, institutional responses, and policy options. *Water Policy*, *9*(S1), 61-74.

World Bank Group. (2016). *Transforming Vietnamese Agriculture: Gaining more for less*. Washington, DC. World Bank. https://openknowledge.worldbank.org/handle/10986/24375

Zektser, I. S., & Everett, L. G. (2004). *Groundwater resources of the world and their use*. PHI.

Zhai, Q., Rahardjo, H., Satyanaga, A., & Dai, G. (2019). Estimation of unsaturated shear strength from soil–water characteristic curve. *Acta Geotechnica*, *14*(6), 1977-1990. https://doi.org/10.1007/s11440-019-00

Zhao, W., Liu, B., & Zhang, Z. (2010). Water requirements of maize in the middle Heihe River basin, China. *Agricultural Water Management*, *97*(2), 215-223. https://doi.org/10.1016/j.agwat