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परियोजना रिपोर्ट
PROJECT REPORT

भारत में सिंचाई की संभावनाएं: रुझान, निर्धारक और कृषि उत्पादकता पर प्रभाव

Prospects of Irrigation in India: Trends, Determinants and Impact on Agricultural Productivity

हर कदम, हर डगर
किसानों का हमसफर
भारतीय कृषि अनुसंधान परिषद
Agrisearch with a human touch

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जनसंख्या में ढाई गुना वृद्धि के बावजूद भारतीय कृषि पुरानी खाद्य कमी से खाद्य आत्मनिर्भरता में बदल गई है। इसे सिंचाई के बुनियादी ढांचे के विस्तार और उच्च उपज देने वाली किस्मों को अपनाने के लिए जिम्मेदार ठहराया जा सकता है। फसल उत्पादकता में सुधार के लिए एक व्यवहार्य और महत्वपूर्ण कारक के रूप में सिंचाई पर जोर देकर सिंचाई का विस्तार क्रमिक नियोजन अवधि में प्राप्त किया गया था। हालांकि, सिंचाई में बड़े पैमाने पर निवेश के बावजूद, खेती का लगभग 53 प्रतिशत क्षेत्र वर्षा पर निर्भर है। दूसरी ओर, भूजल दोहन, लवणता और जलभराव के मुद्दे स्थायी फसल उत्पादन के लिए चुनौतियां पेश कर रहे हैं।

देश में पानी की उपलब्धता में काफी स्थानिक भिन्नताएं हैं। देश का 36 प्रतिशत से अधिक भौगोलिक क्षेत्र कुल जल संसाधनों के 71 प्रतिशत से संपन्न है। कुल क्षेत्रफल के 64 प्रतिशत में, पानी की कमी एक प्रमुख चिंता का विषय है क्योंकि यह क्षेत्र असमान वर्षा और सामान्यता से बार-बार विचलन का सामना करता है। बढ़ते जल संकट से लाखों किसानों की रोजी-रोटी पर असर पड़ने वाला है। स्थिति और भी गंभीर हो जाती है क्योंकि भारतीय कृषि में छोटी जोतों का वर्चस्व है, जिनकी मुकाबला करने की क्षमता कम है। बढ़ते औद्योगीकरण और शहरीकरण को देखते हुए पानी की बढ़ती मांग को देखते हुए पानी की सीमित आपूर्ति का प्रबंधन करना होगा। नतीजतन, सिंचाई विकास में उपलब्धता और उपयोग, प्रभावों और उभरते परिदृश्यों की वर्तमान स्थिति को समझना प्रासंगिक है।

सृजित क्षमता, उपयोग में अंतराल, सिंचाई स्रोतों की बदलती गतिशीलता और हाल के दिनों में वित्तीय प्रदर्शन के संदर्भ में सिंचाई विकास की एक क्षेत्र-वार, साथ ही परियोजना श्रेणी-वार परीक्षा, उपयुक्त नीतियों और वित्तीय आवंटन को तैयार करने के लिए प्रतिक्रिया प्रदान करेगी। भविष्य की योजनाओं में क्षेत्रों में सिंचाई क्षेत्र में। भारत में सिंचाई विकास पर क्षेत्रवार स्थिति और सार्वजनिक व्यय का ज्ञान सिंचाई विकास के लिए सार्वजनिक निधि का उचित वितरण प्रदान करेगा। इन अनुसंधान जोरों ने हमें वर्तमान जांच करने और निष्कर्षों का दस्तावेजीकरण करने के लिए प्रेरित किया।

वर्तमान अध्ययन के निष्कर्ष सतही सिंचाई के सतत विकास और प्रबंधन, भूजल सिंचाई के लिए बिजली दरों को युक्तिसंगत बनाने, सिंचाई उपयोग दक्षता में सुधार और अधिक शोषित जिलों में जल कुशल फसल पैटर्न को बढ़ावा देने से संबंधित नीति निर्धारण के लिए एक मंच प्रदान करते हैं।

परियोजना दल

PREFACE

Indian agriculture has transformed from chronic food scarcity to food self-reliance despite a rise in population by two and a half times. It can be attributed to the expansion of irrigation infrastructures and the adoption of high yielding cultivars. The expansion of irrigation was achieved in successive planning periods by emphasizing irrigation as a viable, workable, and critical factor for improving crop productivity. However, despite the massive investments in irrigation, about 53 percent of the cultivated area is rainfed. On the other side, issues of groundwater exploitation, salinity, and waterlogging are posing challenges to sustainable crop production.

There are considerable spatial variations in the availability of water in the country. Over 36 percent of the country's geographical area is endowed with 71 percent of total water resources. In 64 percent of the total area, water scarcity is a major concern as the region faces uneven rainfall and frequent departures from normality. The increasing water crisis is going to affect the livelihoods of millions of farmers. The situation is further aggravated as Indian agriculture is dominated by small landholdings having poor coping capacity. The limited supply of water has to be managed in the view of increasing water demand, given increasing industrialization and urbanization. Consequently, it is pertinent to understand the current status of availability and use, impacts, and emerging scenarios in irrigation development.

A region-wise, as well as project category-wise examination of irrigation development in terms of created potential, gaps in utilization, the changing dynamics of irrigation sources and financial performance in the recent past, would provide feedback for framing appropriate policies and financial allocation in the irrigation sector across the regions in future plans. Knowledge of region wise status and public expenditure on irrigation development in India will provide for appropriate distribution of public fund for irrigation development. These research thrusts motivated us to take up the present investigation and document the findings.

The findings of the present study provide a platform for policy reframing related to sustainable development and management of surface irrigation, rationalizing power tariffs for groundwater irrigation, improving irrigation use efficiency and promoting water efficient cropping pattern in over exploited districts.

Project Team

Chapter-1

Introduction

1.1 Introduction

During 1950 to 2017, Indian agriculture has transformed from chronic food scarcity to food self-reliance despite a rise in population by two and a half times. It can be attributed to the expansion of irrigation infrastructures and the adoption of high yielding cultivars. The expansion of irrigation was achieved in successive planning periods by emphasizing irrigation as a viable, workable, and critical factor for improving crop productivity. However, despite the massive investments in irrigation, about 53 percent (%) of the cultivated area is rainfed (GoI, 2019). On the other side, issues of groundwater exploitation, salinity, and waterlogging are posing challenges to sustainable crop production.

There are considerable temporal and spatial variations in the availability of water in the country. It is evident because about 36% of the country's geographical area is endowed with 71% of total water resources (Verma and Phansalkar, 2007). The net sown area of the country is about 140.5 million hectares (mha) with a Net Irrigated Area (NIA) of 67.5 mha during TE 2014 (GoI, 2016). This implies that 52% of the net sown area remained rain-dependent during the period. With highly uneven rainfall and frequent departures from normality, water scarcity has become a significant concern. Therefore, the increasing water crisis is going to affect the livelihoods of millions of farmers.

Moreover, the situation is aggravated as Indian agriculture is dominated by small landholdings having poor coping capacity. Therefore, the limited supply of water has to be managed in the view of increasing water demand, given increasing industrialization and urbanization. Consequently, it is pertinent to understand the current status of availability and use, impacts, and emerging scenarios in irrigation development.

Canals and groundwater are the two important sources of irrigation in India. In the country, rainfall is a crucial component of the hydrological cycle for groundwater recharge and the natural surface flow of water. Canal water in a river basin is utilized for irrigation and other purposes through the construction of major and medium storage dams. In addition, a large number of diversion schemes and pumped storage schemes are operational in any river basin. Since independence, the rapid expansion of groundwater irrigation has contributed to 84% of total addition to the NIA.

India has become the most prominent and fastest-growing consumer of groundwater in the world. It has been extensively documented that groundwater is being exploited beyond sustainable levels. With around 20.5 million groundwater structures in 2013-14 (GoI, 2017a), the country is likely to be hurtling towards a severe crisis due to groundwater over-extraction. Quality deterioration associated with overexploitation is also alarming. Therefore, the sustainable development of surface water resources is extremely important for sustainable agriculture in India. For this, a proper assessment of surface water availability is of prime importance.

With this background, the present study analyzes regional variations in irrigation development and utilization patterns and expenditure in creating public irrigation infrastructure. The study also analyzes the status and drivers of groundwater extraction at the district level. The study aims to provide a policy impetus towards sustainable irrigation development in India

1.2 Review of literature

Singh and Gupta (1997) in the study on political economy of large dams in India noted that growth rate of irrigated area continues to fall from 4.23 per cent per year during the 1970s to 3.08 percent per year in 1980s and to 2.56 per cent in the 1990s.

Postel (1999) reported that irrigated area across the world increased from just 8 million hectares (M Ha) in 1800 to 40 M Ha (13.4 M Ha in India) in 1900, to 100 M Ha in 1950 and to 255 M Ha in 1995. Between 1970 and 1982, world irrigated area grew at an average rate of 2 per cent per year. But between 1982 and 1994, this rate dropped to an annual rate of 1.3 per cent.

Selvarajan (2002), in his study on sustaining India's irrigation infrastructure, confirmed that area under irrigation in Uttar Pradesh had decreased from 33.3 lakh ha in TE 1985 to 30.66 lakh ha in TE 2000. Similarly, in Andhra Pradesh, canal irrigated area declined by 11 per cent over the same period. Bihar, Orissa and Tamil Nadu also recorded a similar decline in the canal irrigated area. Together, these five states accounted for 50 per cent of irrigation potential created and 45 per cent of net area irrigated in the country.

Tyagi *et al.* (2002) in their study on the need for proper water management for food security, reported that canal irrigated area increased from 8.2 m ha in 1950-51 to 15.4 m ha in 2005-06 and in the last 10 years there was a declining trend in canal water irrigated area. As opposed to this, the contribution from groundwater to the total irrigation area increased substantially from 5.9 mha in 1950-51 to 35.3 ha in 2005-06.

Lohmar *et al.* (2003) studied the nature of investment in China's irrigation sector. The study noted that decreasing investment in surface water infrastructure in China led to a decline in irrigated area, poor surface water management and growing reliance on groundwater for irrigation.

Hussain and Wijerathna (2004) argued that irrigation reduces poverty both directly and indirectly, where the direct impacts are realized through labour and land augmentation effect that ultimately translates to improved productivity, employment, income and consumption, while the indirect impact is realized through enhanced local economy and improved welfare at macro level.

Huang *et al*. (2005) in the study on irrigation, poverty and inequality in china, used household level cross sectional data to apply a multivariate analysis method. The study found a strong positive correlation between access to irrigation and household income, leading to poverty reduction and equitable income distribution.

Janakarajan and Moench (2006) while comparing land use statistics for India noted that between 1996-97 and 2002-03, the area under canal irrigation declined by 2.4 million ha (42.4 per cent) and the area irrigated by all other sources declined by one million ha (28 percent). The only irrigation source that increased its share was groundwater wells, by 2.8 million ha (more than 9 per cent).

Molden *et al.* (2007) studied the trends in water and agricultural development. The study reported that the world's agricultural land increased by about 24 per cent from 1961 to 2003 to 1.2 billion hectares (ha), 28 per cent of it irrigated, while the area under irrigation nearly doubled from 139 million ha to 277 million ha. Approximately 70 per cent of the world's irrigated land is in Asia, where it accounts for almost 35 per cent of cultivated land.

Namara *et al.* (2007) in the study on economics, adoption determinants, and impacts of micro-irrigation technologies in India reported that the largest adopters of micro-irrigation belong to the middle and rich group of farmers. The most important determinants of micro-irrigation scheme adoption in India include access to groundwater, cropping pattern, availability of cash, and level of education, the social status and poverty status of the farmers.

Inocencio and McCornick (2008) examined trends in the economic performance of irrigation investments in India. The study indicated that the performance of irrigation investments in India by the government and key external funding agencies has been declining with time, whereas at a global level they have, in fact, been on an upward trend. No significant trend is established for the unit cost of the sample irrigation projects in India. The decline in government funding in irrigation projects is consistent with the decline in the budget allocation of the central government for irrigation and the irrigation expenditures of the states, especially since the 1980s.

Ramanayya *et al.* (2008) studied the gap between the irrigation potential created and utilized in southern states of India. The total irrigation potential created in Andhra Pradesh up to the year 1997 was 4.80 mha. Out of this, only 2.84 mha was being irrigated, leaving a gap of 1.96 mha. Under major irrigation projects, the gap during Kharif season was 30.74 per cent wherein during Rabi, it was much less at 8 per cent. The gap in the case of minor irrigation projects varied from 8 per cent during Kharif and 59 per cent during Rabi season. The major reasons for existing gap were erratic rainfall in the catchment, deviating from recommended cropping pattern, poor maintenance of canal systems.

A study carried out by Kohansal and Hadi (2009) reveals that variables such as farm size, educational level, farming as the first job, land slope, heterogeneity of soil and access to loan are the factors that influence the adoption of sprinkler irrigation in Iran.

In Andhra Pradesh, there existed a positive relationship between public expenditure and irrigation development over time. Due to public investment, the total area under irrigation increased to 48.74 per cent in 2008 against 39.24 per cent in 2004. However, of late, declining investment, poor maintenance and low water use efficiency adversely affected the performance of irrigation sector (Chittedi and Bayya, 2012).

Kishore (2013) conducted a study on demand and supply management of water in Gujarat. The study analyzed the demand and supply side interventions and concluded that Gujarat was a water scarce state. Farmers adopted diversification towards high-value crops and dairying for overcoming the difficulties associated with water scarcity. The results indicated that the demand for water for agriculture was unlikely to change. The political leadership, farmers lobbying and diversification within agriculture were important factors influencing demand of water in Gujarat. Over exploitation of the existing water resources was evident though only one-third of the net sown area was irrigated. Redesigning of the existing irrigation facilities was necessary to meet the needs of hitherto un-irrigated areas. The study suggested promoting micro irrigation system to increase the water use efficiency.

Srivastava *et al*. (2014) analysed variations in the irrigation development in India across regions over consecutive five-year plan periods from 1950 to 2007. The study also looked into the impact of irrigation on agricultural performance of the country. The study found that the regional variations in irrigation development caused unbalanced utilisation of the water resources. In north western region, irrigation water was exploited excessively whereas, southern region suffered from severe water stress. Irrigation development was satisfactory in the northern part of the country which aided in better agricultural performance. Regardless of having sufficient water resources, the eastern region of the country had poor irrigation development, adversely affecting agricultural development. The results indicated a positive and significant relationship between irrigated area and crop yield. The study suggested policy and technological interventions to enhance water use efficiency and ensure equitable water distribution.

Bathla (2017) appraised the impact of public investment on agricultural growth and poverty reduction in India. Power subsidies and price structure influenced farm level investment in irrigation infrastructure. An analysis of the average share of public expenditure during 1981–2014 indicated that nearly 27 per cent was allocated to irrigation and flood control. Public expenditure on medium irrigation had a greater share within irrigation and flood control. The estimated results revealed a positive and significant relationship between public irrigation expenditure and agricultural productivity and income.

Nonvide (2017) identified respondent age, gender, extension services, access to credit, market participation, distance from home to irrigation scheme, use of tractor, and rate of fertilizer application as the factors affecting the probability of irrigation adoption. Heckman second stage model showed that adoption of irrigation contributes significantly to rice yield improvement. For robustness checks of the estimated effect of adoption of irrigation on rice yield, the propensity score matching method (PSM) was used. The results of the PSM indicated that the percentage increase in rice yield due to irrigation adoption varies between 63% and 70%.

Kannan *et al*. (2019) analysed irrigation development in the major states using irrigation governance index for service delivery. The main indicators of the index were source wise irrigated area, cropping intensity, stage of groundwater development, and percentage of irrigation potential utilized. The results indicated that Haryana, Punjab, Rajasthan, Uttar

Pradesh and West Bengal were performing better than Assam, Jammu and Kashmir, Himachal Pradesh, and Jharkhand reflecting poor governance in the latter states. The study concluded that promoting good governance in the management of irrigation systems would reduce the gap between irrigation potential created and utilized, increasing water use efficiency.

1.2 Motivation

Not many studies have analyzed the physical and financial performance of irrigation projects across different regions over the years and long-term impact of irrigation on the agricultural sector in India. A region-wise, as well as project category-wise examination of irrigation development in terms of created potential, gaps in utilization, the changing dynamics of irrigation sources and financial performance in the recent past, would provide feedback for framing appropriate policies and financial allocation in the irrigation sector across the regions in future plans. Knowledge of region wise status and public expenditure on irrigation development in India will provide for appropriate distribution of public fund for irrigation development. Importance of irrigation will be known by assessing the impact of irrigation access on agricultural productivity. This study will also help in framing evidence-based region-specific policies for sustainable use of irrigation resources.

1.4 Objectives

1. To study the trends in public expenditure and status of irrigation development in India
2. To identify the factors influencing access to irrigation in India
3. To assess the impact of irrigation development on crop productivity in India

1.5 Report orientation

This report has been systematically divided into four chapters. Chapter 1 provides a brief introduction of the problem, relevant reviews, motivation and objectives of the present investigation. Chapter 2 describes the trends in public expenditure and irrigation development in India. Chapter 3 provides the status and factors influencing access to groundwater extraction in India. In chapter 4, we assessed the impact of irrigation access on productivity of major crops in India. Conclusions and implications are discussed in the final chapter.

Chapter-2

Status of irrigation development and public expenditure in India

2.1 Data and methodology

The present chapter is based on the secondary data collected from various sources. Time series data on the state-wise and source-wise area under irrigation was collected from the 'land use statistics' reports published by the Directorate of Economics and Statistics (DES). Time series data on district wise and source-wise area under irrigation was collected from the district land use statistics reports. The data on irrigation potential created and utilized was collected from the reports of 'water and related statistics' published by Central Water Commission, Ministry of Jal Shakti, Government of India. The time-series data on public expenditure on surface irrigation development in 19 major agricultural states was collected from state finance accounts of the Comptroller and Auditor General of India.

Following Srivastava et al., 2013, states were categorized into four geographical regions for inter-regional analysis (Box 1). Spatial and temporal irrigation trend was examined by analyzing physical and financial progress in irrigation development. The data on public irrigation expenditure, collected under different subheads, was clubbed separately under revenue expenditure and capital expenditure categories. The expenditure data was deflated using a gross fixed capital formation deflator for the base year 2011.

Box 1. Categorization of geographical regions of India

Northern	Southern	Eastern	Western
Haryana	Andhra Pradesh (Erstwhile)	Bihar	Gujarat
Himachal Pradesh	Karnataka	Chhattisgarh	Madhya Pradesh
Jammu and Kashmir	Kerala	Jharkhand	Maharashtra
Punjab	Tamil Nadu	Odisha	Rajasthan
Uttar Pradesh		West Bengal	
Uttarakhand			

2.2 Status and pattern of irrigation development

Historically, irrigation has played a vital role in accelerating agricultural development in India. Irrigation development has facilitated the cropping intensity of the country from 112% in 1950-54 to 140% in 2010-14. As a result, the gross cropped area has increased from 138 mha to 197 mha during the corresponding period with an annual growth rate of 0.54% despite stagnated growth (0.14%) in the net sown area.

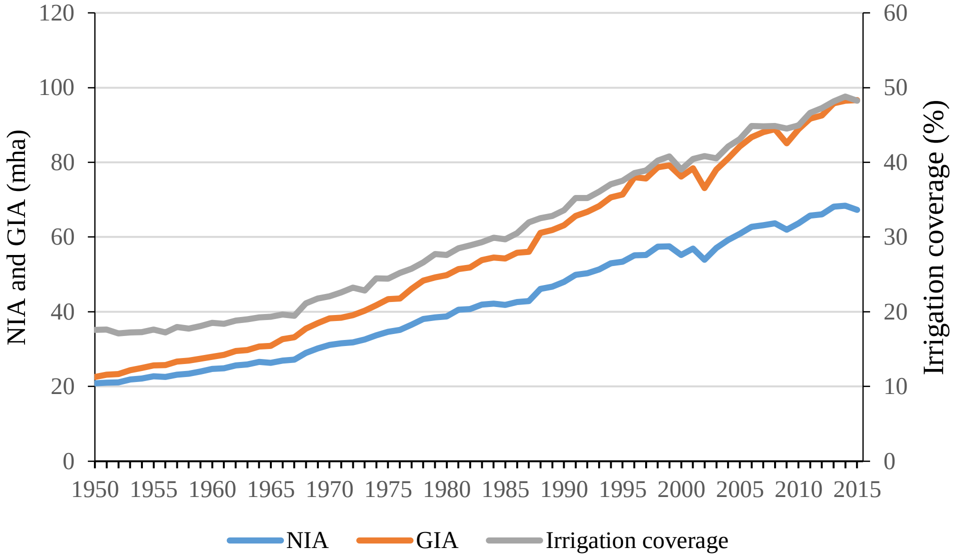

Figure 1. The trend in irrigation coverage in India, 1950-2015

Table 1. Irrigation development in India, 1951-2014

Period	Surface water (%)	Groundwater (%)	Net irrigated area (mha)
1951-60	70.13	29.86	22.67
1961-70	66.72	33.28	27.38
1971-80	57.48	42.52	35.12
1981-90	51.02	48.98	43.35
1991-00	43.38	56.62	53.84
2001-10	38.73	61.27	60.46
2011-14	37.59	62.24	67.16

Data source: Authors' calculations using data from Directorate of Economics and Statistics for various years

The relative share of surface and groundwater sources in the NIA in India is shown in Table 1. The NIA has increased from 22.67 mha during 1951-60 to 67.16 mha during 2011-14. There has been a structural shift in the irrigation sector regarding its relative contribution from different irrigation sources. The share of surface irrigation comprising canal and tank irrigated area, in the total NIA has declined from 70.13% in 1951-60 to 37.59% in 2011-14. Whereas, the share of groundwater irrigated area has increased from 29.86% to 62.24%

during the same period. The intensive use of groundwater due to its reliability and efficiency has resulted in groundwater emerging as the dominating source of irrigation in Indian agriculture.

Region-wise progress in irrigation coverage and irrigation land-use intensity during 1990-2014 is depicted in Table 2. The irrigation coverage has increased over the years across the regions except in the eastern region where it has declined marginally from 33.47% in 1990-94 to 32.67% in 2010-14. During 2010-14, the northern region had the highest irrigation coverage (63.22%) followed by the southern (39.26%) and western regions (39.15%). Concerning irrigation land-use intensity, northern states had witnessed an impressive increase from 134.54% during 1990-94 to 169.25% during 2010-14. Western and eastern states had registered a rise from 116.90 and 118.92% to 126.31 and 135.25%, respectively. However, southern states had witnessed a decline in irrigation land-use intensity from 124.82% to 123.36% during the same period. This decline is mainly attributed to farmers shifting away from less profitable food grain crops to high-value plantation crops (Kumar and Gupta, 2015).

Table 2. Region-wise irrigation coverage and irrigation land use intensity in India

	North	West	East	South	India
Irrigation coverage (%)					
1990-94	48.83	23.63	33.47	30.29	35.43
2000-04	56.09	29.68	32.43	33.18	40.61
2010-14	63.22	39.15	32.67	39.26	47.15
Irrigation land use intensity (%)					
1990-94	134.54	116.9	118.92	124.82	132.46
2000-04	147.07	117.1	137.1	120.1	136.98
2010-14	169.25	126.31	135.25	123.36	140.19

Data source: Authors' calculations using data from Directorate of Economics and Statistics for various years

The region-wise share of surface and groundwater irrigation in the NIA during 1990-2014 is presented in Table 3. It shows that the share of surface irrigation in the NIA has been declining in all the regions. During 2010-14, its share was highest in the eastern region (57%) followed by the southern region (47.27%). Conversely, the northern region had the lowest percentage (25.97%) of surface irrigation in NIA.

On the other hand, the share of groundwater irrigation in the NIA has increased in all the regions. The share of groundwater irrigation in the country has increased from 53.13% during 1990-94 to 62.14% during 2010-14. As per the fifth minor irrigation census (2017), in 2013-14, there were 20.45 million groundwater irrigation structures (including 8.8 million dug wells and 11.67 million tube wells) in the country and 99% of these are constructed by private investment by farmers. It was highest in the northern region (74.03%) followed by the western (70.58%) and southern regions (52.73%). The eastern region had the lowest share (43%) of groundwater irrigation in the country. The overexploitation of groundwater in the north-western states of the country co-exists with low levels of development in the eastern region. Lower groundwater exploitation in the eastern region is mainly due to the inadequate availability of electricity. Alternatively, farmers use diesel, which is a relatively high-priced source of energy, to extract groundwater which accounts for a substantial share (74%) of energy requirement (GoI, 2017a) resulting in lesser utilization of groundwater. This has a bearing on the agricultural performance and poverty scenario in the eastern states (Rijsberman, 2003). As a more reliable and efficient source of irrigation than surface water, the groundwater had a profound impact on better irrigation development in the northern and western regions of the country (Sharma, 2009). However, groundwater is overexploited in the north-western regions where electrified tubewells are dominant which use cheap energy making irrigation development unsustainable (GoI, 2017a).

The abundant availability of water resources and lower utilization of groundwater provides a strong case for reframing policies in the eastern region. Improvement in access and availability of electricity for irrigation coupled with an acceleration in private investment by farmers in groundwater irrigation may significantly enhance farm income in the eastern states. Simultaneously, renewable energy sources like solar energy need to be actively promoted.

Table 3. Region-wise share of surface and groundwater irrigated area in India

Period	North	West	East	South	India
The share of surface irrigation (%)					
1990-94	39.70	38.60	60.30	63.10	46.87
2000-04	29.05	29.29	58.66	51.58	38.03
2010-14	25.97	29.42	57	47.27	37.86
The share of groundwater (%)					
1990-94	61.30	61.40	39.70	36.90	53.13
2000-04	70.95	70.71	41.34	48.42	61.97
2010-14	74.03	70.58	43	52.73	62.14
Net irrigated area (million ha)					
1990-94	18.21	14.65	7.91	9.37	50.50
2000-04	20.65	16.55	9.39	9.41	56.45
2010-14	21.78	23.37	9.19	11.62	66.38

Data source: Authors' calculations using irrigation data from Directorate of Economics and Statistics for various years

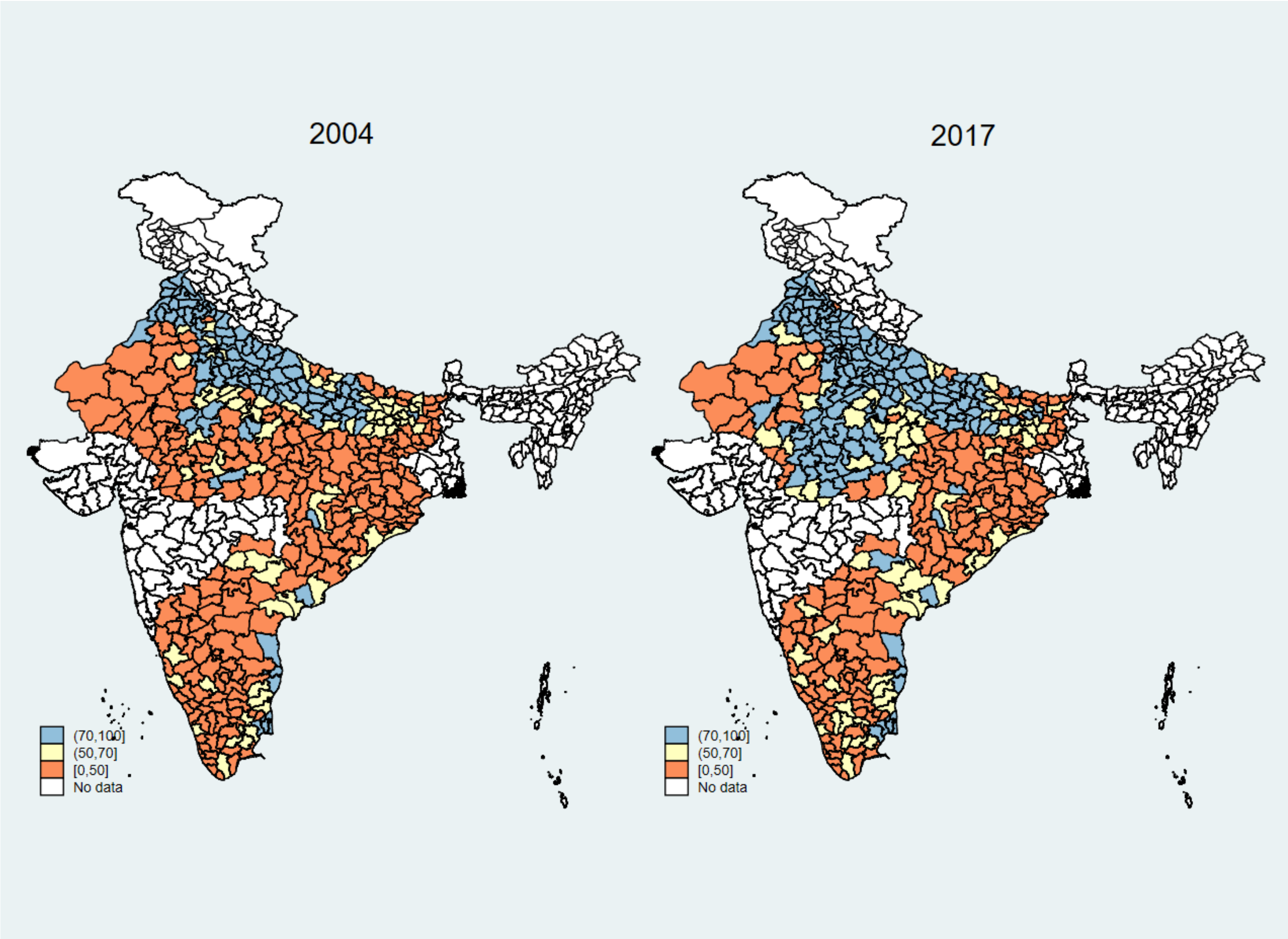

Figure 2. District wise irrigation coverage (%) in India in 2004 and 2017

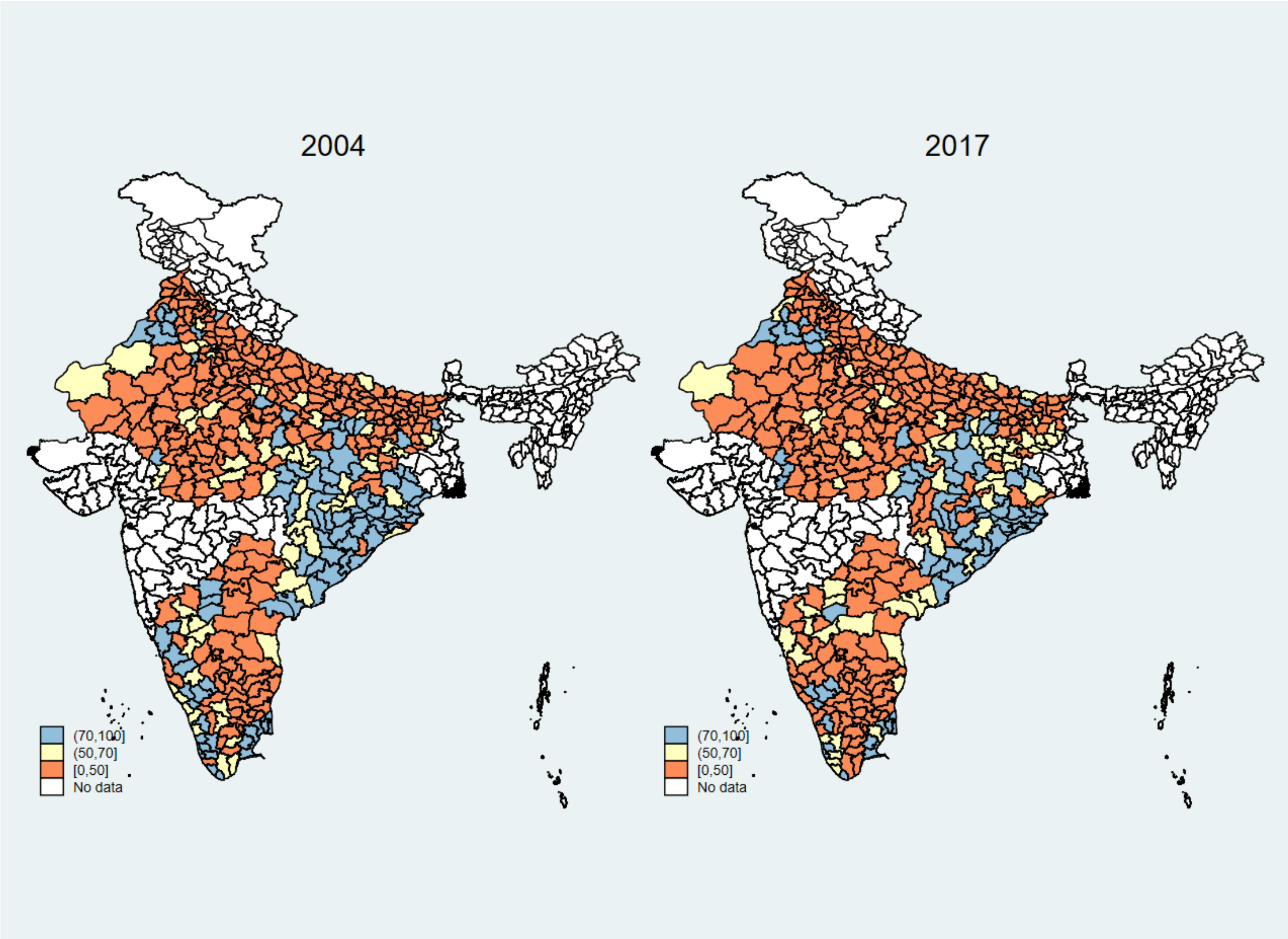

Figure 3. District wise share (%) of surface irrigation in net irrigated area in India in 2004 and 2017

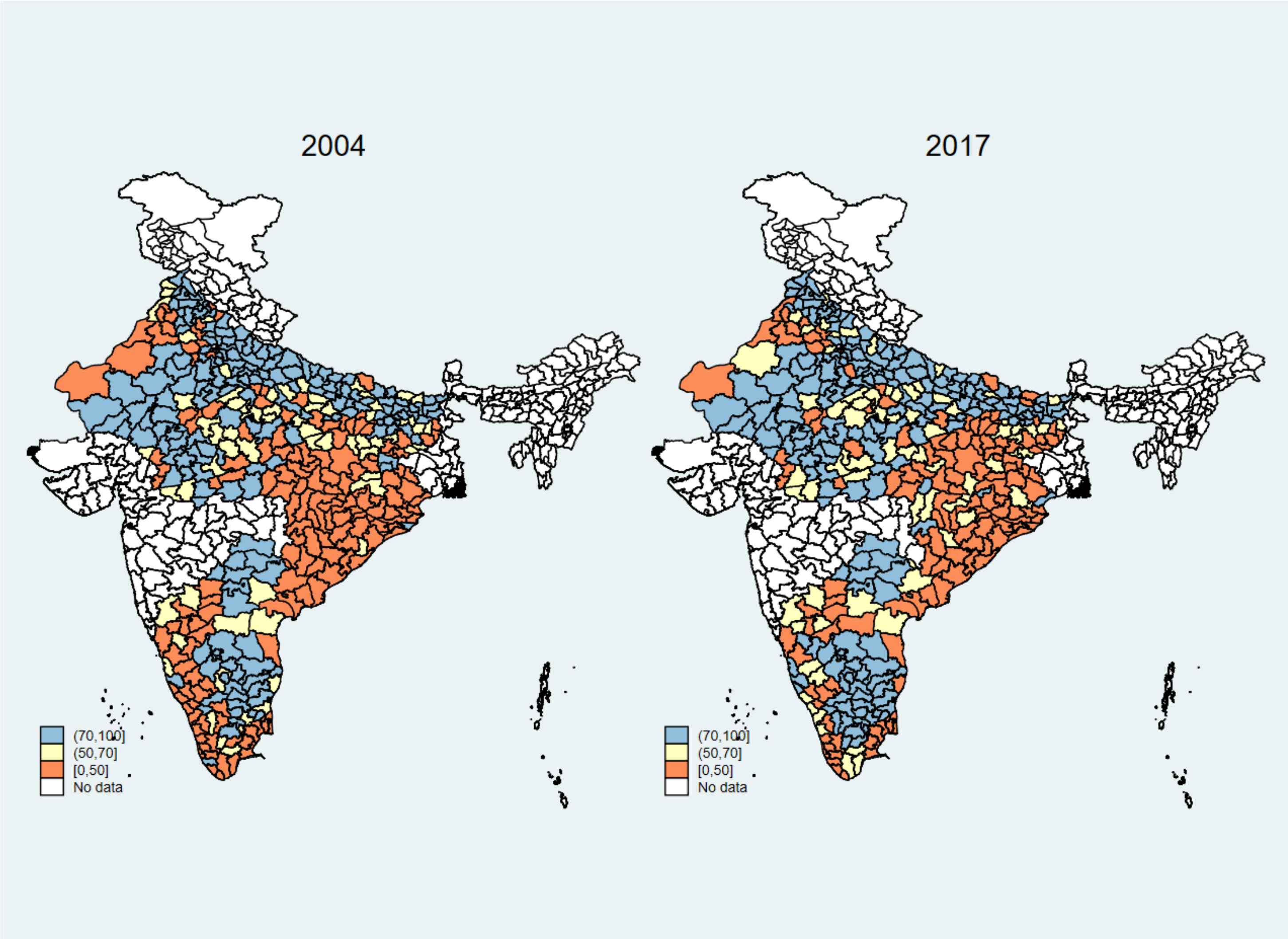

Figure 4. District wise share (%) of groundwater irrigation in net irrigated area in India in 2004 and 2017

Figure 2 shows the district wise irrigation coverage in India between 2004 and 2017. We can see that districts in northern India have shown an improvement in the irrigation coverage of more than 70%. Whereas most of the districts in the eastern and southern regions had an irrigation coverage of less than 50%. Figures 3 and 4 show that surface irrigation is dominant in the eastern region districts and in the coastal districts of southern states, whereas groundwater is the major source of irrigation in the northern states and southern states of Karnataka and Tamil Nadu.

2.3 Public expenditure on surface irrigation development

Public expenditure comprises of capital expenditure and revenue expenditure. Capital expenditure includes productive investment for the creation of irrigation infrastructure. Whereas revenue expenditure includes operation and maintenance, administration expenses, and grants given to Water Users Associations (WUAs). After independence, the first three decades witnessed massive investments in dams, reservoirs, and canal networks through multipurpose river valley schemes. But later, during the 1980s and 1990s, public expenditure on irrigation development declined consistently (Fan et al., 2008). While the costs of creating additional irrigation facilities through major and medium-sized surface irrigation schemes went up, resources to complete these schemes shrank. Consequently, growth in the area irrigated through publicly funded schemes slowed down, creating severe shortages of irrigation water on the one hand and many unfinished irrigation projects on the other (Fan et al., 2008).

During TE 1995, the real public irrigation expenditure (at 2011-12 constant prices) was Rs. 281.85 billion of which 46.3% (Rs.130.6 billion) was a real capital investment, which is also the real investment in the creation of productive assets. During 1996-97, to assist states to complete pending irrigation schemes through central loans and grants, the Government of India introduced the Accelerated Irrigation Benefits Programme (AIBP). Subsequently, during TE 1999, public irrigation expenditure soared to Rs. 342.81 billion with 47.38% of real capital investment.

Overall, the financial allocation to the irrigation sector grew from Rs. 266 billion in TE 1995 to Rs. 697 billion in TE 2014 at a compound annual growth rate of 5.6%. The share of the real capital investment had increased from 45.33% (Rs 121 billion) to 61.75% (Rs. 430

billion) at an annual growth rate of 8%. The bulk of irrigation expenditure (79%) was constituted by major, medium, and command area development projects followed by minor irrigation projects.

The region-wise analysis shows that the allocation of financial resources for irrigation development exhibited significant inter-regional variations. During TE 2014, southern states had incurred the largest share of public expenditure (36.98%) in the country followed by the western states (29.78%). The share of real investment in the total public expenditure was highest in the southern region (63.03%) followed by the eastern (59.67%), western (49.80%), and northern regions (34.4%). The relatively higher share in the southern region was mainly due to the higher cost of creating irrigation potential (Figure 5). The western states had the highest number (1023) of completed and ongoing projects (major, medium, and ERM projects) followed by the eastern (487), southern (443), and northern regions (305) until 2014.

Although public irrigation expenditure has increased in recent years across all regions, it is heavily biased towards the operation and maintenance of irrigation systems in northern states. In northern states, around two-thirds of government spending on irrigation was incurred as revenue expenditure, leaving little for creating productive irrigation assets. The regional variation in irrigation investment was primarily due to varying number, composition, size, the relative cost of the irrigation projects, time and cost overruns in the respective region, and hidden inefficiencies in the execution of projects.

2.4 Cost of creation of irrigation potential

There has been a substantial increase in the per hectare cost of creating irrigation potential over the years (Dhawan, 1993; Government of India, 1999; Fan et al., 2008; Srivastava et al., 2013). For major and medium irrigation projects, the cost has increased from US$ 33.6 and US$ 520 during 1951-56 to US$4230 and US$2270 during 2002-07 at current and constant (1993-94) prices, respectively (Fan et al., 2008). The increase in the cost of creation of irrigation potential was huge from 1980-85 onwards, because of the introduction of the extension and distribution system up to 5–8 ha blocks, the cost of rehabilitation and resettlement, environmental and forest aspects, the inclusion of cost of catchment area treatment, the inclusion of drainage system in command of irrigation projects, increase in establishment costs, etc. (GoI, 1999).

Figure 5 shows the region-wise per ha cost of creation of irrigation potential under major, medium, and Extension, Renovation, and Moderation (ERM) projects during 2005-09 and 2010-14. The per ha irrigation investment was highest (Rs. 12.65 Lakh and Rs. 29.97 lakh) in the southern region and least (Rs. 1.70 Lakh and Rs. 2.95 Lakh) in the northern region of the country during both periods. While, western states witnessed a decrease in the cost of creation of irrigation (from Rs. 6.49 lakh to Rs. 4.66 lakh) during 2005-09 and 2010-14, the escalation in cost was substantial (from Rs. 2.65 lakh to Rs. 5.57 lakh) in eastern states due to time and cost overruns. During 2002-07, the highest number of new projects were initiated in the eastern region without giving due attention to completing ongoing projects (Srivastava et al., 2013). Further delay in the completion of projects had led to declining irrigation potential created from 472 thousand ha to 255 thousand ha during 2004-08 to 2009-13. It reflected the inefficiencies in the implementation of irrigation projects by eastern states.

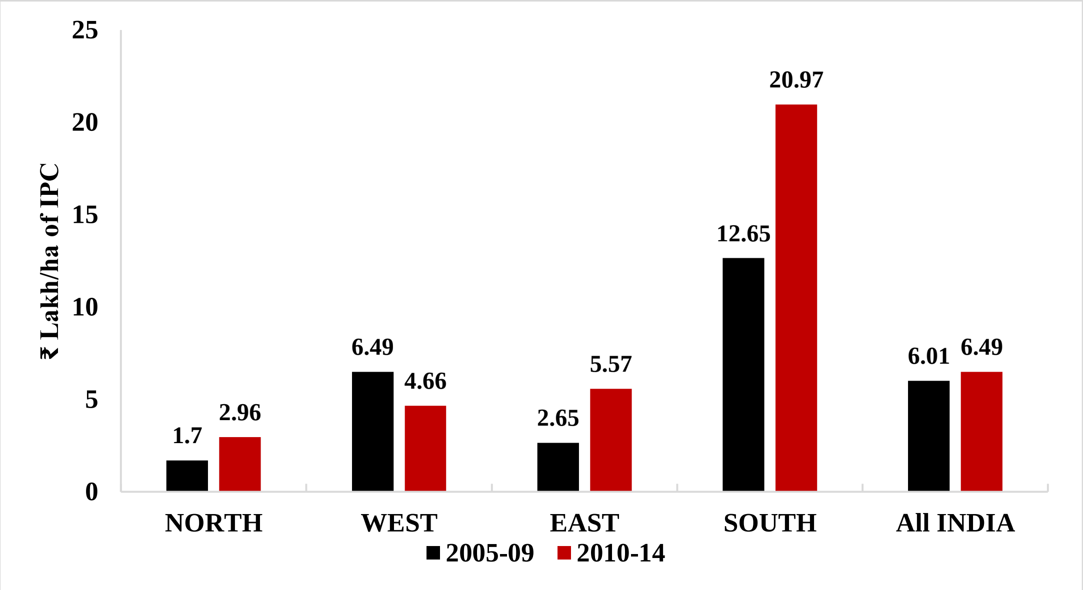

Figure 5. Region-wise per ha cost of creation of irrigation potential under major and medium irrigation projects.

The irrigation sector in India is facing the challenge of time overruns. During 2012-17, 309 new projects were started with backlog projects of 553 from previous years. Of which, only 116 projects were completed at the end of 2011. Then, during 2012-17, another 86 new major, medium, and ERM projects were added along with 322 spilled over projects. These spill-over projects were highest in western (172) and eastern regions (66). The huge backlog of irrigation projects was because too many large projects were initiated without emphasizing the completion of ongoing projects. Although successive five-year plans accorded the highest priority to complete ongoing projects, the initiation of new projects continued unabated. Another major reason for time overruns is the inadequate fund allocation for completing projects as per the implementation schedule prepared at planning.

Table 4. Region wise public expenditure on surface irrigation development in India (at 2011-12 constant prices)

(Rs billion)

	North		West		East		South		India	
	Capital expenditure	Public expenditure	Capital expenditure	Public expenditure	Capital expenditure	Public expenditure	Capital expenditure	Public expenditure	Capital expenditure	Public expenditure
TE 1995	17.93 (30.31)	59.17 (20.99)	28.14 (31.01)	90.77 (32.21)	13.23 (51.62)	25.63 (9.09)	39.60 (54.95)	72.06 (25.57)	130.6 (46.34)	281.8 (100)
TE 1998	22.03 (35.91)	61.35 (19.00)	42.58 (38.28)	111.24 (34.44)	19.73 (58.85)	33.53 (10.38)	37.35 (48.40)	77.18 (23.90)	151.6 (46.93)	323.0 (100)
TE 2001	25.39 (40.99)	61.93 (18.09)	34.40 (32.04)	107.35 (31.37)	22.03 (53.73)	41.01 (11.98)	49.00 (53.27)	91.99 (26.88)	154.6 (45.18)	342.2 (100)
TE 2004	19.92 (32.04)	62.19 (15.51)	50.22 (32.12)	156.35 (38.99)	26.32 (58.85)	44.73 (11.15)	73.04 (63.60)	114.85 (28.64)	245.3 (61.17)	401.0 (100)
TE 2007	20.67 (31.20)	66.24 (12.04)	73.33 (41.19)	178.00 (32.34)	31.52 (59.89)	52.63 (9.56)	164.73 (73.41)	224.39 (40.77)	373.4 (67.85)	550.3 (100)
TE 2010	45.86 (43.87)	104.52 (15.56)	88.93 (39.74)	223.80 (33.32)	43.21 (58.61)	73.72 (10.97)	156.62 (67.87)	230.76 (34.35)	444.9 (66.23)	671.8 (100)
TE 2014	36.38 (34.09)	106.72 (15.31)	103.74 (49.99)	207.52 (29.78)	51.43 (59.70)	86.14 (12.36)	162.40 (63.02)	257.69 (36.98)	430.3 (61.74)	696.9 (100)

Note: TE-Triennium ending average; Figures in parentheses in capital expenditure column are percentage of respective public expenditure; Figures in parentheses in public expenditure column are percentage of public expenditure in India

Chapter 3

Status and drivers of groundwater extraction in India

3.1 Data and methodology

To study the status and factors influencing groundwater extraction in India, data on district wise groundwater extraction was collected from the reports of groundwater statistics of the Central Groundwater Board for the years 2004, 2009, 2013, and 2017. The data on energized tubewells was collected from the reports of minor irrigation census of various years. Following the classification by Central Groundwater Board, GoI, based on their stage of groundwater withdrawal as a percentage of its net availability, districts were classified as safe and unsafe (which includes semi-critical, critical, and overexploited categories). Safe is groundwater extraction from 0 to 50% of the net availability due to groundwater recharge from rainfall, semi-critical from 50-70%, critical from 71-99%, and overexploited100% and above.

Panel data regression

Panel data analysis has advantages over ordinary least square (OLS) regression models in terms of increased precision in estimation due to the increase in the number of observations by combining or pooling several periods of data for each individual. Also, it captures unobserved individual heterogeneity that may be correlated with regressors. In this study, the panel data set consists of 535 districts over 5 years. The fixed effect model (FEM) and the random effect model (REM) were used to analyze the factors influencing groundwater extraction in India.

The FEM has constant slopes but intercepts differ according to the cross-sectional (districts) unit. For *I* classes, *i*–1 dummy variables are used to designate a particular state. It allows for heterogeneity or individuality among districts (units) as each state is allowed to have its intercept value. So, intercept may differ across states but it does not differ over time. In the REM, the intercept is assumed to be a random outcome variable, whereas the random outcome is a function of a mean value plus a random error.

FEM allows different states (cross-section units) to have their intercept terms, though all slopes are the same. The specification of the model is given below:

$$Y_{it} = \alpha_i + \beta_1 X_{1\,it} + \beta_2 X_{2\,it} + \beta_3 X_{3\,it} + \beta_4 X_{4\,it} + \beta_5 X_{5\,it} + e_{it} \quad (1)$$

$$e_{it} \backsim IID(0, \sigma^2{}_e)$$

Where

Y_{it}	=Rate of groundwater extraction as a percentage of net availability of groundwater expressed in the i^{th} district (i=1 to 535) and t^{th} year (t=1 to 5)
X_1	= Proportion of electrified tubewells (%)
X_2	= Annual rainfall (mm)
X_3	= Irrigation coverage (%)
X_4	= Proportion of surface irrigated area (%)
X_5	= Cropping intensity (%)
e_{it}	=error component
$\alpha_i, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$	= parameters to be estimated

REM assumes that individual-specific coefficient α_i is fixed for each time-in-variant and α_i is a random variable with mean value α and intercept of α any cross-section unit is expressed as follows:

$$\alpha_i = \alpha + \epsilon_i \quad (2)$$

$$\epsilon_i \backsim IID(0, \sigma^2{}_{ei})$$

Therefore, REM can be expressed as:

$$Y_{it} = \alpha + \beta_1 X_{1\,it} + \beta_2 X_{2\,it} + \beta_3 X_{3\,it} + \beta_4 X_{4\,it} + \beta_5 X_{5\,it} + w_{it} \quad (3)$$

Where, $w_{it} = \epsilon_i + e_{it}$

w_{it} is a composite error term, ϵ_i is a cross-section error component and e_{it} is a combined time series and cross-section error component.

3.2 Status of groundwater extraction

Figure 6 shows the state-wise groundwater withdrawal as a percentage share of its net availability in 2004 and 2017 in India. The rate of groundwater extraction has increased across the states except in Gujarat. We can see that, in the states of Punjab, Rajasthan, and Haryana, the rate of groundwater withdrawal is beyond its natural replenishing capacity. The rate of groundwater withdrawal in Punjab has increased from 149% in 2004 to 165% in 2017.

Whereas, the states of Rajasthan and Haryana have witnessed an increase from 117% and 105% to 137% and 135% respectively. The NASA assessment showed that during 2002-08, these three states together have lost about 109 km^3 of groundwater (Rodell et al., 2009) and emerged as the most prominent global hotspots of groundwater crisis (Shah, 2009; Chen et al., 2014; Shekhar et al., 2020; Van Dijk et al., 2020). The southern state of Tamil Nadu has also moved towards rapid groundwater depletion from 77% in 2004 to 87% in 2017. The decline in the rate of groundwater extraction from 74% to 59% in Gujarat is attributed to the successful implementation of Jyotirgram yojana which restricted the supply of power to agriculture (Shah and Verma, 2008). The figure shows that the eastern states have witnessed a safe level groundwater withdrawal during the study period.

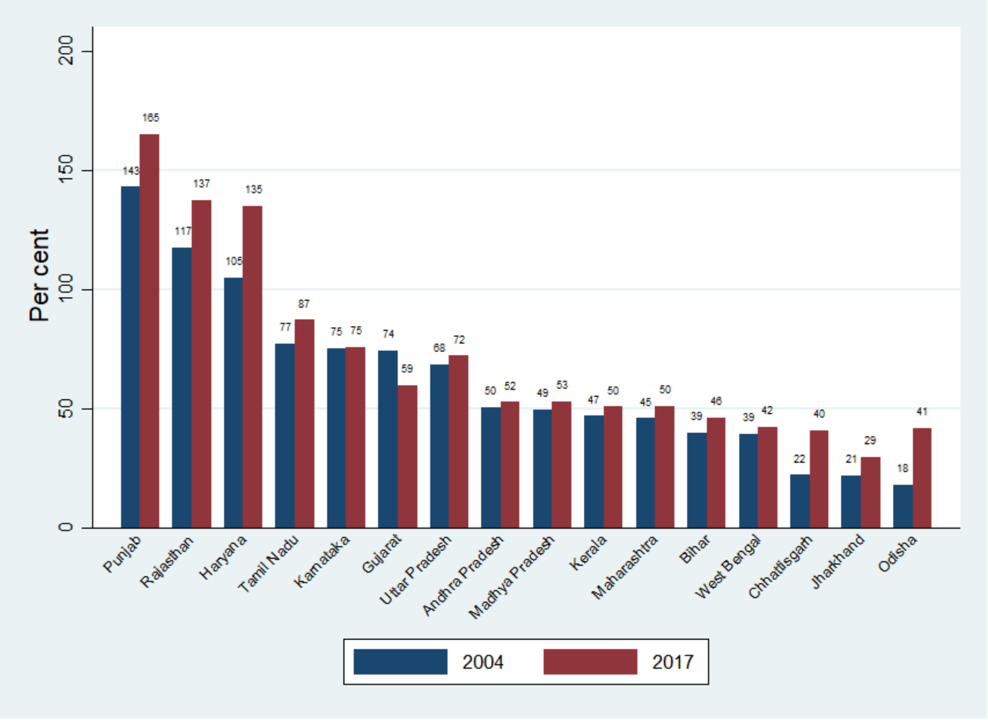

Figure 6. State-wise groundwater withdrawal as a percentage of net availability in India, 2004-17.

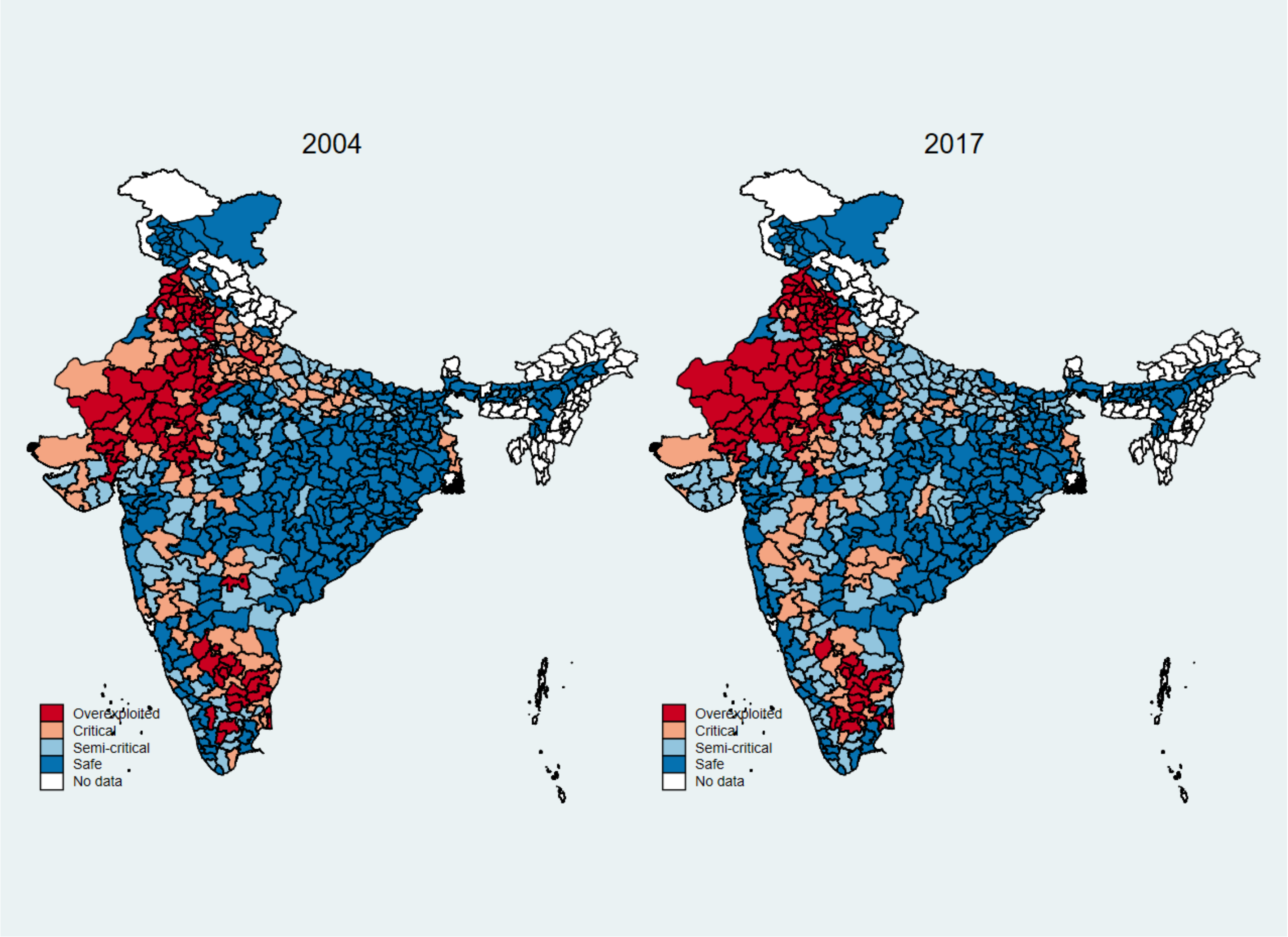

Figure 7. District-wise groundwater depletion in India, 2004-17

3.2 District wise pattern of groundwater extraction

It is evident from Figure 7 that the groundwater overexploited districts are concentrated in two parts of India: Northwestern India comprising Haryana, Punjab, and Rajasthan; and southern India comprising Karnataka and Tamil Nadu. Districts in the eastern part of India had a safer level of groundwater extraction.

The proportion of overexploited districts in Punjab has increased from 75% in 2004 to 90% in 2017 (Figure 8). All the districts in Punjab are under the critical category. In Rajasthan, 82% of the districts are in the overexploited category as against 73% in 2004. Haryana has witnessed an increase in the concentration of overexploited districts from 57% to 71% during the study period, and all the districts in the state were under the unsafe category in 2017. In Tamil Nadu, the proportion of overexploited districts has increased from 31% to 44%, and over 80% of the districts were under the unsafe category in 2017.

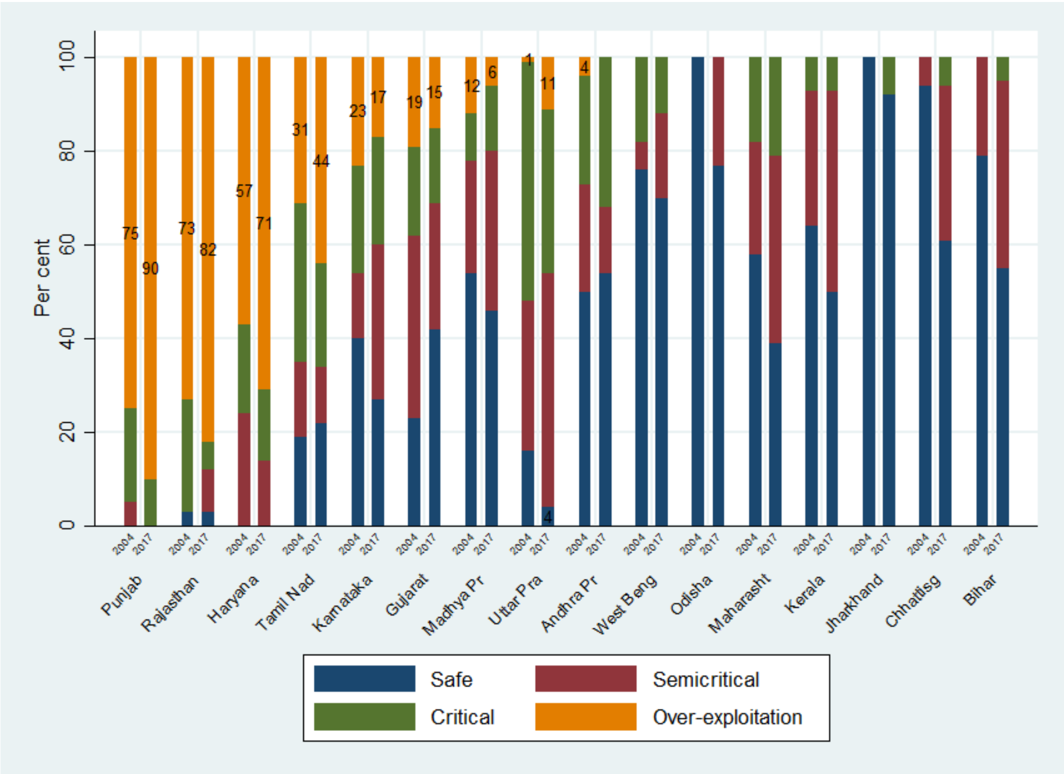

Figure 8. State-wise distribution of districts (%) based on the stage of groundwater development, 2004-17.

The groundwater depletion in the northwestern states began during the green revolution period from the 1960s. During the green revolution, the emphasis was on the complementary role of high-yielding varieties, irrigation, and fertilizers. To boost agricultural productivity, states began subsidizing electricity charges for pumping groundwater for irrigation (Shah et al., 2012). This led to the unabated extraction of groundwater for irrigation using electricity pump sets. Over time, the expansion of input-intensive crop production has led to the depletion of groundwater resources and an increase in production costs. The change in groundwater level was mainly due to pumping rather than variation in rainfall (Asoka et al., 2017; van Dijk et al., 2020). In Punjab and Haryana, at the present rate of groundwater extraction until 2028, there will be a decline in the groundwater level at 2.8 m/year (Shekhar et al., 2020).

Like in North-western India, the groundwater is the major source of irrigation in Karnataka and Tamil Nadu but has been over-extracted owing to prolonged multiyear droughts (Famiglietti 2004; Wada et al., 2010). Here, groundwater is stored within the hard rock subsurface in small, scattered pockets and there is significant spatial variation in the volume of groundwater (Blakeslee et al., 2020). These hard aquifers have limited storage and are prone to depletion at a faster rate than the alluvial aquifers in eastern India.

Until the 1960s, groundwater irrigation was restricted to shallow dug wells. But with the advent of down the hole drilling technology, the groundwater was extracted from the deeper sources using electric pumps. The faster rate of groundwater depletion in these states calls for immediate state intervention to control, regulate, and manage groundwater resources. But enforcement is difficult given the fact that the same states that implement rules to restrict groundwater extraction also offer strong incentives to pump groundwater by providing power subsidies (Shah et al., 2012). In Tamil Nadu, the groundwater (development and management act) was enacted in 2003 to regulate and manage groundwater. However, rules and regulations were not framed under the act and the act was subsequently repealed. The state is providing a special package of fully subsidized electricity to pump groundwater for irrigation. Cultivation of water-intensive crops during the dry season using groundwater irrigation has aggravated groundwater depletion. In Karnataka, the overexploitation of groundwater is the major concern especially in the drought-prone districts with a lack of surface irrigation sources. For instance, in Kolar district, the number of electric pump sets have increased from over 30000 a decade ago to 130000 in 2017. The district has no surface irrigation sources and affected by prolonged multiyear droughts.

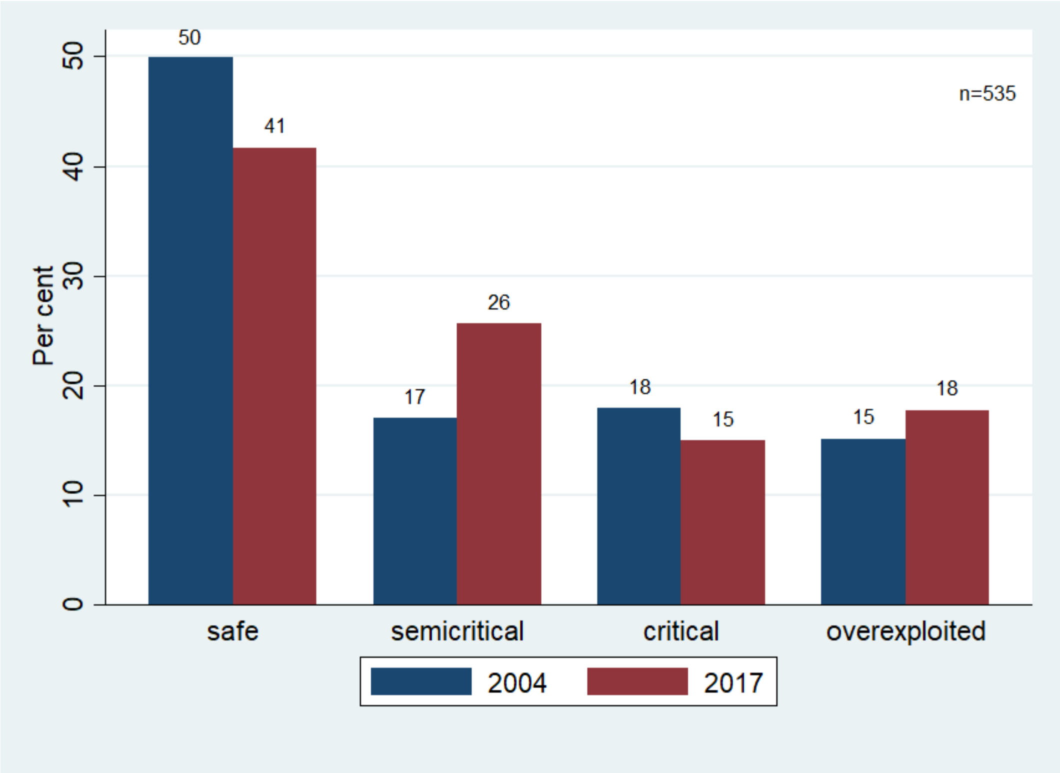

Figure 9. Distribution of districts based on the stage of groundwater development, 2004-17.

Overall, between 2004 and 2017, the proportion of safe districts in India has declined from 50% to 41% (Figure 9). There was also a decline in the proportion of critical districts from 18% to 15%. Whereas the proportion of semi-critical and overexploited districts has increased from 17% and 15% to 26% and 18% respectively.

Figure 10 shows the share of electric pumps in total energized pumps in India. The eastern states of Bihar, Orissa, Uttar Pradesh, and West Bengal have a higher share of diesel pumps in total energized groundwater pumps, whereas, the western and southern states heavily depend on electrified pumps. Eastern states have rich alluvial aquifers with high groundwater storage close to ground level. With a lack of electricity available to agriculture in eastern India, farmers use diesel pumps to extract groundwater (Shah, 2012). While in alluvial aquifers of western states and hard rock peninsular states, with deep and declining groundwater levels, diesel pumps are not suitable and farmers depend on electrified pumps for irrigation.

To manage the over-stressed groundwater resources due to unregulated and heavily subsidized power supply, many states have adopted a policy of rationing of electricity supply

(Ryan and Sudarshan, 2020). Supply rationing restricts the volume of groundwater extracted for irrigation by switching off the electricity grid without affecting non-agricultural users. Earlier, the power rationing was done through random power cuts and by switching off the electricity supply to rural areas for most of the day (Ryan and Sudarshan, 2020). Gujarat was the first state to implement Jyotirgram yojana, an electricity distribution reform scheme, between 2004 and 2007 for providing electricity to irrigation separately from other users by constructing separate feeders (Kishore, 2013). This scheme was successful in arresting groundwater depletion in Gujarat through the rationing of high-quality power with a flat-rate tariff (Shah, 2012). Now, 6 hours/day of high-quality three-phase power is provided to farmers using groundwater irrigation. Lately, the power rationing policy is adopted by groundwater stressed states of Haryana (9 hours/day), Punjab (5 hours/day), Rajasthan (6 hours/day), Karnataka (6 hours/day), and Tamil Nadu (9 hours/day). The states of Andhra Pradesh (7 hours/day), Madhya Pradesh (9 hours/day), Maharashtra (9 hours/day) and have also adopted the power rationing policy with flat tariff.

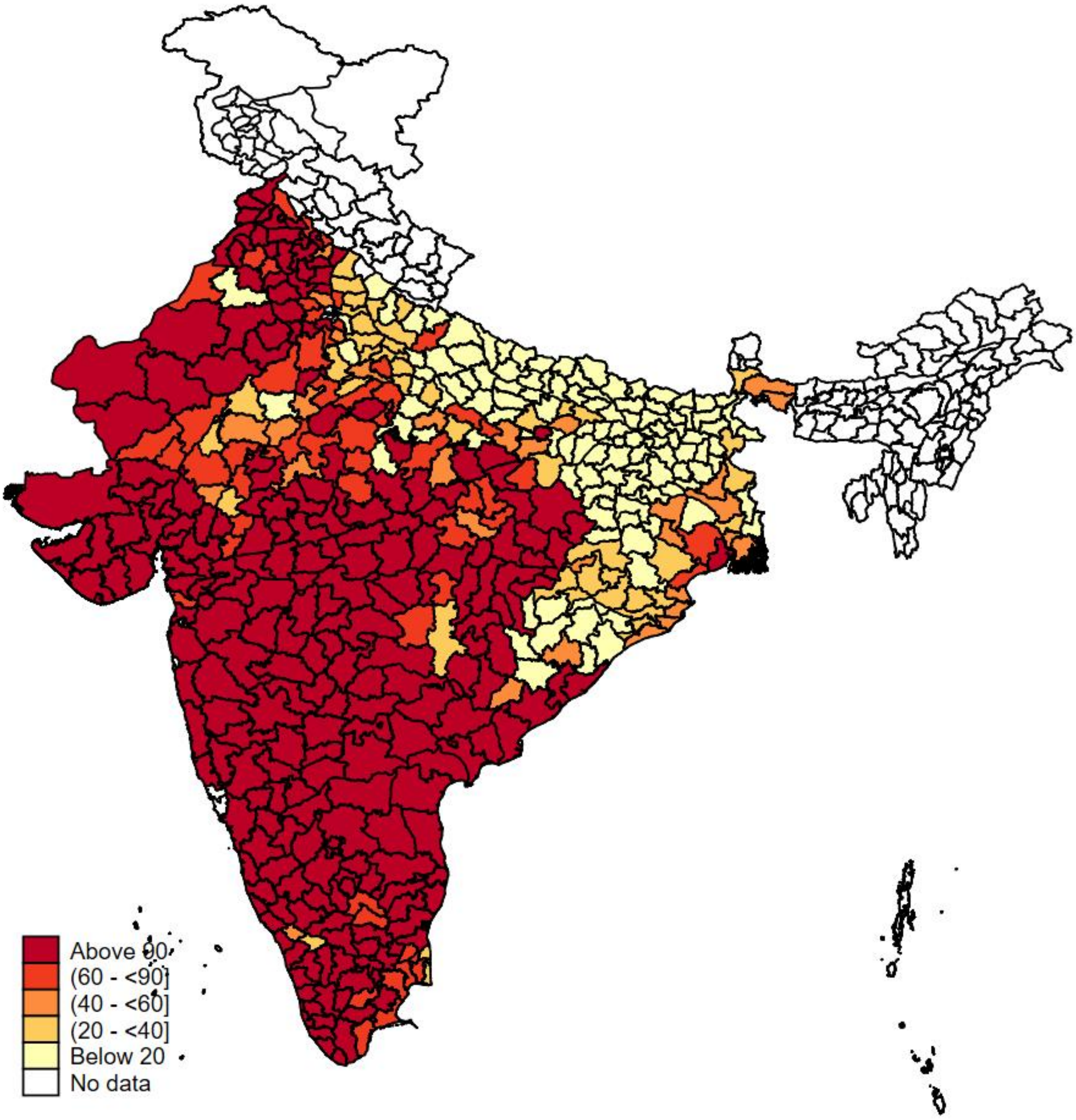

Figure 10. District wise electrified pumps as a percentage of total energized groundwater pumps in India, 2013.

3.3 Drivers of groundwater extraction in India

A summary of irrigation coverage and agricultural output across the different categories of districts based on the rate of extraction of groundwater as a percentage of its net availability in 2004 and 2017 is given in Table 5. Between 2004 and 2017, the rate of groundwater extraction has increased across the districts in India. The average rate of extraction in safe districts in 2017 was 33.29%, whereas, in semi-critical and critical districts, it was 61.16 and 83.02% respectively. The rate of groundwater extraction in overexploited districts was 147.6% in 2017. The safe districts had received higher annual rainfall (1161.35 mm) than the other categories of districts. The overexploited districts are concentrated in the regions with lower rainfall (677.63 mm). The increased rainfall variability with the recurrence of droughts will lead to faster groundwater depletion in the semi-critical, critical, and overexploited districts. The irrigation coverage has increased in all the categories of districts (Figure 11). It was highest (74.13%) in overexploited districts followed by critical (72.67%) and semi-critical (65.69%) districts, whereas it was lowest (48.03%) in the safe districts in 2017.

The surface water, which includes canals and tanks, was the dominant (57.17%) source of irrigation in the safe districts (Figure 12). The proportion of groundwater irrigated area in NIA was highest (83.30%) in overexploited districts followed by critical (74.26%) and semi-critical (68.89%) districts. Between 2004 and 2017, all the districts have witnessed an increase in cropping intensity. In 2017, it was highest (159.14%) in overexploited districts followed by critical (155.53%) and semi-critical (148.25%) districts. The cropping intensity in the safe districts was 138.32% in 2017. The irrigation land-use intensity has also increased across the districts during the study period. In 2017, it was highest (148.68%) in semi-critical and overexploited districts followed by critical (146.73%) and safe districts (126.91%).

To investigate the factors influencing groundwater depletion, a panel data regression model, using district-wise data for the major states for five years, is estimated with the rate of groundwater extraction as a percentage of its net annual availability as the dependent variable. The independent variables included in the model are the energized tubewell density, the share of electrified pumps in total energized tube wells (%), mean annual rainfall (mm), irrigation coverage (%), the share of groundwater irrigated area in NIA, and cropping intensity.

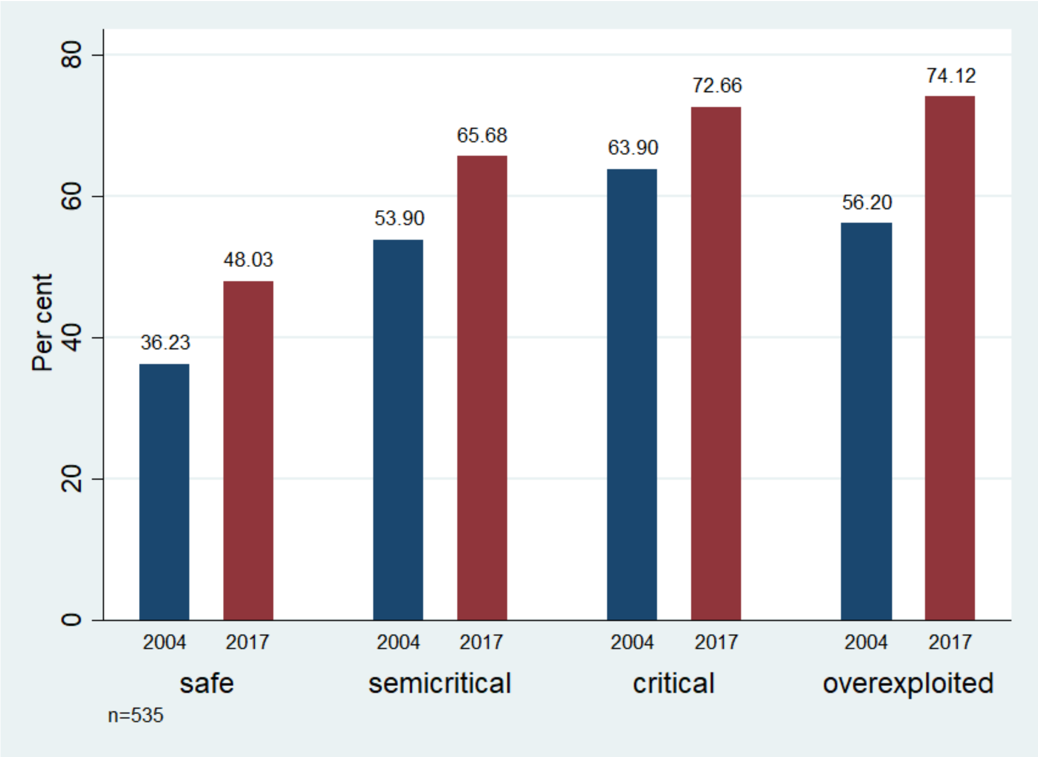

Figure 11. District wise irrigation coverage based on the rate of groundwater extraction (%), 2004-17.

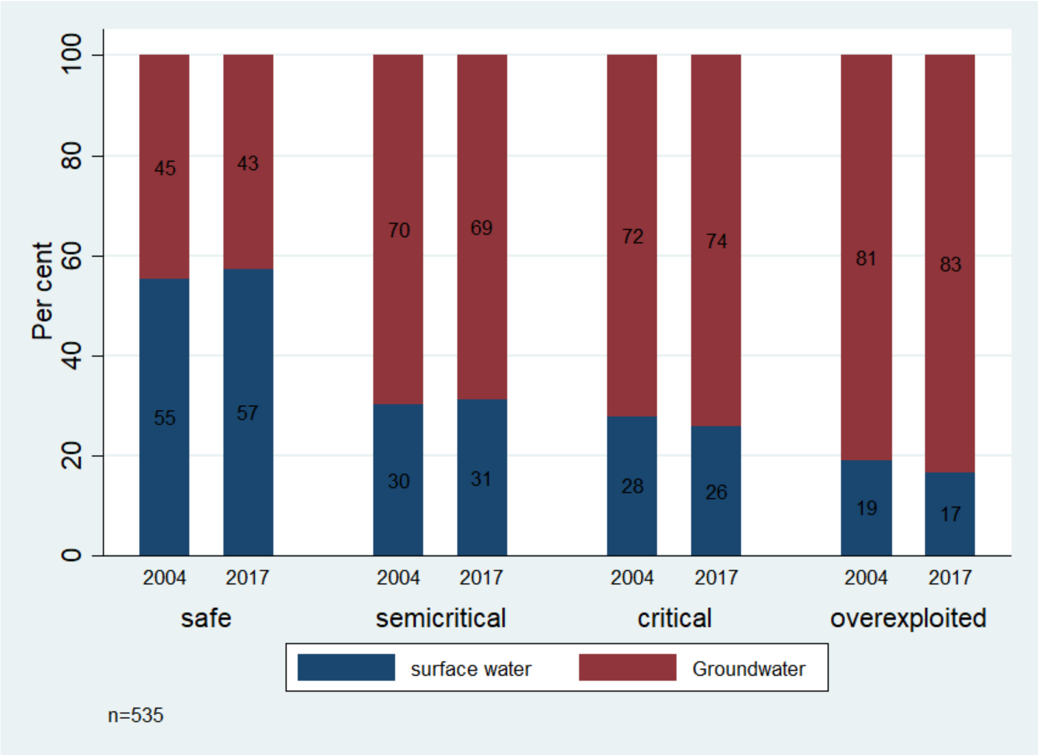

Figure 12. Source wise irrigation coverage based on the rate of groundwater extraction (%), 2004-17.

Table 5. District wise summary of irrigation coverage and agricultural output based on groundwater exploitation in India

Districts category	Safe		Semi critical		Critical		Overexploited	
Year	2004	2017	2004	2017	2004	2017	2004	2017
Rate of groundwater extraction (%)	28.12	33.29	60.39	61.16	80.99	83.02	135.18	147.60
Annual rainfall (mm)	1366.29	1161.35	990.71	943.63	805.16	718.48	650.21	677.63
Irrigation coverage (%)	36.24	48.03	53.90	65.69	63.91	72.67	56.20	74.13
Share of surface irrigated area (%)	55.18	57.17	30.12	31.11	27.84	25.74	19.07	16.70
Share of groundwater irrigated area (%)	44.82	42.83	69.88	68.89	72.16	74.26	80.93	83.30
Cropping intensity (%)	135.14	138.32	138.72	148.25	146.35	155.53	148.65	159.14
Irrigation intensity (%)	123.67	126.91	122.92	148.68	133.57	146.73	127.17	148.64
Area coverage of major crops (%)								
Rice	42.87	47.67	18.82	30.24	19.03	17.11	13.97	16.68
Maize	3.66	4.80	5.61	4.92	5.42	5.62	4.58	3.96
Wheat	10.13	9.82	20.95	22.56	21.62	23.39	19.17	24.22
Pulses	13.06	9.72	14.20	11.90	8.14	10.20	7.32	7.85
Sugarcane	1.18	1.18	2.72	2.89	5.16	5.76	1.32	2.25
Fruits	2.63	2.06	2.34	2.70	2.49	2.29	1.37	1.72
Vegetables	4.27	3.82	2.64	2.99	2.86	3.02	2.16	2.36
Oilseeds	10.04	8.62	13.66	12.22	14.92	14.19	20.67	14.54

Table 6. Housman specification test results

Variables	Dependent variable: Rate of groundwater extraction (%)			
	Fixed (b)	Random (B)	Difference (b-B)	Std. error
Density of energized tubewells	0.0485	0.0485	0.0001	0.0020
Proportion of electrified tubewells	0.4166	0.4162	0.0005	0.0136
Annual rainfall	-0.0121	-0.0121	0.0000	0.0005
Irrigation coverage	0.1286	0.1284	0.0002	0.0063
Surface irrigated area	-0.5733	-0.5733	0.0000	0.0017
Cropping intensity	0.2390	0.2388	0.0003	0.0079

b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg
Test: Ho: difference in coefficients not systematic

chi square value	0.00
Prob>Chi square	1.00

Table 7. Factors influencing rate of groundwater extraction in India (random effect model)

Variables	Rate of groundwater extraction (%)
Density of energized tubewells (No/ha)	0.0485** (0.0241)
Proportion of electrified tubewells (%)	0.4162*** (0.0516)
Annual rainfall (mm)	-0.0121*** (0.0022)
Irrigation coverage (%)	0.1284** (0.0626)
The proportion of surface irrigated area (%)	-0.5733*** (0.0421)
Cropping intensity (%)	0.2388*** (0.0585)
Constant	-51.2069 (9.727)
R squared	0.71
Wald chi square	1468.56
Prob>chi square	0.0000
Observations	641
Time period	2004-2017

Standard errors in parentheses *** p<0.01, ** p<0.05

Both fixed effect and random effect models were used to study the factors influencing groundwater extraction in India at the district level. Hausman specification test was used to identify a suitable model. The results of the Hausman specification test are given in table 6. The p-value>0.05 infers that these two models are indifferent enough to accept the null hypothesis of no systematic difference in the coefficients, and hence random effect model was applied.

Results of the random effect model (Table 6) showed that tubewell density and proportion of electrified tubewells are the significant factors influencing groundwater extraction positively. This implies that providing electricity subsidies for groundwater irrigation leads to a faster rate of groundwater depletion. Farm power subsidies have become a disaster for groundwater resources in India (Shah, 2012). Although electricity supply rationing has been adopted by many states, an increase in new unmetered connections with no/subsidized tariff will lead to pumping more groundwater with the same hours of electricity. Therefore, there is a need for strictly enforcing a power supply rationing regime along with metered connections and a rise in electricity prices. Mukherjee et al. (2010) reported that the metering of tubewells with a high flat tariff rate has reduced the groundwater depletion in West Bengal.

The results revealed that a decline in mean annual rainfall increases the rate of groundwater extraction. Due to the poor reliability of surface irrigation sources during low rainfall years in Gujarat, farmers relied on groundwater irrigation for drought-proofing (Kishore, 2013). There is a significant positive association between the rate of groundwater extraction and the irrigation coverage reflecting an increase in the share of groundwater irrigated area over the years in India due to its reliability and efficiency. The rate of groundwater extraction is low in districts where surface irrigation is dominant. Similar results are reported by Van Dijk et al. (2020). The rate of groundwater recharge is high in the canal irrigated areas due to infiltration and seepage from canals (Joshi et al., 2018). The results demonstrated that the efficient use of existing surface irrigation infrastructure has a dominant influence on groundwater resources. Conjunctive management of surface and groundwater with more efficient irrigation methods can help in sustainable groundwater development in India. There is a positive and significant association between the rate of groundwater extraction and cropping intensity. The rate of groundwater extraction is higher in the districts that have high cropping intensity. In the states of Punjab and Haryana, groundwater irrigation is predominant particularly from November to June (non-monsoon season). During monsoon months, water-intensive crops such as rice, are cultivated with the conjunctive use of surface and groundwater.

Chapter 4

Impact of irrigation development on agricultural productivity in India

4.1 Data and Methodology

The data source for this study is nationally representative 'Situation Assessment Survey of Agricultural Households' conducted by the National Sample Survey Organization (NSSO) of the Government of India in 2013. The survey was conducted in 4529 villages in two visits. A total of 35200 households were interviewed in visit 1 which covered the agricultural period July to December 2012. In the Second visit, 34907 of these households were interviewed again for the agricultural period January to June 2013. We analysed data of 25869 agricultural households. The dataset contains information on irrigated and unirrigated crop production at agricultural household level. This enables to study the extent of difference between irrigated and unirrigated yields of major crops.

Panel Data Regression Model

The fixed effect model (FEM) and random effect model (REM) were used to establish the irrigation-yield relationship and to estimate the impact of irrigation on value of output from agriculture (crop sector). Panel data analysis has advantages over ordinary least square (OLS) regression models in terms of increased precision in estimation due to the increase in the number of observations by combining or pooling several time periods of data for each individual Also, it captures unobserved individual heterogeneity that may be correlated with regressors. In this study, panel data set consists of 14 major states over 22 years.

The FEM has constant slopes, but intercepts differ according to the cross-sectional (states) unit. For I classes, i–1 dummy variables are used to designate a particular state. It allows for heterogeneity or individuality among states (units) as each state is allowed to have its own intercept value. So, intercept may differ across states but it does not differ over time. In the REM, the intercept is assumed to be a random outcome variable, whereas the random outcome is a function of a mean value plus a random error.

FEM allows different states (cross section units) to have their own intercept terms, though all the slopes are same. The specification of the model is given below:

$$Y_{it} = \alpha_i + \beta_1 X_{1\,it} + \beta_2 X_{2\,it} + \beta_3 X_{3\,it} + \beta_4 X_{4\,it} + \beta_5 X_{5\,it} + e_{it} \qquad (1)$$

$$e_{it} \backsim IID(0, \sigma^2{}_e)$$

Where,

Y_{it}	=Value of output from agriculture (crop sector) expressed as Rs/ha in the i^{th} state (i=1 to 14) and t^{th} year (t=1 to 22)
X_1	=irrigation coverage (the share of gross irrigated area in total cropped area)
X_2	=rainfall index (ratio of actual to normal rainfall multiplied by 100)
X_3	=fertilizer consumption (kg/ha)
X_4	=institutional credit (Rs/ha)
X_5	=trend variable (proxy for technological improvement)
e_{it}	=error component
$\alpha_i, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$	= parameters to be estimated

REM assumes that individual specific coefficient α_i is fixed for each time-in-variant and α_i is random variable with mean value α and intercept of α any cross-section unit is expressed as follows:

$$\alpha_i = \alpha + \in_i \qquad (2)$$

$$\in_i \backsim IID(0, \sigma^2{}_{ei})$$

Therefore, REM can be expressed as:

$$Y_{it} = \alpha + \beta_1 X_{1\,it} + \beta_2 X_{2\,it} + \beta_3 X_{3\,it} + \beta_4 X_{4\,it} + \beta_5 X_{5\,it} + w_{it} \qquad (3)$$

Where, $w_{it} = \in_i + e_{it}$

w_{it} is a composite error term including $\in_i$ which is cross section error component and e_{it} which is combined time series and cross-section error component.

Propensity Score Matching

The impact of access to irrigation on yield can be assessed using OLS regression:

$$Y_i = \alpha + \gamma d_i + \delta X_i + \varepsilon_h \quad (3)$$

where Y represents yield, d is a dummy variable which takes value 1 if a farmer has access to irrigation, and 0 otherwise; X_i includes farmer and other characteristics, γ and δ are vectors of parameters to be estimated, and ε is an error term. The impact of irrigation on the yield is measured by the estimates of the parameter γ. If the decision to access to irrigation is based on observable characters, then γ would provide unbiased estimates of the effect of irrigation on yield. But irrigation access decision of farmers may also depend on self-selection. Unobservable factors such as awareness and motivation may influence farmers' decisions of irrigation and therefore, to mitigate this selection bias, we use propensity score matching (PSM) as proposed by Kassie *et al*. (2011), who used PSM to analyse the impact of adoption of groundnut cultivars on farm income and poverty. Birthal *et al*. (2015) also used PSM to study the impact of crop diversification on poverty in India.

Using PSM technique, we estimate a probability model of access to irrigation to obtain a probability or propensity scores of an irrigation access for each household. Household who has access to irrigation(treatment) is then matched to a household who cultivated under unirrigated condition (control) based on propensity scores. The matching is done to estimate the simple average treatment effect for the treated (SATT) which is the mean outcome difference across these two household groups. We use nearest neighbor matching (NNM) method which matches each treatment unit to control unit having very close propensity score. We also use kernel-based matching (KBM) with bootstrap standard errors. KBM uses a weighted average of the control group to construct counterfactual match to each treatment unit (Khandker *et al.*, 2010).

PSM technique is used to find a large group of control households that are similar to the treatment households in all relevant pretreatment characteristics X. Then, the differences between the outcomes of the control group (non-adopters) and of the treatment group (adopters) can be attributed to the treatment (ATT) which is a difference of the outcome variable of interest at time t between two groups, denoted by the superscripts 1 and 0.

$$\mathrm{ATT} = \mathrm{E}\left({\mathrm{Y}_t}^1 | \mathrm{X}, \mathrm{T} = 1\right) - \mathrm{E}\left({\mathrm{Y}_t}^0 | \mathrm{X}, \mathrm{T} = 0\right) \quad (4)$$

X is the vector of household characteristics

Overall treatment effect is estimated by using

$$TOT_{PSM} = \frac{1}{N_T}\left[\sum_{i\varepsilon T} {Y_i}^T - \sum_{j\varepsilon T} \omega(i,j){Y_j}^c\right] \quad (5)$$

N_T is the number of participants i and ω (i, j) is the weight used to aggregate outcomes for the matched nonparticipants j.

4.2 Impact of irrigation development on value of output from agriculture

We used fixed effect and random effect models to assess the impact of irrigation on value of output from agriculture (crop sector) at state level. Hausman specification test was used to identify the suitable model. The results of Hausman specification test are given in table 5. Results reveal that the p-value>0.05 infers that these two models are indifferent enough to accept the null hypothesis and hence random effect model was applied. The R-square value of 0.90 implied that regression model, overall, could explain 90 percent of total variations in the value of output from agriculture.

Table 8. Housman specification test results

Variables	Dependent variable: Value of output from agriculture (crop sector)			
	Fixed (b)	Random (B)	Difference (b-B)	Std. error
Irrigation coverage	44.77	130.15	-85.37	18.00
Rainfall	14.76	6.66	8.10	3.75
Fertilizer	42.66	77.30	-34.63	9.11
credit	0.08	0.13	-0.04	0.00
b = consistent under Ho and Ha; obtained from xtreg				
B = inconsistent under Ha, efficient under Ho; obtained from xtreg				
Test: Ho: difference in coefficients not systematic				
chi square value	9.79			
Prob>Chi square	0.87			

The results of the random effect model (Table 6) showed that irrigation is a significant factor affecting the value of output from agriculture. The estimated coefficient of the rainfall index was not significant but positive. The impact of fertilizer consumption and credit was significant and positive. However, the positive marginal effect of irrigation coverage was more substantial than other variables, as shown by the higher value of estimated coefficients. Therefore, improving irrigation coverage will have significant improvement in the value of output from agriculture. This analysis supports the strong push being made for expanding irrigation coverage through a convergence of different irrigation related programmes under one umbrella programme, Pradhan Mantri Krishi Sinchayee Yojana.

Table 9. Impact of irrigation on value of output from agriculture (Random effect model)

Variables	Value of output from agriculture (crop sector) (Rs/ha)
Irrigation coverage	130.15**
	(51.70)
Rainfall	6.66
	(10.48)
Fertilizer	77.30***
	(10.47)
Credit	0.13***
	(0.02)
Constant	7,260.25***
	(2,461.94)
R squared	0.90
Wald chi square	2872.17
Prob>chi square	0.0000
Observations	308
Time period	1992-2014

Standard errors in parentheses. *** and ** represent 1 and 5% levels of significance, respectively

A simple t-test showed a significant difference between the irrigated and unirrigated yields of major cereals and pulses (Table 10). Polynomial regression further revealed a significant influence of irrigation on the yields of major cereals (Figure 13) and chickpea (Figure 14). However, in the case of pigeonpea, the significant effect of irrigation on yield was not found.

Table10. Mean yields of major crops under irrigated and unirrigated conditions

(Kg/ha)

Major crops	Irrigated yield	Unirrigated yield	t value
Rice	3664.864	2586.728	35.8674***
Wheat	2957.625	1716.988	19.9612***
Maize	2963.312	1587.248	22.0546***
Chickpea	977.7075	689.9603	11.769***
Pigeonpea	836.7053	682.1761	4.4181***

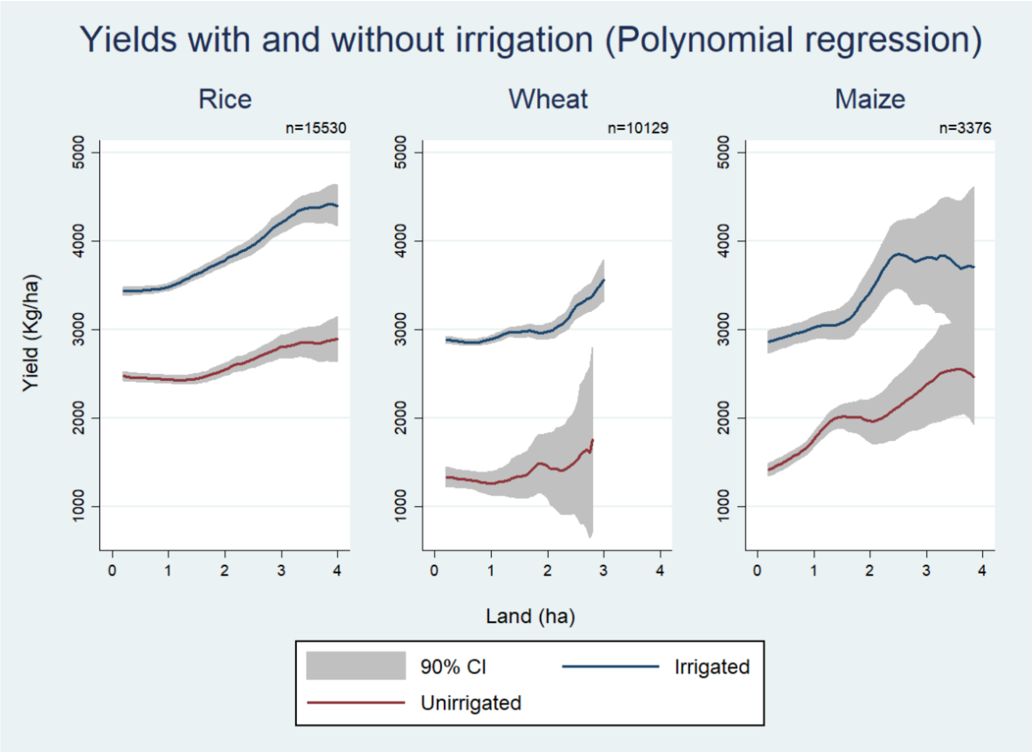

Figure 13. Polynomial regression plots of mean yields of major cereals under irrigated and unirrigated conditions

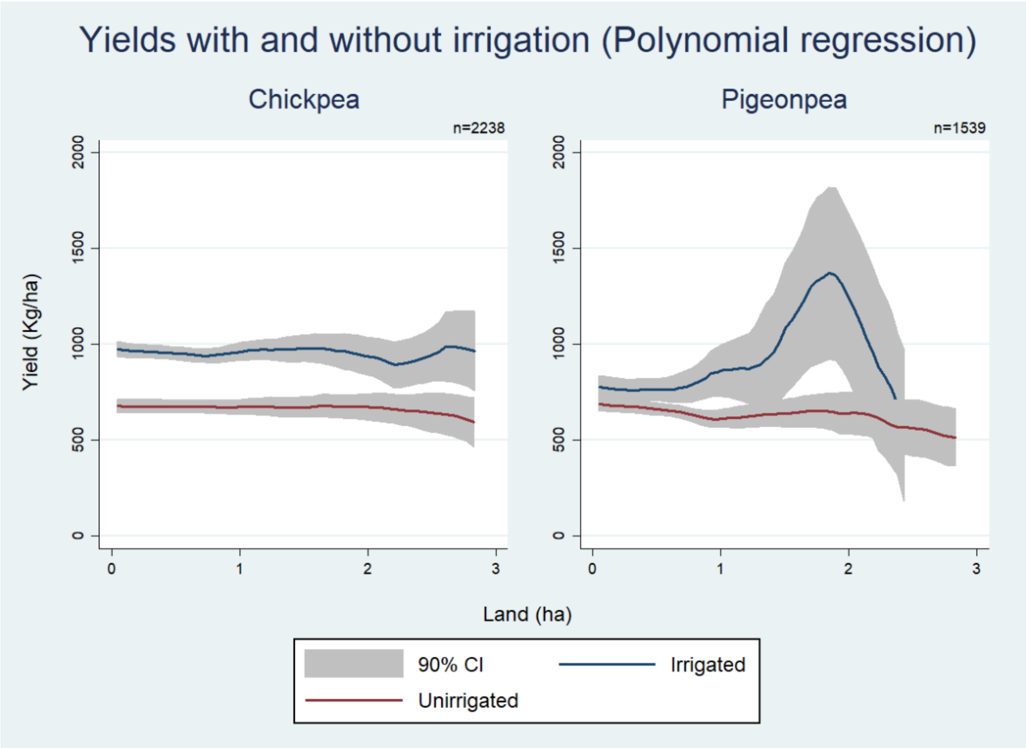

Figure 14. Polynomial regression plots of mean yields of major pulses under irrigated and unirrigated conditions

4.3 Impact of irrigation on crop yields (Propensity Score Matching)

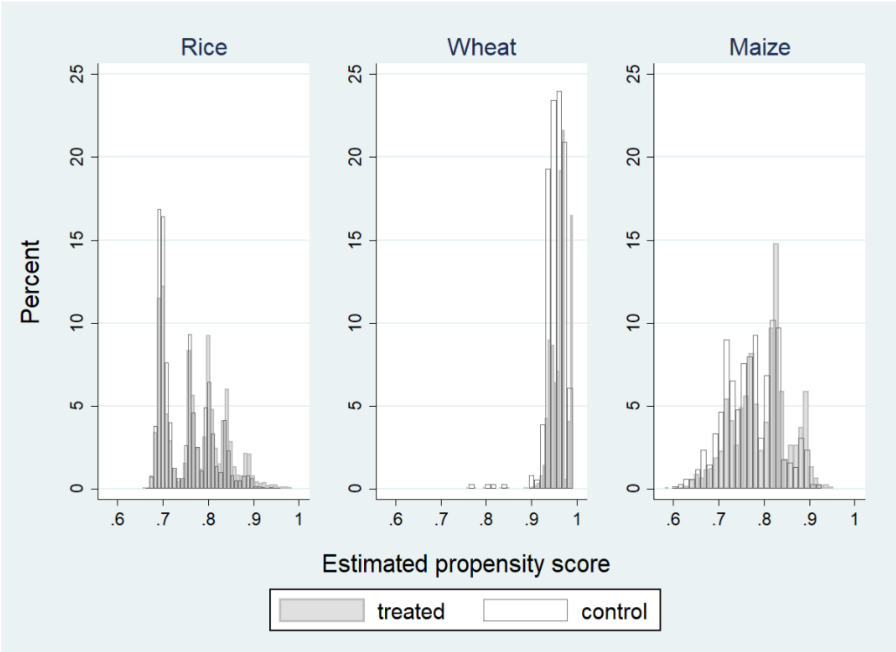

Figure 15. Propensity score distribution and common support for propensity estimations in major cereals

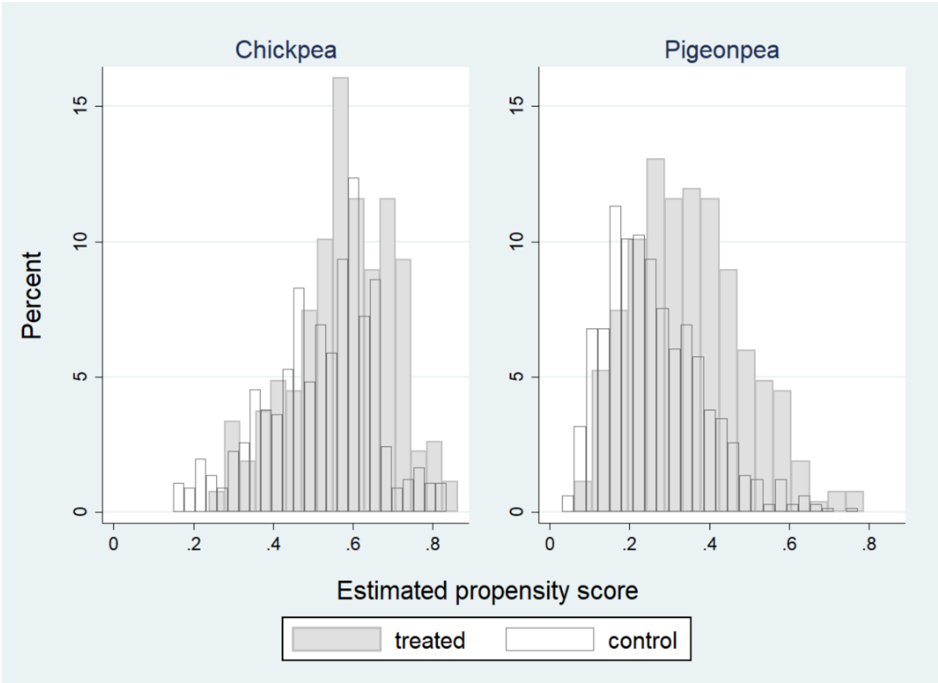

Figure 16. Propensity score distribution and common support for propensity estimations in major pulses

Before turning to the causal effects of irrigation access, the common support condition was checked. It is done after estimating propensity scores of treatments and the control group. Figures 15 and 16 plot the distribution of propensity scores of farm households with access to irrigation superimposed over the same distribution of households without access to irrigation in case of major cereals and pulses, respectively. It is evident from the figure that there is sufficient overlap in the distribution for a common support condition to be satisfied.

Table 11 reports the estimates of the average irrigation effects estimated by NNM and kernel-based matching method. Average treatment effect estimates are reported based on the 1, 3 and 5 nearest neighbour matches. All the analyses were based on the implementation of common support so that the distributions of treatment and control households were located in the same domain. Bootstrap standard errors based on 1000 replications are reported.

The results revealed that irrigation access has a significant positive impact on yields of all the major crops. Irrigation access in case of rice had a significant positive impact on yield in the range from 890.26 kg/ha to 933.52 kg/ha. Kernel-based matching estimates showed an average increase of 922.21 kg/ha. In case of wheat, the average increase due to irrigation was in the range between 1131.55 kg/ha and 1210 kg/ha. There was an increase of 606.45 to 628.23 kg/ha in case of maize. In chickpea, the estimated ATT effect of irrigation on increasing yield is ranged between 265.55 and 296.4 Kg/ha. Whereas in case of pigeonpea, the increased yields are ranged between 223.3 and 300.8 Kg/ha. Kernel-based matching estimates show that the average increase in yields was 271.7 Kg and 290.5 kg in chickpea and pigeonpea, respectively.

Table 11. Impact of irrigation access on yield (kg/ha) in major crops

Number of matches	Variable	Rice	Wheat	Maize	Chickpea	Pigeonpea
m=1	ATT	890.26***	1206.31***	606.45***	296.4***	223.3***
		(49.87)	(107.50)	(98.00)	(39.22)	(68.89)
m=3	ATT	933.52***	1210.00***	612.60***	270.4***	288.4***
		(43.16)	(101.81)	(86.84)	(35.30)	(55.99)
m=5	ATT	927.60 ***	1131.55***	628.23***	265.5***	300.8***
		(42.34)	(102.57)	(84.59)	(34.20)	(52.18)
Kernel-based matching		922.21***	1195.61***	632.85***	271.7***	290.5***
		(27.12)	(81.79)	(79.89)	(30.01)	(53.22)
Observations		9163	9922	3315	1709	931

Standard errors are in parentheses *** p<0.01

सारांश

भारत में कृषि विकास में सिंचाई ने हमेशा सूखा-प्रूफिंग और उत्पादकता बढ़ाने के माध्यम से एक प्रमुख भूमिका निभाई है। वर्तमान अध्ययन 1992 से 2017 तक विभिन्न स्रोतों से एकत्र किए गए द्वितीयक डेटा का उपयोग करके भारत में सिंचाई बुनियादी ढांचे और सार्वजनिक सिंचाई निवेश के विकास में अंतर-क्षेत्रीय असमानताओं का आकलन करता है। अध्ययन जिला-स्तरीय पैनल डेटा का उपयोग करके भूजल निष्कर्षण की स्थिति और ड्राइवरों का भी विश्लेषण करता है। 16 प्रमुख कृषि राज्यों के 535 जिलों के लिए। फसल उत्पादकता पर सिंचाई पहुंच के प्रभाव का आकलन करने के लिए, हम 2013 में आयोजित कृषि परिवारों के राष्ट्रीय स्तर पर प्रतिनिधि स्थिति आकलन सर्वेक्षण के डेटा का उपयोग करते हैं। हमने सिंचाई पहुंच से उत्पादकता लाभ का अनुमान लगाने के लिए एक प्रवृत्ति स्कोर मिलान पद्धति का उपयोग किया, जो देखने योग्य अंतर पर चयन पूर्वाग्रह को समाप्त करता है। सिंचाई की सुविधा वाले किसानों और वर्षा सिंचित परिस्थितियों में खेती करने वाले किसानों के बीच। भूजल सिंचाई के पक्ष में एक संरचनात्मक बदलाव है जबकि सतही सिंचित क्षेत्र के हिस्से में गिरावट आई है। भारत के उत्तरी क्षेत्र का सिंचाई विकास में प्रभावशाली प्रदर्शन था। प्रचुर मात्रा में जल संसाधनों के बावजूद, पूर्वी क्षेत्र में सिंचाई का बुनियादी ढांचा अविकसित है। दक्षिणी क्षेत्र में सतही सिंचाई विकास पर सार्वजनिक व्यय में पूंजी निवेश का उच्चतम हिस्सा था। उत्तरी क्षेत्र में, राजस्व व्यय का प्रमुख हिस्सा था। उच्च लागत और समय की अधिकता के कारण दक्षिणी क्षेत्र में सिंचाई क्षमता के निर्माण की लागत सबसे अधिक थी। उत्तर पश्चिमी राज्यों में निरंतर भूजल की कमी देश के पूर्वी राज्यों में कम उपयोग के साथ-साथ मौजूद है। पैनल डेटा विश्लेषण ने भूजल दोहन की दर पर विद्युतीकृत ट्यूबवेल घनत्व के एक महत्वपूर्ण अनुकूल प्रभाव का खुलासा किया। कम वर्षा वाले जिलों में भूजल दोहन की दर अधिक थी। प्रवृत्ति स्कोर मिलान पद्धति से पता चला कि सिंचाई की पहुंच किसानों के लिए फायदेमंद है और इससे भारत में फसल उत्पादकता में वृद्धि होगी, जिससे सिंचाई कवरेज को और विस्तारित करने की आवश्यकता पर प्रकाश डाला जा सकेगा। ये निष्कर्ष सतही सिंचाई के सतत विकास और प्रबंधन, भूजल सिंचाई के लिए बिजली दरों को युक्तिसंगत बनाने, सिंचाई उपयोग दक्षता में सुधार और अति-शोषित जिलों में जल-कुशल फसल पैटर्न को बढ़ावा देने से संबंधित नीति निर्धारण के लिए एक मंच प्रदान करते हैं।

Summary

Irrigation has always played a dominant role in agricultural development in India through drought-proofing and enhancing productivity. The present study assesses the inter-regional disparities in the development of irrigation infrastructure and public irrigation investment in India using secondary data collected from various sources from 1992 to 2017. The study also analyses the status and drivers of groundwater extraction using district-level panel data for 535 districts of 16 major agricultural states. To assess the impact of irrigation access on crop productivity, we use data from the nationally representative Situation Assessment Survey of Agricultural Households conducted in 2013. We used a propensity score matching method to estimate the productivity gains from irrigation access, eliminating selection bias on observable differences between farmers with access to irrigation and those who cultivate under rainfed condition. There is a structural shift favouring groundwater irrigation while the share of surface irrigated area has declined. The northern region of India had an impressive performance in irrigation development. Despite abundant water resources, irrigation infrastructure in the eastern region is underdeveloped. The southern region had the highest share of capital investment in public expenditure on surface irrigation development. In the northern region, revenue expenditure accounted for the major share. The cost of creation of irrigation potential was highest in the southern region because of the high cost and time over-runs. The unsustainable groundwater depletion in north western states coexists with the underutilisation in eastern states of the country. The panel data analysis revealed a significant favourable influence of electrified tube well density on the rate of groundwater exploitation. Districts with poor rainfall had a higher rate of groundwater exploitation. The propensity score matching method revealed that irrigation access is beneficial to farmers and would lead to increased crop productivity in India, highlighting the need to expand irrigation coverage further. These findings provide a platform for policy reframing related to sustainable development and management of surface irrigation, rationalising power tariffs for groundwater irrigation, improving irrigation use efficiency and promoting water-efficient cropping pattern in over-exploited districts.

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