Water Productivity Mapping of Major Indian Crops

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WATER PRODUCTIVITY MAPPING OF MAJOR INDIAN CROPS

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About the report: This study on *Water Productivity Mapping of Major Indian Crops* explores two primary questions: Are the existing cropping patterns in India in line with the natural water resource endowments of various regions? Are these cropping patterns sustainable from a water-use perspective? The broad findings of the study indicate that there are regions in India which are heading towards unsustainable agriculture with highly skewed distribution of water for certain crops. Rice in Punjab and sugarcane in Maharashtra are classic examples of highly inefficient, iniquitous, and unsustainable use of water resources.

The report presents for the first time, maps on the water productivity of ten major Indian crops across cultivating districts and states. It builds on the expectation that if key decisions regarding irrigation, cropping patterns, input pricing, and incentive structures are predicated on water productivity of crops, it would ensure that water in agriculture is distributed more widely, water-use efficiency is enhanced, and Indian agriculture becomes more sustainable and productive in the long run. Thus, the study seeks to inform targeted policies and investment interventions for meeting the twin objectives of har khet ko pani (water to every field) and 'more crop per drop'.

We hope that this report will encourage policy makers to take note of and trigger an effective response to the looming water crisis faced by the agriculture sector in India.

Maps in this report: These maps have been generated using QGIS 2.18.11 and databases procured from GADM (https://gadm.org/index.html) in November 2016 to represent the relative position and broad outline shapes of districts, states, and the country. The maps represent main land India only in keeping with the scope of the analysis. No one from among the authors, ICRIER, NABARD, or the publishing consultants claims accuracy of the political and administrative boundaries defining the geographical entities represented.

Photographs in this report: All photographs have been digitally procured by ICRIER from commercial websites selling photographs, for the express purpose of publishing this report.

Data sources for figures and tables in this report: All data sources are mentioned below the tables and figures as applicable. Where no sources are mentioned, the exhibits present authors' analyses based on the data sources mentioned in Chapter 2.

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Abbreviations

ADB	Asian Development Bank
BCM	Billion Cubic Meter
BE	Biennium Ending
CACP	Commission for Agricultural Costs and Prices
CAGR	Compound Annual Growth Rate
CCE	Crop Cutting Experiment
CFV	Corporate Farming Ventures
CGWB	Central Ground Water Board
CPRI	Central Potato Research Institute
CRIDA	Central Research Institute for Dryland Agriculture
CWC	Central Water Commission
DBT	Direct Benefit Transfer
DES	Directorate of Economics and Statistics
DOC	Department of Commerce
ET	Evapo-Transpiration
EWP	Economic Water Productivity
FAO	Food and Agriculture Organization
FHP	Farm Harvest Price
FIT	Feed In Tariff
FPO	Farmer Producer Organisation
GoI	Government of India
ICAR	Indian Council for Agricultural Research
ICARDA	International Center for Agriculture Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IRRI	International Rice Research Institute
IWMI	International Water Management Institute

IWP	Irrigation Water Productivity
MoA&FW	Ministry of Agriculture and Farmers Welfare
NABARD	National Bank for Agriculture and Rural Development
NBS	National Bureau of Statistics of China
NITI	National Institution for Transforming India
NSSO	National Sample Survey Organisation
NWM	National Water Mission
OECD	Organisation for Economic Co-operation and Development
PIM	Participatory Irrigation Management
PWP	Physical Water Productivity
SAP	State Advised/Administered Price
SPaRC	Solar Power as Second Remunerative Crop
SPICE	Solar Pump Irrigators' Cooperative Enterprise
TCWU	Total Consumptive Water Use
TE	Triennial Ending
UNESCO	United Nations Educational, Scientific and Cultural Organization
UP	Uttar Pradesh
USDA	United States Department of Agriculture
UTFI	Underground Taming of Floods for Irrigation
WBCSD	World Business Council for Sustainable Development
WP	Water Productivity
WUA	Water Users Association

Foreword

Chairman, NABARD

Water scarcity is looming large in India and agriculture sector accounting for 78 per cent of water use in the country will have to bear this brunt intensely. According to the Central Water Commission (CWC), by 2050 the total water demand will overshoot supply in the country and the share of irrigation will come down to 68 per cent. World Resource Institute (WRI), on the other hand, estimated that 54 per cent of the country's area faces extreme water stress. Hence, improving water use efficiency is the key priority of Indian Agriculture.

I may mention here that NABARD has been a key stakeholder in efforts of Government of India in developing water resources. Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) envisaging the concept of "water for every farm" and "more crop per drop" is one such initiative that targets to improve water productivity, enhance irrigation efficiency by about 20% and bring additional 28.5 lakh ha area under irrigation.

NABARD has been doing responsible financing of irrigation projects under its Rural Infrastructure Development Fund (RIDF) and Long Term Irrigation Fund (LTIF) by encouraging water saving/productivity enhancing measures through formation of water users' associations and synergising micro-irrigation in project areas, among others. Our investments in watershed development and micro-irrigation endeavour to further helped to augment water availability, stabilise crop yield and improve the farmers' income levels.

Taking the agenda further, we initiated a project in NABARD Centre for Research in Agri-Economics set up in Indian Council for Research on International Economic Relations (ICRIER), New Delhi, with Dr. Ashok Gulati in the lead, to study water related issues, among others, over three years. The Centre has prepared 'Water Productivity Mapping of Major Indian Crops' as part of their ongoing research. The aim is to map water productivity of 10 major crops rice, wheat, maize, tur, chickpea, sugarcane, cotton, groundnut, rapeseed & mustard and potato across the country. Water productivity here is measured at 3 levels – Physical Water Productivity that measures output per unit of water use measured in terms of consumptive use, Irrigation Water Productivity, measured as output per unit of irrigation water actually applied and Economic Water Productivity which factors in value terms the economic output produced per unit of water consumed or irrigation water applied. One of the key findings is the significant misalignment in the cropping patterns and available water resource across geographies. The report identified regions of efficient water use or otherwise, which in turn, helped identify regions that need special interventions. It will help all stakeholders including State Government departments, irrigation experts and farmers to take suitable corrective measures to enhance irrigation efficiency in the country in the coming years. This exercise is timely and unique for which I congratulate the study team as also the NABARD team.

Dr Harsh Kumar Bhanwala
Chairman, NABARD

April 2018

Foreword

Director, ICRIER

India is facing a major challenge on the water front. Its per capita water availability of 1544 cubic meters per year, as reported in 2011, has already fallen below the cut off point of 1700 cubic meters, placing it among the water stressed nations of the planet. This situation is likely to have worsened since 2011 and may continue to do so unless drastic reforms are undertaken to manage our scarce water resources more efficiently and in a sustainable manner. And the reforms must start from water use in agriculture as it consumes almost 78 per cent of freshwater resources available in the country. As the economy diversifies away from agriculture and urbanisation increases, inter-sectoral competition for water is going to increase. As a consequence, in relative terms, agriculture's share in fresh water supplies is likely to decrease. But with rising population and per capita incomes, demand for more food, feed and fibre is going to increase. And therein lies the challenge: how to grow more agri-produce with less water on a sustainable basis.

The reforms must start by first changing our mindset that is currently obsessed with raising agricultural productivity per hectare of land rather than per cubic meter of water supplied and/or consumed. It is precisely this change in mindset, which this study seeks to achieve. It makes a serious attempt, presumably the first one, towards estimating gross water productivity at the district level of ten major crops grown in India. It also makes a major foray into estimating state level productivity of three major crops (rice, wheat and sugarcane) per cubic meter of irrigation water supplied. Since irrigation water comes for a cost to both the government and the farmers, it has major implications for irrigation and power policies, along with various programmes and projects.

I expect this report would serve as a blue-print for devising policies and programmes that promote cropping patterns in line with water resource endowment. The focus has to shift from maximising productivity per unit of land area to per unit of water, thus achieving 'more crop per drop'. Investing more in augmenting water supplies may not serve the purpose fully unless it is accompanied by policies and programmes that promote higher water-use efficiency in agriculture. The results of this exercise would surely awaken many a mind to promoting sustainable and productive agriculture, keeping water at the centre of the analysis.

Rajat Kathuria
CEO and Executive Director
ICRIER

Preface

If there is one thing that requires utmost attention for ensuring sustainable development of agriculture in India, it is water. The shrinking per capita fresh water availability witnessed over the last couple of decades poses a major challenge not only for agriculture but overall development of the country. Many experts opine that the future wars would be fought over water, be it inter-country or inter-state (within country) or inter districts (within state). Eruption of tension over water sharing amongst Indian states, especially in the south over Cauvery waters, is well known. Such situations are likely to increase, unless bold steps are taken to not only augment water supplies for agriculture, industry and domestic use, but also use water more efficiently. In a market oriented economy, normally pricing of a resource signals its allocation across sectors and people that can promote its efficient use. However, policies of highly subsidised pricing of water (and power) have led to sub-optimal use of water. The results of such a policy environment has led to over use of water in certain places and certain crops, depleting the stock of water reserves, such as groundwater. This raises a fundamental question of how sustainable is our agriculture.

Overall, 78 per cent of freshwater available in the country is diverted towards agriculture but still only 48 per cent of the gross cropped area has been brought under irrigation. Paddy and sugarcane crops together occupying one-fourth of the gross cropped area consume over 60 per cent of the total irrigation water supplied to agriculture, leaving most of the other crops water deprived.

Given that Indian agriculture is prone to droughts, frequency and intensity of which is likely to increase with climate change, there is a need to utilise its scarce water resource in the best way possible. The present Government has been concerned with the issue and has prioritised agriculture water use through schemes like "Har Khet ko Pani – Water for every field" and "per drop more crop". It has also taken a bold step of interlinking rivers for ensuring better utilisation of the available fresh water resources. However for better water management in agriculture, apart from improvements in the existing policies, programmes and technologies, a change in mindset of its people is very essential. The objective of agriculture development should not be of raising productivity per unit land but increasing productivity per unit water, especially irrigation water. This study makes a humble attempt in that direction.

We have compared and analysed the water productivity of 10 major crops—rice, wheat, maize, chickpea, tur/arhar, groundnut, rapeseed-mustard, sugarcane, cotton, and potato (occupying over 60 per cent of the gross cropped area of the country) with respect to their total consumptive water use (TCWU) estimated by the evapo-transpiration method. The water productivity of these major crops has been mapped at the district level to identify the regions which are hydrologically suitable for the cultivation of these crops. For three of the major water consuming crops, namely rice, wheat and sugarcane, taking away almost 80 per cent of the irrigation water, we have calculated the irrigation water productivity, particularly to highlight the skewed and inefficient irrigation water allocation existing in the country.

In this research publication by an inter-disciplinary team of water professionals and development economists, we have modestly tried to identify the most suitable districts/states, where minimum amount of water can create the maximum physical and economic productivity and benefits. We believe, once this has been achieved on a hydrologically sustainable basis, innovative interventions could be adopted in these regions to achieve 'more value or crop per drop of water'.

Results are rather revealing for paddy in Punjab and sugarcane in Maharashtra. These crops have relatively low irrigation water productivity in these states, indicating clearly that crops are not being cultivated in line with the natural water resource endowment. The need for reform in policies and programmes to rectify the misalignment in cropping pattern from a water perspective is dire. The report includes a number of other important findings and a set of evidence/ experience-based solutions, including water technologies, which we hope will be well-received by all those interested in making Indian agriculture water-smart, water-secure, environmentally sustainable and financially attractive. As Alfred Deakin, a three time Australian prime minister and a water enthusiast who toured India in 1890 had remarked, "*It is not the quantity of water applied to a crop, it is the quantity of intelligence applied which determines the result- there is more due to intelligence than water in every case.*"

Authors

Acknowledgements

This report is part of the study on "Issues Related to Water Use in Agriculture" under NABARD Research in Agricultural Economics: Land, Water and Value-Chains supported by National Bank for Agriculture and Rural Development (NABARD), India.

We express our sincere gratitude to Dr. Harsh Kumar Bhanwala, Chairman, NABARD, Mr. H.R. Dave (DMD, NABARD), Mr. R. Amalorpavanathan (DMD, NABARD), Dr. U.S. Saha (CGM, NABARD), Dr. A.R. Khan (DGM, NABARD) and the Department of Economic Analysis and Research (DEAR) team, NABARD, especially Dr. K.J.S. Satyasai (GM, DEAR), Mr. K.L. Prabhakar (DGM, DEAR) and Dr. Sohan Premi (AGM, DEAR) for sharing with us their valuable comments and reviews necessary for fine tuning our research.

We thankfully acknowledge the support of the International Water Management Institute (IWMI) in the form of vital data and inputs useful for our research. We also sincerely thank the ICRIER agriculture team for their insightful suggestions and comments during our internal presentations. Needless to say, the responsibility of facts, figures, analysis and views expressed in this paper fully rests with the authors.

Executive Summary

The issue: Why this study?

Increasing population and existing climate change scenario is posing a major challenge to the global fresh water resource. This challenge is more visible in agriculture sector, especially of water stressed countries, as it is often the biggest user of fresh water supplies. India is a classic case of this unfolding scenario. India is already categorised as water stressed country in terms of per capita freshwater availability (1544 cubic meter in 2011). Out of the 4 per cent share of global freshwater availability in India, almost 78 cent share of water is consumed by the agriculture sector. UN Population projections (revised) of 2017 show that India will be most populous country on this planet surpassing China by 2024. Most of the studies by OECD, IMF, etc also show that India is likely to register a population growth of about 7 to 8 percent for the coming decade or so. By 2030, India is also likely to have 600 million people living in urban areas, up from current level of about 380 million. What all this implies is that the pressure on water, both for producing more food, feed and fibre as well as for rising urbanization and industrial activity, will be tremendous. In a recent OECD study on global water risk hotspots, India's north-western region has already been identified as one among the three top most water risk hotspots in agricultural production, the others being north eastern China and south western USA. Against this backdrop, ensuring optimum water productivity (output per unit of water used/applied for irrigation by crop) becomes essential to ensure sustainable growth in agriculture. It may be worth noting that water is likely to be a more binding constraint to Indian agriculture than even land, and therefore it is time to change the mind-set from raising agricultural productivity per unit of land to per unit of water. This study is precisely an attempt in that direction.

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In addition to the sustainability issue, inequity in irrigation water use among crops across the country has left a little more than half of Indian agriculture still dependent on rainfall. Paddy in Punjab-Haryana belt and sugarcane in subtropical belt comprising of Maharashtra, Tamil Nadu,

The water guzzlers, paddy and sugarcane, consume more than 60 per cent of irrigation water available in the country, leaving over little for other crops.

Relatively water abundant eastern states of India, lag behind in the production of rice and sugarcane because they have been unable to set up suitable procurement structures for rice or attract sugar mills in the area.

For sustainable water use in agriculture, cropping patterns need to be recalibrated to maximise crop productivity per unit of water consumed or applied for irrigation.

Karnataka and Andhra Pradesh are classic examples highlighting this situation. The water guzzler paddy and sugarcane crop using more than 60 per cent of irrigation water available in the country are largely being cultivated in the most water scarce regions of the country restricting irrigation water availability for other major crops of the region. This situation has emerged over years primarily due to skewed incentive structures for rice and sugarcane in these regions. These incentives manifest in highly subsidized pricing of water, power, fertilizers on one hand, and assured markets for their outputs through procurement of rice in Punjab-Haryana belt, and of sugarcane by sugar factories at government determined prices (FRP or SAP). The relatively water abundant states in eastern region (eastern UP, Bihar, Jharkhand, West Bengal, Assam, and even Odisha), lag behind in production of these crops as they have not been able to erect suitable procurement structures for rice or attract sugar mills in their areas. This has led to a major misalignment in cropping patterns from the point of view of water availability. The hot-spots being Punjab-Haryana belt for rice and Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu for sugarcane.

Our approach

This study attempts to develop first-of-its kind maps and charts for the "Water productivity mapping of major Indian crops" which shall help in improved understanding and targeted policy and investment interventions for improving our agriculture water use. This water productivity report addresses how the cropping patterns (using 10 major crops under study, covering more than 60 per cent of gross cropped area) across states can be re-calibrated with a view to maximise crop productivity per unit of water consumed/applied for irrigation.

The study is spread across pan-India covering the relevant production, climate and water data from all the 640 districts (2011 Census) with detailed analysis for 'dominant districts and states'. In this report, the water productivity has been developed for 10 important crops: cereals (rice, wheat, maize), pulses (chickpea, tur/arhar), oilseeds (groundnut, rapeseed-mustard), commercial crops (sugarcane, cotton), and horticultural crop (potato).The water productivity will be analyzed from three broad perspectives namely – Physical water productivity (crop output per unit of total consumptive water used (TCWU)), Irrigation water productivity (crop output per unit of irrigation water applied by farmers) and Economic water productivity (value of crop output produced per unit of TCWU as well as irrigation water applied) and mapped indicating the suitability of the crop with respect to water use across the region. A further extension to this can be the estimation of economic water productivity to incorporate the concept of 'cost of water to society' incurred by irrigating the crop under study, which can be the future line of research.

Physical water productivity is estimated for all the ten crops across dominant districts. It may be worth noting that the concept of PWP is used by water experts and hydrologists to express the crop productivity with respect to the total water consumed by the crop (from rainfall plus irrigation), considering evapo-transpiration rate of water in the region. However, this concept of PWP can be closer to IWP at field situation, especially for water guzzler crops (that are largely cultivated under assured irrigated), only when the application efficiency of irrigation water is also high. In India, the overall efficiency of surface and groundwater irrigation ranges between 30-65 per cent and 65-75 per cent respectively. The concept of IWP is important as irrigation is what it costs to make the water available for use in agriculture. Hence, IWP, considering the crop output produced per unit of irrigation water applied in the field gives a more accurate picture from economic point of view, especially for water intensive crops like rice and sugarcane. Thus, irrigation water productivity is worked out for the three major crops- paddy, sugarcane and wheat, which occupy about 40 per cent of the gross cropped area and consume more than 80 per cent of irrigation water available in the country. The economic water productivity (EWP) per unit of total consumptive water use is estimated for all the 10 crops, while the EWP per unit of irrigation water applied is calculated for the major water guzzler crops namely paddy, wheat and sugarcane. Irrigation water productivity (IWP) and EWP are calculated for the dominant states, covering at least one per cent of total area under the crop in India and Physical water productivity (PWP) is calculated for the dominant districts, identified as the districts with 95 per cent of cumulative area under the crop in the particular dominant state.

Paddy, sugarcane and wheat occupy about 40 per cent of gross cropped area of India but consume more than 80 per cent of the irrigation water available.

Key findings

Comparing the physical water productivity (PWP) as well as irrigation water productivity (IWP) of rice, wheat and sugarcane with their corresponding land productivity across major states, one can find

Comparing the physical water productivity as well as irrigation water productivity of rice, wheat and sugarcane with their land productivity across major states, one can find significant misalignment in the cropping patterns and available water resources.

In contrast to Punjab and Haryana, states like Chhattisgarh and Jharkhand which display high irrigation water productivity for rice have low irrigation coverage (32 per cent and 3 per cent respectively) and consequently, lower land productivity.

significant misalignment in the cropping patterns and available water resource. This is clearly visible in the case of sugarcane and rice showing almost a perverse relation between land productivity and irrigation water productivity in certain regions.

Punjab reports the highest land productivity of rice (4t/ha). In Punjab and Haryana, the PWP is also high to the tune of 0.57 kg/m^3 and 0.4 kg/m^3 respectively. However the IWP in these states is found to be relatively low at 0.22 kg/m^3, indicating the inefficient irrigation water use (see Figure 1-a). The existing almost free electricity policy in agriculture in Punjab and Haryana has led to indiscriminate groundwater exploitation (depleting water table at the rate of almost 70 to 120cm/year as per the World Bank report, 2010) and non-judicious water use in agriculture. The high land productivity owing to assured irrigation, added with effective and assured procurement policy for paddy further encourage farmers to cultivate this crop despite the rising water sustainability issues. In contrast to Punjab and Haryana, states like Chhattisgarh and Jharkhand which display high irrigation water productivity have low irrigation coverage (32 per cent and 3 per cent respectively) and subsequently lower land productivity. The under developed procurement policy for paddy and low power supplies to agriculture in these states has further resulted in lower profitability levels of rice cultivation in these states, despite the hydrological suitability of the region. Thus there exists a serious misalignment in rice cropping patterns with respect to the water resource availability in India, which needs to be corrected with effective demand side as well as supply side policies.

Sub-tropical belts of Tamil Nadu, Karnataka, Maharashtra and Andhra Pradesh have high land productivity but low IWP for sugarcane.

For sugarcane, Tamil Nadu reports the highest level of land productivity (105.3 t/ha) as well as PWP (14.01 kg/m^3). As in the case of rice, one observes somewhat perverse relation between land productivity and IWP in sugarcane also. The tropical belts of Uttarkhand, Uttar Pradesh and Bihar report higher levels of IWP but lower levels of land productivity (Figure 1-b). At the same time, the sub tropical belts of Tamil Nadu, Karnataka, Maharashtra and Andhra Pradesh have high land productivity but lower levels of IWP values. This indicates the stated mismatch between sugarcane cropping pattern and water resource availability, which needs to be corrected by suitably adjusting the price of power and irrigation water, and by promoting more efficient technologies (such as drip) for irrigating sugarcane crop in these regions. The sugar licensing policy of preferring cooperatives sugar factories over private ones was one of the major reasons for the shift in the sugarcane growing belt from Bihar and eastern Uttar Pradesh towards the water stressed sub tropical belts of Maharashtra, Karnataka and Tamil Nadu. But this is not in line with water resource endowment of the region.

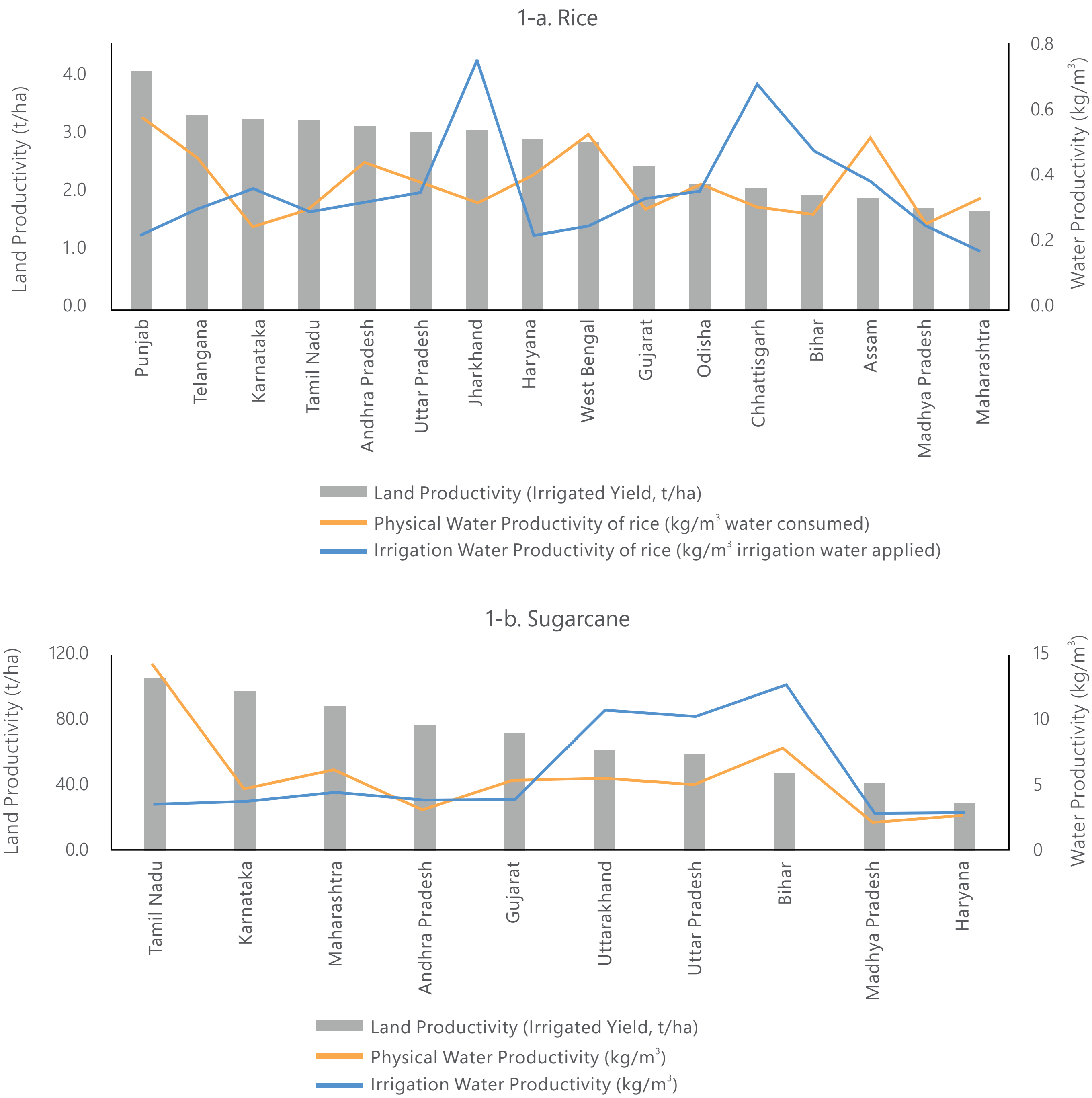


Figure 1. Comparison of land and water productivity of rice (1-a) and sugarcane (1-b) across major producing states

At the present level of water stress existing in the country there is need to re-calibrate the cropping patterns in line with their IWP (particularly for water guzzler crops like rice and sugarcane), and not remain obsessed with only their land productivity. Else, country will be moving towards unsustainable agriculture from water availability point of view, raising risks for the farmers, and promoting extreme inequity in the use of scarce water resources.

Strategic policy options

A. Specific policy implications emerging from study:

a. Re-aligning cropping pattern with available water resource endowments across states: The hydrological suitability of water guzzlers like rice and sugarcane are found to be somewhat perverse with respect to their major regions of production. With the help of the water productivity report prepared for the 10 major crops under study, cropping patterns can be improved and effectively re-aligned with respect to water availability, using suitable demand side and supply side policy interventions.

b. Price policy reforms: The root cause responsible for the misalignment between cropping pattern and water resource availability can be attributed to the inability in production of the water guzzler crops in the water abundant states owing to highly subsidized pricing of water, power, and fertilizers, and assured prices (government determined) of their outputs in other agriculturally advanced states.

Shift from a price policy approach of heavily subsidising inputs to an income policy approach of directly transferring funds into the accounts of farmers on per hectare basis

- ◊ Effective pricing of water and electricity in agriculture (at least recovering the O&M costs), carried out in sync with their improved quality and timely supply.
- ◊ Improved procurement policies for crop outputs (particularly rice and sugarcane) in the states with high IWP.
- ◊ Shift from price policy approach of heavily subsidizing inputs to income policy approach of directly giving money into the accounts of the farmers on per hectare basis (direct benefit transfer of input subsidies), and letting prices be determined by market forces.

c. In case, it is not possible to carry out reforms in pricing of water and power, the second best solution will be to ration irrigation water supplies in canal irrigation system through a 'warabandi' type system, and power supplies by limiting the hours to supply power for irrigation through a separate dedicated feeder line for irrigation (as was done in Gujarat).

d. Understanding and adopting best practices across the world as well as across the states of our country. Feasibility of the improved water management technology may be taken up in the form of pilot studies in the bright spots and model districts identified in the study and evaluated for large scale dissemination across the country.

B. Other supporting policies:

a. Improving irrigation efficiency of both canal as well as groundwater irrigation by adoption of precision irrigation technology like micro irrigation. Adoption of solar irrigation, with provision to sell excess solar energy back to the grid, helps to improve the water-energy nexus.

b. Infrastructure development for water management through investing on rainwater harvesting and artificial recharge structures.

c. Encourage Participatory Irrigation Management through WUAs, FPO and Corporate Farming Ventures

These are some of the specific and supporting demand-side and supply side policies emerging from the study, which with suitable financial support through various schemes and funding opportunities from institutions like NABARD can be effectively implemented across the country. The Government of India has given NABARD the task to raise corpus of Rs 40000 crore towards Long term irrigation fund for fast tracking the completion of 99 prioritised irrigation projects and Rs 5000 crore Micro irrigation fund to implement the concept of per drop more crop in irrigation water use. These signal towards the emphasis and confidence that the Government lays upon NABARD in the improvement of the existing irrigation and agriculture water use scenario in India.

Apart from this, orienting and designing the other supporting agriculture development funds and schemes of NABARD like Farm sector promotion fund, Producer organization development fund, National Adaption Fund for Climate Change (NAFCC), agriculture market infrastructure projects and alternate infrastructure funds in tune with the region-specific hydrological suitability of the crops can help in re-aligning the cropping pattern of the country focusing on water use optimization.

NABARD in collaboration with state governments can focus on creating and implementing "sustainable crop-water use pilot projects" in model districts identified in the study.

This water productivity report developed for the 10 major crops in India can act as a blueprint to identify and prioritise optimal water use based cropping pattern for states and major districts and streamline these funds accordingly. Further NABARD in collaboration with state Governments can focus on creating and implementing “sustainable crop-water use pilot projects” in model districts identified in the study. These projects after thorough evaluation may be scaled up to other laggard districts, if found feasible.

In sum total, Indian policy makers need to awaken and respond to the looming water crisis. The beginning has to be made from agriculture, which is the largest consumer of freshwater (about 78 per cent); and within agriculture focus on bringing efficiency in the use of water in water guzzler crops like rice and sugarcane, especially in regions where their IWP is low despite high land productivity. These are the hotspots for policy action. Let it start with Punjab for rice and Maharashtra for sugarcane. Success in these two states can show the way for others to follow and India can have a sustainable development of its agriculture.

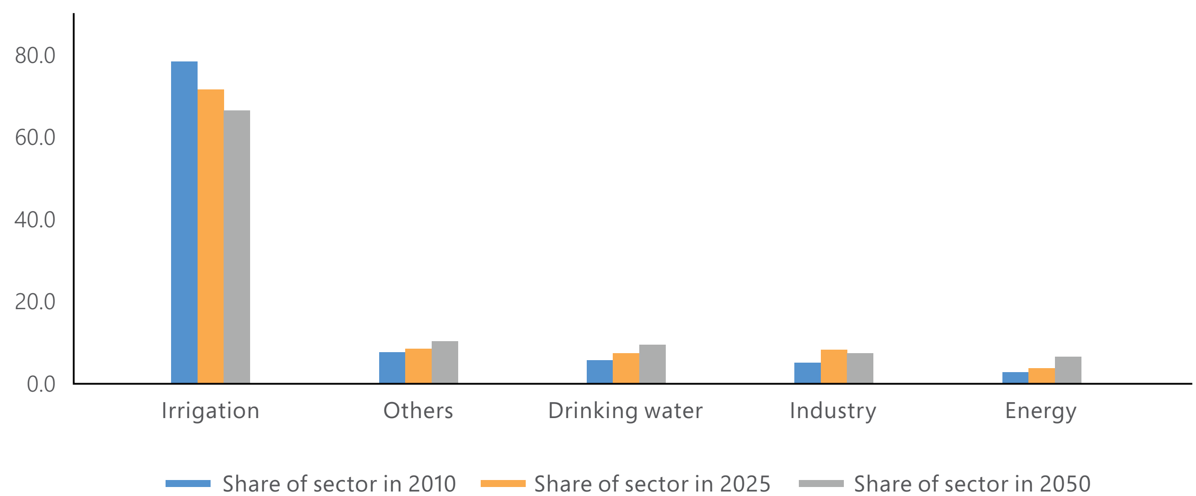
1

Water Productivity

Concept, Importance and Measurement

1.1 Introduction

It is widely recognised that the world is facing an unprecedented water crisis and among the key factors influencing this situation are water management issues in the agricultural sector. Two basic factors are critical- first, the agricultural sector is by far the largest user of freshwater (Molden, 2007); and second, water use in agriculture tends to have lower net returns as compared to other competing uses (Scheierling et al., 2014). Estimates suggest that in the next three decades, the global food systems will need 40-50 per cent more freshwater than today. Municipal and industrial demand for water will increase by 50-70 per cent during this period, while demand for energy sector will increase by 85 per cent. India faces high water stress and the country is amongst those with the most fragile and uncertain water resources in the world. Irrigation sector with almost 78 per cent share dominates the present and future water use scenario in India (Figure 2).One of the main response to these emerging challenges is to focus on improving water productivity in agriculture, as even small improvements could have large implications for local and national water budgets and allocation policies. This view is shared by Global Water Partnership (2000), UNESCO (2009) and FAO (2012, 2016) which consider demand management as an important option to cope with water scarcity, with improving agricultural water productivity as the single most important avenue for managing water demand in agriculture.



Source: (CWC, 2015)
Note: Values as projected by NCIWRD: National Commision on Integrated Water Resources Development

Figure 2. Share of different sectors in water use in India during 2000 and projected for 2025 and 2050

Land, labour and water are the critical resources in agricultural production. However, unlike land and labour productivity, the concept of Water Productivity (WP) though existent from a long time, became prominent only recently especially in the developing countries (Barker et. al., 2003). The famous slogan of '*More Crop per Drop*' (Molden, 1997) or '*Per Drop More Crop*' as rechristened by the Indian Prime Minister featured throughout the past decade in analyses of WP of crops, cropping systems and agricultural production systems (Kijne et. al., 2003; Amarasinghe et al., 2007 ; Amarasinghe and Smakhtin, 2014). Improving WP at scales of fields, farms, irrigation systems and river basins (Zwart and Bastiaanssen, 2004; Gulati et al., 2005; Kumar et al., 2008; Sikka et al., 2009; Cai and Sharma, 2010) and across sectors of agriculture, domestic, industry and environment has been the central argument in discourses on averting water crisis and ensuring water security to vulnerable populations and regions of the world. Many countries in the world (IWMI, 2001; Rosegrant et. al., 2002) and large intensive water-use regions within the countries (Rodell et al., 2009; Singh, 2011) are breaching the thresholds of physical and economic water scarcities.

Originally, crop physiologists defined water use efficiency as the amount of biomass or marketable yield per unit of transpiration or evapo-transpiration (Viets, 1962). Irrigation scientists and engineers used the term water (or irrigation) use efficiency as "the ratio of irrigation water transpired by the crops of an irrigation farm or project during their growth period to the water delivered from a river or other natural source into the farm or project canals during the same period of time (Israelsen, 1932). In spite of some improvements, this concept of water use efficiency provides only a partial view because it does not indicate the total benefits produced, nor does it specify that water lost by irrigation is often used by other users downstream (Seckler et al., 2003). The current focus of water productivity has evolved to include the benefits and costs of water used for agriculture in terrestrial and aquatic ecosystems (Molden et al., 2007). In its broadest sense, it reflects the objectives of producing more food, income, livelihoods and ecological benefits at less social and environmental cost per unit of water consumed (Sharma, Molden and Cook, 2013). Physical water productivity is defined as the ratio of agricultural output to the amount of water consumed (from all available source of water like rainfall, irrigation, etc). The concept of total consumptive water use (TCWU) used in PWP, is measured based on the evapo-transpiration rate in the region. For irrigation intensive crops like paddy, sugarcane

Physical water productivity is defined as the ratio of agricultural output to the amount of water consumed (from all available sources of water like rainfall, irrigation, etc).

For irrigation intensive crops like paddy, sugarcane and wheat, PWP alone does not reflect the actual field situation, as the volume of irrigation water applied in field is often more than the actual water requirement of the crop.

and wheat, this scientific estimation of water productivity based on PWP alone does not reflect the actual field situation, as the volume of irrigation water applied in field is often more than the actual water requirement of the crop owing to the low overall efficiency of the surface as well as groundwater irrigation system. Thus, we have introduced the concept of irrigation water productivity, which estimates the crop productivity with respect to unit volume of irrigation water applied by the farmer. IWP and the corresponding economic water productivity has been estimated for three major water guzzler crops namely rice, wheat and sugarcane which consume over 80 per cent of the total available freshwater for irrigation in the country.

a. Physical water productivity is defined as the ratio of agricultural output to the amount of water consumed from all available sources including irrigation, rainfall etc. (kg of produce per cubic metre of water consumed (through evapo-transpiration) during crop growth, kg/m^3).

b. Irrigation water productivity is defined as ratio of the crop output to the irrigation water applied by the farmer/ irrigation system either through surface canals, tank, pond or the well and tubewell during the crop growth. Thus irrigation is an economic activity and the farmer has to incur certain expenditure to apply the water (kg/m^3).

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

Depending upon the professional interest and expected outcome, water productivity is viewed differently in its concept and measurement. Water productivity is also scale dependent- from plant to plot to farm to agricultural system to command area and river basin to an administrative unit of district, state, country or global. Common supply side approach to overcome water stress in most developing countries, including India, is to develop additional surface and groundwater resources and provide subsidised energy to exploit these resources (Gulati and Narayanan, 2003; Johl; 2017). However, more sustainable option for increasing production under growing water scarcity is to increase productivity of water under existing uses of water. With the help of the estimated IWP demand-side policy initiatives can be formulated which may help in re-aligning the existing mismatch between the cropping pattern and water resource availability in the country.

The concept can also be used to relate water use in a particular sector to wider goals of nutrition, jobs, welfare, and the environment. Productive use of water is of special interest in water scarce regions and where the farmers need to realise the full benefits of fertilisers, high quality seeds, tillage, and the labour, energy and machinery. Targeting high water productivity can reduce the cost of cultivation of crops and lower energy requirements for water withdrawal. Improved WP also reduces the need for additional land and water resources in irrigated and rain fed systems (Molden et al., 2010). With no gains in water productivity, average annual agricultural evapo-transpiration could double in the next 50 years (de Fraiture et al., 2007). Measurement and improvement of water productivity is thus an important response to growing water and land scarcity, optimisation of other production inputs and improved incomes and environment.

A key problem with the concept is that the term 'agricultural water productivity' is often used quite vaguely. There is little systematic analysis on the instruments available for improving water productivity, including which interventions may be suitable for a particular crop, situation or region. A popular intervention to realise 'more crop per drop' is the provision of subsidies/ support to farmers for adoption of more capital-intensive technologies (micro irrigation etc.). These practices may reduce on-farm irrigation water applications and sometimes improve crop yields, but may not necessarily provide *real* water savings. (Scheierling et al., 2014; Perry and Steduto, 2017).

1.2 Status of water productivity in India

There are no national estimates available to show the status of water productivity in agriculture and other sectors in India- though numerous studies at smaller scales of farms or commands or the specific areas of interest and for some crops have been conducted. Key indicators for Asia and the Pacific (ADB, 2017) show that though total Internal Renewable Freshwater Resources for India remain stable at 1446 BCM, other indicators have undergone a large change during 2002-2014 (**Table 1**) due to large population growth and

Table 1

Internal freshwater resources and overall water productivity of selected countries in Asia and Pacific

Country	Internal Renewable Freshwater Resources (cubic metre per person per year)			Annual Freshwater Withdrawals, BCM	Water Productivity in 2014*
	2002	2014	Change (per cent)		
P.R. China	2141	1999	(-)6.8	604	14
Bangladesh	771	652	(-)16.7	36	4
India	**1326**	**1103**	**(-)16.8**	**648**	**3**
Indonesia	9288	7839	(-)15.6	113	8
Singapore	145	107	(-)26.2	–	1,493
Australia	25213	20527	(-)3.42	19	65

*GDP in constant 2010 US dollars per cubic metre of total fresh water withdrawal

Notes: Internal freshwater resource as calculated by FAO aquastat, relates to freshwater resource available within the country.
Internal Freshwater resource = Total freshwater resource - External freshwater resource

Source: ADB, 2017, FAO aquastat

one of the lowest overall water productivity forcing farmers, households and industries to further increase the freshwater withdrawals.

India has one of the lowest values of water productivity (**Table 1**) and further economic value of water in agriculture is much lower than in other sectors. Growing physical shortage of water and scarcity of economically accessible water owing to increasing cost of production and supply of the resource has always challenged the researchers and planners with increasing productivity of water use in agriculture in order to get maximum production or value from each unit of water used or applied (Kijne et al., 2003, Kumar and Amarasinghe, 2009). Improving water productivity in agriculture is the cornerstone of any water demand management in India.

Given the large spatial variation and monsoonal pattern of rainfall, Indian agriculture is highly dependent on rainfall behaviours. On evaluation at district level, the per hectare economic productivity of all crops taken together was found to be almost almost 1.6 times higher under largely irrigated condition as compared to under largely rain fed condition during biennial ending 2011-12 (Chand, 2017). Even districts at the same level of irrigation show large differences in aggregate productivity. Variation in productivity at same level of irrigation and lower yield levels of most crops in India compared to world averages are due to poor level or low adoption of improved technology. Chand (2017) remarked that enhancing access to irrigation and technological advancement are the most potent instruments to raise agricultural productivity. Presently, more than 50 per cent of the agricultural land in the country remains unused for half of the productive period mainly due to lack of access to water to meet crop water requirements. Even in the irrigated areas, there is not enough water available throughout the year both due to physical and economic water scarcity. Irrigation is also the pre-requisite for diversification of agriculture to high value crops like fruits and vegetables, commercial crops and floriculture and spices. National data shows that shifting one hectare area from staple crops to commercial high value crops has the potential to enhance economic returns by 147 percent (NITI, 2017). This illustrates that the water-centric interventions help both in improving the agricultural productivity and move closer to the cherished goal of 'Doubling Farmers Income by 2022'.

Currently, more than 50 per cent of the agricultural land in the country remains unused for half the productive months due to lack of access to adequate water. Even in irrigated areas there is not enough water available throughout the year.

India is already facing a severe water crisis; creation of large additional water resources is hugely capital and technology intensive, is contested by environmentalists and potentially affected stakeholders and above all has long gestation period. The alternative groundwater resource is already over-exploited in the north-west, central and southern regions and has serious energy issues and quality concerns in the eastern region. Watershed development can provide some cushion in the mainly undulating and hilly rain fed regions but are inadequate during times of drought or for cultivation of high value agricultural crops. One of the important solutions shall be to map and significantly improve the water productivity of the important agricultural crops as agriculture uses almost 78 percent of the available fresh water resources. This will help to re-align the cropping pattern based on the hydrological suitability rather than with just the land productivity, thus ensuring sustainable agriculture development. Prevailing water productivity of all sectors is appallingly low in India at US$ 3/ m^3 as compared to other Asia-Pacific countries e.g. US$ 8/m^3 in Indonesia, US$ 14/m^3 in China, US$ 65/m^3 in Australia and as high as US$ 1,493/m^3 in Singapore (ADB, 2017). In terms of the agricultural crops, the largest global consumer of rice in terms of water is India. Chapgain and Hokestra (2011) estimated that total water footprint of rice in India was 2020 m^3/t as compared to 971 m^3/t in China even with China's rice productivity level 2-times higher than India. Zwart and Bastiaanssen (2004) compared measured agricultural water productivity (crop yield per unit of actual evapo-transpiration) values for major crops and found wide ranges amounting to 0.6-1.7 kg/m^3 for wheat, 0.6-1.6 kg/m^3 for rice and 1.2-2.7 kg/m^3 for maize indicating 'tremendous opportunities for maintaining agricultural production with 20-40 per cent less water resources. Alauddin and Sharma (2013) suggested that technology diffusion was the causal factor of water productivity and intelligent food trade could reduce the national/ global water use. Management of irrigation water appears to play a crucial role in influencing technical efficiency. Empirical results from several field level studies and surveys indicate that water-centric technical efficiency is on average much lower than output oriented technical efficiency, indicating that farmers and related institutions could become significantly more efficient in water use, given the present state of technology, policy and input use.

Since agriculture uses almost 78 per cent of the available fresh water in the country, mapping the water productivity of major crops and improving it significantly can provide an effective solution to the fresh water deficit challenge.

Keeping in mind these large water issues in the agricultural sector, opportunities and challenges for improving the cropping pattern based on water productivity and the avenues for investments in the rural water sector, the study on "Water Productivity of Important Agricultural Crops in India" was planned with the following objectives:

1.3 Study objectives

Specific objectives of the study were to:

i. To estimate the crop and water productivity of important agricultural crops in the dominant districts and states of India.

ii. Map the variation in crop, and physical- irrigation and economic-water productivity of important agricultural crops in India to develop the first of its kind '*Water Productivity mapping of major Indian crops*'.

iii. Understand the underlying causes of mismatch in cropping pattern with respect to the water resource availability and water productivity across the Indian states and collate the technical and policy interventions for its improvement.

Spread of the study is pan-India covering the relevant production, climate and water data from all the 640 districts (2011 Census) with detailed analysis for 'dominant districts and states'. This report on water productivity has been developed for 10 important crops: cereals (rice, wheat, maize), pulses (chickpea, tur/arhar), oilseeds (groundnut, rapeseed-mustard), commercial crops (sugarcane, cotton), and horticultural crop (potato).

This report on water productivity has been developed for 10 important crops: cereals (rice, wheat, maize), pulses (chickpea, tur/arhar), oilseeds (groundnut, rapeseed-mustard), commercial crops (sugarcane, cotton), and horticultural crop (potato).

1.4 Organisation of the report

The remainder of the report is organised as follows. Conceptual issues for Water Productivity, Methodology, data sources and limitations of the study are elaborated in Chapter 2. This report presents the detailed Water Productivity analysis for 10 major agricultural crops of India. Further the Report is sub-divided in five Sections: Section-I, Cereals (Chapter 3 to 5 on Rice, Wheat and Maize), Section-II, Pulses (Chapter 6, 7 on Chickpeas and Tur/Arhar), Section-III, Oilseeds (Chapter 8 and 9 on Rapeseed/Mustard and Groundnut), Section-IV, Commercial Crops (Chapter 10 and 11 on Sugarcane and Cotton) and Section-V, Horticultural Crop (Chapter 12 on Potato). Conclusions and Policy Recommendations emerging from the report are presented in Chapter 13.

2

Methodology for Estimation of Water Productivity

Physical, Irrigation and Economic Perspectives

Water productivity assessment can quantify sustainable water use in agriculture and thereby inform economic policy. It may, therefore, ensure intelligent and informed allocation of the scarce resource across crops to meet the present demand without foregoing the needs of future generations.

The concept of water productivity started gaining importance since the realization of increasing threshold being faced by countries and regions on account of its available water resource, particularly with respect to the huge allocation towards agriculture sector. Water productivity serves as a plausible option for quantifying the extent of sustainable water use in agriculture and thereby proposing suitable economic policies to ensure intelligent and informed allocation of the scarce resource among crops to meet the present demand without foregoing the needs of the future generation.

Several studies on water productivity of crops have been attempted to understand the quantity of output generated in relation to the total consumptive water use (TCWU) of the crop, mostly expressed in terms of kg/m^3 (Quantity of crop output produced in kilogram per cubic meter of TCWU). However in our study we go a step beyond and also express the water productivity with respect to the actual irrigation water applied for the three major water guzzling crops namely paddy, sugarcane and wheat, consuming more than 80 per cent of water available for irrigation. Further, we have calculated the economic water productivity by taking into account the value of crop output created per unit of TCWU and irrigation water applied. This will serve as an important tool for economic policy makers to relate it to the concept of sustainability and efficiency of water use in agriculture.

In the present study thus we attempt to analyze the agricultural productivity from the water use perspective and aim to develop a national water productivity report for important agricultural crops of India. Ten major crops comprising of three cereal crops – Rice, Wheat, Maize; two pulse crops – Chickpea and Tur; two oilseeds – Rapeseed-mustard and Groundnut; one vegetable crop-Potato and two commercial crops – Sugarcane and Cotton have been identified for the analysis. As per the 2013-14 statistics, these 10 crops, together cover about 63 per cent of gross cropped area (200 m.ha) in India with rice occupying 44.14 m.ha (21.9 per cent), wheat, 30.47 m.ha (15.2 per cent), cotton, 11.96 m.ha (5.9 per cent), chickpea, 9.93 m.ha (4.9 per cent), maize, 9.07 m.ha (4.5 per cent), rapeseed & mustard, 6.65 m.ha (3.3 per cent), groundnut, 5.51 m.ha (2.7 per cent), sugarcane, 4.99 m.ha (2.5 per cent), tur, 3.90 m.ha (1.9 per cent) and potato, 1.20 m.ha (0.6 per cent). The water productivity will be analyzed from three perspectives namely – Physical water productivity (at district level), Irrigation water productivity and Economic water productivity (at State level) and mapped indicating the suitability of the crop with respect to water use across the region. A further extension to this can be the estimation of net economic water productivity, to incorporate the concept of 'cost of water to society', by considering the cost of irrigation water applied in addition to the value of crop output considered in calculation of EWP. Since there is huge variation in the irrigation water price across states, the estimation of net economic water productivity can throw more light in comparing the sustainability of water use in agriculture. Thus this can be taken up as the future line of research. Details on these approaches are discussed in the following sub sections.

For the water productivity analysis in the study, filters have been applied to the data on states and districts, growing the crop under consideration, to identify dominant districts (in the case of physical water productivity approach) and the dominant states (in case of all the three water productivity approaches).

- **First filter**: Out of all the states cultivating a particular crop, states that cover at least one per cent of total area under the crop in India are selected. These form the ***Dominant States*** for crop under consideration.
- **Second filter:** From the dominant states filtered for the particular crop, the cropped area under each district was arranged in ascending order and top districts covering 95 percent of cumulative area under the crop in the particular state are selected. The selected districts form the ***Dominant Districts*** for the particular crop under consideration.
- These dominant districts and dominant states formed the universe of the study and further analysis on Physical, Irrigation and Economic Water Productivity was carried out on the data belonging to these districts and states for each of the selected crop. For further details refer Sharma et al. (2010).

Since, there is a huge variation in irrigation water prices across states, Net Economic Water Productivity may serve as a better statistic for comparing the sustainability of water use in agriculture across regions. This could be taken up as a future line of research.

2.1 Physical Water Productivity

Several studies in the past have estimated physical water productivity (PWP) for important agricultural and horticultural crops. Over the years the methodology, data sources and analytical techniques have been changed or modified. Some of the earlier studies such as Ahmad et al. (2009), and Cai and Sharma (2010) have also used remote sensing and mathematical algorithms for evapo-transpiration, and weather and census data to measure water productivity of rice and wheat in selected basins. Others have calculated total consumptive water-use (TCWU) for

PWP is defined as a ratio of total crop output or production to TCWU.

PWP is calculated for each district that predominantly cultivates the particular crop.

a particular crop to calculate crop water productivity (Amarasinghe and Sharma, 2009; Sikka, 2009). TCWU for a crop is the sum of the amount of water that a crop transpires during the course of its growth and the amount of water that evaporates from the surface on which the crop is cultivated. Though the studies that used TCWU were more complete in terms of considering various aspects of water consumption and crop growth, they fell short on temporal and spatial coverage and variations. In 2009, Amarasinghe et al. improved on the previous assessment of TCWU (Allen et al., 1998) by considering average monthly rainfall vis-a-vis mean annual rainfall, and calculated local level evapo-transpiration and crop coefficients for different stages of crop growth. Currently, much clarity has been achieved in the methodology in calculating crop water productivity.

In this study PWP is defined as a ratio of total crop output or production to TCWU. The TCWU takes into account water available from rainfall as well as man-made irrigation sources. It is expressed as kg/m^3. The PWP is calculated at district level for the dominant districts cultivating the particular crop. The resulting PWP is thus mapped at district level.

Physical Water Productivity (PWP in kg/m^3) of the area of interest is estimated by:

Equation 1

$$PWP = \frac{\sum_{i \in crops} \text{Average yield}_i \, X(\text{Area}_i^{IR} + \text{Area}_i^{RF})}{TCWU}$$

where,

The total seasonal/ annual TCWU of a district is estimated as:

Equation 2

$$TCWU = \sum_{k \in seasons} \sum_{i \in crops} (TCWU_{ki}^{IR} + TCWU_{ki}^{RF})$$

Equation 3

$$TCWU_{IR} = \sum_{k=seasons} IRA_{ik} \sum_{j=months} \sum_{j=\text{growth periods}} kc_{kl}^{l} * ET_{PJ} * {}^{d_{lj}}/n_j$$

Equation 4

$$TCWU_{RF} = \sum_{k=seasons} RFA_{ik} \sum_{j=months} \sum_{j=\text{growth periods}} (kc_{kl}^{l} * ET_{PJ}, Effrf_j) * {}^{d_{lj}}/n_j$$

In the above equations, $TCWU_{IR}$ is the Total Consumptive Water Use for irrigated cropped area for i^{th} crop and $TCWU_{RF}$ is the Total Consumptive Water Use for rain fed area under the same crop under consideration. Total water consumption for i^{th} crop for a district (TCWU) is the sum of $TCWU_{IR}$ and $TCWU_{RF}$. The other variables in Equation 3 and Equation 4 are described below:

- IRA_{ik} and RFA_{ik} respectively represent irrigated and rain fed areas of i^{th} crop in the k^{th} season.
- *l* is the number of growth periods during the cropping season. To capture the variation in crop growth stage 10-day long segments are considered for estimation. Growth season of the crop shall determine the number of growth periods.
- d_{lj} is the number of days in the j^{th} month for the lth growth period.
- nj is the number of days of the j^{th} month.
- kc is the crop coefficient for i^{th} crop in the lth growth period of the k^{th} season.
- $Effrf_j$ is the effective rainfall for the period of the month in which crop is grown. This is calculated as a proportion of the average monthly rainfall (AMR).
- If for an area AMR ≤ 250mm, then Effrf = AMR x (1-0.25*AMR)/125. But when AMR ≥ 250 mm, then Effrf = 125+0.1*AMR.

Besides these data points, two separate evapo-transpiration multipliers are also included in the equations. In Equation 3, the irrigated multiplier involves second and third summations with ith crop ET represented by (kc^{l}_{kl} .ET_{pj}), where ET_{pl} is the potential evapo-transpiration during the lth growth period. As mentioned earlier, it is assumed that for irrigated crop, irrigation meets the full water requirement, even though in reality this might not be true in some cases. In Equation 4, for the rain fed crop the multiplier is taken as the minimum value of (i^{th} crop ET. $Effrf_j$).

The data sources for calculating the main variables for arriving at PWP values at district level are listed below:

a. Data for season-wise cropped area, irrigated area, total crop output and land productivity (yield) at the district level for the crops are obtained from *District Wise Crop Production Statistics and District Wise Land Use Statistics at Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India*[1]

b. Data was collected for two years- 2009-10 and 2010-11; the latest and most updated data available at the district level. The idea is to take the two year average to account for seasonal and annual variations.

c. For TCWU, data are collected for multiple parameters including water requirement of crop, precipitation and evapo-transpiration, seasonal crop coefficients for different crops, irrigation, and crop calendar. The data again have been considered for 2009-10 and 2010-11. The main sources of the water and climate related data points include IWMI Global Climate Atlas[2]; Indian Meteorological Department and the state level information on crop calendar and related statistics.

d. Ratio of the average crop productivity for the district to the average Total Consumptive Water Use during

[1] http://aps.dac.gov.in/APY/Public_Report1.aspx accessed on various dates during 2016 and 2017).

[2] IWMI (International Water Management Institute). 2001. IWMI Climate and Water Maps, Colombo, Sri Lanka: International Water Management Institute CD-Rom

the crop growth for a given district provides the values for average Physical Water Productivity which were further analyzed and mapped to understand the variability, identify blind spots and bright spots of productivity, understand the underlying factors for variation and then suggest interventions for sustainability and improvement.

2.2 Irrigation Water Productivity

Estimation of IWP across states can help to understand where each unit of applied irrigation water will be most productive.

Estimation of 'Irrigation Water Productivity' across states shall help to understand where each unit of applied irrigation water will be most productive. This is a practical indicator which helps in estimating the crop output obtained with respect to the actual irrigation water applied by the farmer, which may be higher or lower than the TCWU of the crop. In general the irrigation efficiency of surface irrigation system (30-65 per cent) as well as groundwater irrigation (60-75 per cent) system are low. Owing to the low irrigation efficiency, the volume of irrigation water applied is more than the actual crop water requirement calculated based on the evapo-transpiration rate. Thus for water guzzler crops like rice, sugarcane and wheat, which depend on irrigation intensively and together consume more than 80 per cent of the freshwater available for irrigation in the country, there is a need to move beyond PWP and adopt IWP for better representation of field situation.. The irrigation water productivity has been estimated at the state level owing to district level data limitations and considering as many data points as available through studies and operational projects for the given crop in the state.

In the study, Irrigation Water Productivity (IWP in kg/m^3) is estimated as follows:

Equation 5

$$IWP = \frac{\{\text{Irrigated Yield of } i^{th} \text{ crop} \times \text{Irrigated area under } i^{th} \text{ crop}\}}{\text{Irrigation water applied per unit area of } i^{th} \text{ crop} \times \text{Irrigated area under } i^{th} \text{ crop}}$$

To estimate the amount of applied irrigation water for crop cultivation, we used a variety of information available through the large farmer surveys and government reports like price policy reports for Kharif crops and sugarcane published by Commission for Agricultural Costs and Prices (CACP), recommendations of the state irrigation departments and the estimates made by the ICAR Water Management Research Centres.

State level average irrigated and unirrigated yields of the crop were obtained from Crop Cutting Experiments (CCE) as published in 'Consolidated Results of Crop Estimation Survey on Principal Crops' published by NSSO for the year 2009-10 and 2010-11. Simple average for 2009-10 and 2010-11 was used as proxy for irrigated and un-irrigated crop yield in various states. The authors are fully aware of the micro-level variations in water applied to rice and other crops and the return flows within a district and the state, and it was not the objective of the study to capture those variations and only provide macro-level inter-state variations. This can be considered as a limitation of the study.

2.3 Economic Water Productivity

The economic water productivity has been approached in two ways:

a. **Economic Water Productivity (EWP) per unit of total consumptive water use (TCWU)**: It measures the monetary value of the crop output produced per unit volume of total consumptive water use (TCWU) of the crop. This has been evaluated for all the 10 crops under study.

Equation 6

$$EWP = \frac{\text{Average yield of i}^{\text{th}}\text{ crop} \times \text{Area under i}^{\text{th}}\text{ crop} \times \text{Farm Harvest Price of i}^{\text{th}}\text{ crop per unit quantity of crop output}}{\text{TCWU of the i}^{\text{th}}\text{ crop}}$$

b, **Economic Water Productivity (EWP) per unit of irrigation water applied:** It gives the estimate of the value of crop output produced per unit volume of irrigation water applied by the farmer for the cultivation of the crop. This has been evaluated for three major water guzzling crops namely rice, sugarcane and wheat.

Equation 7

$$EWP = \frac{\text{Irrigated yield of i}^{\text{th}}\text{ crop} \times \text{Irrigated area under i}^{\text{th}}\text{ crop} \times \text{Farm Harvest Price of i}^{\text{th}}\text{ crop per unit quantity of crop output}}{\text{Irrigation water applied per unit area of i}^{\text{th}}\text{ crop} \times \text{Irrigated area under i}^{\text{th}}\text{ crop of crop output}}$$

The source of data pertaining to irrigated yield, irrigated area and irrigation water applied were already discussed in the subsection 2.1. To convert the crop output to monetary value the numerator is multiplied with the Farm Harvest Price (FHP) of the crop existing in the particular state. Average FHP value for the period 2009-10 and 2010-11 are used for the study as the other database used in the study pertains to the same period.

2.4 Presentation of results

As part of the data analysis, the results have been presented on maps using QGIS software. It gives a visual representation of the spatial distribution of cropped area, irrigated area, production, yield and different indices of water productivity for different crops in India. This is very helpful in developing the *Water Productivity Mapping for Important Agricultural Crops of India*.

Series of the district wise data on the cropped area, production, productivity and Physical Water Productivity was also arranged in ascending order and divided into 5-equal groups (~20 per cent each) and the variation in each cluster was studied and plotted. This approach was especially useful in identification of the 'bright spots' and 'hot spots' for each of the analyzed variable.

Water Productivity report follows a matrix approach where for each of the important crop the different types of Water Productivity are analyzed and discussed in detail and important findings and recommendations summarized (**Table 2**). Efforts are made to make it visually appealing for ease in comprehension both by the water professionals, economists, agricultural policy planners and donors and investors.

Table 2

Crop and water productivity matrix for the organisation of the water productivity report

Crop/ Crop group	Physical Water Productivity, kg/m^3 of water consumed	Economic water productivity based on TCWU, (Rs/m^3)	Irrigation Water Productivity, kg/m^3 of irrigation water applied	Economic Water Productivity based on irrigation water applied, (Rs/m^3)
Cereals				
Rice	✓	✓	✓	✓
Wheat	✓	✓	✓	✓
Maize	✓	✓		
Pulses				
Chickpeas	✓	✓		
Tur/ Arhar	✓	✓		
Oilseeds				
Rapeseed-Mustard	✓	✓		
Groundnut	✓	✓		
Commercial Crops				
Sugarcane	✓	✓	✓	✓
Cotton	✓	✓		
Vegetable Crops				
Potato	✓	✓		

2.5 Assumptions and limitations of the study

Crop growth, water application and its response to marketable output and the prices realized by the farmers are very local phenomenon and vary from farm to farm and even within a given farm. This data is important but difficult to handle for policy level studies. The present study has adopted a macro-level approach where some of these nuances may be masked. Following are some of the important assumptions and limitations of the study and the readers may kindly consider the same while applications of the results, comparison with other studies and policy and investment decisions:

i. District is considered as an administrative unit and crop and water related datasets and the analysis and recommendations are considered uniform across the district.

ii. Where district level data were not available, average of the multi-point data across the state and average of the crop-cutting experiments for irrigated and rain fed yields in the state were used to estimate the state level data.

iii. Water consumption/ application was considered as the main variable for variation in crop production and all other inputs/ variables were considered uniform across the district/ state which in a large data set shall be averaged out.

iv. Economic water productivity comparison becomes clearer and more appropriate when we consider the cost of irrigation water also, i.e. when the denominator of economic water productivity based irrigation water applied, is also expressed in value terms. The cost of irrigation water is highly varied across the districts of the state based on the terrain of the state, water availability etc. This exercise has not been done in the present study but we look forward to continue that as an extension to this study in future.

3

Rice

3.1 Introduction

Rice is the staple of Asia and it is central to the food security of about half of the world population. Rice is also one of the largest water consumers in the world and the crop receives as much as 34-43 per cent of the total world's irrigation water. IRRI (2013) estimated that total seasonal requirement for a 100-day rice crop can be as high as 670 mm–4450 mm with a typical value of 1500 mm/season. As such competition for water resources is becoming intense in many of the world's rice producing areas. Inefficient use of water for crop production has depleted aquifers and reduced river flows, and many river basins like Indus, Krishna and Yellow River no longer have sufficient water to meet the demands of agriculture, industry and urban centres. As competing demands for fresh water and the real cost of the water and energy to supply the surface and groundwater intensify, rice growers will need to considerably improve the water productivity of their farming systems.

In 2015-16, around 471 million tonnes of rice was consumed worldwide. The production figure for the same period was around 472 million tonnes (USDA, September 2017). China and India together contributed almost 50 per cent rice production to the world in 2014-15, followed by Indonesia (10 per cent), Bangladesh (7 per cent) and Vietnam (6 per cent) (DES, 2016). However the concern to be noted in the context is that, as per the OECD report on water hotspots, the "rice baskets of the world", China and India, also emerge as the top countries facing future water risks. North eastern China producing a share of 10 per cent rice production in the country and north western India comprising of Punjab and Haryana and contributing to almost 15 per cent production of rice in the country, has been globally identified as the water stress hot spots (OECD, 2017). Thus in the attempt to ensure domestic as well as global food security, in addition to their attempts to increase land productivity, researchers and policy makers need to focus upon understanding and undertaking measures for improving the water productivity status of the rice growing regions of the country as well as the world.

As per the OECD report on water hotspots, the "rice baskets of the world", China and India, also emerge as the top countries facing future water risks.

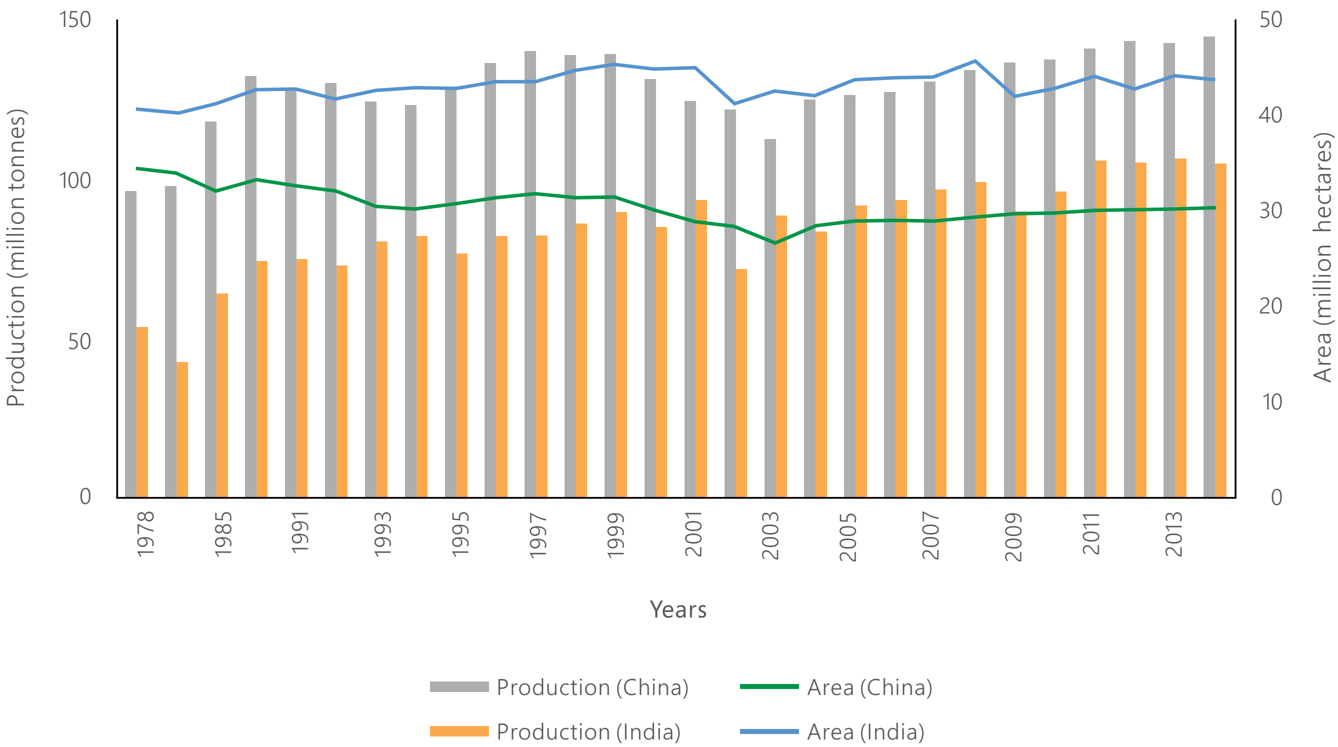
3.2 Rice in the world

Globally, rice is produced in 118 countries across the world, however, the top 10 countries (nine out of them being Asian countries) alone account for almost 85 per cent of global rice production (Table 3). Asia alone accounts for more than 90 percent of the world paddy production and consumption (FAO, 2014).

Table 3
Top paddy producers in the world (2014)

Country	Area (million ha)	Production (million tonnes)	Yield (tonne/ha)	Production share (per cent)
World	163.0	741	4.6	100.0
China	30.3	207	6.8	27.9
India	43.9	157	3.6	21.2
Indonesia	13.8	70.8	5.1	9.6
Bangladesh	11.3	52.3	4.6	7.1
Viet Nam	7.8	45.0	5.8	6.1
Thailand	10.7	32.6	3.0	4.4
Myanmar	6.8	26.4	3.9	3.6
Philippines	4.7	19.0	4.0	2.6
Brazil	2.3	12.2	5.2	1.6
Japan	1.6	10.5	6.7	1.4

Source: India – Directorate of Economics and Statistics (DES); China – NBS (National Bureau of Statistics of China)



Source: India - Directorate of Economics and Statistics (DES); China - NBS (National Bureau of Statistics of China)

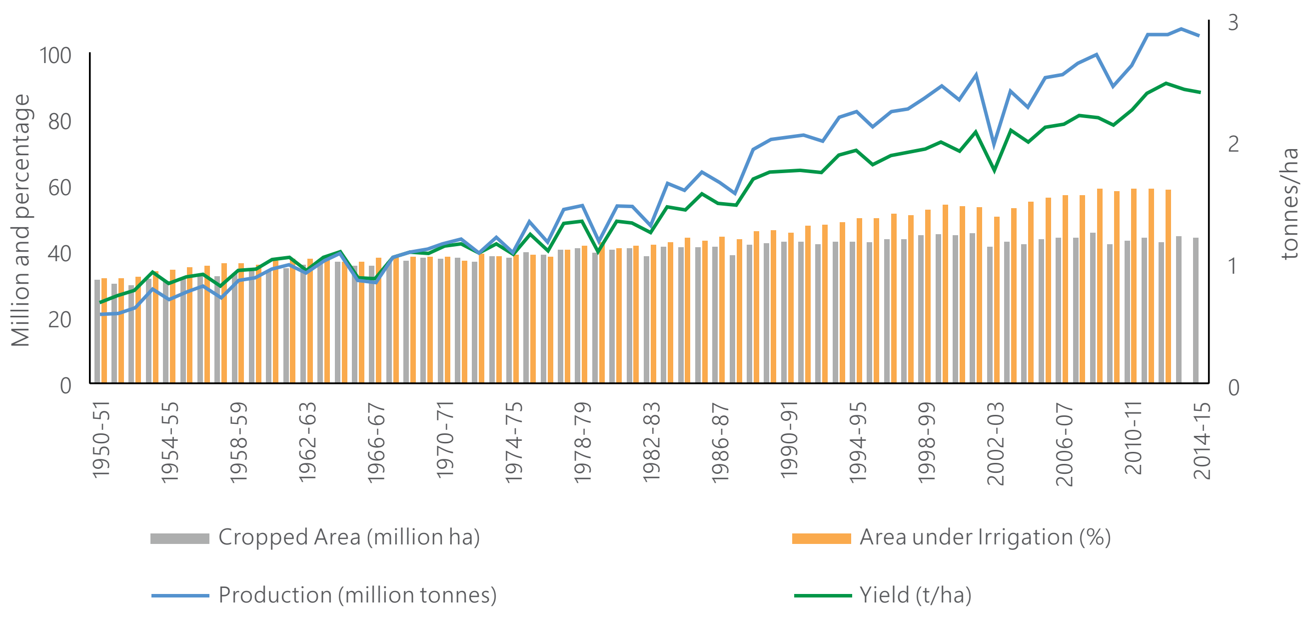
Figure 3. Comparison of rice cultivation area and production trends in India and China

India has the largest area under rice cultivation in the world with a global share of almost 27 per cent. In terms of production, China stands first followed by India with a share of almost 28 per cent and 21 per cent, respectively in the world production. Despite being the top rice producer globally, India conspicuously stands at 62nd position in terms of productivity. The productivity of paddy in India is about 3.6t/ha which is even below the world average of 4.5t/ha and is about half that of China's productivity of 6.8t/ha (**Figure 3**). The commendable point about China's paddy productivity is that, over the years it has brought down its area under paddy cultivation but maintained its production levels, thereby accelerating productivity and at the same time saving the precious water and land resources for other competing uses in agriculture and other sectors. Almost all the paddy fields (~ 99 per cent) in China receive assured irrigation, while in India the irrigation cover for rice crop is only around 60 per cent. Hence for achieving domestic as well as global food security in a sustainable manner, thrust should be laid upon not only increasing the land productivity of rice but also its water productivity.

3.3 Rice in India

3.3.1 Rice area in India

Rice is the most important cereal food crop of India and is cultivated under widely varying conditions of latitudes and altitudes, and climate and seasons covering most states. In 2010-11 the gross cropped area in India was 197.6 million ha, out of which rice was cultivated on 42.7 million ha which translates to more than one-fifth of the total area. Map 1 below shows the rice growing districts in India which are more than 550 in number out of the total 640 districts in the country. This makes rice the single largest crop grown in India.



Source: (DES, 2016)

Figure 4. Growth in cropped area and area under irrigation, production and yield of rice in India during 1950-2015

In India, the production and productivity trends of rice, since the early seventies (era of Green revolution), closely mirror the growth of area under irrigation. As large regions of the crop still depend upon monsoon rains to meet the crop water needs, the years of drought (as 2001) or deficient rainfall (as 2009) produce large deficits in productivity and production (Figure 4).

Some states in India predominantly produce rice and have large percentage of their agricultural land under it. To narrow down focus of the study to such states, area under rice for each state and their share in India's total cropped area under rice was calculated. The states that at least contributed one percent of rice area to India's total rice area were considered. There were 16 states that met this criterion. These states cover 93 percent of the total rice area and 96 percent of rice production in India and because of this large share, they are considered as our universe for the purpose of this study (Table 4). A distinction was made among the states based on the season in which they cultivate rice. List of the major states along with the seasonal variation is given below. Here *kharif* and autumn are considered under **Season-1** whereas *rabi*, summer/*boro*, and winter are considered under **Season-2**. About 61 per cent of rice is cultivated in the main kharif season (Season 1) and 39 percent in winter and summer season (Season 2).

Table 4

States with at least one per cent of India's rice cultivation area (lakh ha) and their respective dominant rice growing seasons

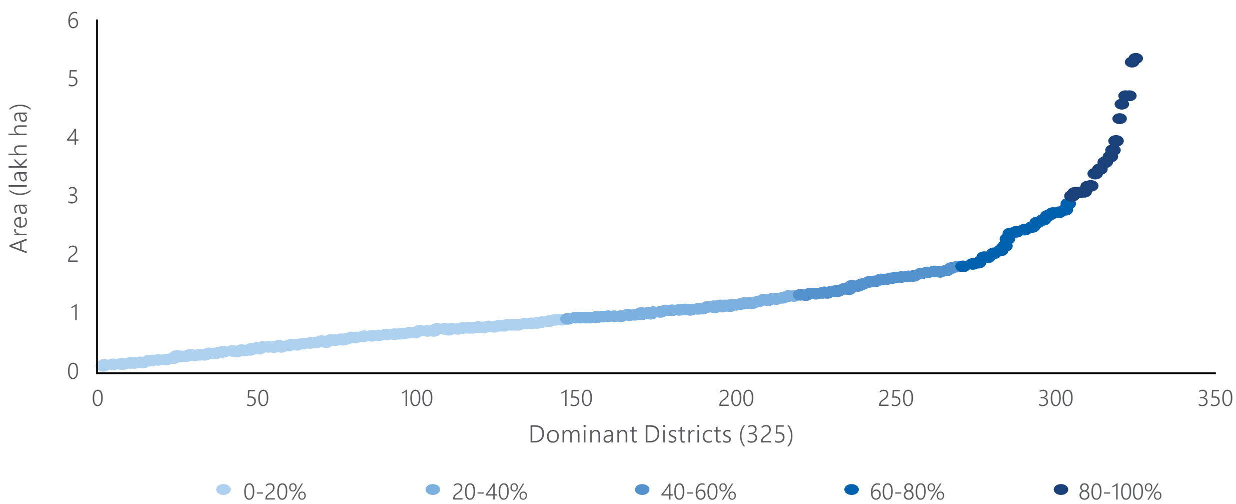
Season-1 Dominant area (lakh ha)			
States	Total rice area	Season 1 area	Season 2 area
Uttar Pradesh	55.3	55.1	0.2
Punjab	26.9	26.9	0.0
Andhra Pradesh	24.4	15.8	8.6
Tamil Nadu	17.9	17.9	0.0
Madhya Pradesh	15.1	15.1	0.0
Telangana	15.0	8.3	6.7
Karnataka	14.4	10.7	3.7
Maharashtra	14.1	14.1	0.0
Haryana	11.7	11.7	0.0
Gujarat	7.2	6.7	0.5

Season-2 Dominant area (lakh ha)			
States	Total rice area	Season 1 area	Season 2 area
West Bengal	53.9	19.9	34.0
Odisha	41.2	6.3	34.8
Bihar	28.4	5.0	23.4
Assam	23.7	3.0	20.8
Jharkhand	8.7	1.5	7.3
Total for India	357.9	218.0	140.0

The above data clearly indicates that the range of area under rice is very wide. State with the largest area under rice is Uttar Pradesh and has almost 8-times more area than the one with the least area, which is Gujarat. Such variation in area is mostly a function of physical area of the states, their geographic location, climate and other factors. This skew in area distribution also becomes clear when top (Uttar Pradesh, West Bengal, Odisha, Chhattisgarh, Bihar) and bottom five states (Karnataka, Maharashtra, Haryana, Jharkhand, Gujarat) are compared. The former group consists 55 percent of the total rice area while the latter group holds only 14 percent under them.

Map 1. Total rice cultivating states and districts in India—rice is the single largest crop in the country

Such contrast in area distribution is also observed at the district level. To sharpen the focus, the study considered such districts which contributed to 95 percent of the total cultivated area in the selected state and there were a total of 325 such districts. When these districts are equally divided in to 5 groups with each group contributing 20 percent of the area, the group with the largest districts only contain 21 districts. On the other hand, the bottom group which also contributes 20 percent of the area under rice but has lesser areas in each district contains 146 districts. The pattern for all the 5 groups can be seen in the graph below (Figure 5) while Map 2 shows spatial distribution and pattern of extent of rice cultivation area in dominant districts and states in India.



Note: Each cluster has 20 percent of the total rice cultivated area.

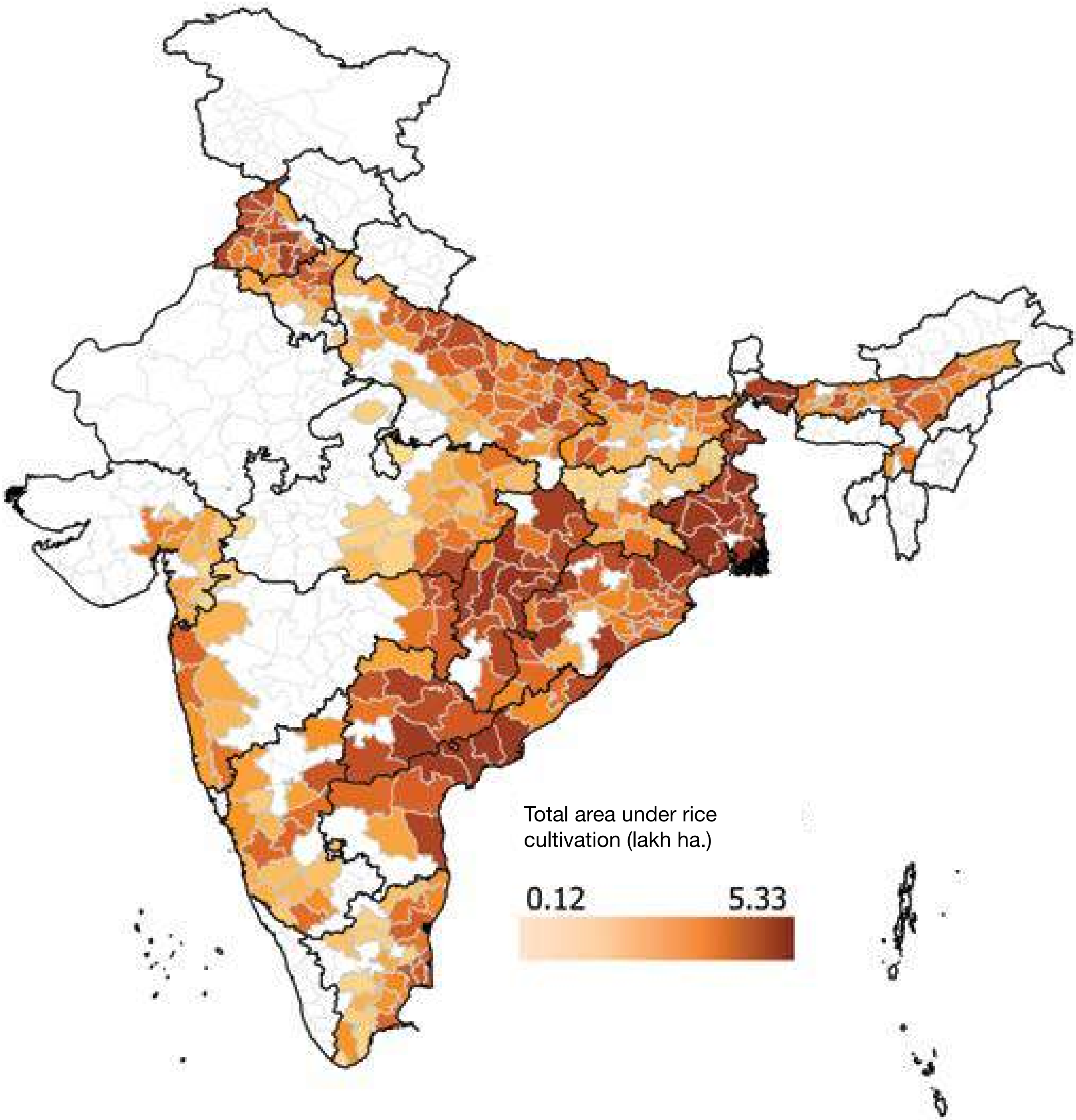
Figure 5. Variation in clustering of area-wise percentage of dominant rice growing districts

Clustering of the districts shows that 80 percent of the area under rice cultivation is limited to just 175 districts in the country and the future targeting of the rice development programs may primarily consider these districts.

3.3.2 Rice Production in India

Total production of rice in India for BE 2010-11 was close to 92.2 million tonnes[3]. The 16 dominant states selected for this study contributed 86.1 million tonnes, which comprised of above 93 percent of the total rice production. Some of the states such as Uttar Pradesh, West Bengal and Odisha with a proportionally larger area and states like Punjab and Andhra Pradesh with comparatively smaller area formed the top-5 rice producing states in India. Of the 86.1 million tonnes rice production, these five states alone contributed

[3] Based on the total of district level data for BE 2010-11. (Source: http://aps.dac.gov.in/APY/Public_Report1.aspx)



Map 2. Variation in extent and spatial distribution of rice cultivating area in dominant districts and states of India—Rice Map of India

a 58 percent share. Table **5** below lists in descending order the dominant states by their quantity of rice production in India.

Table 5

Rice production for dominant states in India

Rank	States	Production, lakh tonnes
1	West Bengal	130.53
2	Uttar Pradesh	116.43
3	Punjab	105.52
4	Andhra Pradesh	74.17
5	Odisha	71.98
6	Tamil Nadu	53.63
7	Chhattisgarh	52.82
8	Telangana	46.77

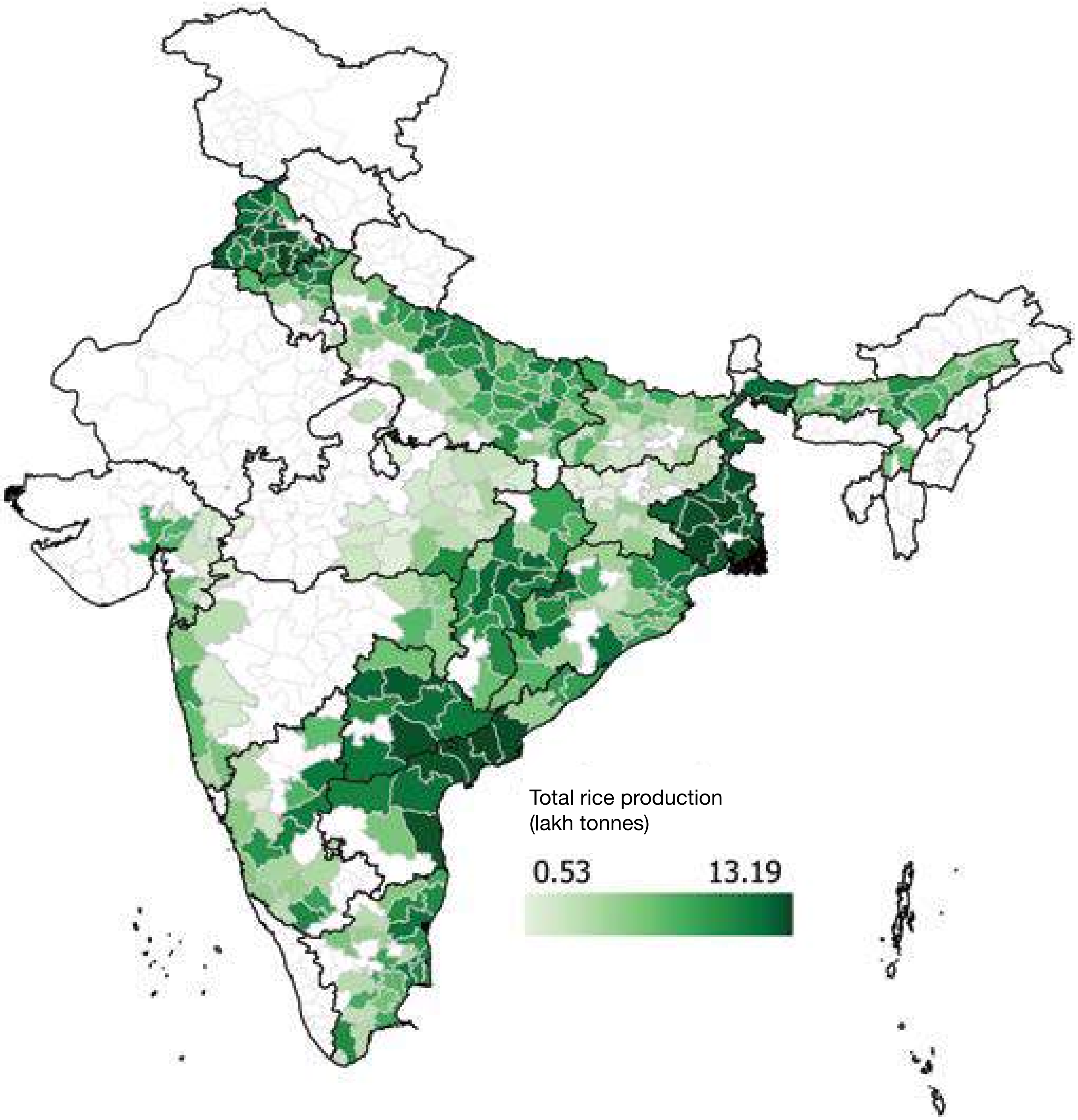
Rank	States	Production, lakh tonnes
9	Assam	44.59
10	Bihar	36.85
11	Karnataka	36.60
12	Haryana	34.17
13	Maharashtra	17.47
14	Madhya Pradesh	14.69
15	Gujarat	14.24
16	Jharkhand	10.50

The district level variation in rice production range is shown in Map 3. This variation can be more clearly represented by dividing the production range into five equal groups with each group contributing 20 percent to the total production. The top group comprising of 16 districts (top 5 per cent districts) belong to four states namely Andhra Pradesh, Punjab, Telangana and West Bengal *produce* 20 *per cent of all rice produced in the country*. Thus these districts truly hold key to our rice security and are the 'rice baskets' of India. These top districts, as shown in Map 4, alone contribute 20 percent to total rice production while occupy just 14 percent of the area. The bottom group holds 54 percent of districts (174) and also contribute the same amount as the top group.

3.3.3 Yield of Rice in India

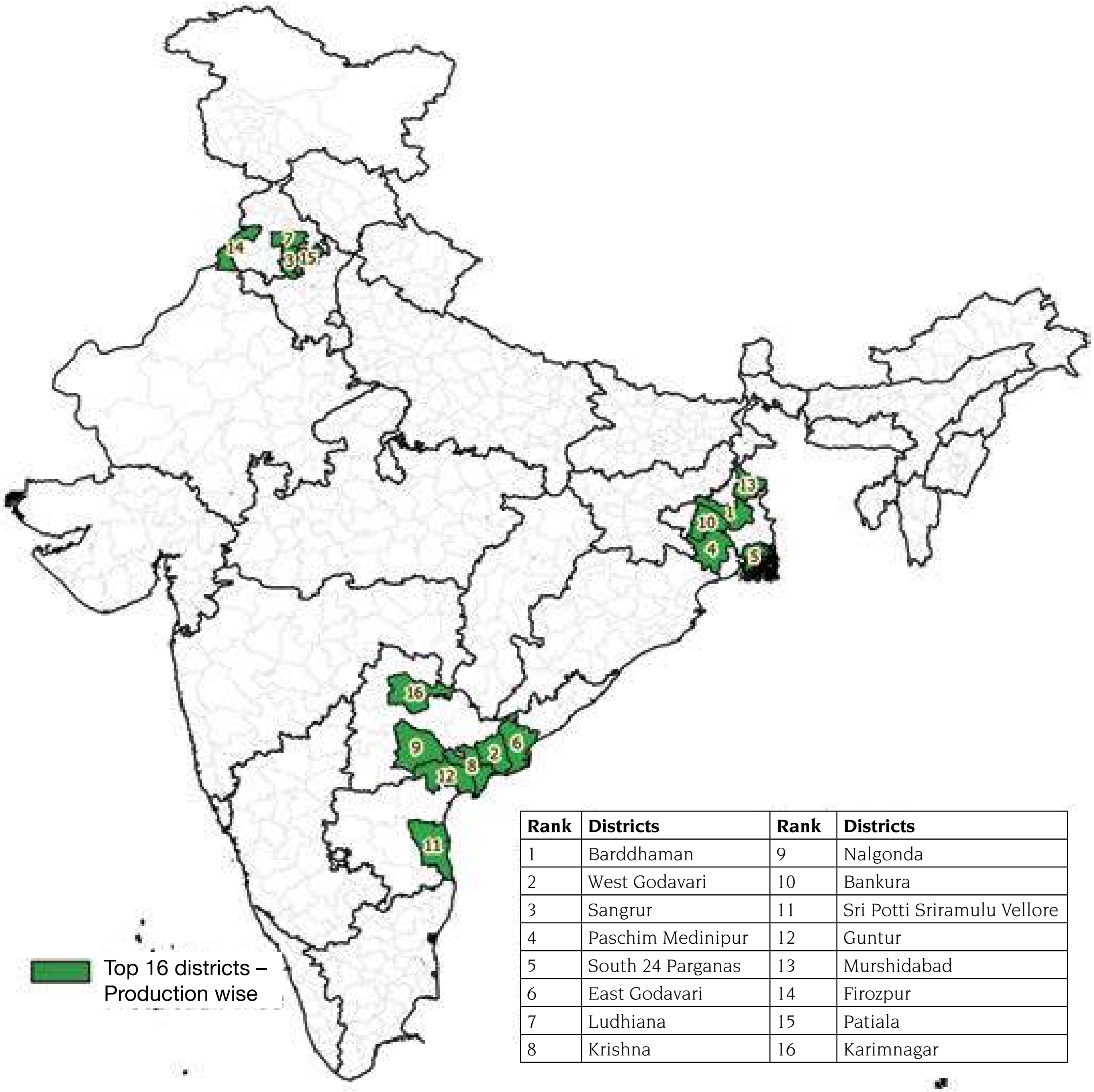
Yield of a crop is an important parameter as it integrates the outcome of given resources (land, climate, rainfall), inputs (seed, fertiliser, irrigation, disease and pest control) and human ingenuity (labour, capital, technology, knowledge, innovation) (Ellur et al., 2013). Improvement in yield is the constant endeavour of all stakeholders as this will help in fighting hunger and ensuring food security. Data analysis in this study suggests that the average rice yield in India is around 3.6t/ ha (compared to global average of 4.5t/ha) but contains in itself a wide range of yield variation.

The highest rice yield of above 5 t/ha was observed in Dindigul, Tamil Nadu whereas the lowest value of less than 0.5 t/ha was observed in Tikamgarh, Madhya Pradesh and number of other districts. In general, average rice yields in Season 2 which is fully irrigated, is higher than Season 1 yields. The distribution of high yielding states indicates that northern states of Punjab and Haryana and the southern states of Tamil Nadu, Telangana and Andhra Pradesh top the list. States like Chhattisgarh, Bihar, Jharkhand, and Madhya Pradesh have the lowest yields and are also economic laggards indicating a strong nexus between rice productivity and economic ranking of the state.



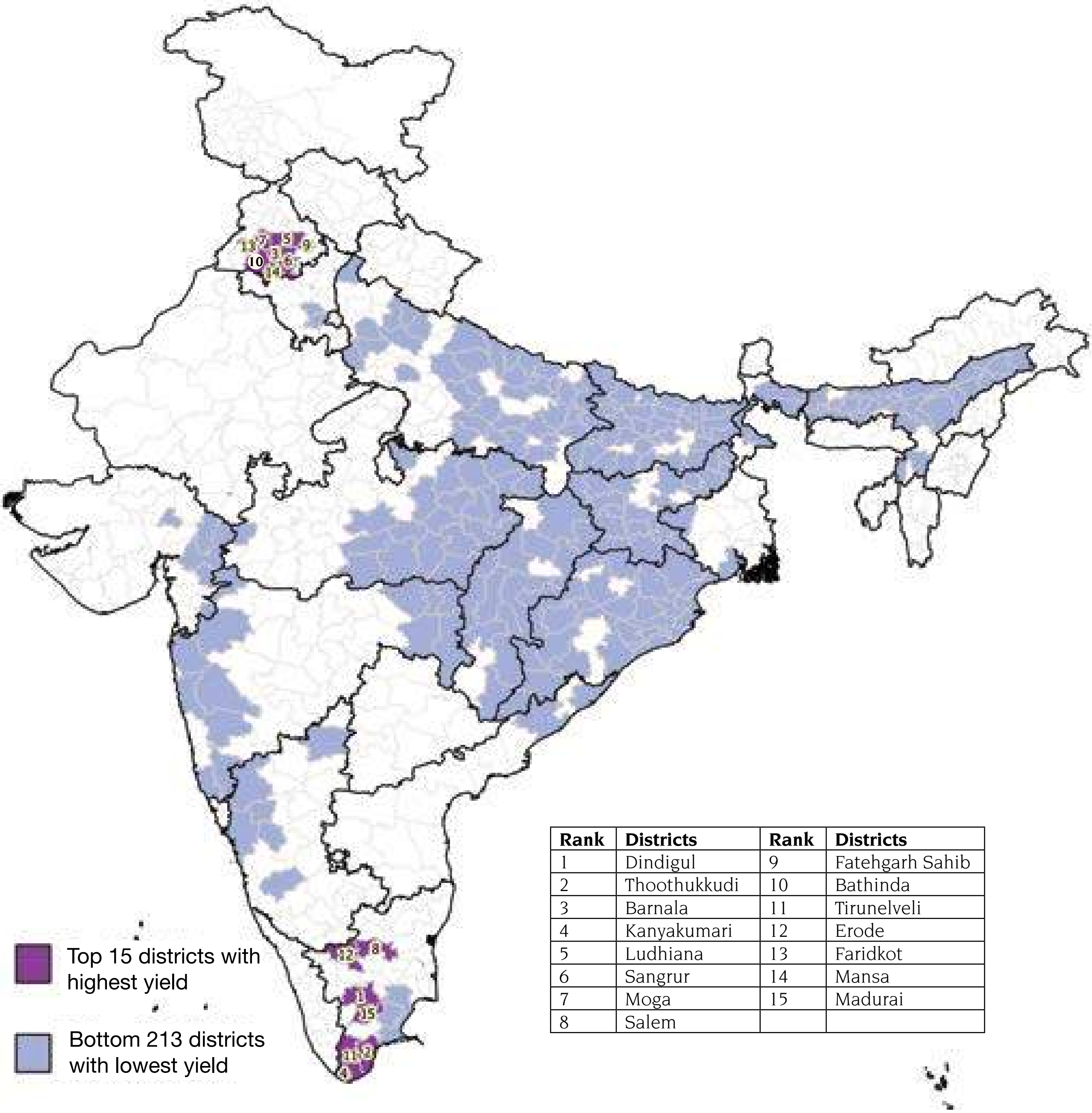
Note the clustering in the states of Punjab, West Bengal, Telangana and Andhra Pradesh

Map 3. Variation in rice production in the dominant rice districts of India



Rank	Districts	Rank	Districts
1	Barddhaman	9	Nalgonda
2	West Godavari	10	Bankura
3	Sangrur	11	Sri Potti Sriramulu Vellore
4	Paschim Medinipur	12	Guntur
5	South 24 Parganas	13	Murshidabad
6	East Godavari	14	Firozpur
7	Ludhiana	15	Patiala
8	Krishna	16	Karimnagar

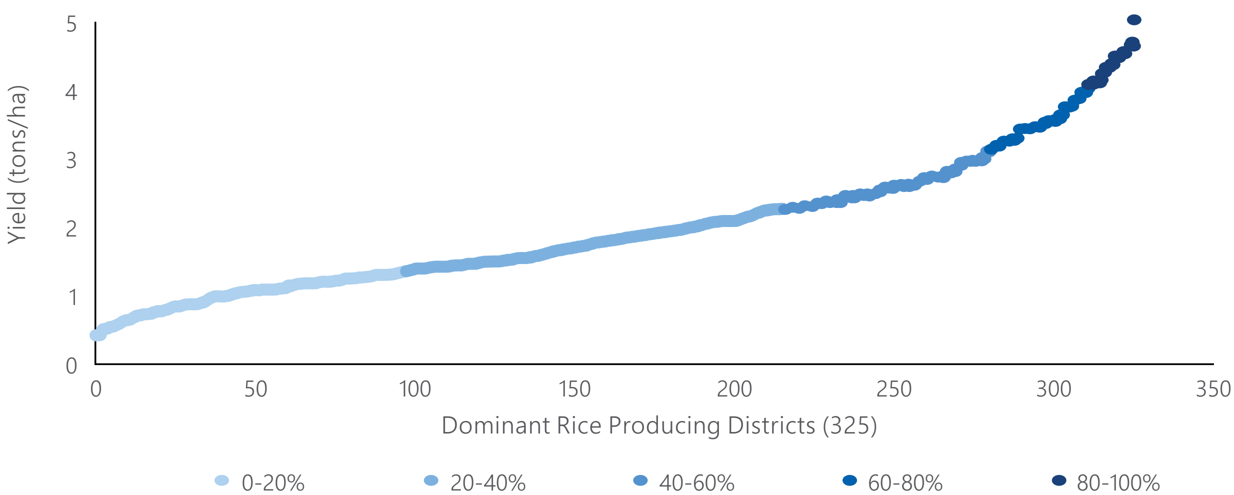
Map 4. Top 16 rice producing districts in India—'Rice Basket'—contributing 20 percent of the total rice production in India



Rank	Districts	Rank	Districts
1	Dindigul	9	Fatehgarh Sahib
2	Thoothukkudi	10	Bathinda
3	Barnala	11	Tirunelveli
4	Kanyakumari	12	Erode
5	Ludhiana	13	Faridkot
6	Sangrur	14	Mansa
7	Moga	15	Madurai
8	Salem		

Map 5. The tiny 'bright spots' (15 districts) and vast 'hot spots' (213 districts) of rice productivity in India (Punjab alone has eight top high yielding districts)

District level analysis of rice yield highlights even more yield variation across different regions in the country. Dividing yield range into 5 equal groups for the dominant districts shows that bottom 40 percent of the yield range (0.43 t/ha to 2.27 t/ha) contains more than 210 districts (out of 325), that is, 65 per cent of the districts (see Map 5). This suggests that even for the districts where land under rice cultivation is high, yield is very low which pulls down the national average. Besides several other factors, these 210 districts have below average coverage under assured irrigation. Top 20 percent of the yield range group has a total of just 15 districts with an average yield of 4.43 t/ha comparable to the average global yield (Figure 6). These top yielding districts are located in Punjab and Tamil Nadu. The variation across the groups can be seen in the graph below (Figure 6). Map 5 shows the 15 districts with highest yield along with the 213 districts with low yield.



Note: 200 rice producing districts (61.5 percent) have an average yield of less than 2 t/ha.

Figure 6. Clustering of the variation in rice yield for the dominant rice producing districts in India

3.4 Water use in rice

Rice is unique among the major food crops in its ability to grow in a wide range of hydrological situations, soil types and climates (McLean et al., 2002). Important agro-ecologies of rice include upland rice, rain fed lowland rice, irrigated lowland rice and flood-prone rice. It is also one of the largest water consumers in the world. However, ironically the major rice-producing countries of the world, China and India, are also the leading countries facing current and future water risks globally (OECD, 2017).

Chapagain and Hoekstra (2011) estimated that the global water footprint of rice production is 784 km^3/year[4]

[4] 1 km^3 = 1 Billion cubic metre (BCM) of water

with an average of 1325 m^3 /ton (0.755 kg/m^3) which is 48 per cent green (rainwater), 44 per cent blue (irrigation), and 8 per cent grey (waste water). There is an average additional 1025 m^3 /ton of percolation in rice production. The virtual water flows related to international trade was 31 km^3 /year. In India, hydro-thermal regime favourable for rice cultivation throughout the year, is available in the eastern, north-eastern and the coastal areas. But rice is now a principal crop also in the semi-arid north-western and central parts of the country. Kampann (2007) estimated that in India, for average rice production of 130.9 million tonnes during 1997-2001 the total water footprint was 373.1 BCM, which is about 39.3 per cent of the total water footprints of 949 BCM for the total crop production.

3.4.1 Irrigation requirement of rice

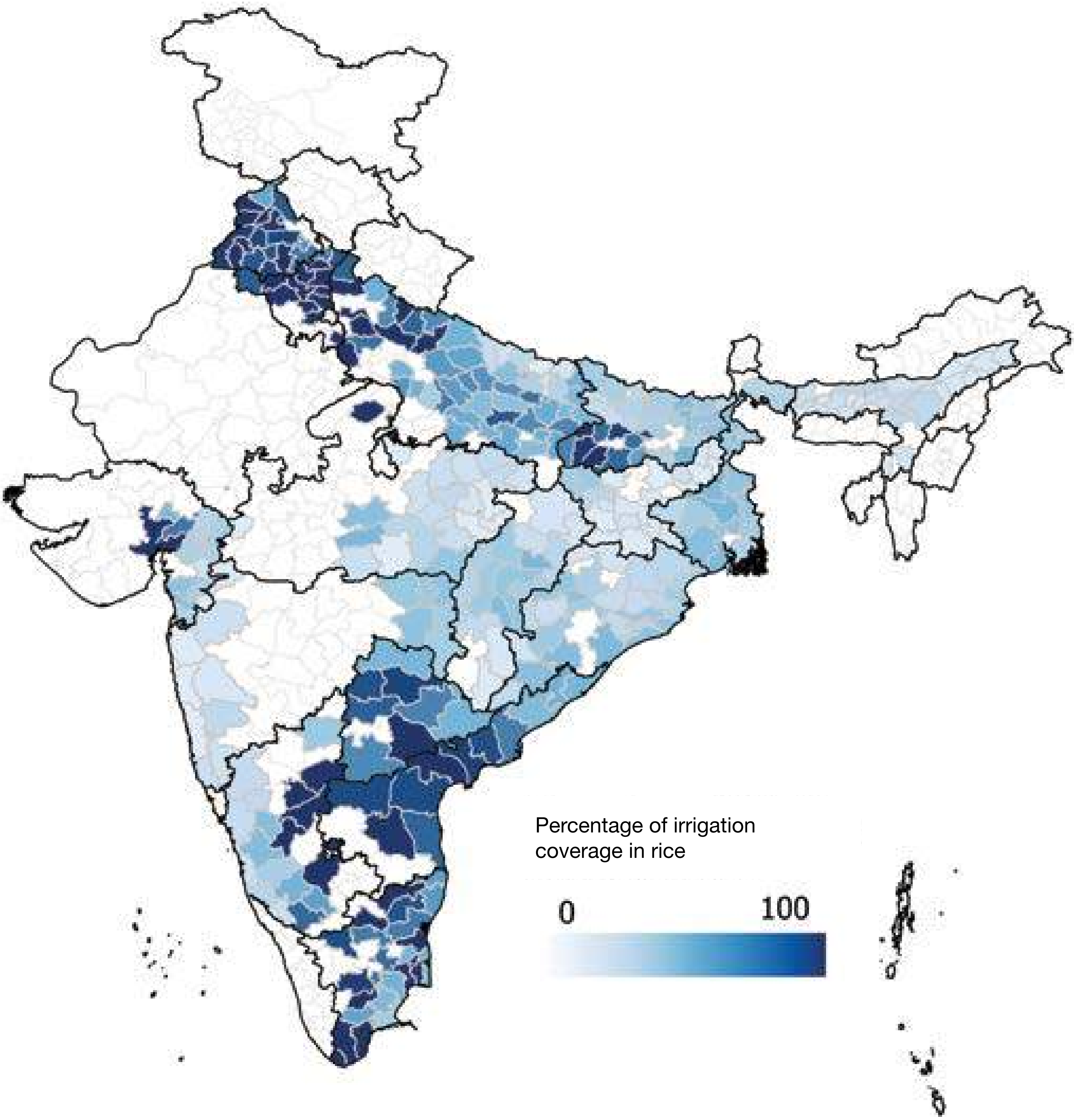
Rice cropped area under irrigation stands at 24.99 mha which is a little less than 60 per cent of total area under rice cultivation. Rice irrigation alone accounts for about 28 per cent of the total gross irrigated area[5] in the country. In almost all the public financed major and medium surface irrigation projects developed, water resource is largely appropriated by rice (and sugarcane). Similarly, a significant part of the energy subsidy provided to agriculture in agriculturally important states of India (Punjab, Haryana, Andhra Pradesh, Telangana, Tamil Nadu and others) is also used for irrigating the rice crop.

Rice irrigation alone accounts for about 28 per cent of the gross irrigated area in the country.

Out of the 325 districts in consideration in the study, 22 percent have more than 99 percent irrigated area. On the other hand there are 33 districts with less than 1 percent or almost nil irrigation i.e. they are fully dependent on rain. Moreover, 188 districts which constitute close to 58 percent of the total have Season 1 also irrigated in various proportions in addition to meeting complete irrigation requirements of Season 2. This is based on the assumption that Season 2 comprising of *rabi* is wholly dependent on irrigation as it is the non-rainy season. Map 6 shows the distribution of rice irrigated districts in India. States with some of the highest proportion of cropped area under irrigation (as an average of districts under irrigation) include Punjab and Haryana with almost cent percent, Tamil Nadu with 94 per cent and Andhra Pradesh with 95 per cent irrigation coverage under rice. Assam is the least irrigated state with a mere 5 per cent irrigation coverage. Uttar Pradesh enjoys close to 80 per cent irrigation in rice cultivation while West Bengal has half of the rice crop under irrigation, mainly during the

Assam is the least irrigated state with a mere 5 per cent irrigation coverage.

[5] 2010-11



Note the vast region of under- and un-irrigated rice in the eastern India, where a small irrigation shall produce large benefits. (Irrigated Rice Map of India)

Map 6. Variation of rice irrigation in districts of India non-rainy boro rice. These states of Uttar Pradesh, Punjab, West Bengal, Andhra Pradesh and Tamil Nadu which hold high levels of irrigation, together contribute more than proportionately to production as compared to their area under rice cultivation.

However, in several national and international studies on water hotspots, the high rice producing north western-region of India comprising, Punjab, Haryana and western Uttar Pradesh have been globally identified as the water risk hotspots thereby raising serious concerns regarding the medium-to-long term sustainability of irrigated rice production in India. This water issue will in turn affect the food security of India as the region contributes to above 50 per cent of the national stock of the staple rice in the country (OECD, 2017). Thus for achieving domestic as well as global food security in a sustainable manner, thrust should be laid upon not only on increasing the land productivity but also the water productivity of rice crop.

Though, information on production and productivity of rice at sub-national and national level are available, a good understanding of how efficiently (or inefficiently) the nation is using its precious water resources for providing water to the country's single largest water user is not available. The first logical step towards this goal shall be to map the water productivity of rice and then prioritise the technical and policy pathways for the improvement in its cropping pattern across the states.

As an attempt towards addressing this research gap, we have estimated the water productivity in rice across three dimensions, namely, physical water productivity, irrigation water productivity and economic water productivity as discussed in the methodology chapter. The following section presents the results for total consumptive water use by the rice crop, physical, and economic water productivity, and 'irrigation water productivity' and their interactions for the dominant rice cultivating districts and states in India.

3.4.2 Water use in rice

Sixty percent of rice in India is provided with irrigation and the remaining primarily depends on natural rainfall. Water intensive irrigation practices for rice result in the consumption of about one-third of total water required for agriculture in India. This study estimated the Total Consumptive Water Use (TCWU) of 221.2 km^3 (221 BCM) per year for rice production in India.

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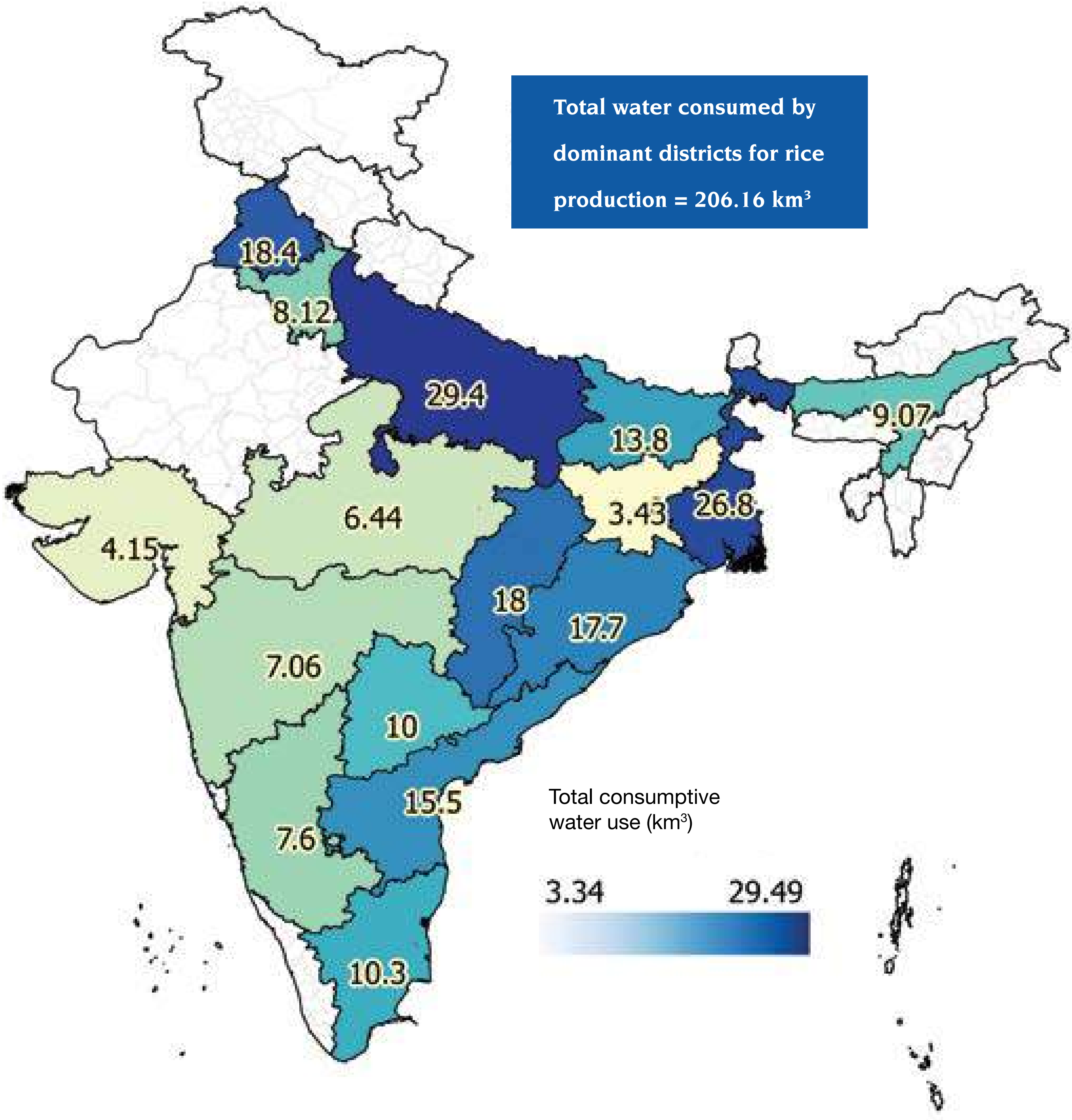


Map 7. Total consumptive water use during rice cultivation in major rice growing states of India—Rice Consumptive Water Use Map of India

More than 93 percent of this water is consumed in the dominant rice districts identified in this study. State-wise TCWU calculated as sum of all major rice growing districts in each state is given in Map 7 showing a range from 3.34 to 29.49 km^3 with darker shades representing higher TCWU.

Total consumption of water for rice is a function of total area, crop condition and the prevailing climate during rice cultivation. So, some of the states including Uttar Pradesh, West Bengal, Odisha, and Chhattisgarh that have large area under rice also consume most amount of water. The only anomaly here is Punjab where the absolute area under rice is less than many states emerge as the third highest in terms of water consumption for crop cultivation. Since the irrigation efficiency in India is relatively low, the TCWU is usually an underestimation of the water diverted to the fields in the actual field situation. Thus the irrigation water applied in field by the farmer is considered and IWP is evaluated and compared. The available surface water alone is insufficient to meet Punjab's total irrigation needs. This indicates that rice cultivation has been adopted through exploitation of ground water that has reached unsustainable levels. Even surface and groundwater together fall short of Punjab's total irrigation needs. On the other hand the state of Bihar has low water consumption indicating that the water needs of the crop are not fully met. For the states with less area under rice, the collinear relation to water consumption holds true. When the data is disaggregated at the district level and the water consumption range is divided into 5 equal groups, we find that close to 70 percent of the districts fall in the bottom 40 percent group. Low water consumption in large number of the districts indicates that water needs of the crop are not fully met during the entire crop growth season either due to inefficiencies of the canal irrigation system or the high cost of diesel operated irrigation water pumping in the eastern states (Kumar et al., 2008; Singh et al., 2008).

Since irrigation efficiency in India is relatively low, the TCWU is usually an underestimation of the water actually diverted to the fields.

3.4.3 Water Productivity of Rice

Water productivity for rice and its interaction with other production inputs like varieties, fertilisers, tillage and irrigation etc. has been extensively studied at the plot, field and farm scale (Ladha et al,. 2003; Jat et. al., 2009; Uphoff et al., 2011; Mahajan et al., 2012; Sharma et. al., 2015).Some studies have also attempted to estimate the water productivity at the irrigation command, and sub-basin level (Zwart and Bastiaanssen, 2004; Tuong et al., 2005; Kumar and Amarsinghe, 2009; Deelstra et al., 2016). Recently, the use of remote sensing and census data has been made to estimate the water productivity at higher levels of basin, or a large region (Bastiaanssen et al, 2003; Ahmad et al., 2009; Cai etal., 2011 ; Cai and Sharma, 2010). However, owing to the data and methodological challenges, only limited efforts have been made (Kampman; 2007; Chapgain and Hoekestra, 2011) to comprehensively study the land and water productivity of rice or for that matter any other crop at the sub-national and national level in India. Given the severe water scarcity in many parts of the country on one hand and low water use efficiency of about 40 to 60 percent in Indian agriculture (NWM, 2009), a comprehensive assessment of water productivity at the national level is needed to develop the appropriate pathways for its sustenance and improvement. Estimating physical, irrigation and economic water productivity for rice, thus becomes critical for agriculture, water and energy policies.

3.4.3.1 Physical Water Productivity (PWP)

The two components to estimate PWP include TCWU and total production. TCWU includes irrigated and rain water that is available for the crop growth. PWP measures rice output per unit of water consumed by the crop and its measurement unit is kilogram per cubic meter of water (kg/m^3). Based on this one can talk about extent of efficiency (or inefficiency) in water use and thus help in identifying the drivers of water stress in a region. However, value of PWP in itself is a function of water use and not a function of the source of water used and may not directly tell about over-exploitation of water. So data from PWP analysis may be used in conjunction with other hydrological, agricultural, irrigation water and energy use and other economic factors to arrive at wider policy implications (Molden and Oweis, 2007).While interpreting the PWP data it is also important to keep in mind that productivity is a function of soil and climatic conditions, crop and variety choices, irrigation infrastructure, fertilizer use, availability of energy, and several other factors which are assumed exogenous in this study.

The top three districts in the country with the highest PWP are Dhubri (0.90), Marigaon (0.79), and Kamrup (0.67) in Assam.

Physical water productivity for rice was calculated at the district level and then aggregated at the state and national level. The aggregate PWP results show that Punjab with 100 per cent assured irrigation and high yields has the highest physical water productivity as here on average 0.57 kg of rice can be grown with one cubic meter of water. However, this higher productivity in an otherwise water-scarce region has caused several hydrological and economic exigencies (Singh et al., 2009; Kalkat et al., 2006). But at the disaggregated district level, the top three districts with the highest PWP are from Assam with PWP level of 0.90 (Dhubri), 0.79 (Marigaon) and 0.67 (Kamrup) which far exceeds the average of 0.36 for the dominant rice districts. This clearly indicates that hydro-ecology of Assam and similar other regions is the natural habitat and most suitable for high water productivity of rice.

For further understanding of this aspect; major rice growing districts were divided into five groups based on PWP by dividing the range into five groups of equal size. The top group contains few districts from Assam, as other districts have lower yield possibly due to flooding and lower use of inputs, thus contributing smaller share in the total production. The second highest group has 20 districts which are mostly from Punjab and West Bengal. This group also has the highest average yield. This translates into 6 percent of total districts with high PWP contributing 14 percent of total production. Some of the top districts with the highest PWP can be observed in **Map 8** below.

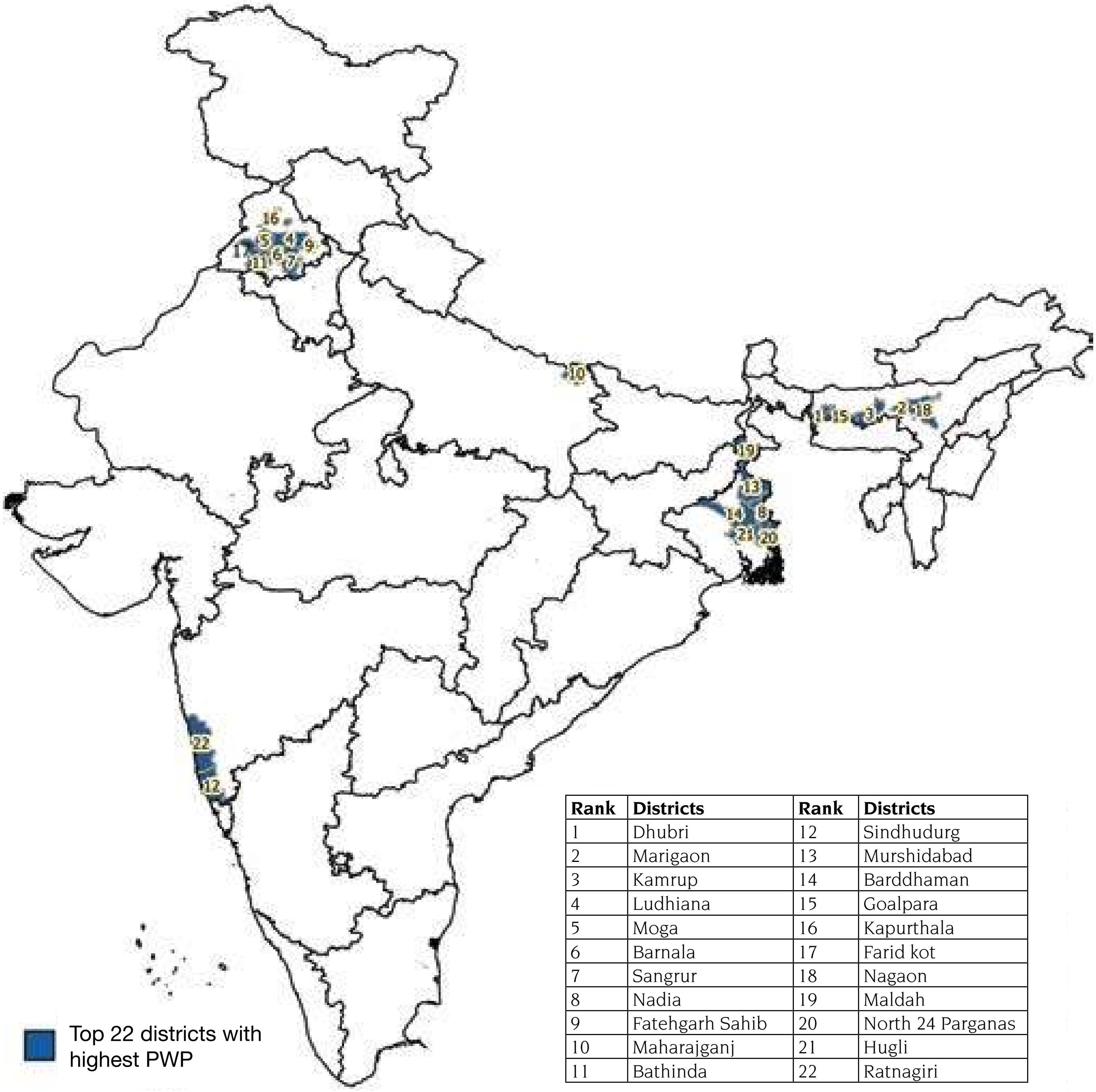
Further analysis revealed that vast majority of 214 rice growing districts occupying 55 percent of the rice cropped area have a PWP below the average of 0.36 and contribute only about 44 per cent to total production. Many of these districts are located in eastern Uttar Pradesh, Bihar, Madhya Pradesh, Tamil Nadu, Karnataka, Jharkhand and Odisha. National rice development efforts should be mainly targeted to these districts. Remaining 111 districts have PWP higher than average of 0.36 and these districts occupy 45 per cent of the area and contribute 56 per cent to total production. These 111 districts are geographically concentrated in Assam, Punjab, western Uttar Pradesh, West Bengal, Andhra Pradesh and Odisha among others. Since within the states, variation are very large particularly in Uttar Pradesh and Odisha, policies and practices have to be carefully implemented and executed at the district levels.

Table 6

Physical water productivity of rice (kg/m^3) for dominant rice growing states in India

Rank	States	PWP	Rank	States	PWP
1	Punjab	0.57	9	Maharashtra	0.33
2	West Bengal	0.52	10	Jharkhand	0.32
3	Assam	0.51	11	Chhattisgarh	0.30
4	Telangana	0.46	12	Tamil Nadu	0.30
5	Andhra Pradesh	0.44	13	Gujarat	0.29
6	Haryana	0.40	14	Bihar	0.28
7	Uttar Pradesh	0.37	15	Madhya Pradesh	0.25
8	Odisha	0.37	16	Karnataka	0.24

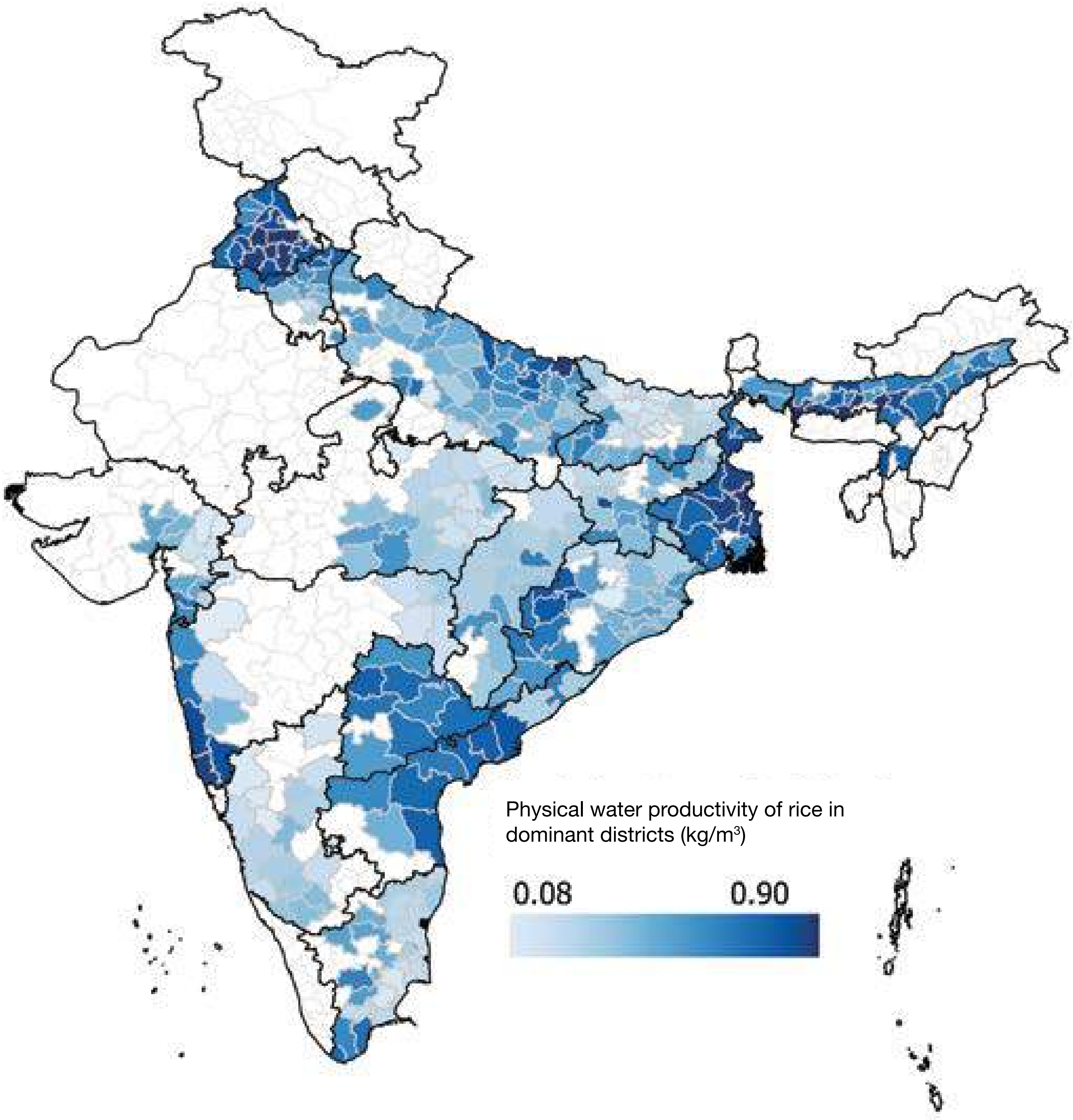
As noticed in the table above (Table 6), the average PWP values for the top states are almost twice as much as the bottom ones indicating a considerable scope for improvement of the water productivity. The table is followed by Map 9 that shows the PWP values at the district level, where one can observe the variation in water productivity (in greater detail) across space. Higher water productivity is generally observed in the districts which have greater control and reliability of the water supply or through use of groundwater through affordable energy sources.



Rank	Districts	Rank	Districts
1	Dhubri	12	Sindhudurg
2	Marigaon	13	Murshidabad
3	Kamrup	14	Barddhaman
4	Ludhiana	15	Goalpara
5	Moga	16	Kapurthala
6	Barnala	17	Farid kot
7	Sangrur	18	Nagaon
8	Nadia	19	Maldah
9	Fatehgarh Sahib	20	North 24 Parganas
10	Maharajganj	21	Hugli
11	Bathinda	22	Ratnagiri

Note: These 22 districts together form 40 per cent of dominant districts with high PWP

Map 8. Top 22 districts with highest physical water productivity for rice in India



Map 9. Variation in district level physical water productivity for rice in India—Rice Water Productivity Map of India

3.4.3.2 Irrigation Water Productivity: Productivity of Applied Irrigation Water to Rice

Rice crop is a natural habitat of wetland ecosystems and thrives under well-drained high rainfall conditions. As monsoon rains are inherently uncertain, erratic and variable by nature, this need to be supplemented by assured irrigation during dry spells, monsoon breaks or deficient rainy seasons. Since the advent of green revolution and introduction of high yielding dwarf rice varieties; the cultivation of rice has also spread to non-traditional areas of Punjab, Haryana, western Uttar Pradesh, and Madhya Pradesh. These areas now totally depend upon developed surface and groundwater resources and almost 100 per cent of the rice crop is irrigated. At the national level, average yield of rice under irrigated conditions is more than twice the average yield levels under rain fed conditions.

Table 7

Variation in applied irrigation water, average irrigated yields, irrigation water productivity of rice and water resource availability conditions across major rice growing states of India

States	Average yield of irrigated areas, kg/ha	Average farm applied irrigation water@, cm	Applied Irrigation Water Productivity (kg/m^3)	Water resource availability condition
Maharashtra	1672	100.0	0.17	Highly stressed
Haryana	2898	132.5	0.22	Highly stressed
Punjab	4010	180.0	0.22	Highly stressed
West Bengal	2827	117.6*	0.24	Safe#
Madhya Pradesh	1717	67.5	0.25	Stressed
Tamil Nadu	3175	110.0	0.29	Stressed
Telanagna	3300	110.0	0.30	Stressed
Andhra Pradesh	3084	100.0	0.31	Safe in coastal areas
Gujarat	2425	73.0	0.33	Stressed
Odisha	2126	60.0	0.35	Safe
Uttar Pradesh	3000	86.6**	0.35	Safe
Karnataka	3193	88.5	0.36	Stressed
Assam	1886	50.0	0.38	Abundant
Bihar	1936	40.0	0.48	Safe
Chhattisgarh	2050	30.0	0.68	Safe
Jharkhand	3000	40.0	0.75	Safe

@ Based on large farmer surveys, state based Rice Knowledge Management Portal, and various reports of ICAR-AICRP on Water Management. # Some districts in West Bengal are affected by arsenic (As) in groundwater.

* In West Bengal during Kharif season the irrigation water requirement for rice is lesser and may go down to even 71.5 cm (source: Kharif price policy 2013-14, CACP) owing to abundant water availability through rainfall. Hence during the Kharif season the irrigation water productivity in West Bengal can up to 0.40 kg/m^3, being efficient like the other eastern states of Assam and Bihar.

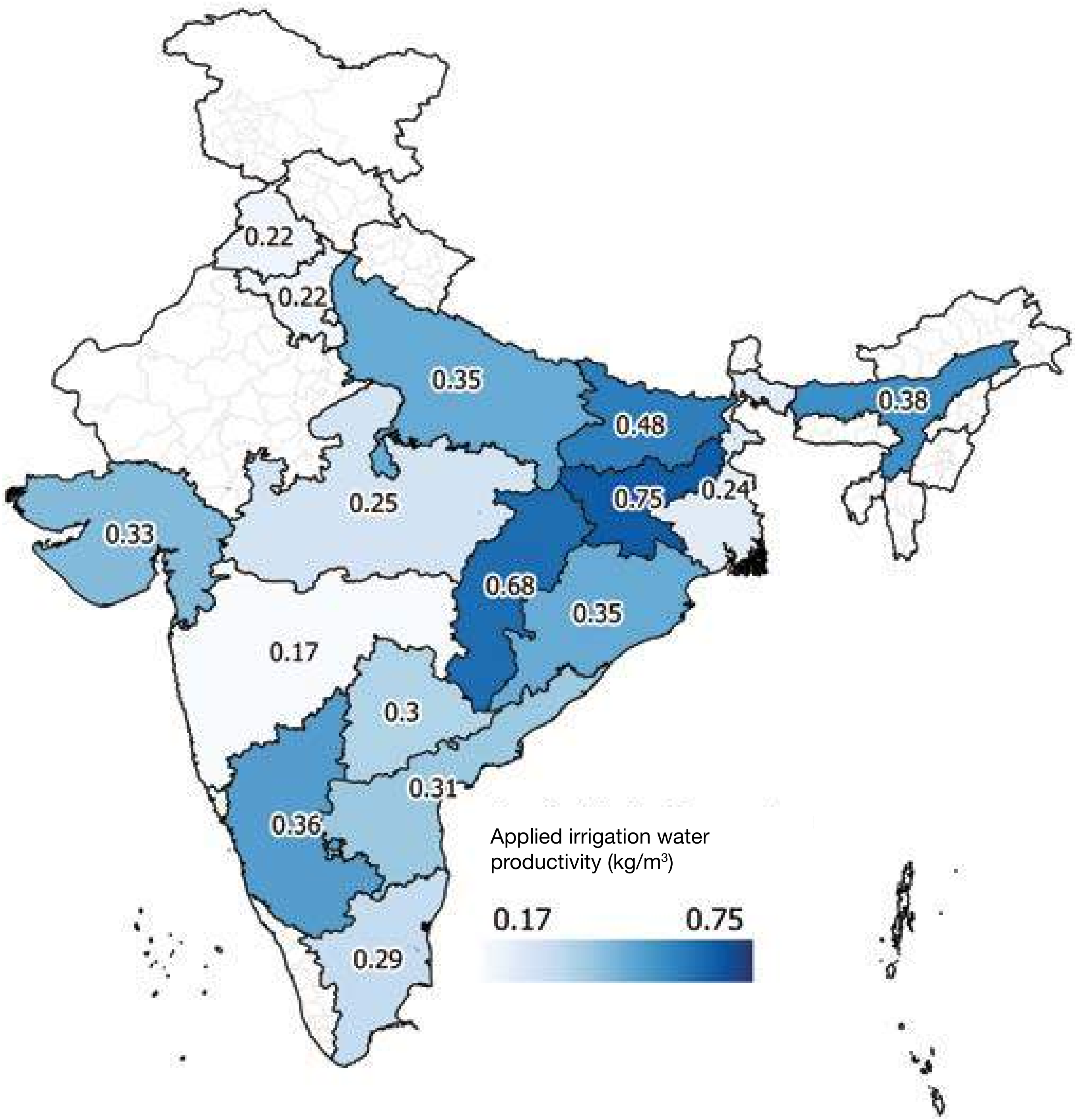
** For Uttar Pradesh state the irrigation water applied in paddy has been taken as weighted average of irrigation water applied in Eastern, Central and Western regions respectively, (using area under rice as the weights). In comparatively water abundant Eastern UP the lower level of irrigation water applied is taken = 38cm, while for Central and Western UP, the upper limit of irrigation water applied = 110 cm (Source: Kharif price policy reports 2013-14, CACP) is used.

This study made an attempt to understand the water productivity of each unit of applied irrigation water for cultivation of rice under major rice growing states representing varying rice agro-ecologies (Table 7).Depending upon the seasonal availability and economic accessibility farmers apply irrigation water varying from a low of just 30 cm in Chhattisgarh to as high as 132.5 cm in Haryana and 180 cm in Punjab. Generally, the areas with hot summers and lower rainfall conditions facing 'highly stressed' and 'stressed' water conditions need to apply higher amounts of irrigation water than the relatively 'safe' and 'abundant' water regions in the east and coastal districts. The only exception is West Bengal where about 63 per cent of the irrigated rice is cultivated during the non-rainy winter/ *boro* season. However for the Kharif grown rice crop in West Bengal, the irrigation water requirement is around 71.5 cm, raising the irrigation water productivity to 0.39 kg/m^3, which is on par with other eastern states like Assam and Bihar. Lower values of irrigation water productivity was recorded in water stressed states of Maharashtra, Haryana, Punjab and higher values were observed in water abundant states like Jharkhand and Chhattisgarh.

In the low irrigation productivity states each additional unit of applied irrigation water produced much smaller productivity benefits and as such further aggravated the water stress conditions. These values are quite different compared to physical water productivity, which only considers consumptive water use rather than manmade irrigation water. The contrast comes through more prominently when these figures are spatially presented (Map 10). The map shows that eastern parts of India have much higher irrigation water productivity. In other words, yield per unit of applied irrigation water is higher in states that should be naturally growing rice as compared to dry states like Punjab and Haryana where the crop is grown only through irrigation. Cultivation of irrigated rice in the dry Maharashtra needs to be further discouraged as it neither has yield advantage nor the surplus water to provide irrigation (except in the small Konkan belt).

Eastern states of India have much higher IWP. In other words, yield per unit of applied irrigation water is higher in the water abundant states that should be naturally growing rice as compared dry states like Punjab and Haryana where cultivation of rice is mainly supported by irrigation facilities.

The irrigation-water productivity and physical water productivity values are plotted along with percentage area under irrigation in each state, more interesting findings are observed (Figure 7).The states are arranged in descending order of irrigation water productivity. Jharkhand with mere three per cent irrigation level has the highest irrigation water productivity followed by Chhattisgarh with 32 per cent rice area irrigated.



Note the great advantage of applied irrigation water in the states of Bihar, Jharkhand, Chhattisgarh and Assam (Applied Irrigation Water Productivity of Rice in India)

Map 10. Variation in applied irrigation water productivity in different states of India—Rice Irrigation Water Productivity Map of India

Bihar with irrigation water productivity of 0.48kg /m³ and having 54 per cent irrigated area and Assam with an IWP of 0.38 kg/m³ and 6 per cent irrigated area closely follow the list. All these states have small but critical irrigation water requirements. Increasing area under irrigation and augmenting and efficiently using the available irrigation water shall help to substantially improve rice productivity in these regions.

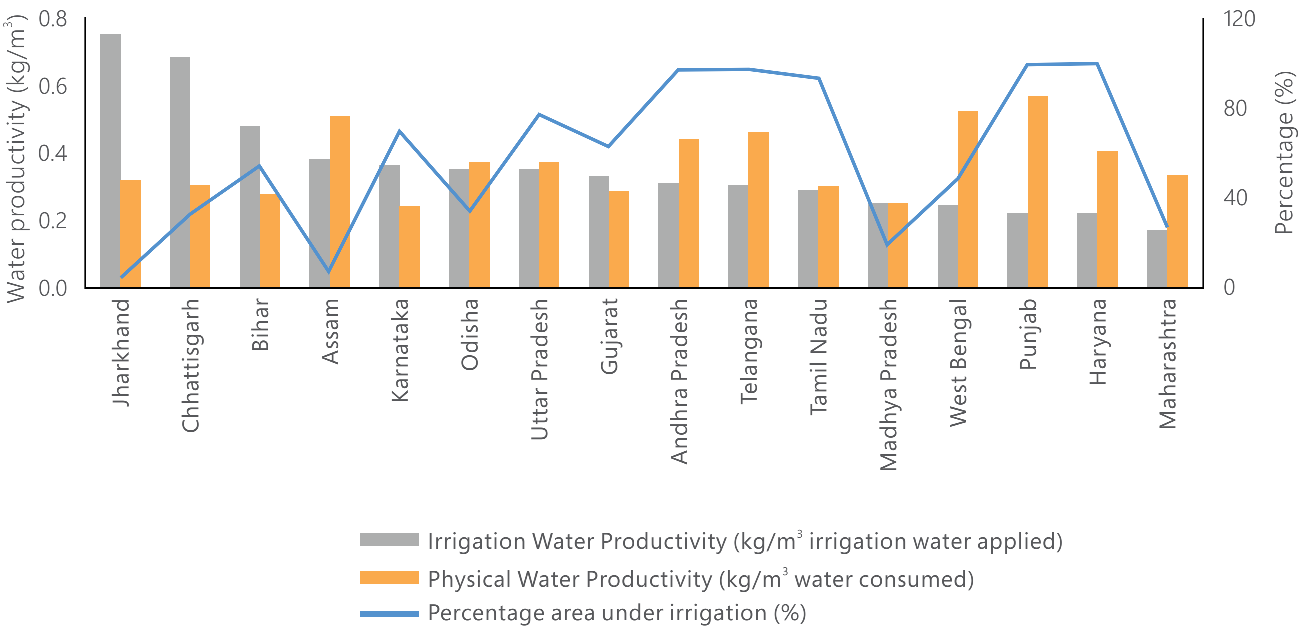


Figure 7. Applied irrigation water productivity and proportion of rice irrigated area in different states of India

On the other hand, Punjab and Haryana with almost 100 percent assured irrigation for paddy have one of the lowest irrigation-water productivity at 0.22 kg/m³ and are thus responsible for continuous and fast depletion of the groundwater resources through free or highly subsidised farm energy. The worst irrigation water productivity is seen in Maharashtra at 0.17kg/m³ as the irrigated rice districts have neither the yield advantage, as obtained in Punjab and Haryana, nor sufficient water to meet the high water requirements of paddy as only 26 per cent of the rice area is irrigated. To summarize these numbers, one can say that states with higher irrigation-water productivity have yet achieved only lower irrigation levels (due to regionally skewed policies for agricultural development in India) while states with lower water productivity have achieved very high irrigation levels (with the exception of Maharashtra). As seen in the map, most of these states that record higher irrigation-water productivity and have lower irrigation levels are located in the eastern belt, and receive higher rainfall as compared to the north-west region of Punjab and Haryana. Given their agro-climatic conditions, crop cultivation requires less man-made irrigation and ample water availability makes rice cultivation suitable in the eastern belt. Thus, the crop output per irrigation water applied is much higher in states of Bihar, Odisha, West Bengal, Assam, Chhattisgarh, and Jharkhand as compared to states of Punjab, Haryana, Tamil Nadu, Andhra Pradesh and Telangana. This means states like Punjab and Haryana, which require more irrigation water input to produce unit output of paddy, are less suited for rice production

Imperfect water pricing policies, skewed procurement policies, inadequate electricity supply and the disruptive input subsidies cause serious mismatch between the hydrological suitability and rice cropping pattern in India.

The EWP-irrigation water is much higher for Chhattisgarh (Rs 11.66/ m^3) and Jharkhand (Rs 9.01/m^3) indicating that any investment made in even small irrigation systems in these states is likely to produce large economic benefits.

as compared to the eastern belt. In order to meet the high water needs of the crop in Punjab and Haryana, receiving relatively lesser amount of rainfall, farmers have been over-exploiting the ground water reserve over the years. This also has serious economic implications both for the individual farmers due to dwindling profits and for the state which is facing bankruptcy due to humungous farm power subsidies.

Existing imperfect water pricing policies, skewed procurement policies, inadequate electricity supply and the disruptive input subsidies cause serious mismatch between the hydrological suitability and rice cropping pattern in India.

3.4.3.3 Economic Water Productivity (EWP)

To better understand and compare the water productivity across the states, we have calculated the economic water productivity of paddy across the states. The economic water productivity gives a measure of the monetary value created per cubic meter of water consumed or applied in the form of irrigation.

We have calculated the EWP of paddy with respect to the TCWU as well as irrigation water applied. The FHP is available only for paddy and not for rice across the states and hence the PWP and IWP values calculated for rice were converted for paddy and EWP has been calculated for paddy. As expected, the EWP-irrigation water is much higher for the states of Chhattisgarh (Rs 11.66/m^3), and Jharkhand (Rs 9.01/m^3) indicating that any investments made in provisioning of even small irrigation in these states is likely to produce large economic benefits. The EWP – TCWU was found to be highest in Haryana (Rs 12.39/m^3) and Punjab (Rs 10.85/m^3) which however recorded lower EWP-irrigation water applied values of Rs 6.82 and Rs 4.19 per cubic metre, respectively. This indicated that with respect to the rate of irrigation water applied, Haryana and Punjab do not display a sustainable economic water productivity scenario. The non-judicious irrigation water application in these states may result in drastic sustainability issues in agriculture sector as a whole. Thus efforts should be made to shift the paddy cultivation to more sustainable ecosystems like the eastern belts of India. For this it is really important to incentivise the farmers to improve rice productivity in the eastern region. As rural electrification and farm-power allocation and consumption are low in these states, farmers have to depend upon costly diesel-pump based irrigation. Keeping in view the large irrigation water needs for rice crop, farmers either highly economise on irrigation water or totally deprive the crop from application of any irrigation even during long dry spells , monsoon breaks and deficient monsoon seasons. In states like Andhra Pradesh, Punjab, Haryana and Tamil Nadu where farmers have access to nearly free power and highly subsidised/ free canal water there is a general tendency to over-irrigate the crop leading to low values of economic water productivity with respect to irrigation water use. This strong water-energy nexus leading to wasteful use of both water and energy needs in one region and depriving the poor farmers to meet the urgent water needs in another region need be addressed on priority. For better comparison of EWP and understanding of the sustainability issue, there is a need to incorporate the state-wise cost of irrigation water applied in the calculation of Economic water productivity, which may be taken up as a future line of research.

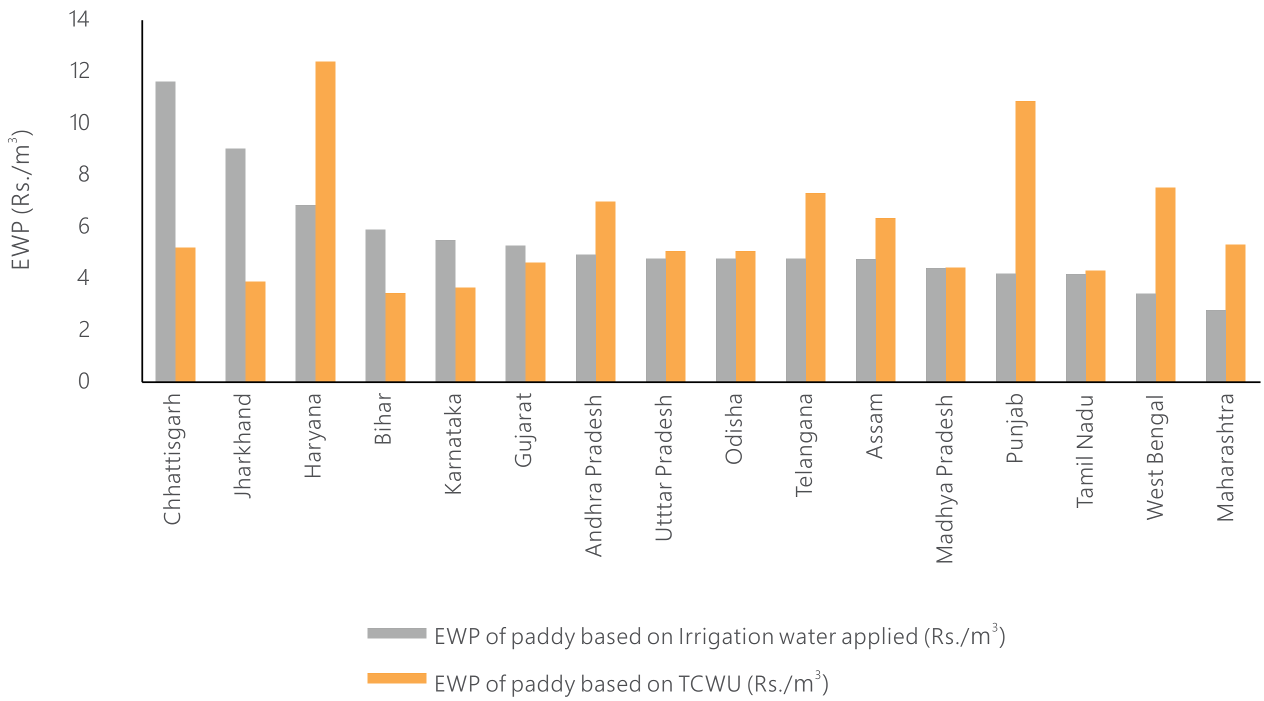


Figure 8. Economic water productivity of paddy in different states of India

Maharashtra has the least economic water productivity of applied irrigation water and thus makes a strong case that all the amount of irrigation water being diverted to less remunerative paddy cultivation may be re-allocated to less water consuming crops like pulses and oilseeds, or to cotton, fodder for dairy animals and horticultural plantations.

3.4.3.4. Comparative analysis of land and water productivity

A comparative analysis of the different indices of land productivity and the different indices of water productivity of rice is possible through a close examination of the data presented under Table 8.

IWP is the highest in Jharkhand (0.75kg/ m^3), followed by Chhattisgarh and Bihar. These states are best suited for rice cultivation if provided with small but critical irrigation facilities.

The following points emerge out of the comparative analysis:

- Physical water productivity of rice is the highest in states like Punjab, Andhra Pradesh and Haryana due to high levels (near 100 percent) of manmade irrigation and in states like Assam and West Bengal due to availability of the naturally occurring favourable rainfall status. In case of the north western belts comprising Punjab and Haryana, the high crop productivity supported by favourable policy environment in the form of free electricity supply and other suitable input subsidy policies, favourable procurement policies and assured market price policy and minimum support price (MSP) encourage the farmers to cultivate the crop despite the threats of long term sustainability. Consumption of water is high in these states and mainly supported through groundwater (former group) causing hydrological and economic distress manifested through depleting water tables and mounting energy subsidies for groundwater pumping. The prevailing situation is unsustainable in the medium to long term. Physical water productivity is low in the states of Karnataka, Madhya Pradesh, Bihar and Gujarat.
- With irrigation, the productivity level of the rice crop shows an incremental yield gain of 2.1 times higher than the rain fed yields. As such Irrigation Water Productivity is the highest in Jharkhand (0.75kg/ m^3), followed by Chhattisgarh and Bihar. These states are best suitable for rice cultivation if provided with small but critical irrigation water needs. On the contrary, the states which make excessive and wasteful use of the available irrigation water as Punjab and Haryana have the lowest use of irrigation water at just 0.22 kg of rice per cubic metre of applied water. These states must plan to shift at least a part of their rice area from the 'water risk hot-spot' blocks to the eastern states (Jharkhand, Chhattisgarh, Bihar) and diversify the existing rice based cropping pattern towards other less water consuming crops like maize with assured processing technology support and dairy farming and can invest in water saving technologies like precision irrigation or SRI (System of Rice Intensification) practices for improving water use-efficiency.
- Economic Water Productivity is a function of the productivity levels and the Farm Harvest Prices of rice declared by the central government as Minimum Support Price or the state level prices. States in the north-western region and some southern states have well developed markets, procurement systems and supporting policies. States in the

eastern region face the double whammy of low productivity and almost the lowest Farm Harvest Prices due to imperfect markets and inefficient procurement systems. Though the EWP with respect to TCWU is high in the north western states of Punjab and Haryana, however when the economic water productivity in terms of irrigation water applied is considered eastern states like Chhattisgarh (Rs 11.66/m^3), and Jharkhand (Rs 9.01/m^3) emerge as the efficient irrigation water users. As mentioned in section 3.2.4, owing to the irrigation intensive nature of paddy crop, it is the IWP and EWP based on irrigation water applied that gives the more realistic picture of misalignment in cropping pattern in rice cultivation in the country. Further, this throws light on the water sustainability issue prevailing with respect to rice cultivation in the water scarce north western regions of India.

Table 8

Comparative values of different indices of physical, irrigation and economic water productivity of rice for the dominant rice cultivating states of India

States	Land productivity (Irrigated yield) (kg/ha)	Physical Water Productivity of rice (kg/m^3 TCWU)	Economic Water productivity of paddy (Rs/m^3 TCWU)	Irrigation Water Productivity of rice (kg/m^3 irrigation water applied)	Economic Water productivity of paddy (Rs/m^3 irrigation water applied)	Percentage share in All India rice production
Punjab	4010	0.57	10.85	0.22	4.19	11.97
West Bengal	2827	0.52	7.49	0.24	3.46	14.61
Assam	1886	0.51	6.35	0.38	4.73	5.14
Telangana	3300	0.46	7.31	0.30	4.77	5.32
Andhra Pradesh	3084	0.44	6.99	0.31	4.93	8.38
Haryana	2898	0.40	12.39	0.22	6.82	3.85
Odisha	2126	0.37	5.05	0.35	4.77	8.00
Uttar Pradesh	3000	0.37	5.05	0.35	4.78	12.09
Maharashtra	1672	0.33	5.33	0.17	2.75	1.99
Jharkhand	3000	0.32	3.84	0.75	9.01	1.60
Chhattisgarh	2050	0.30	5.14	0.68	11.66	5.96
Tamil Nadu	3175	0.30	4.29	0.29	4.15	6.21
Gujarat	2425	0.29	4.63	0.33	5.27	1.60
Bihar	1936	0.28	3.44	0.48	5.90	4.78
Madhya Pradesh	1717	0.25	4.35	0.25	4.35	1.69
Karnataka	3193	0.24	3.62	0.36	5.43	4.12

Note: All India Production (BE 2010-11) = 92.2 million tonnes based on aggregation of district level data. The production share included in the table is aggregate from all corresponding rice producing districts in the dominant states and not just from the dominant districts.

Since the FHP of rice for all states was not available, we have calculated the EWP of paddy by dividing the PWP and IWP of rice by a factor 0.67 (conversion factor used to convert paddy to rice) and multiplying with the FHP of paddy across states.

3.5 Conclusions

States like Punjab, and Haryana, despite having higher land productivity and nearly 100 per cent irrigation cover under rice reported a low irrigation water productivity indicating the need for a shift in their rice based cropping pattern as well as improvement in the efficiency of irrigation water use. On the other hand the states like Chhattisgarh, Jharkhand, Odisha, Bihar and Assam must be encouraged for rice production owing to their suitability in terms of land as well as water productivity.

The following steps can be adopted as a way forward towards promoting rice cultivation in suitable regions in terms of land and water productivity:

Reallocate 10-15 per cent of the area under rice to less water consuming high value crops, dairy and fodder production, and horticultural orchards.

i. The existing regions of high yields and physical water productivity located in the states of Punjab, Haryana, Andhra Pradesh and Tamil Nadu consume excessively large quantities of irrigation water causing water stress and economic distress. Farmers and the governments in these states need to :(a) reallocate a part of the rice area (~ 10-15 per cent) to other less water consuming high value crops, dairy and fodder production, and horticultural orchards (b) invest in improved irrigation water management practices like precision irrigation,.

ii. Each unit of applied irrigation water for rice has the highest productivity in the states like Jharkhand, Bihar, Chhattisgarh, Assam and Odisha where rice crop is either under-irrigated or faces water stress during critical periods due to monsoon breaks, dry spells, deficient rains and farmers have little or no resilience. Irrigation needs are small but critical. Policies must be focused towards: (a) improving/ ensuring the procurement policy of the crop (b) ensuring better market price reforms and assured realisation of minimum support price (MSP) (c) investing in improving and expanding the public irrigation systems, (d) significantly improving the rural electrification and farmers access to affordable power- comparable to support at the national level (e) deeper penetration of the solar-powered pumps with assured grid connection in regions with low penetration of electricity supply, and (f) better spread of extension and input services including improved seeds for pushing up the production frontiers.

iii. To solve the issue of misalignment of cropping pattern with hydrological suitability, there is a need to move from price policy approach of heavily subsidizing inputs to income policy approach of directly giving money into the accounts of the farmers on per ha basis (direct benefit transfer of input subsidies), and letting prices be determined by market forces. This approach particularly in the case of power subsidy can help to mitigate the problem of over-exploitation of groundwater in the water scarce north western India and thereby help in reducing the unscrupulous and injudicious water use in rice cultivation in these regions.

iv. Rice areas in states like Maharashtra and Madhya Pradesh have low yields and have poor indices for physical- irrigation and economic-water productivity (with respect to irrigation water applied). These states must substantially reduce or discontinue rice production and adapt to more remunerative alternative pulse and oilseed crops, fodder for dairy animals, and horticultural plantations.

v. Spread of the benefits of Minimum Support Prices, state level subsidies and bonuses, efficient markets and rice procurement systems integrated as Farm Harvest Prices available to the farmers is highly variable and limited to few states and regions. Large rice producing states like West Bengal (14.61 per cent share in production) and Uttar Pradesh (12.09 per cent share in production) have lower levels of EWP with respect to irrigation water applied, despite having higher IWP than Punjab and Haryana. These states need immediate and effective market reforms so that farmers are able to realise higher Economic Water Productivity.

To realign cropping patterns to hydrological suitability, we need to move from the prevailing price policy approach of heavily subsidised inputs to an income policy approach wherein, input subsidies are directly transferred to the farmer's bank account and prices are left to market forces.

4

Wheat

4.1 Wheat in the world

Wheat is the most consumed food grain in the world occupying a share of almost 29 per cent in total food grain consumption. About 15 per cent of the global caloric intake is supplied by wheat. Globally, wheat is cultivated on 220m ha with a total production of 729 million tonnes (mt) with an average productivity of 3.31 t/ha. India and China together produced almost 35 per cent of world's wheat production. Top ten wheat producing countries together produce almost 70 per cent of the total production from 60 per cent of global wheat area (Table 9).However, yield stagnation in major wheat growing regions is seen as the result of complex set of factors, including slowing rates of genetic enhancement, loss of soil fertility, declining input-use efficiency, and biotic and abiotic stresses (Shiferaw et al., 2013).

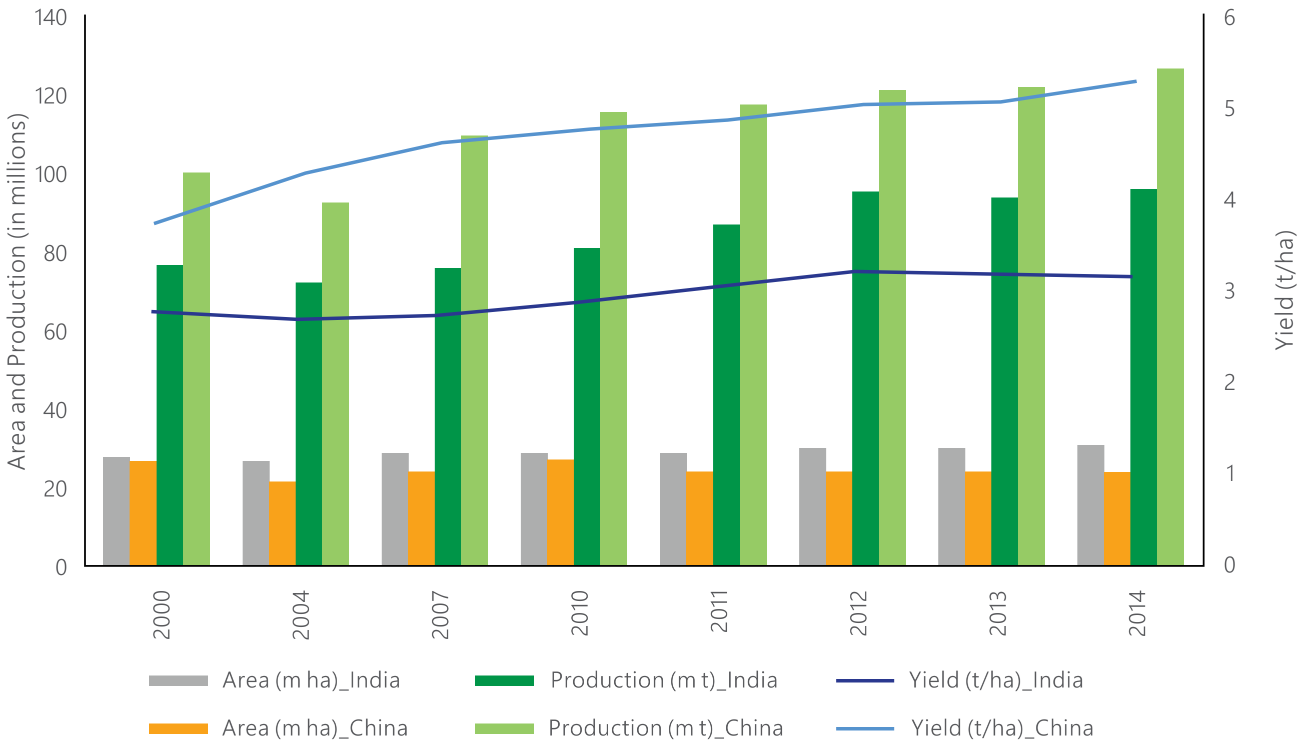
Table 9
Top ten wheat producers in the world (2014)

Country	Area (million ha)	Production (million tonnes)	Yield (tonne/ha)	Production share (per cent)
World	220	729	3.3	100
China	24.1	157	6.5	21.5
India	30.5	95.9	3.1	13.2
USA	18.8	55.1	2.9	7.6
France	5.3	39.0	7.4	5.4
Canada	9.5	29.3	3.1	4.0
Pakistan	9.2	28.2	3.1	3.9
Germany	3.2	27.8	8.6	3.8
Oceania	12.7	25.7	2.0	3.5
Australia	12.6	25.3	2.0	3.5
Ukraine	6.0	24.1	4.0	3.3

Source: (DES, 2016), FAO[6]

China and India are the top producers of wheat in the world (Figure 9). Globally, India ranks first with 13.9 per cent share in world's wheat area, while in terms of production, it stands second after China with almost 39 per cent lesser production and productivity lag of about 52 per cent (NBS, 2014).Both the increase in crop yield and reduction in water consumption through improvement in basin efficiency contribute to the increase in water productivity (Cai and Rosegrant, 2003).The lower land productivity of wheat in India despite having higher area and almost 94 per cent irrigation coverage necessitates the need to analyse the water productivity status of the crop and locate the low-efficiency districts and states to ensure sustainable and improved production.

[6] http://www.fao.org/faostat/en/#data/QC



Source: FAO

Figure 9. Comparison of wheat cultivated area and production trends in India and China

4.2 Wheat in India

In India, wheat is the second largest consumed food grain after rice. Since the advent of Green Revolution in the 1960s, there has been considerable growth in the cultivated area, coverage under high yielding dwarf wheat varieties, use of chemical fertilizers, mechanization and above all the coverage under irrigation- which now stands at above 94 percent. All these factors lead to significant growth in productivity and total production (Figure 10). In 2014-15, India produced 95.9 million tonnes of wheat from a cultivated area of 30.5 m ha with an average productivity level of 3.14 t/ha.

4.2.1 Dominant districts for wheat cultivation

In 2009-10 and 2010-11, wheat was cultivated in 490 districts across 24 states in India. It covered 290.7 lakh ha of cropped area, which produced a total of around 870 lakh tonnes with an average yield of 2.99 t/ha[7]. Out of the 11 dominant wheat producing states[8], 283 districts were identified as dominant districts which

[7] Based on the district level production data for BE 2010-11 (Source:http://aps.dac.gov.in/APY/Public_Report1.aspx)

[8] Procedure for identifying dominant states and dominant districts are detailed in the Methodology chapter of the paper. Due to unavailability of TCWU data for Himachal Pradesh, its districts are not considered in our analysis.

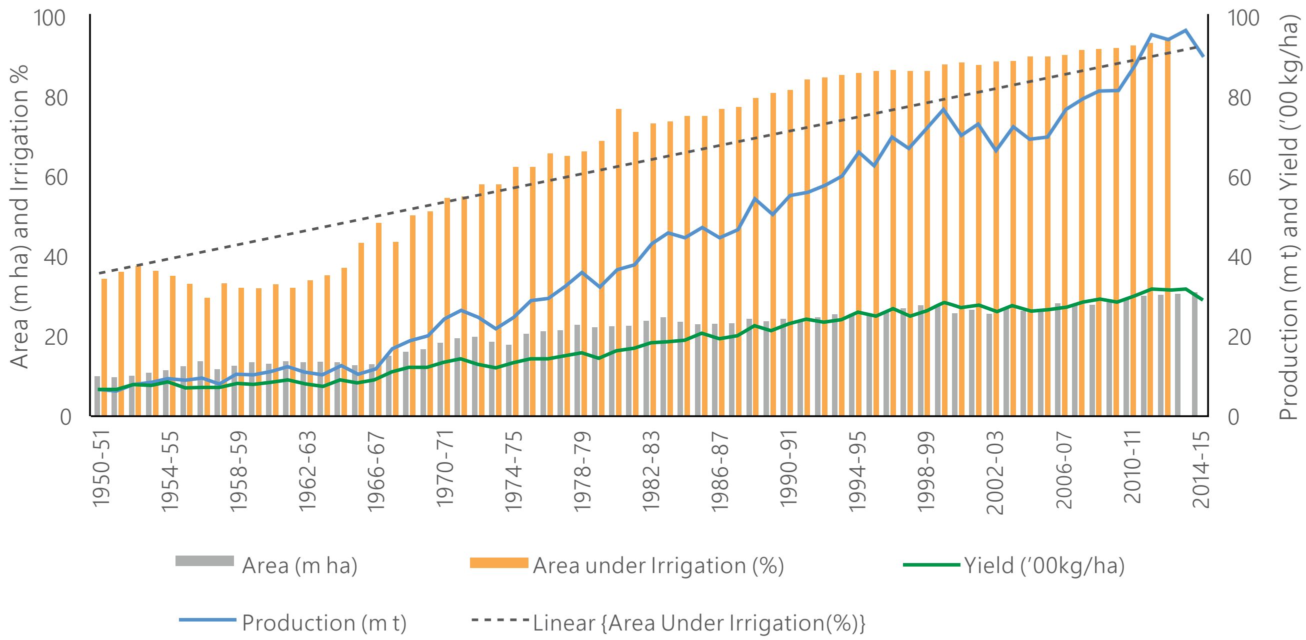
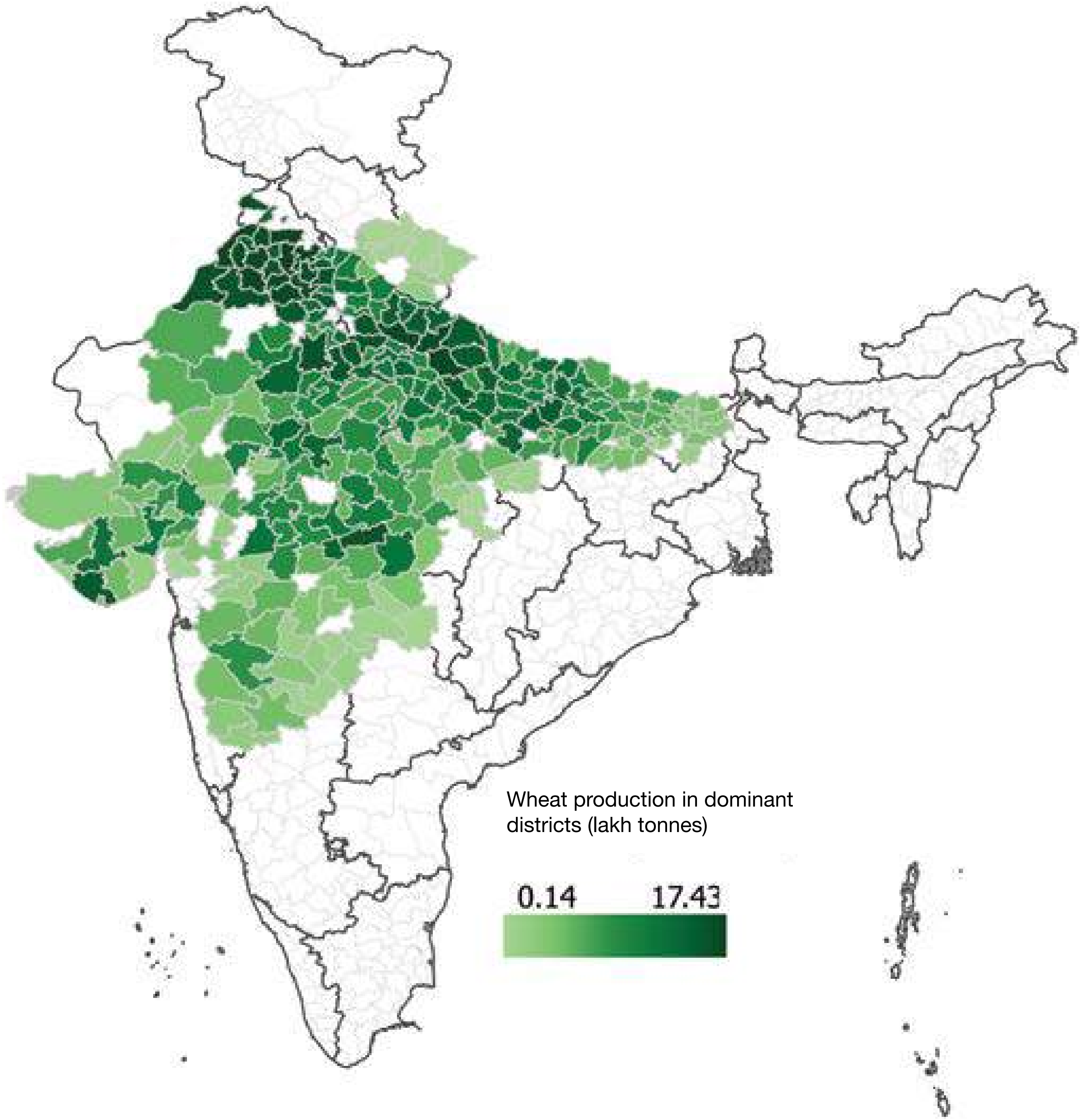


Figure 10. Trend in cropped area and area under irrigation, production and yield of wheat in India during 1950-2015

covered 277 lakh ha area (95 per cent of wheat cropped area) and produced 842 lakh tonnes (97 per cent of wheat production) with an average yield of 3.04 t/ha. After eliminating the districts with outlier Physical Water Productivity (PWP) values using verified statistical method[9], we were left with 255 dominant districts across 9 states (Map 11).Unlike rice which is wide spread, cultivation of wheat is limited to northern, north-western and central districts of India. These districts had 260 lakh ha under wheat, producing a total of 787 lakh tonne. Further detailed district wise analysis for production, productivity, and physical- , irrigation-, and economic-water productivity of wheat was done using this data base.

On arranging these districts in the ascending order of production and grouping them in 5 clusters, each contributing 20 per cent to the total production, it was found that 131 districts covering 7.5 mha (28.9 per cent of the wheat cultivated area) had the lowest average yield of 2.1 t/ha (Table 10). Besides other production limitations, comparatively lower irrigation coverage in these districts might be the main constraint as the yield levels in other production groups increased with the irrigation intensity. The largest production of wheat was concentrated in just 15 districts (5.9 per cent of total wheat districts) which covered 3.8 mha area (14.7 per cent of total area) and produced 16.3 million tonnes with an average productivity level of 4.3 t/ha. These are the 'bright spots' in India's wheat production and focus needs to be laid upon these districts to target improved productivity base, ensuring sustainable water use.

[9] PWP values are arranged in ascending order and values of quartile 1 (Q1) and quartile 3 (Q3) are calculated. Then inter-quartile range (IQR) is calculated by subtracting Q1 from Q3. The thresholds for small and large outliers are calculated from these formulas Q1-1.5 IQR and Q3+1.5 IQR, respectively.



Map 11. Variation in wheat production in dominant wheat districts of India

Table 10

Main characteristics of the five production clusters of the dominant wheat districts in India

Production percentile group	Number of districts	Percent of districts	Area (mha)	Percent of area	Production (mt)	Average yield (t/ha)	Percent irrigated
0-20 per cent	131	51.4	7.5	28.9	15.6	2.1	85
20-40 per cent	52	20.4	5.6	21.5	15.6	3.0	96
40-60 per cent	34	13.3	4.7	18.1	15.4	3.4	99
60-80 per cent	23	9.0	4.4	16.8	15.7	3.7	100
80-100 per cent	15	5.9	3.8	14.7	16.3	4.3	100
Total	255	100.0	26.0	100.0	78.7	3.03	95

4.3 Water use in wheat

4.3.1 Water use and irrigation water requirement in wheat

Unlike rice, wheat crop responds favourably to optimal irrigation and cannot withstand excessive water application. However, if the water stress prevails during the crop's 'critical growth stage' (Table **11**), it may result in negative impact on the crop yield. For instance, in water stressed states like Punjab which has almost 80 per cent of its cropped area under the rice-wheat rotation, the threat posed by the water-intensive *kharif* rice crop to the groundwater status, affects the water availability for the *rabi* wheat crop, thereby reducing its potential output.

Table 11

Critical crop growth stages for scheduling irrigation to wheat crop

No. of available irrigations	Crown root initiation	Tillering	Late Jointing	Flowering	Milking	Dough
One	√					
Two	√			√		
Three	√		√		√	
Four	√	√		√		√
Five	√	√	√	√	√	
Six	√	√	√	√	√	√

Source: FAO

The deficient southwest monsoon showers result in probable reduction in water availability for *rabi* crops in India. Further, the climate change scenario result in extreme heat and water scarcity leading to higher soil moisture stress and increased evapo-transpiration, increasing the need for irrigation in summer and *rabi* seasons. Thus being a *rabi* crop, wheat yield may be affected by the moisture deficit and heat stress even more than irrigated rice crop (OECD, 2017).

On an average, wheat crop needs 45 cm of water, which may vary with type of soil, prevailing climate, and crop variety and irrigation method. Heavy deep soils with good water holding capacity may require only 3 to 4 heavy (7 to 10 cm) irrigations whereas 6 to 8 light irrigations (5 cm) may be required in sandy soils. Adjustments need to be made for seasonal rainfall and climatic anomalies like frosts during early growth and hot winds towards maturity.

Water being a critical input for improving wheat productivity, it is essential to understand the efficiency of water use with respect to the output produced. For this, as attempted in the case of rice, the PWP, IWP and EWP for wheat were estimated and mapped across states to understand the efficiency of water use with respect to the output produce.

4.3.2 Water productivity in wheat

4.3.2.1 Physical Water Productivity (PWP)

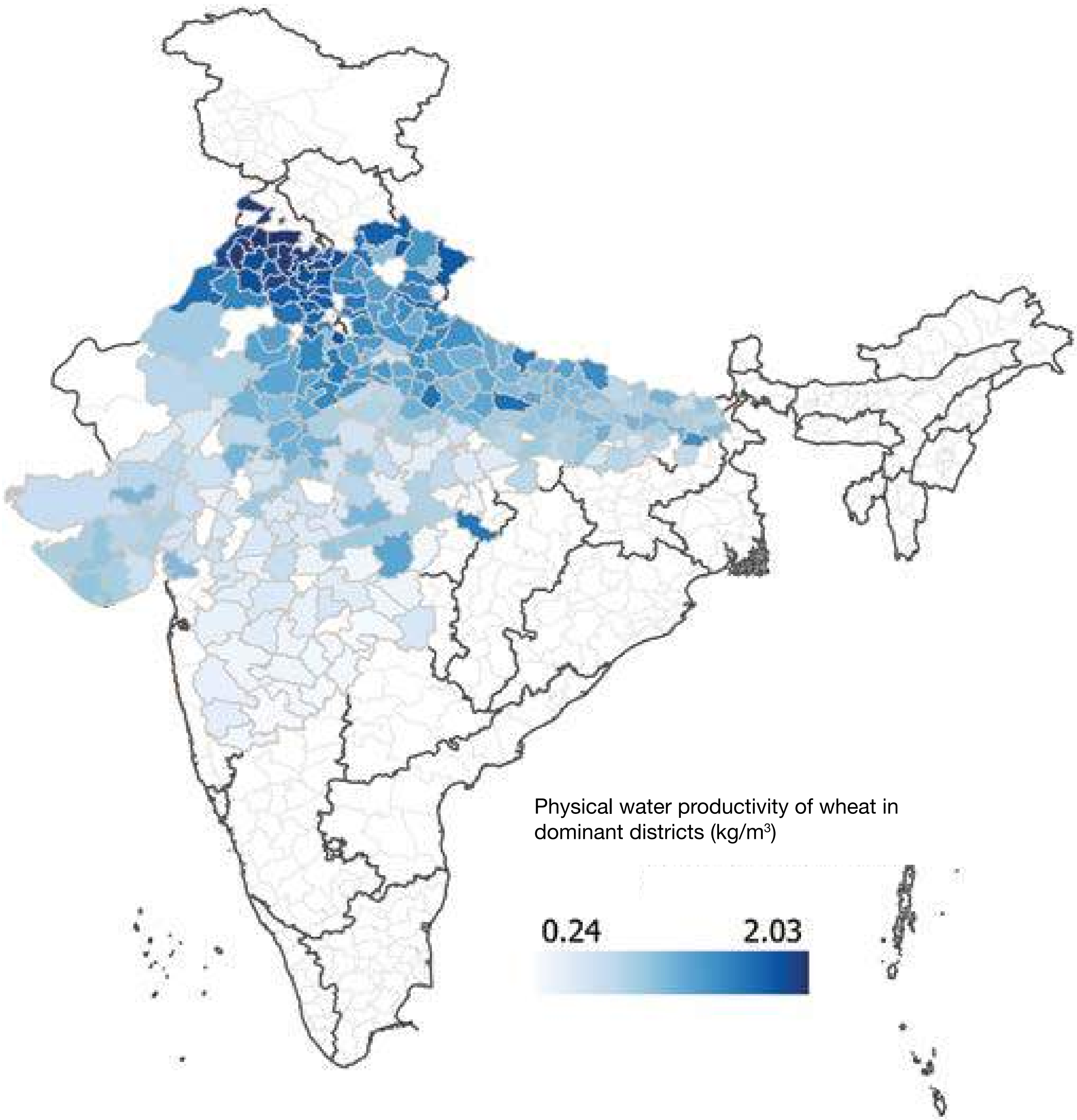
Physical water productivity was calculated at the district level and aggregated for the state and national level. Data presented in Table 12 shows the variation of Total Consumptive Water Use (TCWU) and water productivity across different production clusters in India. Wheat crop consumed a total 82.7 km^3 (82.7 BCM) to produce 78.7 mt of grains with an average physical water productivity (PWP) of 0.95 kg/m^3 but with a variation of 0.69 to 1.65 kg/m^3 . This is close to the world average of water productivity for wheat at 0.90 kg/m^3 but much less than in China where irrigated wheat water productivity is uniformly high at 1.3 kg/m^3 and evenly distributed (Gini of 0.09) (Brauman et al., 2013).

Table 12

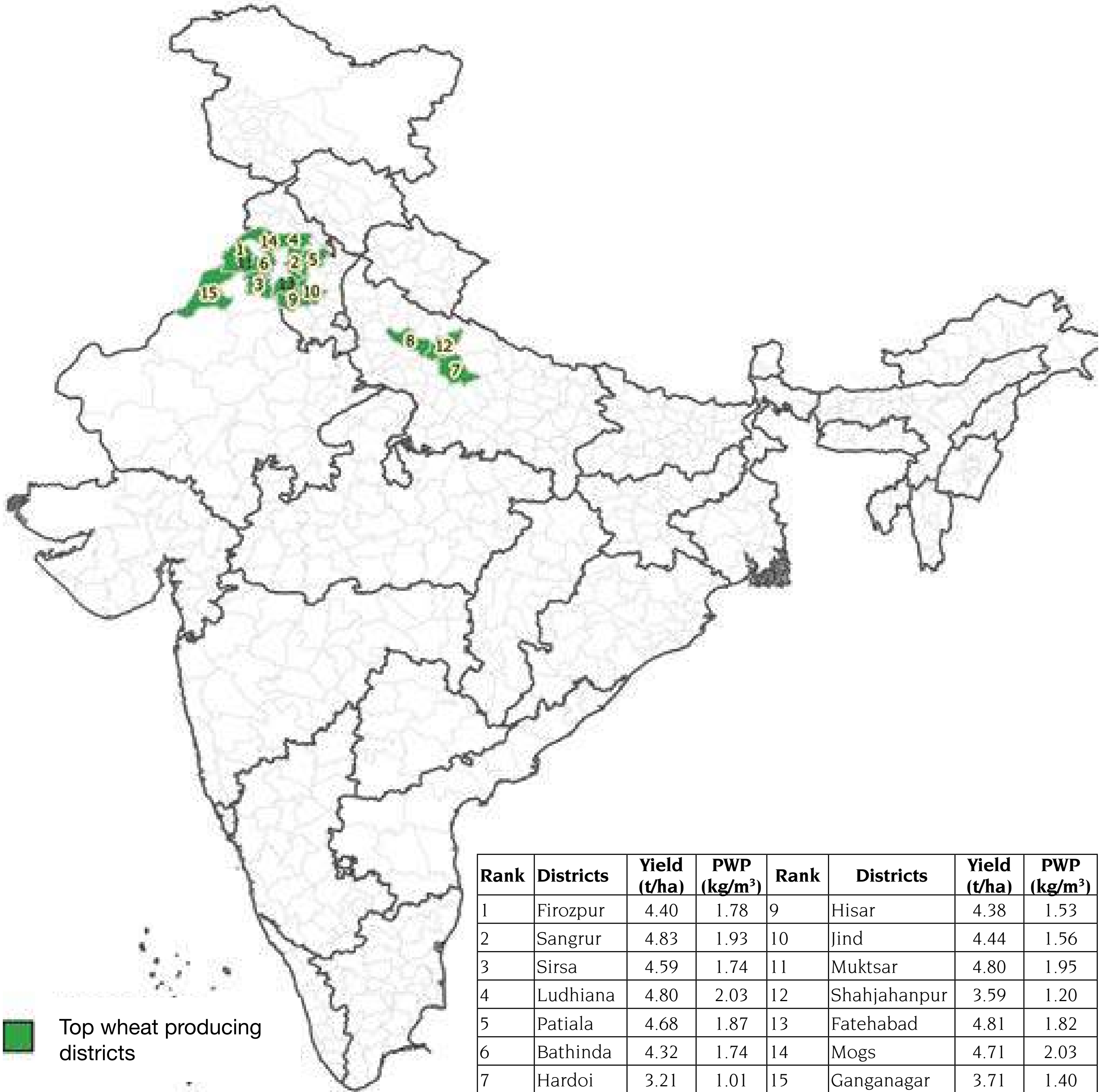
Production, productivity, total consumptive water use and physical water productivity of wheat in dominant wheat production groups of India

Production Percent Groups	Total production, million tonnes	Average productivity, t/ ha	Total Consumptive Water Use (km^3)	Percent Total Consumptive Water Use	Physical Water Productivity (kg/m^3)
0-20 per cent	15.6	2.1	25.1	30.3	0.69
20-40 per cent	15.6	3.0	18.7	22.6	0.91
40-60 per cent	15.4	3.4	15.2	18.4	1.12
60-80 per cent	15.7	3.7	13.4	16.2	1.24
80-100 per cent	16.3	4.3	10.3	12.4	1.65
Total/ Average	78.7	3.0	82.7	100.0	0.95

Map 12 exhibits that there exists a huge variation in water productivity amongst the lowest and best performing districts (with a range of 0.24 to 2.03 kg/m^3). A large number of districts in Maharashtra and Gujarat displayed low levels of PWP. Punjab has the highest level of physical water productivity for wheat (1.88 kg/m^3) when considered for the state as whole followed by Haryana (1.57 kg/m^3) (Figure 11). The districts in eastern UP and Bihar also displayed low levels of PWP when compared to the western UP region. Though



Map 12. Variation in physical water productivity across the dominant wheat producing districts—Wheat Water Productivity Map of India



Rank	Districts	Yield (t/ha)	PWP (kg/m^3)	Rank	Districts	Yield (t/ha)	PWP (kg/m^3)
1	Firozpur	4.40	1.78	9	Hisar	4.38	1.53
2	Sangrur	4.83	1.93	10	Jind	4.44	1.56
3	Sirsa	4.59	1.74	11	Muktsar	4.80	1.95
4	Ludhiana	4.80	2.03	12	Shahjahanpur	3.59	1.20
5	Patiala	4.68	1.87	13	Fatehabad	4.81	1.82
6	Bathinda	4.32	1.74	14	Mogs	4.71	2.03
7	Hardoi	3.21	1.01	15	Ganganagar	3.71	1.40
8	Budaun	3.43	1.12				

Map 13. Yield and physical water productivity of top 15 wheat producing districts in India

at one level it is a matter of serious concern, at another level it presents a good opportunity for efficient water use and improved productivity in the vast wheat agri-scape of India.

The PWP for the top 15 wheat producing districts representing the 'bright spots' is displayed in Map 13. The districts of Moga and Ludhiana in Punjab had the highest physical water productivity of 2.03 kg/m^3, followed by 1.95 kg/m^3 in Mukatsar and 1.93 kg/m^3 in Sangrur. This is mainly due to the high land productivity levels in Punjab gained through the use of improved varieties, optimum fertilization, agronomic practices, laser levelling of fields and large scale pumping of groundwater to meet high irrigation water requirements of the crop.

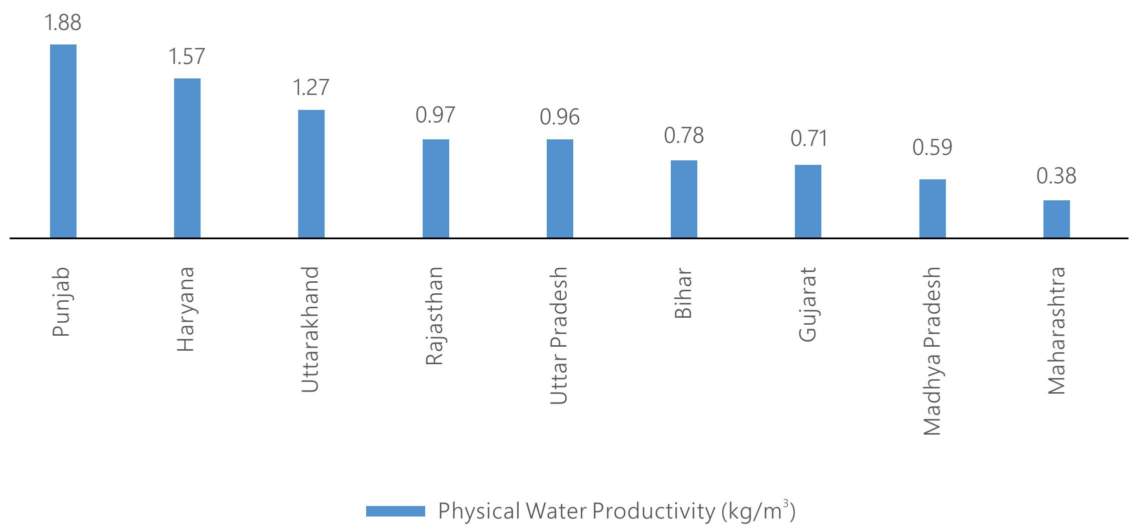


Figure 11. Physical water productivity (kg/m^3) for dominant wheat growing states in India

'Bright spots' of 15 top wheat producing districts are located in Punjab, Haryana, Rajasthan and western Uttar Pradesh. Together these districts produce 20 per cent of the total wheat production in India (Ranks are with respect to the total wheat production in the district)

4.3.2.2 Irrigation Water Productivity

Low irrigation water productivity in the states of Madhya Pradesh, Uttar Pradesh, and Rajasthan can be brought close to the levels of Punjab and Haryana through sound on-farm water management policies and this has been amply demonstrated through good farm ponds, provision of adequate power for tube wells, improvement in the canal distribution network and sprinkler irrigation which shall substantially improve the yield and irrigation water productivity. In states like Bihar, the problem is more deep rooted as wheat sowing itself gets delayed due to late harvest of the paddy crop. Also, farmers economise on irrigation water use due to high cost of diesel based-irrigation. Moreover, mechanization and adoption of improved varieties and agronomic practices has not sufficiently penetrated. The data also demonstrates that in the drier climates of Gujarat and Maharashtra farmers should desist from cultivating wheat under rain fed conditions as the yields are abysmally low. Wheat farmers in the high hills of Uttarakhand also have limited options, but provision of even one or two critical irrigations through farm ponds/ local streams is the most important input for high productivity of wheat. This is evident from the gap in irrigated and rain fed yield of the crop across states as given in Table 13. On an average at all India level, the irrigated yield of wheat is more than twice that of the unirrigated yield. In the vast wheat growing areas of Uttar Pradesh (36.3 per cent of total area), wheat yields can be improved by more than 50 per cent through adequate supply of irrigation water.

Table 13

Response of wheat crop to irrigation, irrigation water applied by the farmers and irrigation water productivity of wheat in major wheat growing states of India

States	Percent contribution to total wheat area	Average irrigated yield, kg/ ha	Average unirrigated yield, kg/ha	Ratio of irrigated to unirrigated yield	Average irrigation water applied by the farmers, (mm)	Irrigation water productivity, kg/m^3 of applied irrigation water
Uttarakhand	1.40	3110	960	3.24	300	1.04
Maharashtra	4.43	1766	825	2.14	280	0.63
Gujarat	4.60	3002	674	4.45	420	0.71
Bihar	7.84	2110	1715	1.23	280	0.75
Haryana	9.23	4408	3927	1.12	420	1.05
Punjab	9.61	4312	1968	2.19	350	1.23
Rajasthan	9.96	3242	1540	2.11	420	0.77
Madhya Pradesh	16.64	2229	1114	2.00	420	0.53
Uttar Pradesh	36.30	3112	2100	1.48	350	0.89
Total/ Average	100.00	3032	1647	2.21	360	0.84

Source: Data based on the results from National Crop Cutting Experiments—2009, 2010 and other sources

4.3.2.3 Economic Water Productivity

Economic water productivity is a measure to capture the value of economic gains made through consumption of the unit amount of water (Rs/m^3). Besides the centrally announced Minimum Support Price, different states have varying Farm Harvest Price, highest being in the states of Punjab and Haryana. Economic Water Productivity was calculated to evaluate the value of output produced per unit TCWU and amount of irrigation water applied by the farmers. Punjab and Haryana recorded the highest levels of EWP with respect to TCWU as well as per unit volume of irrigation water applied (Figure 12). Unlike rice, the EWP with respect to irrigation water use as well as TCWU was following the same trend in case of wheat. One of the implication is that in wheat the irrigation water use is efficient without any significant over exploitation of the resource. Madhya Pradesh owing to its higher irrigation requirement but lower irrigation water productivity reported the lowest economic water productivity in comparison to other states, despite having an attractive level of farm harvest price. In Maharashtra owing to its low irrigated yield level, the IWP and EWP were comparatively lesser than most of the other states. Thus in Maharashtra there is a need to focus upon better varieties of wheat and other factors of production to improve the IWP and EWP.

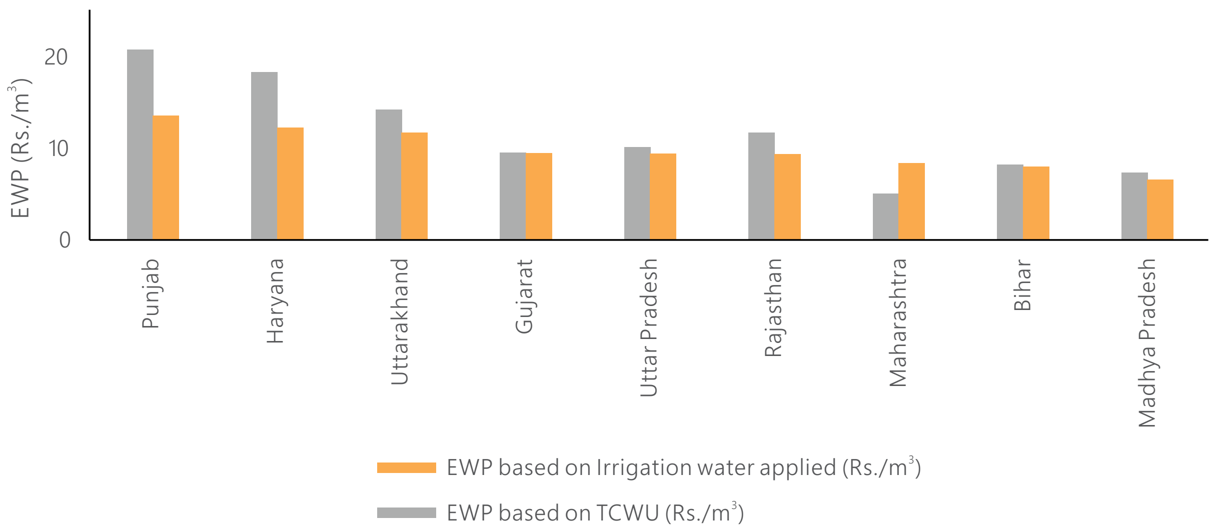


Figure 12. Economic water productivity of wheat

Interestingly, the states of Bihar, Uttar Pradesh, Madhya Pradesh, Gujarat and Maharashtra showed considerable improvement in yield in response to irrigation. As such sincere and concerted efforts need to be made to improve the spread of canal irrigation and access to groundwater to improve the low wheat yields in these states. WBCSD (2017) recommended smart varieties, smart crop management, mixed farming systems, improved blue water (irrigation) and green water (rain water) management, efficient farm operations and mechanisation, bridging the yield gaps, efficient fertiliser application, making use of the trade and prices and reducing crop losses and waste as the ten solution areas for a water-smart agriculture in India.

4.4 Conclusions

- Global wheat production of 729.9 mt from 220.4 m ha stands at an average productivity of 3.31 t/ha. China and India account for more than 30 per cent of world's wheat production, but average wheat yield of China (6.50 t/ha) is more than twice than average wheat yield in India (3.15t/ha).
- With a production of 95.9 mt from 30.5 mha of cultivated area in the non-monsoon season, wheat is the second most important food crop of India. About 90 per cent of the total wheat crop is irrigated with average water needs of 45 cm, but with lot of variation among regions and states.
- Though spread over 490 districts across 24 states, the dominant production of wheat is limited to 255 districts across 9 states which account for nearly 95 per cent of total area and production of wheat in India.
- Clustering trend of dominant wheat production districts shows that largest production of wheat is concentrated in just 15 districts which cover 3.8 mha and produce 16.3 mt with an average productivity of

4.3 t/ha. These districts are the 'bright spots' and water and agronomic management practices there can help to transform the large base (131 districts, with average yield of 2.1 t/ha) of low production.

- This study estimated that wheat crop in the dominant districts consumed a total of 82.7 km^3 (82.7 BCM) of water to produce 78.7 mt of wheat with an average physical water productivity of 0.95 kg/m^3 which is close to the world average of 0.90 kg/m^3 but much less than in China at 1.31 kg/m^3. Table 14 compares the physical, irrigation and economic water productivity of wheat across the states.

Table 14

Comparison of physical, irrigation and economic water productivity of wheat in the major wheat growing states of India

States	Land Productivity (t/ha)	Physical water productivity of wheat (kg/m^3)	Economic water productivity of Wheat (Rs/m^3 of TCWU)	Irrigation water productivity (Rs/m^3 of irrigation water applied)	Economic Water Productivity, (Rs/ m^3 of applied irrigation water)	Percentage share in all India wheat production
Uttarakhand	2.3	1.27	14.10	1.04	11.54	0.98
Maharashtra	1.7	0.38	4.94	0.63	8.19	2.32
Gujarat	3.0	0.71	9.44	0.71	9.44	4.23
Bihar	2.3	0.78	8.11	0.75	7.80	5.46
Rajasthan	3.3	0.97	11.45	0.77	9.09	10.30
Madhya Pradesh	2.0	0.59	7.08	0.53	6.36	10.39
Haryana	4.4	1.57	18.21	1.05	12.18	12.68
Punjab	4.6	1.88	20.68	1.23	13.53	18.18
Uttar Pradesh	3.0	0.96	9.98	0.89	9.26	33.26

Note: All India total Wheat Production (BE 2010-11) = 87.01 million tonnes based on aggregation of district level data. The production share included in the table is for all corresponding wheat producing districts in the dominant states and not just the dominant districts.

- There is a huge variation in Physical Water Productivity with a range of 0.24 to 2.03 kg/m^3 with large number of districts in Bihar, eastern Uttar Pradesh, Madhya Pradesh, Gujarat and Rajasthan with low levels of water productivity. This presents a good opportunity for efficient water use and improved productivity in the vast low-performing wheat agri-scape of India.
- The importance of adequate irrigation to wheat is evident from the large gap in yields between the irrigated and rain fed crop and the ratio can be as high as 4.45 in Gujarat, 2.0 in Madhya Pradesh and 1.48 times in Uttar Pradesh with the national average at 2.21times. This indicates that provision of irrigation, especially in the low performing districts and states, can potentially improve the yield by 2.21 times of the present levels.
- Even in the irrigated fields, farmers apply varied amounts of irrigation water from a low of 280 mm in Bihar to high of 420 mm in Punjab and Haryana. Punjab has the highest level of Irrigation Water Productivity of 1.22 kg/m^3 followed by Haryana at 1.05 kg/m^3 and terai regions of Uttarakhand at 1.04 kg/m^3. Madhya Pradesh, Maharashtra and Gujarat in the hot and dry central region have low irrigation water productivity and should discourage expansion of wheat in water stressed regions.

- Economic water productivity is a measure to capture the value of economic gains made through the consumption of the unit amount of water. Due to low yields added with high water requirement in Madhya Pradesh and low farm harvest price in Bihar, economic water productivity is found to be low in these states. Alternate marketing channels and improvement of market imperfections must be ensured in Bihar so that farmers receive better farm harvest price and have sufficient incentives to invest in good irrigation and improved varieties and practices. Adoption of efficient irrigation methods must be promoted to ensure optimum irrigation water use in Madhya Pradesh.

4.5 Way forward

Based on the estimation and comparison of land and water productivity across the major wheat growing states in India, it can be concluded that water consumption in wheat is generally efficient, though scope for improvement exists. States like Punjab and Haryana which reported a high land productivity value, also reflected a high level of IWP indicating the suitability of crop in the region. However, if water management technologies like sprinkler irrigation is implemented in these states, there is further scope of conserving the available water resources and thereby sustainably improving the productivity as well as profitability. In almost all states, an improved yield was obtained with irrigation facility. In states like Uttarakhand (58.7 per cent) and Maharashtra (73.9 per cent) where the irrigation coverage in wheat in less than the all India average of 93.6 per cent, there is a scope to improve irrigation cover by adoption of water saving technologies like micro irrigation. This will improve both the land as well as water productivity.

Even in the irrigated fields, farmers apply varied amounts of irrigation water from a low of 280 mm in Bihar to high of 420 mm in Punjab and Haryana. Punjab has the highest level of Irrigation Water Productivity of 1.22 kg/m^3 followed by Haryana at 1.05 kg/m^3 and terai regions of Uttarakhand at 1.04 kg/m^3. Madhya, Maharashtra and Gujarat in the hot and dry central region have low irrigation water productivity and should discourage expansion of wheat in water stressed regions. Rural electrification and solar energy must be promoted to ensure timely and affordable options of irrigation from ground water sources.

Alternate marketing channels and improvement of market imperfections in Bihar and Uttar Pradesh must offer good Farm Harvest Price so that farmers have sufficient incentives to invest in good irrigation and improved varieties and practices for a water-smart agriculture.

5

Maize

5.1 Maize in the world

Maize, also called the 'golden grain', is cultivated widely throughout the world and has the highest production among all the cereals. The worldwide production of maize was more than 960 million tonnes (mt) in 2013-14. It is an important staple in many countries and is also used in animal feed and industrial applications. Global maize production has grown at a CAGR of 3.4 per cent over the last decade from 716 mt in 2004-05 to 967 mt in 2013-14. Area under maize cultivation in the period has increased at a CAGR of 2.2 per cent, from 146 mha in 2004-05 to 177 mha in 2013-14, the remaining increase in production is due to increase in productivity. Productivity of maize has increased at a CAGR of 1.2 per cent from 4.9 t/ha in 2004-05 to 5.5 t/ha in 2013-14. USA is the largest producer of maize in the world (37 per cent) followed by China (22 per cent), Brazil (7 per cent), EU (7 per cent), Ukraine (3 per cent), Argentina (3 per cent), India (2 per cent), Mexico (2 per cent), and rest of the world (17 per cent). USA is also the largest exporter of maize in the world.

5.2 Maize in India

Maize is predominantly a *kharif* (rainy season) crop with 85 per cent of the area under cultivation in the season followed by spring and winter season maize. Winter maize is especially popular in Bihar and other eastern states. After rice and wheat, maize is the third most important cereal crop. Maize accounts for nearly 9 percent of total food grain production in the country. The crop adds more than Rs 100 billion to the agricultural GDP apart from providing employment to over 100 million man-days at the farm and downstream agricultural and industrial sectors. In India maize is used as human food (25 per cent), poultry feed (49 per cent), animal feed (12 per cent), industrial products (12 per cent) and beverages and seed (1 per cent each). Maize has witnessed an impressive growth and production has grown at a CAGR of 5.5 per cent over the last decade from 14 million tonnes in 2004-05 to 23 million tonnes in 2013-14. Area under maize cultivation during this period has increased at CAGR of 2.5 per cent from 7.56 m ha in 2004-05 to 9.4 mha in 2013-14. Remaining increase in production is due to increase in productivity mainly contributed by high yields of winter maize and improvement in irrigated area. Despite adoption of single cross hybrids in several states and recent improvements in maize productivity, it remains low at 3.04 t/ha as compared to average maize productivity of 7.8 t/ha in USA and 6.1 t/ha in China. Indian maize

Maize production has grown at a CAGR of 5.5 per cent over the last decade from 14 million tonnes in 2004-05 to 23 million tonnes in 2013-14.

productivity level is just half of what China has achieved in recent years. Area, production and yield of maize and also increase in the percentage area under irrigation are shown in Figure 13. In India only 25 per cent of the maize cultivated area is under assured irrigation and the rest 75 per cent of the rain fed crop faces the uncertanities of monsoon and this is one of the main reason for low adoption of hybrid varieties and the low yields.

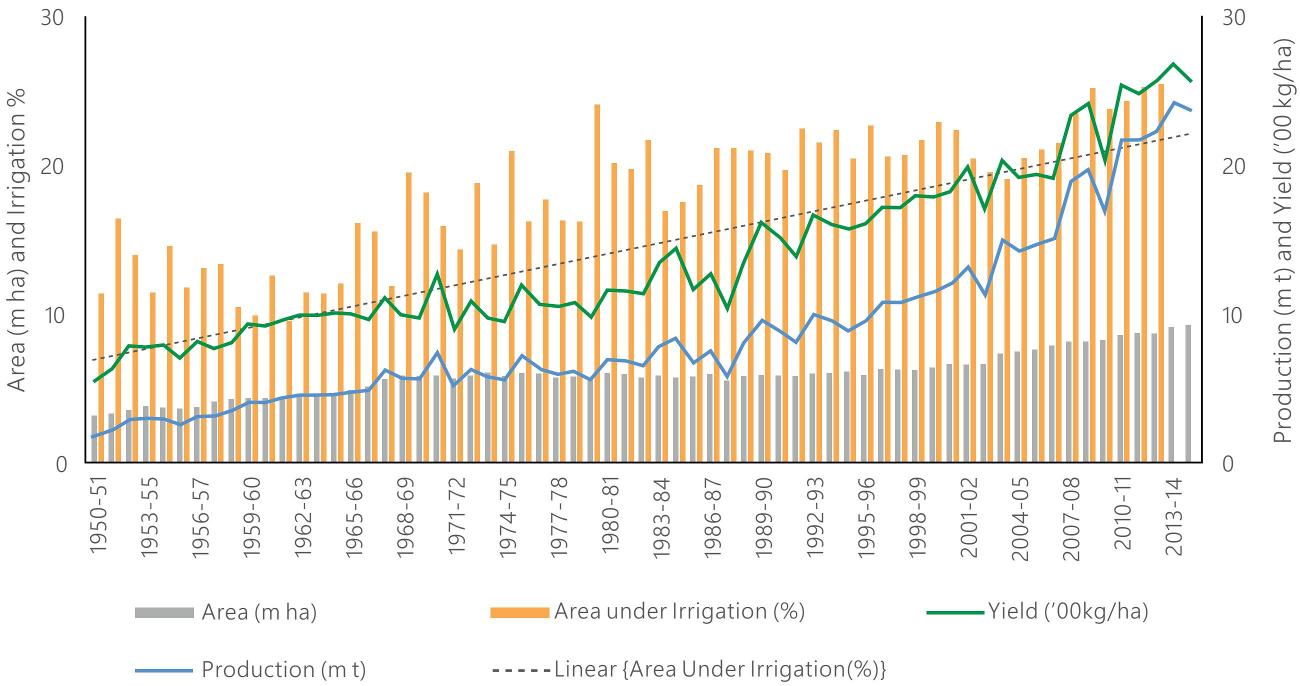


Figure 13. Changes in cultivated area, production, yield and area under irrigation for maize during 1950-51 to 2014-15 in India

Starting from few fields in 1960, winter maize crop is now cultivated in 1.2 million ha in the country and 0.5 million ha in Bihar state alone. The irrigated crop has a large window for sowing and is planted after rice harvesting during 20 October -15 November or even later. The favourable factors for this phenomenon has been better water management as the crop was not affected by water logging and overcast sky, the climate was mild with favourable temperature and 7-9 hours of sunshine for higher leaf area and photosynthetic activity, reduced incidence of diseases and insect pests, better response to every unit of fertiliser, better plant stand and weed management. The crop is generally sown on raised beds on the southern sides of the east/west ridges for better germination and requires only 4 to 6 irrigations as compared to more than 20 irrigations for *boro* (winter) rice cultivated during the same season. The average productivity of the winter maize is about two times the national average though individual farmers have harvested more than 8 t/ha. Studies by CIMMYT showed that Benefit-Cost ratio for cultivation of winter maize was 2.4 as compared to 1.53 for boro rice and 1.85 for wheat crop.

5.2.1 Dominant Districts for Maize Cultivation

Maize is widely cultivated in India under varying agro-ecologies. According to the 2009-10 and 2010-11 district level data, around 7.8 mha was under maize cultivation and this area was distributed across 509 districts spread across 23 states. The total production in India was 18.9 mt with the average yield of 2.42 t/ha. The water consumption data suggest that a total of **19.4 km^3 (19.4 BCM)** of water was consumed for maize cultivation in India.

As per the methodology of the study, the maize cultivating districts and states were filtered down to focus on the dominant districts in terms of area. There are 296 dominant districts spread across 14 dominant states for cultivation of maize. The data was further cleaned to exclude Himachal Pradesh (for which water consumption data was not available) and wide outliers of physical water productivity. As such, there are 239 dominant districts which cover an area of 5.98 mha and produce 14.6 mt with average yield of 2.44 t/ha. Spread of these dominant districts and variation in production is shown in Map 14.

In the first part of the analysis, the dominant districts are arranged in an ascending order and divided in to 5 groups with each group contributing 20 per cent of production. The distribution of maize production under these groups is graphically presented in the scatter plot below (Figure 14).

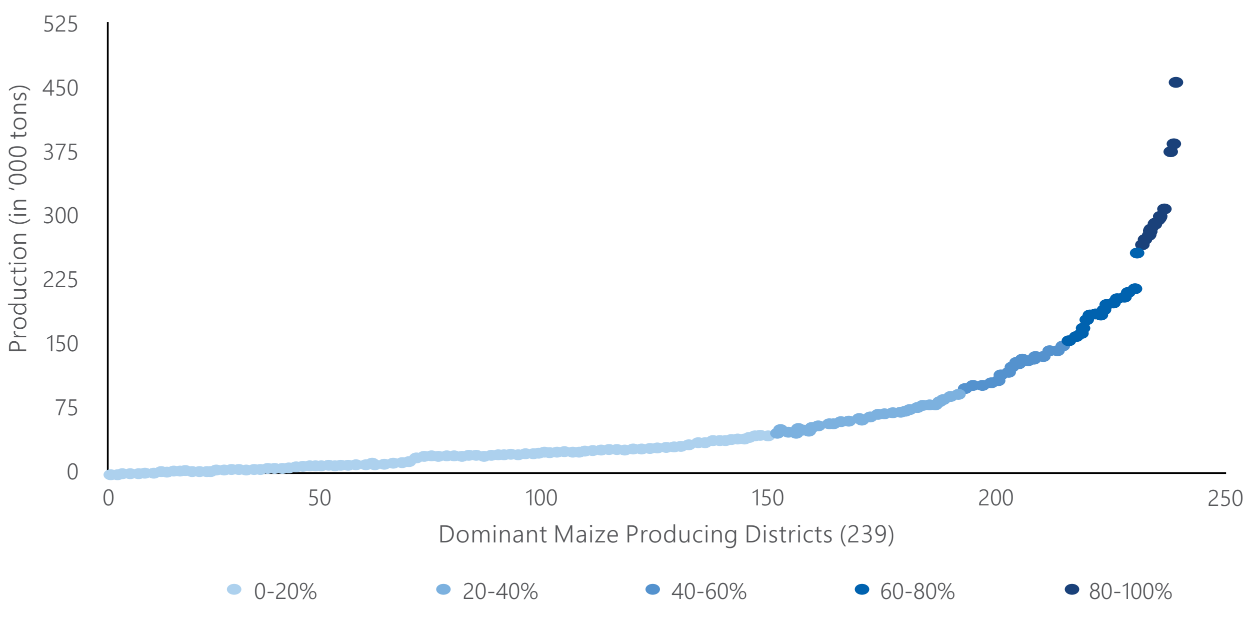
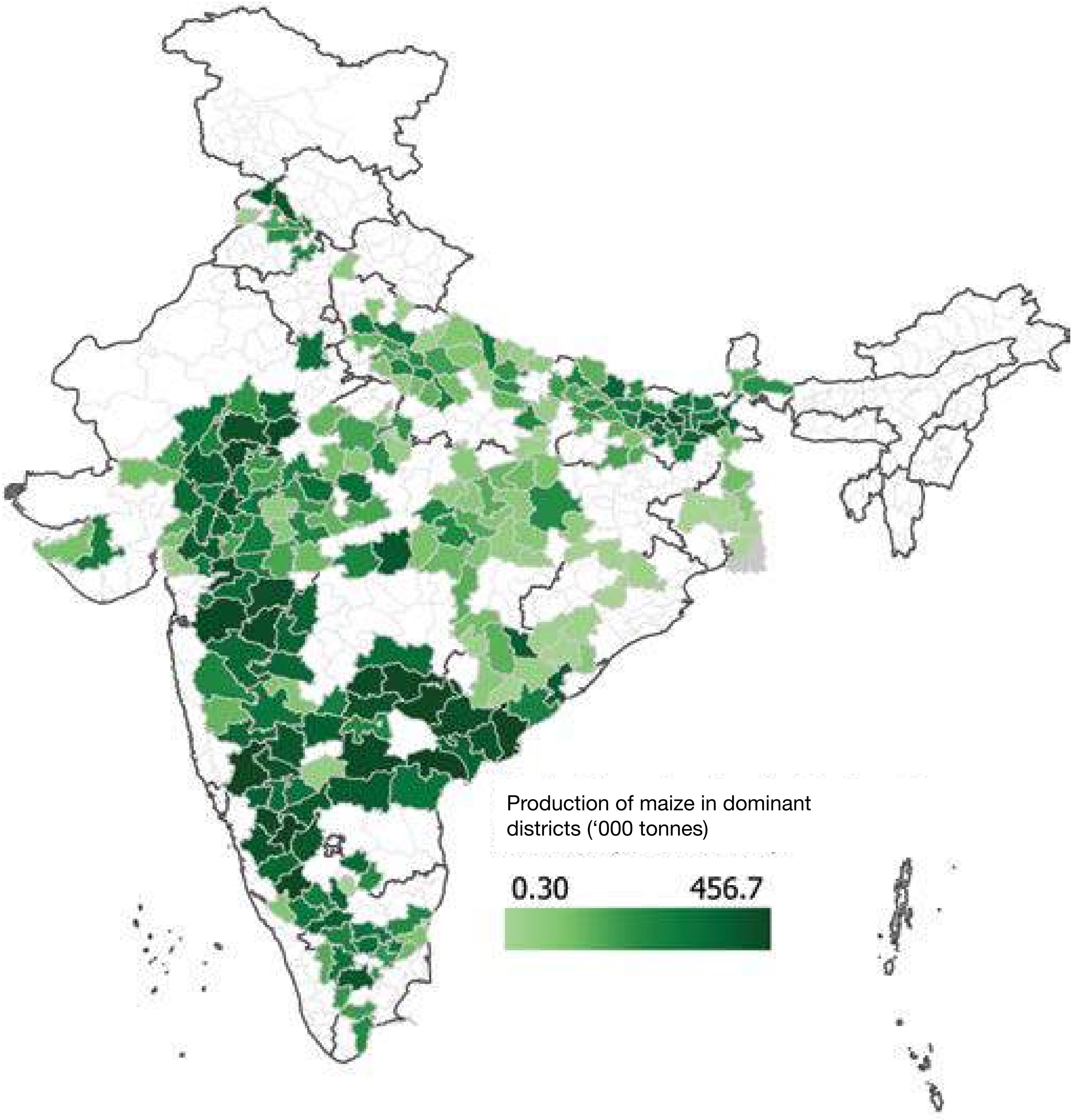


Figure 14. Scatter plot of maize production in the dominant maize districts of India



Map 14. Variation in production in the 239 dominant maize districts of India: Maize production map of India

The values of multiple variables considered in the study for these groups are also presented in the table below (Table 15). As one can see top 25 districts make up just above 10 per cent of the total dominant districts and they contribute 40 per cent of the total maize production. These districts constitute the 'maize basket' of India.

Table 15

Production-wise groups for area, total production, average yield, total consumptive water use and physical water productivity of maize in the dominant maize growing districts of India

Production wise groups	Number of districts	Percent of districts	Area (mha)	Percent area	Total production (m t)	Average yield	Percent irrigated	TCWU (km^3)	Percent TCWU	PWP (kg/m^3)
0-20 per cent	149	62.3	1.73	28.96	2.90	1.68	26.01	5.09	28.22	0.57
20-40 per cent	42	17.6	1.43	23.95	2.89	2.02	22.02	3.60	19.96	0.80
40-60 per cent	23	9.6	1.05	17.59	2.85	2.71	35.95	3.24	17.96	0.88
60-80 per cent	16	6.7	1.05	17.62	3.06	2.90	29.56	3.66	20.33	0.83
80-100 per cent	9	3.8	0.71	11.87	2.93	4.12	48.40	2.44	13.54	1.20
Total/ Average	239	100.0	5.98	100.00	14.63	2.44	30.09	18.03	100.00	0.81

These figures suggest and it can be verified from the data below that the average yield in these top districts is more than 2-times higher (4.92 t/ha) than the average yield for the country (2.31 t/ha) for the same period. The more worrying trend is for the first group of 149 districts covering 29.0 per cent of the maize area but have a very low maize yield of 1.84 t/ha. These constitute the rain fed maize production districts which when supplied with critical irrigation shall have much larger impacts in improving the yields (Table 16).

Table 16

Effect of irrigation level on maize yield in Tamil Nadu

Level of irrigation	Maize yield (kg/ha)
Normal irrigation	5960
Application of 75 per cent of water requirement	4429
Application of 50 per cent of water requirement	3221
Mean	4537

Irrigation SEd: 102; CD (0.05): 252 kg/ha

Source: Parthasarathy et al., 2013

5.3 Water use in maize

5.3.1 Water use and irrigation requirements of maize

Water management of maize and water productivity depends on the crop season. About 85 per cent of maize cultivation coincides with monsoon season and thus is majorly grown as a rain fed crop. In drier climates with assured facilities, irrigating at critical stages (young seedlings, knee-high stage, flowering and grain filling) brings significant increase in crop yield. First irrigation should be applied very carefully so as to not submerge the ridges and furrows or the plain fields. In raised bed planting system and limited water availability conditions, the irrigation water can also be applied in alternate furrows to save irrigation water. In rain fed areas, tied ridges are helpful in conserving the rainwater for its availability in the root zone for longer period. As maize is very sensitive to water congestion and water logging, quick drainage should be ensured in high rainfall areas or in case of a high rainfall event in other regions. For a high yield of about 5 t/ha the maize crop shall have a water requirement of 44 mm in 0-20 days; 161 mm in 20-50 days, 207 mm in 50-80 days and 82 mm in 80-100 days with a total of 495 mm in 100 days of active crop growth (Shankar et al., 2012).

Winter maize needs frequent and small irrigations to provide protection against frost and also to meet water requirements. Generally, 5-7 irrigations are sufficient to raise a high productivity winter maize crop.

Average yield of maize in the dominant districts varies from 1.84 t/ha to 4.92 t/ha with lower productivity in about 62 per cent of the districts.

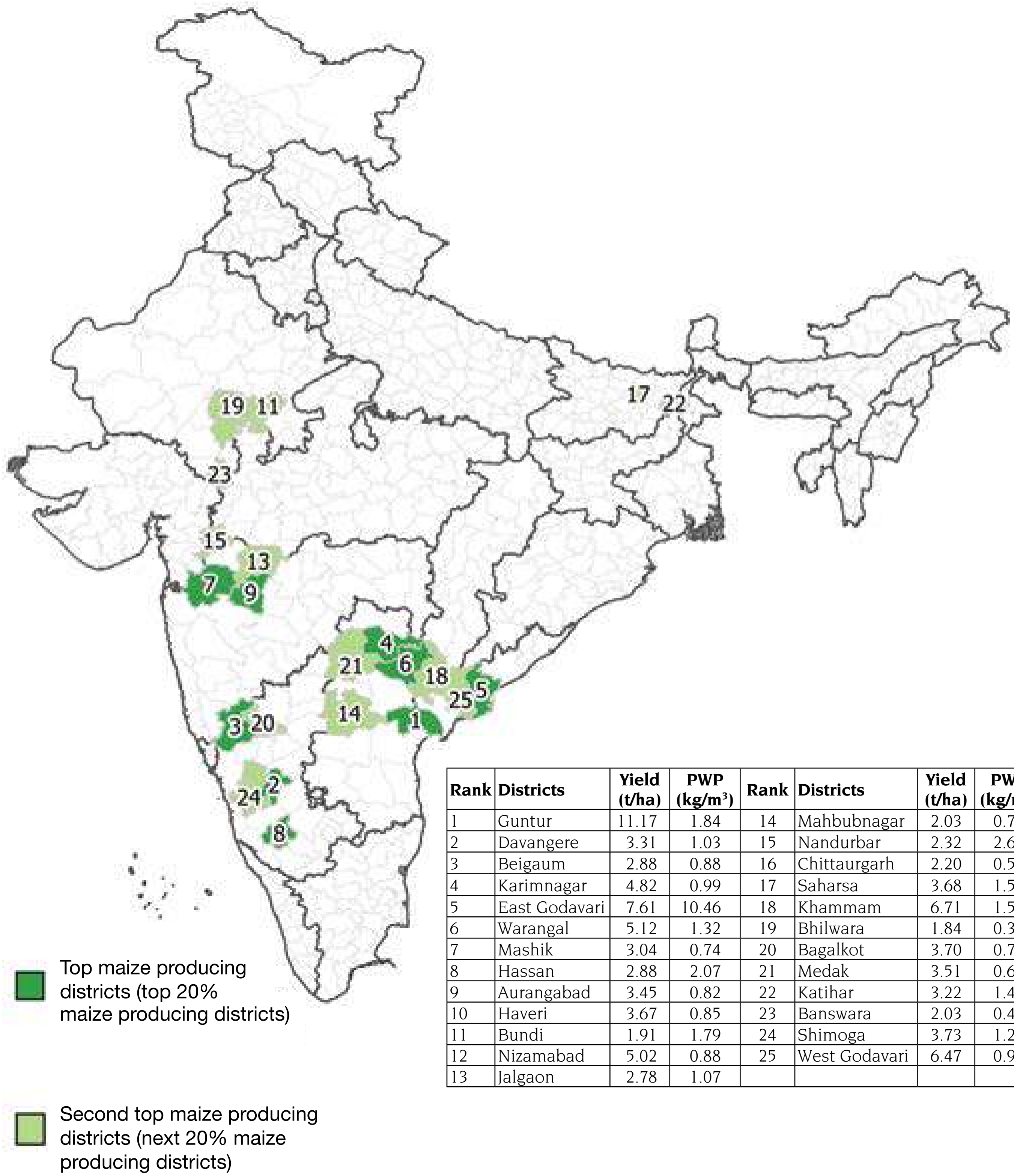
5.3.2 Water Productivity of Maize

5.3.2.1 Physical Water Productivity

Maize production in India varies from cultivation under purely rain fed and moisture stress conditions to fully irrigated conditions under kharif and winter season. Winter maize cannot be cultivated without assured irrigation. As such the average yield of maize in the dominant districts varies from 1.84 t/ha to 4.92 t/ha with lower productivity in about 62 per cent of the districts indicating a large unexploited potential for improvement of maize productivity. It is only less than 4 percent of the districts (total of 9 districts) covering 11.9 percent of total area which have an average productivity of 4.92 t/ha (Map 15).

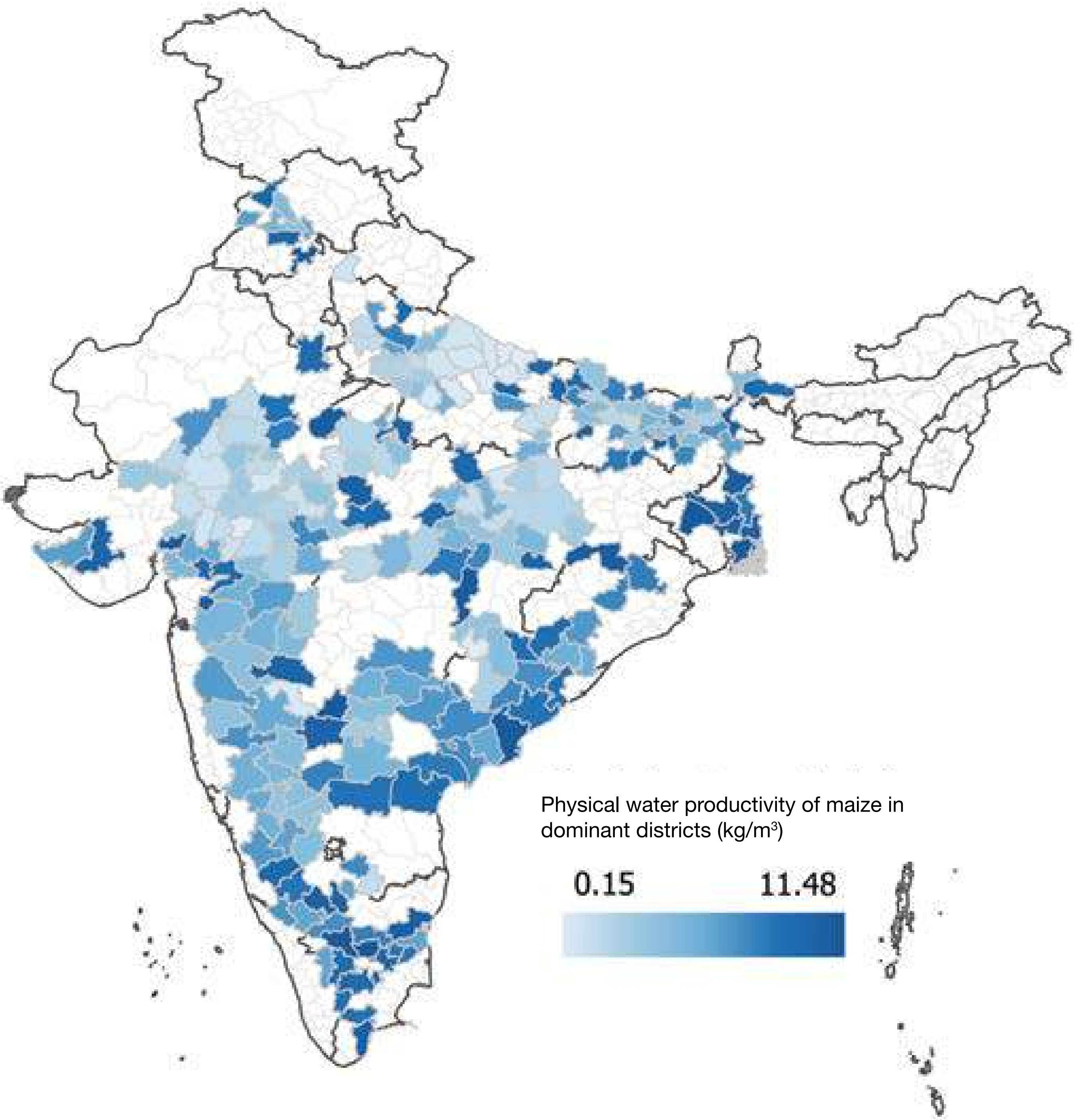
Total water consumed for production of maize in the dominant districts is 18.02 km^3 (18.02 BCM).

Total water consumed for production of maize in the dominant districts is 18.02 km^3 (18.02 BCM). The range for PWP for maize in India varies from



Rank	Districts	Yield (t/ha)	PWP (kg/m³)	Rank	Districts	Yield (t/ha)	PWP (kg/m³)
1	Guntur	11.17	1.84	14	Mahbubnagar	2.03	0.78
2	Davangere	3.31	1.03	15	Nandurbar	2.32	2.67
3	Beigaum	2.88	0.88	16	Chittaurgarh	2.20	0.54
4	Karimnagar	4.82	0.99	17	Saharsa	3.68	1.55
5	East Godavari	7.61	10.46	18	Khammam	6.71	1.54
6	Warangal	5.12	1.32	19	Bhilwara	1.84	0.34
7	Mashik	3.04	0.74	20	Bagalkot	3.70	0.74
8	Hassan	2.88	2.07	21	Medak	3.51	0.64
9	Aurangabad	3.45	0.82	22	Katihar	3.22	1.42
10	Haveri	3.67	0.85	23	Banswara	2.03	0.41
11	Bundi	1.91	1.79	24	Shimoga	3.73	1.25
12	Nizamabad	5.02	0.88	25	West Godavari	6.47	0.98
13	Jalgaon	2.78	1.07				

Map 15. Yield and physical water productivity of the top 25 maize production districts in India (These 25 districts produce 40 percent of total maize in the country)



Map 16. Variation in physical water productivity of maize across dominant districts for maize cultivation in India

a low of 0.16 kg/m^3 to as high as 11.5 kg/m^3 with the average PWP of 1.83 kg/m^3. These findings need to be considered along with the fact that the top performing districts occupy large share of area (approximately 30 per cent of total area under maize) and consume 33.8 per cent of total water for maize. But one of the interesting observations comes in the form of average PWP values for these districts. The data suggest that they don't necessarily use water in the most efficient manner resulting in lower levels of PWP as compared to other production groups.

This happens due to the nature of the crop as the over-irrigated crop tends to enhance its leaf area index with lower Harvest Index but higher stover content. So the crop needs to be optimally irrigated and fertilized. This finding is corroborated with bivariate correlation results. The correlation result suggests that districts producing more maize and consuming more water in the process may not necessarily have higher PWP (Table 17).

Table 17

Correlation between production, average yield and total consumptive water use with physical water productivity of maize

		Production	Avg Yield	Avg TCWU	PWP
Production	Pearson Correlation	1	.564**	.707**	-.012
	Sig. (2-tailed)		.000	.000	.852
	N	239	239	239	239
Avg Yield	Pearson Correlation	.564**	1	.182**	.223**
	Sig. (2-tailed)	.000		.005	.001
	N	239	239	239	239
Avg TCWU	Pearson Correlation	.707**	.182**	1	-.353**
	Sig. (2-tailed)	.000	.005		.000
	N	239	239	239	239
PWP	Pearson Correlation	-.012	.223**	-.353**	1
	Sig. (2-tailed)	.852	.001	.000	
	N	239	239	239	239

**. Correlation is significant at the 0.01 level (2-tailed).

Among the dominant maize producing states, West Bengal tops the rank with PWP of 5.1kg/m^3, while Rajasthan records lowest PWP vale of 0.9 kg/m^3 (Figure 15). Andhra Pradesh with highest yield of 4.48 t/ha among the dominant states has low PWP value 2 kg/m^3, indicating the inefficient water use in the state. Efficient water use is needed in such high maize yielding states to ensure sustainable water use during production.

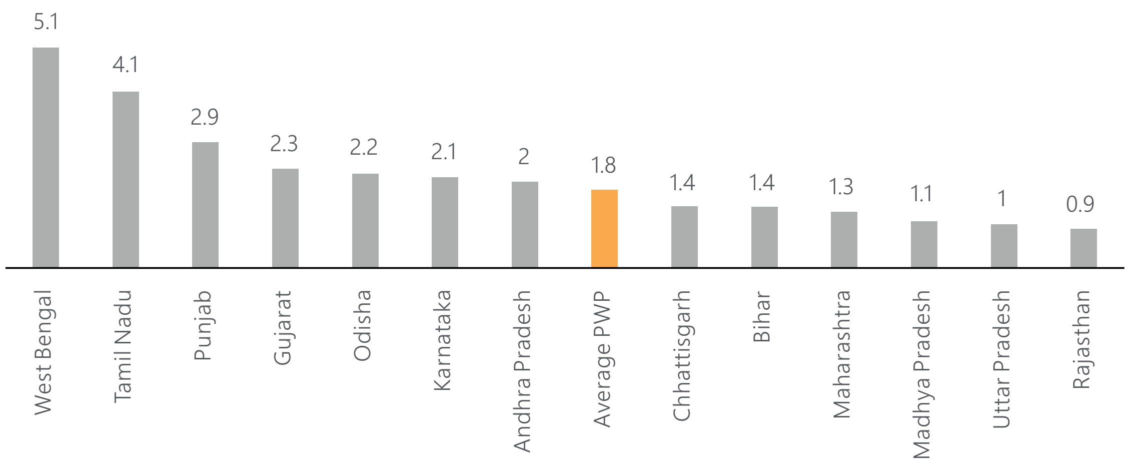


Figure 15. Physical water productivity (kg/m³) of maize across dominant maize producing states

5.3.2.2 Economic Water Productivity

The second part of the analysis divides the data variables at the state level. The data below (Table 18) is arranged based on the share of maize production for each dominant state. Some of the key points that stand out are:

i Karnataka has the highest share in maize area (17.3 per cent) and maize production (20.7 per cent). However in terms to productivity it lags behind, with yield of 2.9t/ha, physical water productivity (PWP) of 2.07 kg/m³ and corresponding lower economic water productivity (EWP) of just Rs 18.85 per cubic meter of water consumed. On the other hand, West Bengal with yield of 2.6t/ha, almost equivalent to Karnataka, has a much efficient water use scenario with PWP of 5.06 kg/m³ and EWP of above Rs 39 per cubic meter of water consumed.

ii. Bihar has low EWP (Rs 10.81/m³) and low PWP (1.43kg/m³) value, but its yield (2.7 t/ha) is higher than the national average of 2.3t/ha. However, due to imperfect markets and procurement policies, Farm Harvest Price of maize at Rs 772/ 100kg is one of the lowest in the country. This indicates there exist opportunities for ensuring sustainable maize production in Bihar.

iii. States best suitable for maize cultivation with respect to their high yield and high EWP are Tamil Nadu, West Bengal and Punjab while in states, with low EWP but better yields, like Karnataka, Bihar and Maharashtra, improved maize production can be ensured through efficient water use through micro irrigation technologies. In Tamil Nadu, Andhra Pradesh and Punjab maize value chains need to be appropriately developed for ensuring better returns to farmers, thereby promoting its adoption in these states.

Table 18

Economic water productivity of maize across dominant maize producing states in India

States	Total area (mha)	Percent Area	Total Production (m t)	Percent Production	Percent Irrigation	Yield (t/ha)	TCWU (km^3)	Average FHP (Rs/qntl)	Economic Water Productivity (Rs/m^3)
Tamil Nadu	0.15	2.59	0.65	4.44	52.73	4.19	0.22	995.0	40.80
West Bengal	0.05	0.80	0.17	1.14	43.00	3.48	0.07	772.3	39.39
Punjab	0.14	2.36	0.44	3.03	62.76	3.14	0.37	1238.5	35.92
Gujarat	0.44	7.34	0.61	4.18	3.89	1.39	1.16	1011.5	23.26
Andhra Pradesh	0.64	10.74	2.88	19.67	52.67	4.48	2.23	951.0	19.02
Karnataka	1.03	17.27	3.03	20.69	46.41	2.93	3.02	897.4	18.85
Odisha	0.06	1.01	0.15	1.03	5.53	2.51	0.07	836.5	18.40
Chhattisgarh	0.09	1.46	0.14	0.96	5.53	1.6	0.25	1013.5	14.19
Maharashtra	0.6	9.96	1.63	11.17	13.00	2.74	1.79	846.0	11.00
Bihar	0.57	9.53	1.61	10.98	72.33	2.82	1.91	772.3	10.81
Madhya Pradesh	0.75	12.51	1.06	7.24	1.99	1.41	2.17	884.5	9.73
Uttar Pradesh	0.58	9.64	0.87	5.92	43.79	1.5	1.95	868.5	8.69
Rajasthan	0.88	14.79	1.4	9.55	0.99	1.58	2.82	958.5	8.63
Total/Average	5.98	100	14.63	100	30.09	2.44	18.03		

iv. Gujarat has high EWP and PWP values but low yield. Improved varieties need to be introduced, so that the advantage of higher water productivity can be realized along with ensuring better production.

5.4 Conclusions

Maize is yet another cereal crop cultivated widely on 9 million ha in India. Much of maize (more than 75 percent) is used for poultry feed and starch and less than 25 percent of it goes for direct human consumption. Almost 76 per cent of maize in India is grown in rain fed areas. However with efficient irrigation during the critical growth stages, the crop shows significant increase in yield. In states like Punjab, Andhra Pradesh and Tamil Nadu with more than 50 per cent maize area under irrigation and higher levels of economic water productivity, value chains in maize must be developed to promote remunerative cultivation of the crop. While in states like Bihar, Karnataka and Maharashtra with high yield potential but low economic water productivity, adequate irrigation and efficient water use practices must be adopted in addition to vibrant marketing opportunities through value chains. Gujarat which has better water productivity but relatively lower yields need to introduce high yielding maize varieties thereby ensuring the sustainable and optimal crop production.

6

Chickpea (Gram/*Chana*)

6.1 Chickpea in the world

Chickpea (*Cicer arietinum* L) is a cool season major pulse crop. It is cultivated in about 60 countries of which 85 per cent are in Asia, 5.5 per cent in Africa, 4.6 per cent in Oceania, 3.5 per cent in Americas and the rest 1.2 per cent in Europe (FAO)[10]. India is the largest chickpea producer and contributes 72 per cent to the global production. Other major chickpea producing countries are Pakistan, Turkey, Iran, Myanmar, Australia, Ethiopia, Canada and Mexico. Chickpea as a staple food and as a snack is an important protein source for the vegetarian diet. There are two distinct types of chickpea called ***desi*** and *kabuli* that differ in size, color and surface of the seeds. Potential yield of chickpea is estimated at 5.0 t/ha while its average global yield is 0.98 t/ha. The obvious reasons are cultivation under energy starved conditions on marginal and sub-marginal lands with no or low input management, late sowing, higher degree of susceptibility to both biotic and abiotic stresses, unavailability of quality seeds of high yielding varieties, poor or no use of plant protection measures, lack of winter precipitation and inadequacy of stored soil moisture leading to poor land and water productivity.

6.2 Chickpea in India

Chickpea is the major pulse crop and has a share of about 43.5 per cent in the total pulse production in the country. All India trend in cultivated area, total production, average yield and the area under irrigation for the chickpea crop since 1950 is shown in Figure 16. Presently, chickpea crop is cultivated in about 8.5 mha, with a total production of 7.6 mt and an average productivity of 900 kg/ha.

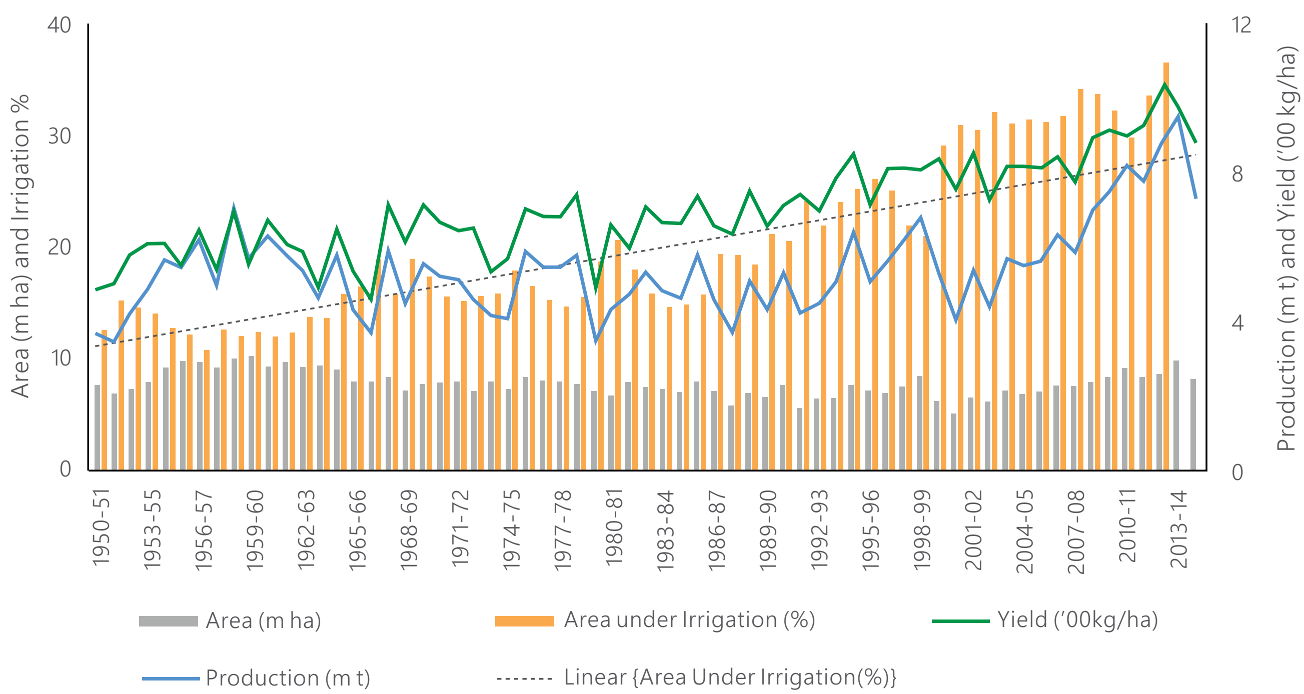


Figure 16. All India trend in cultivated area, total production, average yield and the area under irrigation for the chickpea crop since 1950 (DES, 2016)

[10] http://www.fao.org/faostat/en/#data/QC

Chickpea also contributes the single largest share in India's export basket of pulses, with a share of 65.5 per cent in 2016-17

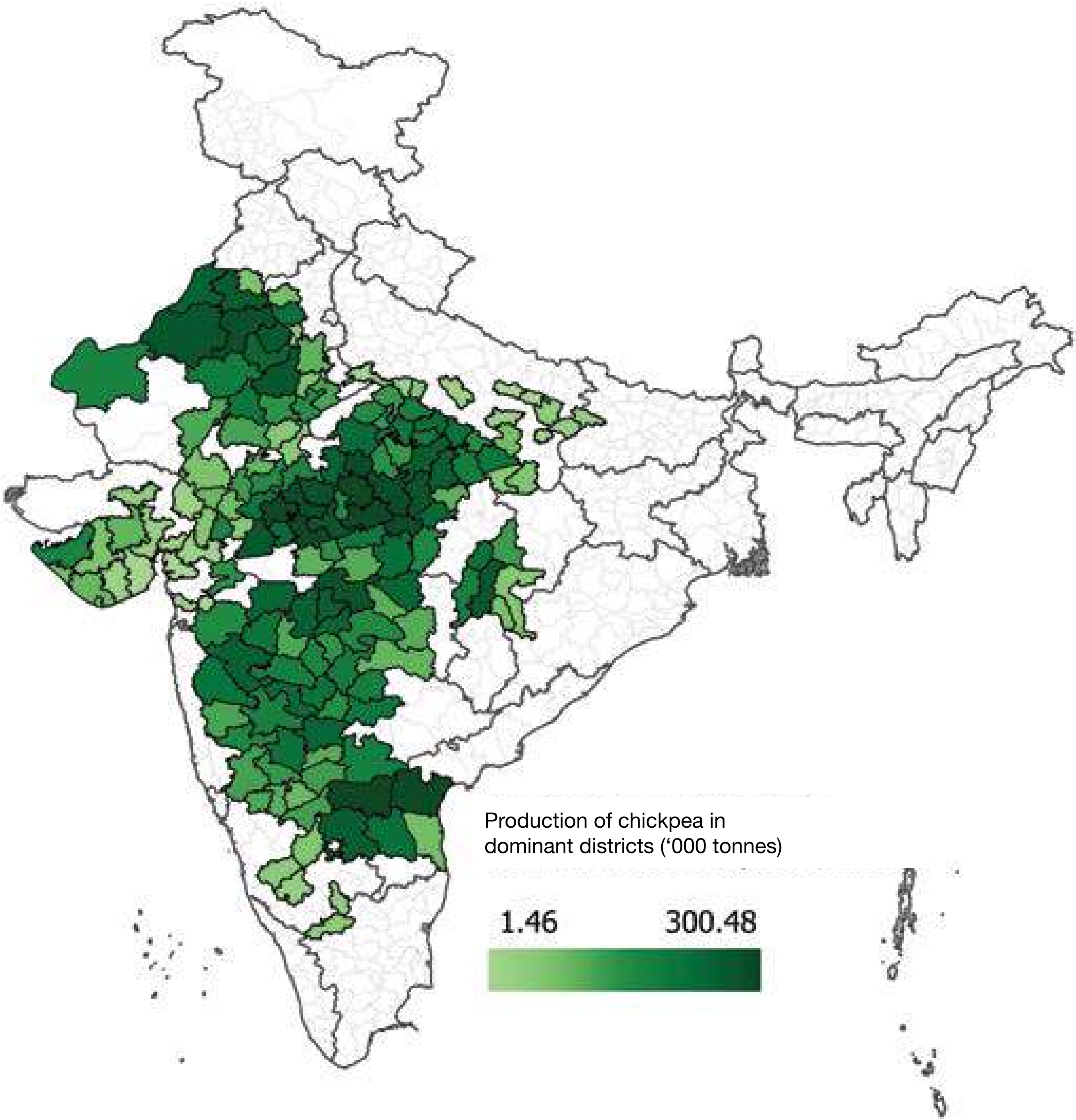
From a meagre 12.5 per cent in 1950-51, the irrigation cover in chickpea has at present reached 35.2 per cent. The close linear relationship between area under irrigation and yield indicates that the crop responds favourably to irrigation. In the last four decades, the area, production and productivity of chickpea fluctuated widely. There has been a major shift (about 4.0 million ha) in chickpea area from northern India (cooler, long-season environments) to central and southern India (warm, short-season environments). Some of the states like Punjab, Haryana, Uttar Pradesh and Bihar have lost considerable area of chickpea whereas other states like Andhra Pradesh, Maharashtra, and Karnataka have brought in additional area. Chickpea crop has witnessed an impressive growth in area, production and productivity in India during the past decade. It is interesting to note that the growth rate of chickpea production was 5.89 per cent during last one decade which is much higher than other crops. During 2013-14, chickpea production exceeded 9.5 million tonnes attaining highest peak in production in the history of its cultivation in India (Anonymous, 2014-15). Chickpea also contributes the single largest share in India's export basket of pulses, with a share of 65.5 per cent in 2016-17, which was much lower than 88.3 per cent in 2015-16.

6.2.1 Dominant districts for chickpea cultivation in India

District wise data for 2009-10 and 2010-11 indicated that Chickpea is grown in 20 states and one union territory. Cropped area of about 8.11 mha is spread across 268 districts. The total annual chickpea production is above 7.3 mt with the average yield of 0.9 t/ha.

All India Chickpea data was filtered down to conduct analysis for the dominant production districts. This brought down the number of states from 20 to 9 states. The district level filter got the total number of districts to 172. These districts cultivate 7.75 mha area under chickpea with a total production of 6.9 mt and an average yield of 0.9 t/ ha. These district level filtered data was further cleaned for the outliers. After this step, there were 157 districts with a total production of 6.8 mt from 7.56 mha with an average yield of 0.9 t/ha. Variation in production (in absolute terms) of chickpea across these 157 dominant districts is shown below in the map (Map 17).

Production of chickpea is now concentrated in the states of Madhya



Map 17. Variation in production in the 157 dominant chickpea districts of India

Pradesh, Rajasthan, Maharashtra, Karnataka and Andhra Pradesh. After the era of Green Revolution the traditional base of chickpea in Punjab, Haryana, Uttar Pradesh and Bihar has now moved to the central and southern states with the largest concentration in Madhya Pradesh.

Table 19 shows the distribution for area, production, and yield for chickpea. The distribution clearly points out that Madhya Pradesh is the top state with close to 38 per cent share in India's total chickpea area, almost 40 per cent contribution in total production and with average yield of 0.94 t/ha, slightly higher than all India average yield of 0.90 t/ha. Another interesting fact that comes through about Madhya Pradesh's chickpea cultivation is that 50 per cent of the area is irrigated, which is highest in India and almost 18 per cent higher than all India average. The states of Maharashtra and Rajasthan come after Madhya Pradesh in terms of area and production share. But it is Andhra Pradesh (1.27 t/ha) followed by Gujarat (1.05 t/ha) that show highest yield rates of more than 1 t/ha.

Table 19

Variation in cultivated area, production, yield and percent irrigated area under the major chickpea growing states of India

States	Area (m ha.)	Percent area	Production (m t)	Percent production	Yield (t/ha.)	Percent irrigated
Madhya Pradesh	2.86	37.85	2.68	39.5	0.94	49.4
Maharashtra	1.31	17.37	1.17	17.15	0.89	24.6
Rajasthan	1.3	17.2	1.03	15.19	0.79	33.6
Andhra Pradesh	0.59	7.83	0.75	11.07	1.27	NA
Karnataka	0.56	7.44	0.35	5.11	0.62	22.6
Uttar Pradesh	0.44	5.82	0.35	5.15	0.8	16.2
Chhattisgarh	0.25	3.3	0.23	3.36	0.91	26.2
Gujarat	0.15	1.96	0.15	2.28	1.05	NA
Haryana	0.09	1.24	0.08	1.21	0.87	14.2
Total/Average	7.56	100	6.8	100	0.9	32.5

Similar to the analysis for other crops, these 157 districts were divided into 5 groups with each group contributing 20 per cent of the total production. Scatter plot of the dominant districts is shown in Figure 17. The bottom-most group is made up of 90 districts (57 per cent of all districts) that cumulatively contribute 20 per cent of production, cover 22 per cent of the total area with an average yield of 0.8 t/ha. These figures suggest that these are mostly small districts with lower yield level. The top two groups have only 20 districts (12.7 per cent of districts) that contribute 40 per cent of total chickpea production (Table 20) in India. This shows that the crop has a small agro-climatic niche' where most of the cultivation of this crop is concentrated. The data also suggest that these top producing districts are also large in size and chickpea production is a dominant rabi crop as these 20 districts cover 37 per cent of the total chickpea area. Higher yield in these production groups is supported by higher percentage of area under irrigation (41 to 43 percent) as compared to other groups (23 to 25 per cent). Irrigation water needs of chickpea crop are small but significantly improve the crop yields.

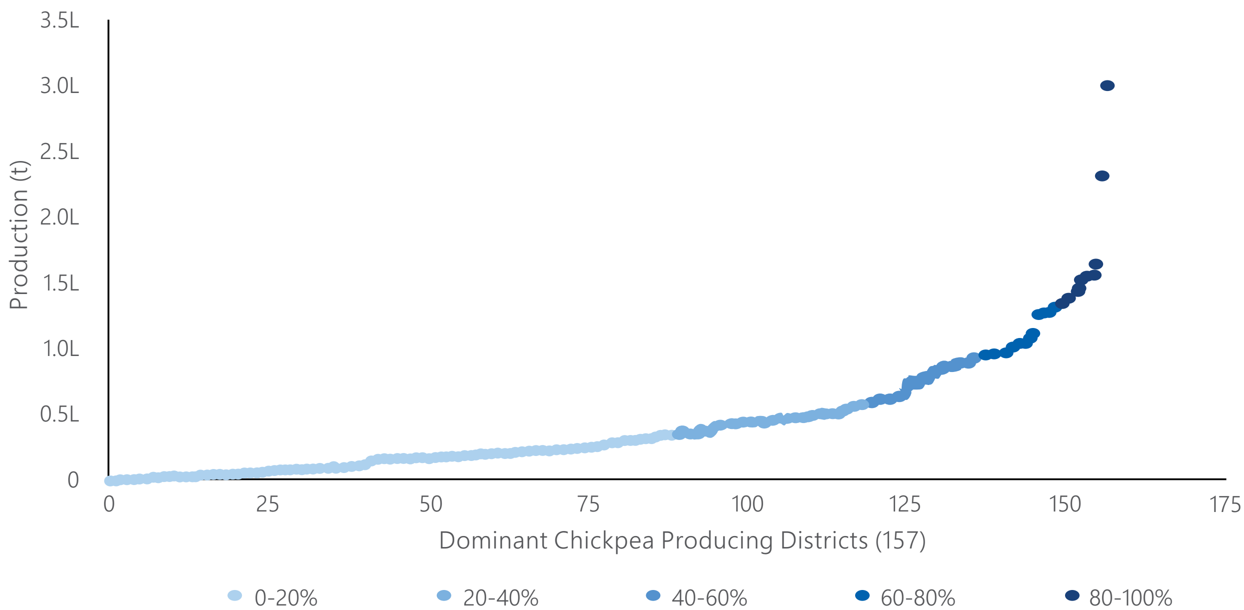


Figure 17. Scatter plot of chickpea production in the dominant chickpea districts of India

Table 20
Variation in coverage of districts, area under cultivation, production and yield of chickpeas under the main production groups of chickpea in India

Production wise groups	Number of districts	Percent of districts	Area (m ha.)	Percent area	Production (m t)	Yield (t/ha)	Percent area irrigated
0-20 per cent	90	57.3	1.66	22.0	1.33	0.80	25.8
20-40 per cent	29	18.5	1.61	21.3	1.35	0.84	23.7
40-60 per cent	18	11.5	1.50	19.8	1.37	0.92	31.0
60-80 per cent	12	7.6	1.52	20.2	1.32	0.87	43.4
80-100 per cent	8	5.1	1.27	16.8	1.42	1.12	41.0
Total/Average	157	100.0	7.56	100.0	6.80	0.90	32.5

6.3 Water use in chickpea

6.3.1 Water use and irrigation requirement of chickpea

Chickpea crop is better adapted to low water supply and is able to extract conserved moisture in deep soils. It is normally cultivated as rain fed crop. Seed yield improves significantly under properly scheduled irrigations. The crop requires light irrigations as excessive watering results in extra vegetative growth and reduces the grain yield. In case of moisture stress and poor winter rains, first irrigation at pre-flowering stage, second at branching/ flowering stage and the last at pod-development stage are very helpful (Table 21). Total irrigation water requirement of the crop varies between 100-150 mm. Chickpea crop is intolerant to excessive soil water, especially during the early stages of growth and on fine-textured soils; good drainage is essential.

Table 21
Effect of irrigation application on seed yield, water use, water-use efficiency and economics of chickpea cultivation at Rahuri, Maharashtra

Treatment Irrigation Schedule (ET_c)	Grain yield (kg/ ha)	Water used, mm	Water-use efficiency (kg/ ha-mm)	Benefit: cost ratio
60 per cent of ET_c	1972	95.0	20.8	1.66
80 per cent of ET_c	2322	124.4	18.7	1.95
100 per cent of ET_c	2372	153.8	15.4	1.99
C.D. (5 per cent)	298	-	-	0.23

Source: (ICAR-AICRP on Chickpea Annual Report, 2013-14)

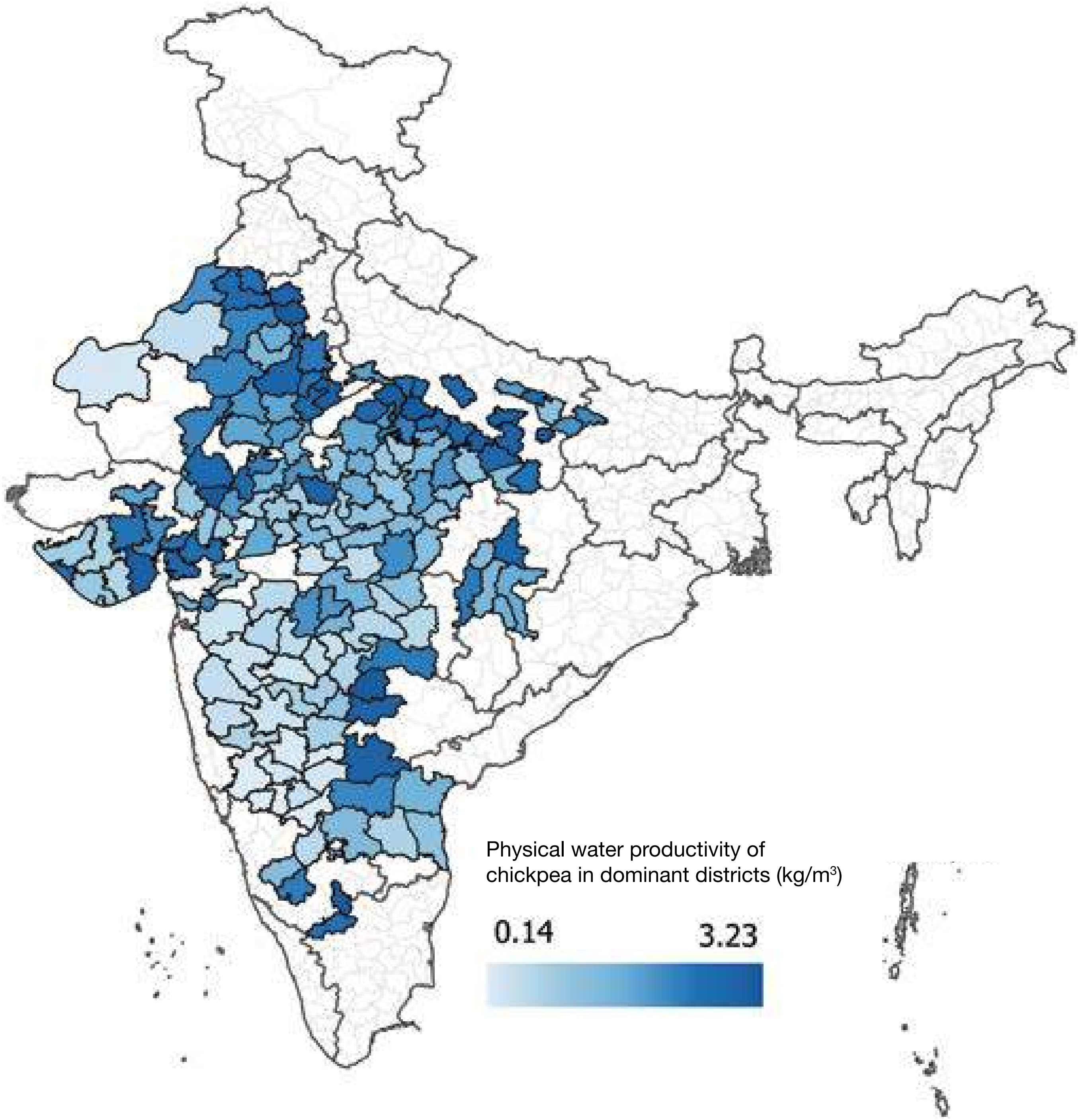
6.3.2 Water Productivity of Chickpea

6.3.2.1 Physical Water Productivity

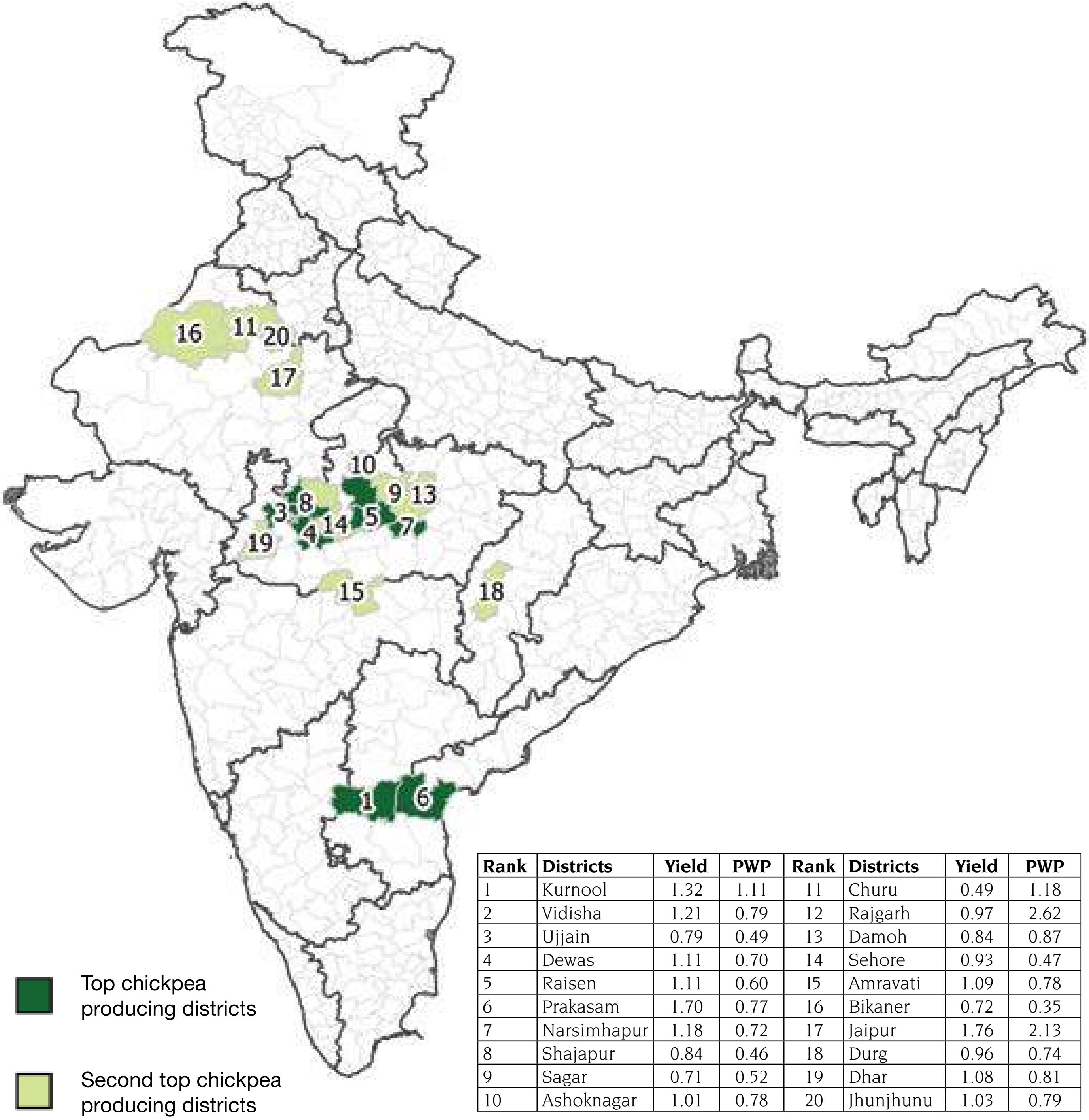
Total Consumptive Water Use for chickpea production in the dominant chickpea production districts in India is 10.7 km^3 (10.7 BCM). The water consumption figures for the 5 production-wise groups suggest that the

Table 22
Variation in total consumptive water use and physical water productivity across different production groups of chickpea production in India

Production wise groups	Production (m t)	Total Consumptive Water Use (km^3)	Percent of Total Consumptive Water Use	Physical Water Productivity (kg/m^3)
I. 0-20 per cent	1.33	2.6	24.0	0.52
II. 20-40 per cent	1.35	2.2	20.4	0.62
III. 40-60 per cent	1.37	2.2	20.1	0.64
IV. 60-80 per cent	1.32	1.8	16.4	0.75
V. 80-100 per cent	1.42	2.1	19.1	0.69
Total/Average	6.80	10.7	100.0	0.63



Map 18. Variation in physical water productivity of chickpea across dominant chickpea districts of India: Chickpea water productivity map of India



Rank	Districts	Yield	PWP	Rank	Districts	Yield	PWP
1	Kurnool	1.32	1.11	11	Churu	0.49	1.18
2	Vidisha	1.21	0.79	12	Rajgarh	0.97	2.62
3	Ujjain	0.79	0.49	13	Damoh	0.84	0.87
4	Dewas	1.11	0.70	14	Sehore	0.93	0.47
5	Raisen	1.11	0.60	15	Amravati	1.09	0.78
6	Prakasam	1.70	0.77	16	Bikaner	0.72	0.35
7	Narsimhapur	1.18	0.72	17	Jaipur	1.76	2.13
8	Shajapur	0.84	0.46	18	Durg	0.96	0.74
9	Sagar	0.71	0.52	19	Dhar	1.08	0.81
10	Ashoknagar	1.01	0.78	20	Jhunjhunu	1.03	0.79

Map 19. Physical water productivity in top chickpea producing districts of India

Group-I consumes the largest share of water, which is close to 1/4th of the total water for chickpea production. But this group demonstrates the lowest level of PWP at 0.52 kg/m^3. Average physical water productivity for chickpea production is 0.63 kg/m^3 (Table 22). Remaining groups (except 60-80 per cent group) consume comparable amount of water but the two top most groups have higher PWP than the rest. When the analysis is coupled with the area under irrigation under these a clear trend emerges on the positive impact of limited amount of irrigation on improvements in water productivity of the chickpea crop.

The variations of Physical Water Productivity values across these dominant districts are shown in the map (Map 18).

As shown in the Map 18, the range in variation of water productivity is very large- from a low of 0.14 to the high of 3.23 kg/m^3 , a factor of 23 times indicating a very large potential for improving the water productivity of chickpea. Available water harvested through rainwater or use of shallow groundwater shall have the highest value in chickpea as the crop just needs 50 to 100 mm of water and the gains are spectacular. Highest water productivity is observed in the border districts of UP and Madhya Pradesh (Bundelkhand), northern Rajasthan and Telangana. Large number of districts in Madhya Pradesh, Maharashtra and Karnataka have very low physical water productivity from the chickpea crop.

These 20 districts are the most critical for chickpea production in the country and contribute 40 percent to the total chickpea production. Kurnool district in Andhra Pradesh is the highest chickpea producing district with productivity of 1320 kg/ha and water productivity of 1.11 kg/m^3. Madhya Pradesh has the highest number of high chickpea producing districts. Jaipur district in Rajasthan has the highest average yield of 1760 kg/ ha with a very high water productivity of 2.13 kg/m^3 (Map 19)

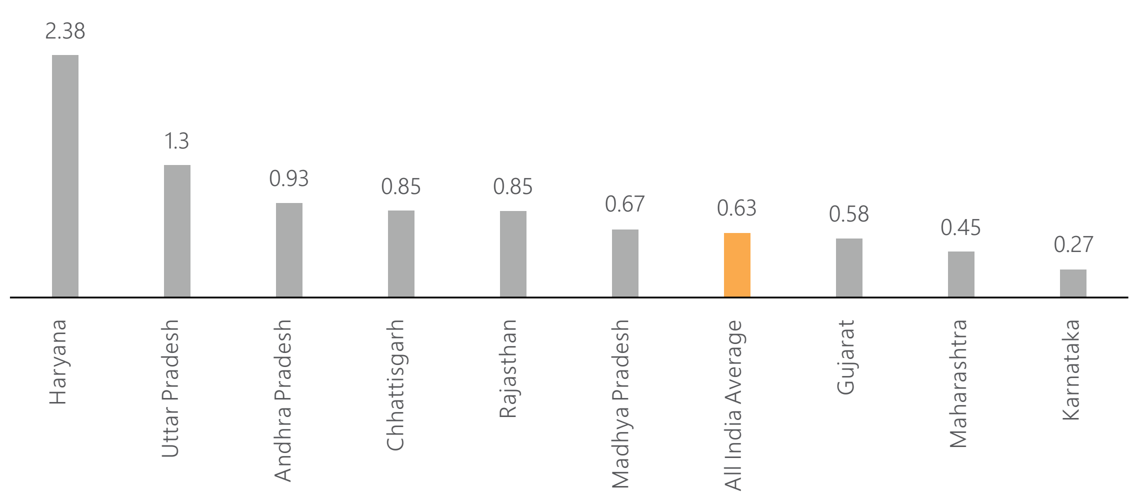


Figure 18. Physical water productivity (kg/m^3) of chickpea across major states

In case of physical water productivity, Haryana and Uttar Pradesh are the top two states. Haryana's PWP value is more than 3.5 times higher than all India average. So, Haryana's agro-climate is extremely suitable for production of chickpea and reclaiming the lost area of chickpea to other water requirements can be part of a larger solution for the large negative water balance of the state. The case of Karnataka is a concerning one as it has under 7.5 per cent of area share but consumes 12 per cent of water with the lowest PWP among states at 0.27kg/m^3 (Figure 18).

6.3.2.2 Economic Water Productivity

More than 37.5 per cent of the TCWU for chickpea cultivation in India is used in Madhya Pradesh. Other states that consume higher share of water for chickpea cultivation include Maharashtra, Karnataka, and Rajasthan. The highest value of EWP in chickpea is reported in Haryana state (Rs 53.4/m^3), while in Madhya Pradesh, the top chickpea producing state of India, the EWP value hovers around Rs 14.3/m^3, way below the average EWP value of the dominant chickpea producing states (Rs 21.1/m^3). The low PWP and EWP of chickpea in Madhya Pradesh having 49 per cent of its area under irrigation, point towards the inefficient water use in crop production (Table 23).

Table 23

Variation in total consumptive water use and physical water productivity among the major chickpea growing states of India.

States	Production (m t)	TCWU (km^3)	Farm Harvest Price (Rs)	Total Economic Value (Rs in crore)	Economic Water Productivity (Rs/m^3)
Andhra Pradesh	0.75	0.81	2275.5	1711.5	21.2
Chhattisgarh	0.23	0.27	3140.5	716.4	26.8
Gujarat	0.15	0.27	2136.5	330.5	12.4
Haryana	0.08	0.03	2245.5	184.1	53.4
Karnataka	0.35	1.26	2120.5	736.0	5.8
Madhya Pradesh	2.68	4.03	2143.0	5752.2	14.3
Maharashtra	1.17	2.59	2023.5	2358.6	9.1
Rajasthan	1.03	1.21	2242.5	2314.5	19.1
Uttar Pradesh	0.35	0.27	2147.0	751.5	27.8
Total/Average	6.80	10.73	2185.8	14855.4	21.1

The correlation analysis between area, production, yield, Total Consumptive Water Use, Physical Water Productivity and the percent irrigated area is presented in Table 24.

Table 24
Pearson correlation for the different variables for chickpea production in India

		Area	Production	Yield	TCWU	PWP	Irrigated Area
Production	Pearson Correlation	.916**	1	.145	.804**	-.124	.683**
	Sig. (2-tailed)	.000		.070	.000	.121	.000
Yield	Pearson Correlation	-.129	.145	1	-.093	.267**	-.075
	Sig. (2-tailed)	.106	.070		.247	.001	.349
TCWU	Pearson Correlation	.812**	.804**	-.093	1	-.477**	.764**
	Sig. (2-tailed)	.000	.000	.247		.000	.000
PWP	Pearson Correlation	-.185*	-.124	.267**	-.477**	1	-.257**
	Sig. (2-tailed)	.020	.121	.001	.000		.001
Irrigated Area	Pearson Correlation	.729**	.683**	-.075	.764**	-.257**	1
	Sig. (2-tailed)	.000	.000	.349	.000	.001	
Sample size (N)		157	157	157	157	157	157

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Main findings from the correlation analysis are;

i. When it comes to productivity, chickpea is an interesting crop as higher yields are not associated with water availability. But districts with high yield also are likely to use water more efficiently resulting in higher PWP values. In fact, the results show that high water consumption might lead low water use efficiency as the coefficient between TCWU and PWP is negative and highly significant.

ii. This shows that the crop needs a cooler environment and in case of deficient winter rains, the crop may be provided with just one or two light irrigations at the critical stages of branching and pod development.

iii. Chickpea crop has high economic value in India and also good export potential. In water deficient areas and where farmers are able to harvest some monsoon rain water in small farm ponds, chickpea is an ideal crop. This finding is validated by the relation between irrigated area, yield and Physical Water Productivity.

iv. The crop responds very well to small irrigation, and being indeterminate pulse crop, more water actually leads to higher vegetative growth and poor partitioning between biomass and seed yield sometimes resulting in low productivity.

6.4 Conclusions

Chickpea is a major *rabi* pulse crop and has a share of 43.5 per cent in total pulse production in India. Despite being a rabi crop, its irrigation coverage in India is only 35.2 per cent. Though the irrigation requirement for the crop is very low (10 cm-15 cm), yet correlation results suggest that there exists positive linear relationship between crop yield and area under irrigation.

The average PWP of Chickpea is 0.63 kg/m³.

Chickpea has a very high average EWP of Rs. 21.1/m³ with the highest value of Rs 53.4/m³ in Haryana. Under water scarcity conditions, chickpea is an ideal crop and produces 'more value for each drop of water'.

The Total Consumptive Use for Chickpea production in India is 10.7 km³ and the average Physical Water Productivity of Chickpea is 0.63 kg/m³.The top chickpea producing states like Madhya Pradesh and Maharashtra lag behind in terms of PWP values. Thus efficient water management need to be adopted in these states to ensure better water productivity in addition to the existing higher yield (land productivity) status. Among the top chickpea producing districts identified, Rajgarh district of Madhya Pradesh and Jaipur district of Rajasthan record high PWP values. Lessons can be learned from these bright spots in ensuring better production in a water sustainable way.

As compared to other crops, chickpea has a very high average Economic Water Productivity of Rs 21.1/ m³ with the highest value of Rs 53.4 kg/m³ in Haryana. This means under scarcity and stress conditions, chickpea is an ideal crop and produces 'more value for each drop of water'.

Chickpea yields are higher under cooler and longer growth season of northern states (Punjab, Haryana, Rajasthan, and Bihar) as compared to warmer central and southern states. Provision of small but controlled irrigation through wells/ tubewells significantly improves land and water productivity. So the lost area from the northern states need to recovered for higher chickpea production and productivity. The crop also has a good export potential and assured domestic demand through an established value chain.

7

Pigeon Pea
(*Tur*/ *Arhar*/ Red gram)[11]

[11] The terms Pigeon pea, Tur, arhar, red gram have been used interchangeably in the text.

7.1 Pigeon pea in the world

Pigeon pea (*Cajanus cajan*) is native to India and migrated to countries in Asia, Africa, Europe and the Americas. Today, pigeon peas are cultivated in 23 sub-tropical and tropical countries, but India is by far the largest producer, consumer and also importer of pigeon peas. Other major global producers are Myanmar, Malawi, Kenya, Tanzania, which together with India produce almost 97 per cent of World's pigeon pea. In the last five decades, with the global acreage increasing by 1.5 times, from 2.8 mha to 7.0 mha, the global production reached 4.8 million tonnes with average productivity of 695.3 kg/ha. In 2015-16, pigeon pea production in India was estimated at 2.46 mt and per hectare yield was 656 kg (DES, 2016). Despite being the largest producer, owing to the existence of huge demand-supply gap, India continues to import pigeon pea. In 2016-17, India imported 0.7 mt of pigeon pea, about 1.5 times more than the preceding year. (DOC, GoI)[12]. Lack of suitable drought and pest-resistant varieties for medium and short duration crops, moisture stress to the crop during critical crop growth stages and imperfect markets along with price volatility are the major reasons hindering the improved growth and adoption of crop in India.

7.2 Pigeon pea in India

Pigeon pea is not as widely adopted and grown in India as it could be because 95 per cent of the crop is rain fed, suitable drought and pest-resistant varieties are lacking, and the markets are imperfect.

Pigeon pea is the second important pulse crop in India after gram. Multiple utility of the plant (grain, fodder, vegetable, fuel, thatching etc.) along with its ability to produce economic yields under moisture stress conditions makes it an important crop in rain fed and dryland areas. India produces about 67 percent of the total global output of the crop (FAO)[13]. Currently, major producers of arhar/ tur in India are Madhya Pradesh (25 per cent), Maharashtra (19 per cent), Karnataka (11 per cent) and Gujarat (10 per cent) together contributing more than 65 per cent share in total production (DES, 2016). Pigeon pea was a major crop in Uttar Pradesh in pre-Green Revolution era. However, the advent of canal and tubewell irrigation in the state resulted in migration of farmers from cultivation of tur to paddy (which was more remunerative and stable crop in irrigated conditions) thus limiting tur cultivation to semi-arid tropical drylands. The crop is cultivated in an area of about 3.75 mha. While the area under tur cultivation has increased by about 6.8 per cent over the last two

[12] Commerce.gov.in/eidb/default.asp
[13] www.fao.org/faostat/en/#data/QC

decades, production and productivity has remained consistently low on account of crop being grown largely under rain fed areas. Presently, less than 5 per cent of the crop is under irrigation (Figure 19). Consequently, production trends in India indicate intense fluctuations with productivity dropping by up to 25 per cent in drought conditions. While there is tremendous demand for tur dal in India, focus on increasing production and productivity remains inadequately addressed.

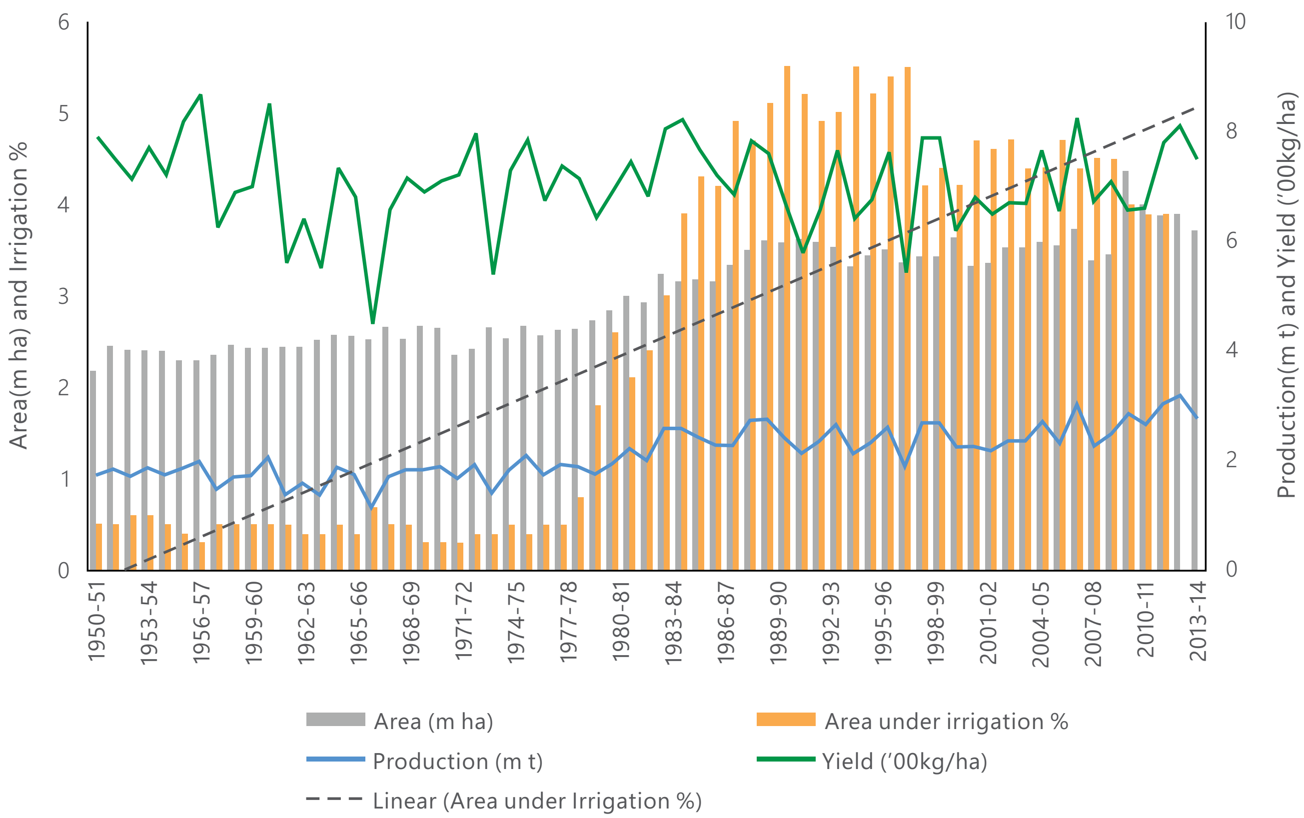
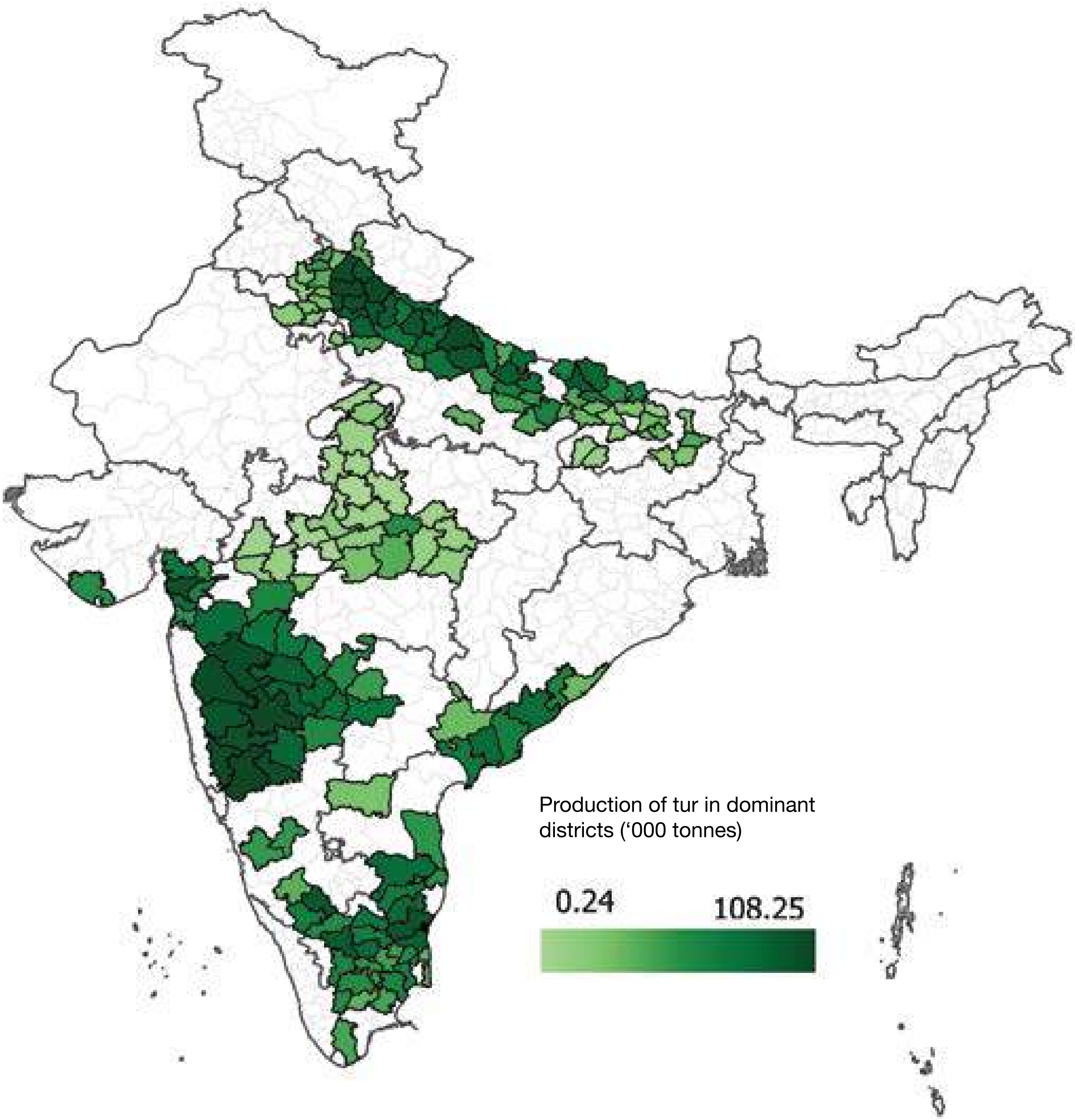


Figure 19. All India tur (arhar): area, production, yield, irrigated area (1950-2014)

7.2.1 Dominant districts for pigeon pea cultivation

The data for pigeon peas obtained from the Ministry of Agriculture for 2009-10 and 2010-11 highlights its importance in India's food scenario. The crop is cultivated in 21 states and one union territory spread across 463 districts. The average of total area under tur cultivation during the period was 3.92 mha, while the total production was 2.66 million tonnes with the average yield of 683 kg/hectare. To narrow down the focus of study, like other crops, the all India data is filtered down using the state and districts filters. This criterion identifies 169 dominant districts spread over seven dominant states (Maharashtra, Madhya Pradesh, Uttar Pradesh, Gujarat, Karnataka, Chhattisgarh, Andhra Pradesh and Telangana) for pigeon pea production in



Map 20. Variation in production across 167 dominant tur districts of India

India. To cut down the skew in our analysis, few district outliers (Gulbarga and Kanpur Dehat) are taken out which left us with 167 districts across 7 states. These districts cover 85 per cent of area and production of Tur in India and their yield is similar to all India yield. Map 20 shows these districts and presents the range in production.

In the next stage of the analysis, these dominant districts are divided based on production into five percentage groups. Each of these groups contributes 20 per cent of total production. Scatter plot of these production groups is shown in Figure 20. Maximum number of 117 districts (or more than 70 per cent of the dominant districts) are included in the first group and covers more than 1/4th of the total area under Tur (Table 25). The average yield of this group is also the lowest compared to others. Because of its low yield, despite covering large area and most number of districts, the first group only contributes 20 per cent of the total production. This stands in stark contrast when the top percentage groups are considered. The top two groups contain only 13 districts, less than 8 per cent of the total number of dominant districts considered. They cover 33 per cent of the total area and contribute almost 40 per cent in total production. These districts have some of the highest yield of around 810 kg/ha. Highest average yield of 1270 kg/ha is observed in Latur district of Maharashtra.

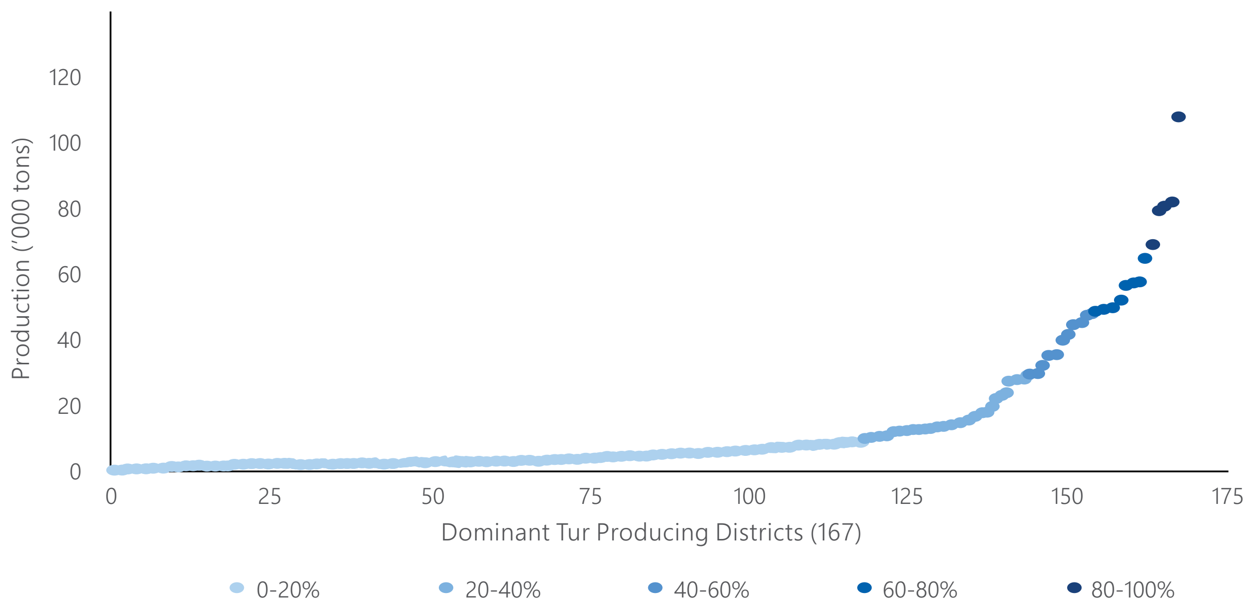


Figure 20. Scatter plot of tur production in the dominant tur districts of India

The second part of the analysis summarizes data at the state level. The data below (Table 26) points out that Maharashtra has the largest area under Tur (1.16 m ha or 36.25 per cent of total area) but only 2 per cent of the crop is irrigated. Only Uttar Pradesh which cultivates tur as a rabi crop on the residual soil moisture has coverage of about 13 per cent under irrigation. At the national level, less than 4 per cent of the crop is under irrigation which is a major factor for low level of national productivity at 660 kg/ha.

Table 25

Production-wise percentage groups for pigeon pea production in India

Production wise percentage groups	Number of districts	Percent of districts	Area (m ha.)	Percent Area	Production (m t)	Yield (t/ha)	Area under irrigated (m ha.)	Percent Irrigated
0-20 per cent	117	70.1	0.82	25.7	0.42	0.51	0.05	6.51
20-40 per cent	26	15.6	0.72	22.4	0.41	0.58	0.01	1.22
40-60 per cent	11	6.6	0.60	18.9	0.43	0.71	0.01	2.17
60-80 per cent	8	4.8	0.52	16.4	0.44	0.83	0.02	4.37
80-100 per cent	5	3.0	0.53	16.6	0.42	0.79	0.03	4.75
Total/Average	167	100.0	3.20	100.0	2.11	0.66	0.12	3.86

Table 26

State-wise distribution of area, production, productivity and area under irrigation for the dominant pigeon pea producing states in India

States	Area (m ha.)	Production (m t)	Yield (t/ha)	Total irrigated area (m ha.)	Percent irrigated
Andhra Pradesh	0.54	0.23	0.42	0.01	1.61
Chhattisgarh	0.05	0.02	0.48	0.00	0.05
Gujarat	0.26	0.25	0.95	0.02	6.25
Karnataka	0.40	0.23	0.57	0.03	7.54
Madhya Pradesh	0.47	0.22	0.47	0.01	1.11
Maharashtra	1.16	0.92	0.79	0.02	2.00
Uttar Pradesh	0.31	0.24	0.77	0.04	12.77
Total/Average	3.20	2.11	0.66	0.12	3.86

7.3 Water use in pigeon pea

7.3.1 Water use and irrigation requirement of pigeon pea

Productivity and water requirements of the crop are differentiated on the basis of their cultivation period or duration- medium duration (accounting for 80 per cent of total production), early duration (15 per cent) and long duration (5 per cent). Depending upon variety, soil and agro-climate; period of growth can vary from 150 to 280 days. Pigeon pea crop in the semi-arid south-central and north-west states is cultivated during rainy season (June/July- October/ November) and in the flood-affected high rainfall regions of eastern UP, Bihar and West Bengal after the recession of floods (September/ October- January). The June planted crop responds very well to 1 or 2 pre-monsoon irrigations. No irrigation is required during monsoon, but in case of drought or long dry spell during the reproductive period of growth, supplementary/life-saving irrigations should be given. A total of just 20-25 cm of water is sufficient to raise a good crop.

Pigeon pea is very sensitive to excess moisture or water congestion and requires good drainage. Ridge planting is effective in areas of high rainfall and/ or poor drainage. During the crop growth water should not stand anywhere in the field.

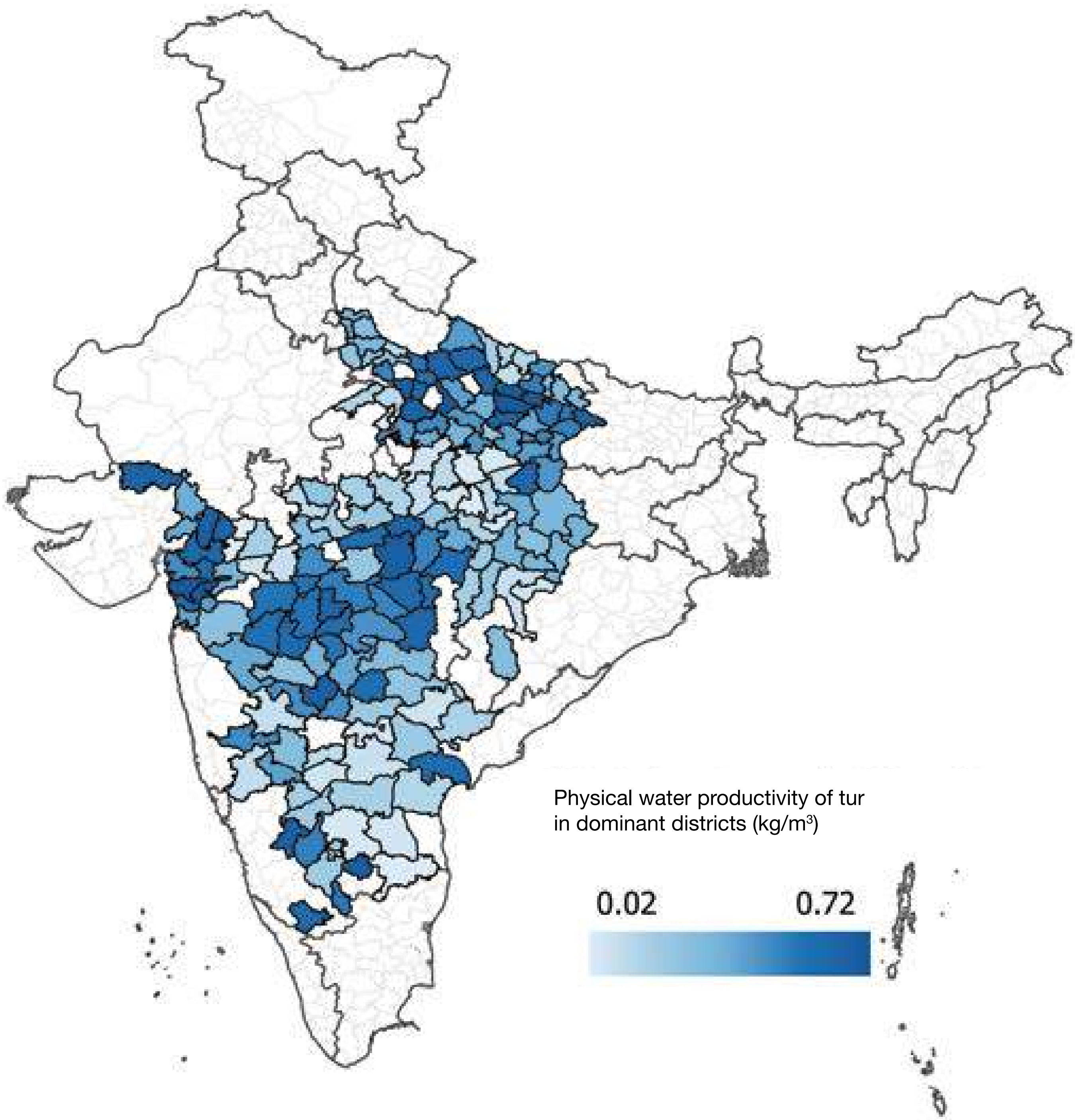
7.3.2 Water Productivity

7.3.2.1 Physical water productivity

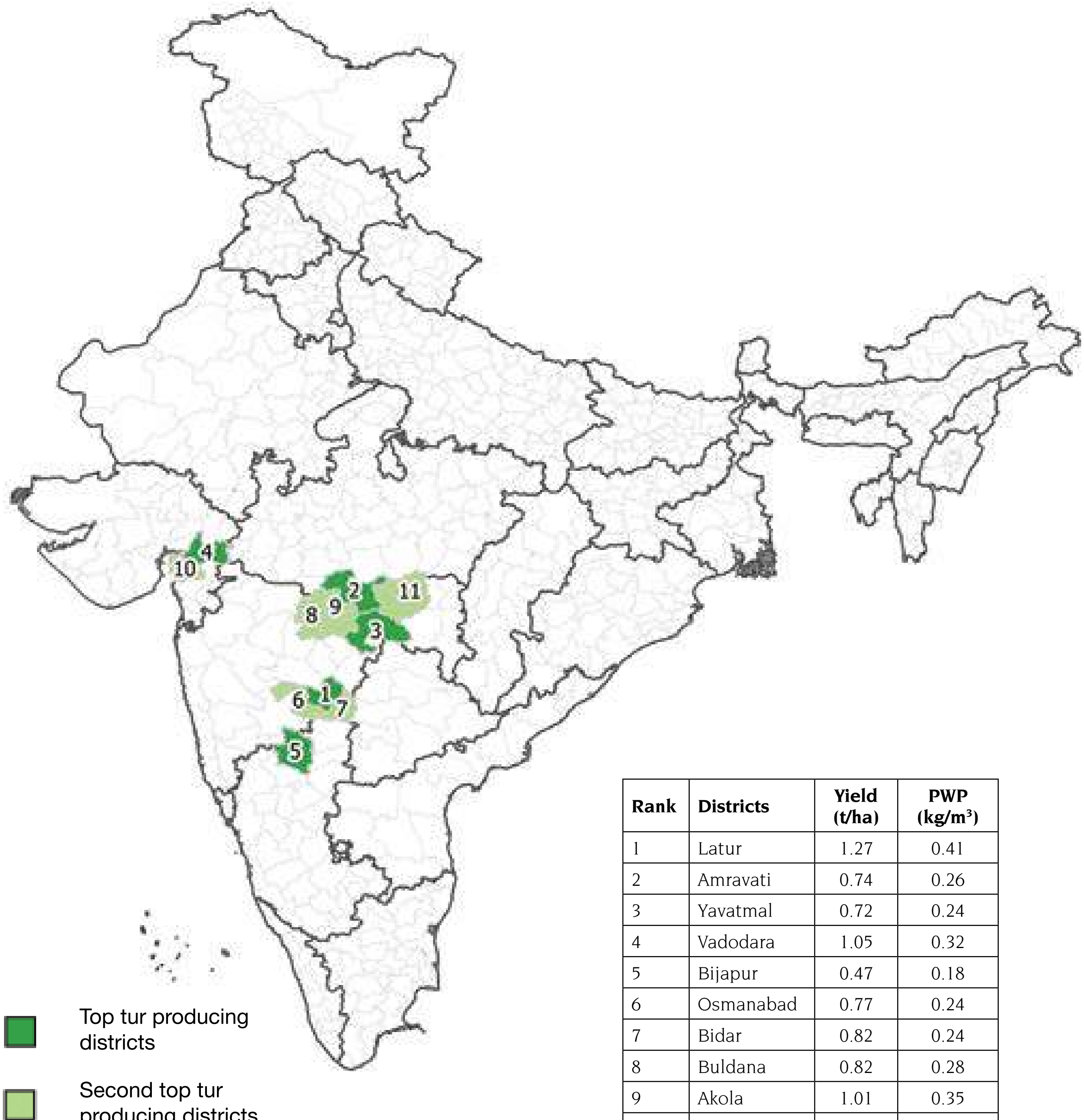
It was estimated in the study that, almost 87 per cent of the Total Consumptive Water Use (TCWU) for pigeon pea cultivation in India (9.73km^3) was consumed by the dominant pigeon pea districts. Highest TCWU was in Maharashtra state followed by Andhra Pradesh and Madhya Pradesh. State wise variation in water use and Physical Water Productivity is shown in Table 27. There is considerable variation in Physical Water Productivity across the dominant districts which varies from a low of 0.22 kg/m^3 to a high of 0.72 kg/m^3 (Map 21).

Table 27
State-wise variation in total consumptive water use and physical water productivity for pigeon pea production in India

States	Production (m t)	TCWU (km^3)	Percent TCWU	Physical Water Productivity (kg/m^3)
Andhra Pradesh	0.23	1.65	16.87	0.14
Chhattisgarh	0.02	0.14	1.47	0.17
Gujarat	0.25	0.81	8.26	0.31
Karnataka	0.23	1.35	13.88	0.17
Madhya Pradesh	0.22	1.32	13.52	0.17
Maharashtra	0.92	3.50	35.82	0.26
Uttar Pradesh	0.24	1.00	10.20	0.24
Total/Average	2.11	9.76	100.00	0.22



Map 21. Variation in physical water productivity of tur across dominant tur districts of India



Rank	Districts	Yield (t/ha)	PWP (kg/m³)
1	Latur	1.27	0.41
2	Amravati	0.74	0.26
3	Yavatmal	0.72	0.24
4	Vadodara	1.05	0.32
5	Bijapur	0.47	0.18
6	Osmanabad	0.77	0.24
7	Bidar	0.82	0.24
8	Buldana	0.82	0.28
9	Akola	1.01	0.35
10	Bharuch	0.79	0.24
11	Nagpur	0.88	0.31
12	Washim	0.88	0.30
13	Wardha	0.72	0.25

Map 22. Physical water productivity of top performing Tur districts in India. (Ranks are with respect to total production in the district)

Thirteen top-most pigeon pea producing districts along with their yield levels and physical water productivity are presented in Map 22. Interestingly, 9 out of the 13 top districts are located in Maharashtra. Latur district in Maharashtra has the highest production, productivity (1270 kg/ha) and physical water productivity of 0.41 kg/$m^{3.}$

The correlation analysis of the different variables affecting production, water use and water productivity are presented in Table 28.

Table 28
Correlation analysis between yield, water use and physical water productivity for pigeon pea production in dominant Indian states

Variable	Pearson Correlation					
	Area	Production	Yield	TCWU	Percent Irrigated	PWP
Area	1	.903**	.024	.976**	-.106	.010
Production	.903**	1	.286**	.897**	-.089	.237**
Yield	.024	.286**	1	.041	.138	.856**
TCWU	.976**	.897**	.041	1	-.081	-.024
Percent Irrigated	-.106	-.089	.138	-.081	1	-.091
PWP	.010	.237**	.856**	-.024	-.091	1

i. As with most other crops, the relationship between area and production comes through very clearly for Tur as well. Districts with more area under Tur produce more of the pulse.

ii. The interesting finding is that high production of Tur is related to more water consumption (which again is a function of large area as the co-efficient between Area and TCWU is positive, significant and very close to 1) but not necessarily area under irrigation. This may be possibly due to very low areas under irrigation (about 5 per cent only) which is below the threshold level to cause a significant variation.

iii. High yield for Tur is a function of how effectively/efficiently water is being (highly significant with PWP) used rather than water availability (not significant with TCWU) and area irrigated.

iv. Higher Physical Water Productivity results in higher yield but water availability and irrigation are a determining factor for high Physical Water Productivity.

7.3.2.2 Economic water productivity

Pigeon pea cultivated in the semi-arid climates of Gujarat and Maharashtra makes good use of the available rainfall and crop is quite suitable in these states. As such the economic water productivity is the highest in Gujarat followed by Maharashtra (Table 29). Farmers in these states need help in construction of small on-farm water storages and apply critical irrigation during the long dry spells and also after the withdrawal of the monsoons. Economic water productivity is also good in Uttar Pradesh where the crop was earlier cultivated in large areas. Uttar Pradesh proportionally produces higher volume of Tur mainly due to high productivity and PWP. It is the only state with highest percentage of irrigation for Tur. The crop needs to be further promoted in the districts of Bundelkhand, Rohilkhand and other areas in eastern UP where wheat sowing is delayed due to late recession of the flood waters. Economic Water Productivity is very low in the states of Andhra Pradesh, Madhya Pradesh and Karnataka where the crop is cultivated on marginal soils and allowed to suffer due to moisture deficit conditions. Economic Water Productivity shall also be considerably improved in case all the states provide Farm Harvest Price comparable to Chhattisgarh.

Table 29

Total economic value and economic water productivity of pigeon pea crop in the dominant pigeon pea production states in India

States	Production (m t)	TCWU (km^3)	Farm Harvest Price (Rs/100 kg)	Total Economic Value (Rs Crore)	Share of economic value	Economic Water Productivity (Rs/m^3)
Andhra Pradesh	0.23	1.65	3500	806.3	10.1	4.90
Chhattisgarh	0.02	0.14	5650	113.0	1.4	7.90
Gujarat	0.25	0.81	3835	958.8	12.0	11.90
Karnataka	0.23	1.35	3970	914.0	11.4	6.75
Madhya Pradesh	0.22	1.32	3650	804.4	10.1	6.10
Maharashtra	0.92	3.50	3820	3516.3	44.0	10.06
Uttar Pradesh	0.24	1.00	3690	886.0	11.1	8.90
Total/Average	2.11	9.76	3790	7998.9	100.0	8.20

7.4 Conclusions

Pigeon pea (tur) is the second major pulse crop cultivated in India after chickpea and occupies an area of around 4 million ha. However the crop has irrigation coverage of only 4.3 percent in India, which makes its yield lower than world average yield. In 2016-17, almost 0.7 million tonnes of tur was imported to India, which was almost 1.5 times more than the preceding year's import. The study reveals that pigeon pea, being a less water intensive crop like most pulse crops, is most suitable in terms of physical water productivity in Latur district of Maharashtra. This is an indication that pigeon pea is a favourable option to ensure sustainable agriculture production in water scarce regions of India. The average economic water productivity of pigeon pea in Gujarat and Maharashtra are even higher than the All India average of Rs 8.20/$m^{3.}$ The water guzzler sugarcane crop (EWP of around Rs 12 per cubic metre of TCWU and EWP of around Rs 9 per cubic metre of irrigation water applied) in Maharashtra which is almost on par with the economic water productivity of less water intensive pigeon pea crop (Rs 10.06/m^3). But unless the price volatility and market imperfections are resolved, the adoption of the crop among farmers cannot be promoted. Over the years, the poor procurement policy of pulses has been dis-incentivising the farmers by and large across the country. This has led to a shift towards water guzzling crops like paddy, wheat and sugarcane and pulses being grown in poorly irrigated areas by resource poor farmers. The study concludes that if farmers are provided with remunerative prices, assured market and critical irrigation, pigeon pea can emerge as a sustainable and profitable replacement crop in water scarce regions of India.

8

Groundnut

8.1 Groundnut in the world

Groundnut (*Arachis hypogea*) a native of Brazil reached east coast of India in around 1800 AD. World production of groundnuts in the 2016-17 was 29.8 million tonnes (shelled basis)[14] (USDA, 2017)[15]. Five top groundnut producing countries- China, India, Nigeria, USA and Sudan produce almost 78 per cent of the world's groundnut (FAO[16]). China is the largest producer of groundnut in the world producing 11.6 mt (shelled basis), from 4.62 mha and average yield of 2.49 t/ha (China Statistical Yearbook, 2016) which is almost double that of world average productivity of 1.12 t/ha.

8.2 Groundnut in India

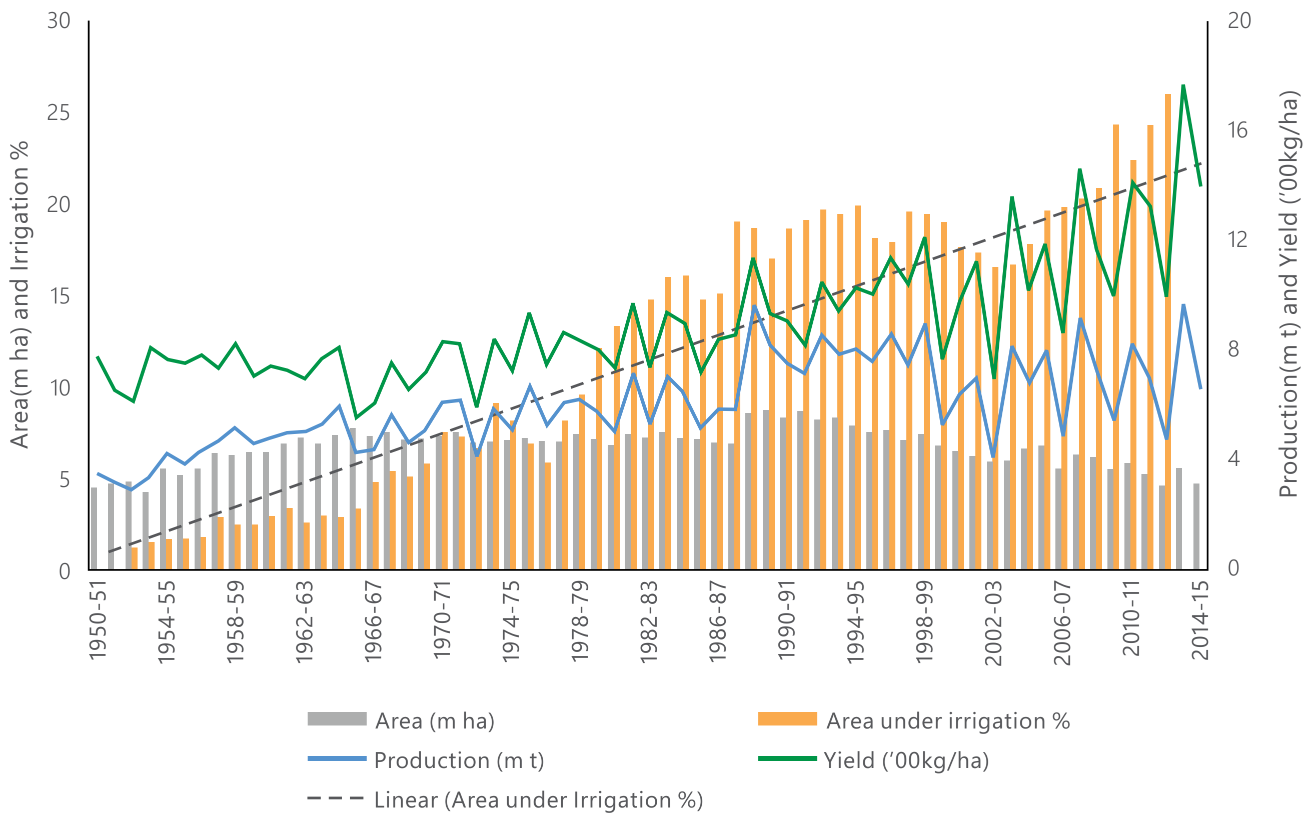
India is the second largest producer of groundnut in the world after China and the leading exporter of shelled groundnuts (600,000 tonnes for 2015). Groundnut accounts for about a quarter of all oilseeds in the country. However, groundnut production in India is highly vulnerable to rainfall deviations and displays huge fluctuations (Figure 21) from year to year as the crop is cultivated in light textured soils and about 74 per cent of the planted area is under rain fed conditions. There are two groundnut growing seasons in India: kharif and rabi. Kharif season accounts for 85 percent of the total and cultivated primarily in Gujarat, Rajasthan, Andhra Pradesh, and Maharashtra. Rabi groundnut is grown in the southern states of Tamil Nadu, Karnataka and Telangana. USDA estimates India's groundnut production for 2017-18 at 6.5 million tonnes, about 3 per cent less than last year's bumper production. The reduction in yield was reported due to the deficit rainfall in some of the major groundnut producing states like Andhra Pradesh, Madhya Pradesh and Maharashtra. Harvested area shall be almost 6 per cent less than the previous year due to shift towards cotton crop. The 2017-18 status of groundnut in India shows contradiction in comparison to 2016-17. In 2016-17, there was a 41 per cent increase in production and 21 percent increase in area in comparison to its preceding year. Ironically, last year's increase was attributed to a shift of distressed cotton farmers to less risky groundnut crop. Yield is estimated at 1.3 t/ha, 18 per cent higher than last year because of favourable monsoons (USDA, 2017). Though

India is the second largest producer of groundnut in the world after China and the leading exporter of shelled groundnuts.

In 2017-18, a reduction in groundnut yield was reported due to deficit in rainfall in major groundnut producing states like Andhra Pradesh, Madhya Pradesh, and Maharashtra.

[14] Shelled groundnut: Groundnut after removing the shells (recovery rate = 70 per cent)
[15] https://apps.fas.usda.gov/psdonline/circulars/oilseeds.pdf
[16] http://www.fao.org/faostat/en/#data/QC

with large fluctuations in production, the area under irrigation and the average productivity has witnessed an improvement during the last decade.

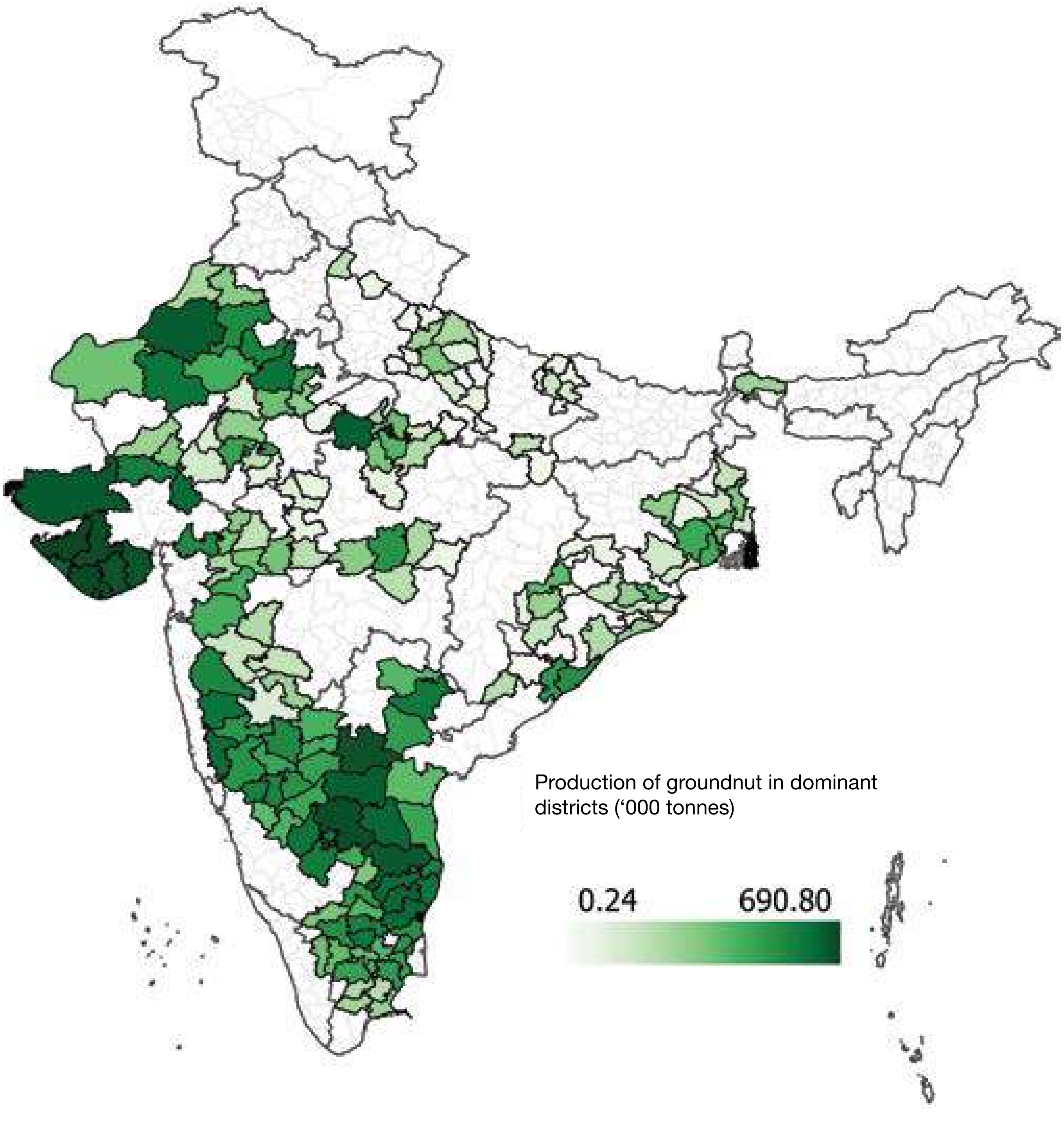


Note: The large intra-annual variation in yield and production, and decline in cultivated area.

Figure 21. Changes in cultivated area, production, yield and area under irrigation for groundnut during 1950-51 to 2014-15 in India

8.2.1 Dominant Districts for Groundnut Cultivation in India

The extent of area in India where groundnut is grown is large. The district and state level data for 2009-10 and 2010-11 shows that the crop was grown across 20 states and 2 UTs. Overall 386 districts cultivated groundnut to some degree and the total area under the crop was 5.67mha. Total production of groundnut was 6.76 million tonnes. To focus on the dominant states and districts, area wise filters were applied in two steps. This criterion narrowed the number of dominant districts to 175 across the 10 dominant states (Map 23). The total area under groundnut in these districts is 5.46 m. ha and at an average yield of 1.18 t/ha, a total of 6.44 million tonnes are produced. Thus the total area and production of groundnut in these dominant districts is more than 95 per cent of India's total area and production of groundnut. For detailed analysis at the district level,



Map 23. Variation in production of groundnut across dominant groundnut districts of India

all 175 dominant districts are arranged in ascending order for production and then divided into five groups with each group cumulatively contributing 20 per cent of the total groundnut production in India. Table 30 shows the data for different variables for these groups. It can be noticed that the production wise distribution highlights the skew in the data.

Table 30
Production-wise groups, production, yield and irrigated area under dominant groundnut production districts in India

Production wise groups	Number of districts	Percent of districts	Area (m ha.)	Percent area	Production (m t)	Yield (t/ha)	Percent irrigated
0-20 per cent	134	76.6	1.11	20.40	1.25	1.12	35.43
20-40 per cent	24	13.7	1.03	18.94	1.24	1.20	32.57
40-60 per cent	10	5.7	1.00	18.41	1.31	1.30	19.58
60-80 per cent	5	2.9	1.48	27.21	1.29	0.87	8.47
80-100 per cent	2	1.1	0.82	15.04	1.36	1.65	0.00
Total/Average	175	100	5.46	100.00	6.44	1.18	19.31

There are 134 or more than 76 per cent of the districts in the first group and they produce the same amount as the 2 districts or 1.1 per cent of the districts in the last group (Figure 22). When some of the groups are combined, the difference is highlighted further. The first two groups contain more than 90 per cent of the districts and contribute roughly 40 per cent of the groundnut production. On the other hand the last two groups contain a mere 4 per cent of the districts and they too contribute 40 per cent of the total production. These seven districts constitute the 'groundnut bowl' of India.

The productivity data presented in the table shows that the production in these groups cannot be solely contributed to yield difference even though productivity for the top two districts is much higher than rest of the districts. As mentioned earlier, groundnut is not too sensitive to water availability. The distribution of irrigated area shows that as one move from the first to the last groups, the irrigation percentage progressively drops and it becomes zero for the last group. The few districts that produce the most amount of groundnut in India have a well distributed rainfall pattern and suitable climate and have little area under irrigation for the crop.

The state wise area, production and productivity in the dominant groundnut production states is given in Table 31. Gujarat is the leading state with about one third of the total area and about 40 percent of the total groundnut production in the country. Only 10.5 per cent of the crop is under irrigation. Therefore, groundnut yield at 1.42 t/ha is good but lower than Tamil Nadu (2.23 t/ha) with 35.8 per cent irrigation. Swain (2014) concluded that water deficit and low irrigation was a critical factor for improving the groundnut yield in Gujarat. Karnataka and Andhra Pradesh together have more than 40 per cent area under groundnut but with poor yield levels.

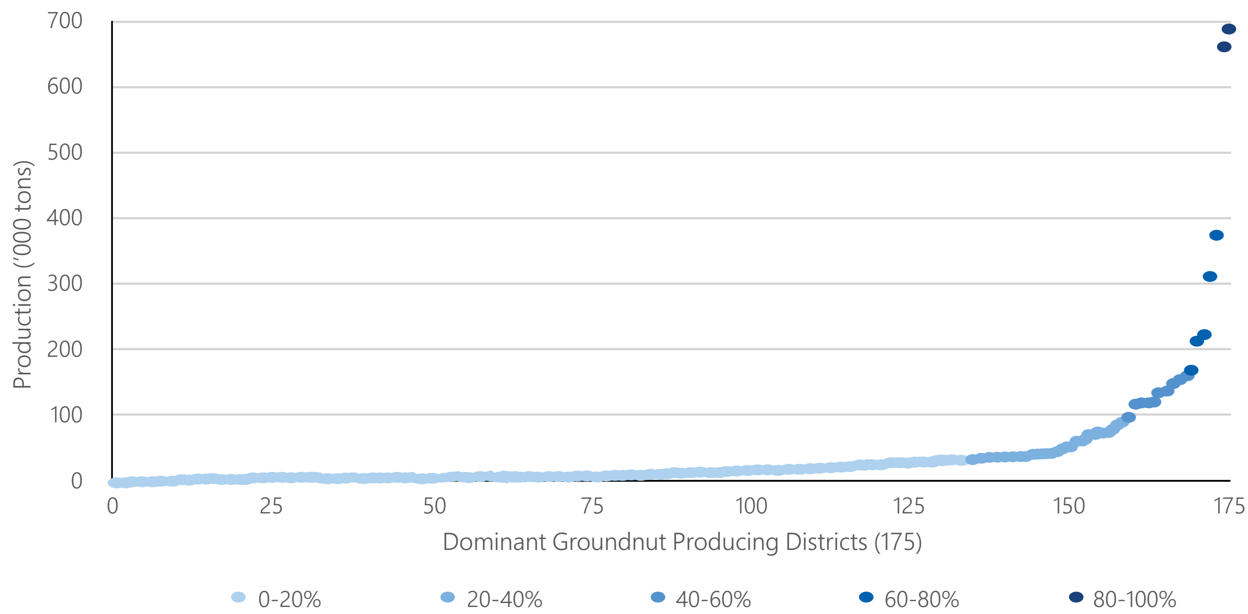


Figure 22. Clustering pattern of the dominant groundnut production districts in India

Table 31
Area, production, yield and area under irrigation for dominant groundnut production states in India

States	Area (m ha.)	Percent area	Production (m t)	Percent production	Yield (t/ha.)	Percent irrigation
Andhra Pradesh	1.42	26.06	1.16	18.00	0.82	19.68
Gujarat	1.81	33.18	2.57	39.86	1.42	10.50
Karnataka	0.82	15.11	0.51	7.97	0.62	28.99
Madhya Pradesh	0.20	3.64	0.27	4.17	1.35	8.51
Maharashtra	0.26	4.74	0.30	4.62	1.15	21.00
Odisha	0.07	1.33	0.09	1.33	1.18	19.18
Rajasthan	0.33	6.10	0.51	7.84	1.52	77.18
Tamil Nadu	0.39	7.13	0.87	13.48	2.23	35.79
Uttar Pradesh	0.09	1.57	0.07	1.10	0.83	2.86
West Bengal	0.06	1.13	0.11	1.64	1.71	82.00
Total/Average	5.46	100.00	6.44	100.00	1.18	22.71

8.3 Water use in groundnut

8.3.1 Water use and irrigation requirement of groundnut

Groundnut crop can be grown successfully in places receiving a minimum rainfall of 500 mm and a maximum of 1,250 mm. Rainfall should be well distributed during flowering and pegging stage of the crop. Rainfall required for pre-sowing operations is 100 mm, for sowing it is 150 mm, and for flowering and pod development an evenly distributed rainfall of 400-500 mm. Crop cannot withstand frost, long drought and water stagnation.

In kharif, advancing the sowing date by 10-15 days with one pre-sowing irrigation can increase the yield substantially. Life saving irrigations are required during moisture deficit periods. A good rabi crop can be obtained with 8-9 light irrigations (~5 cm each). Summer groundnut during the hot season may require about 11-12 irrigations. In undulating and light soils, irrigation with micro-sprinklers and sprinklers is highly efficient.

8.3.2 Water productivity

8.3.2.1 Physical Water Productivity

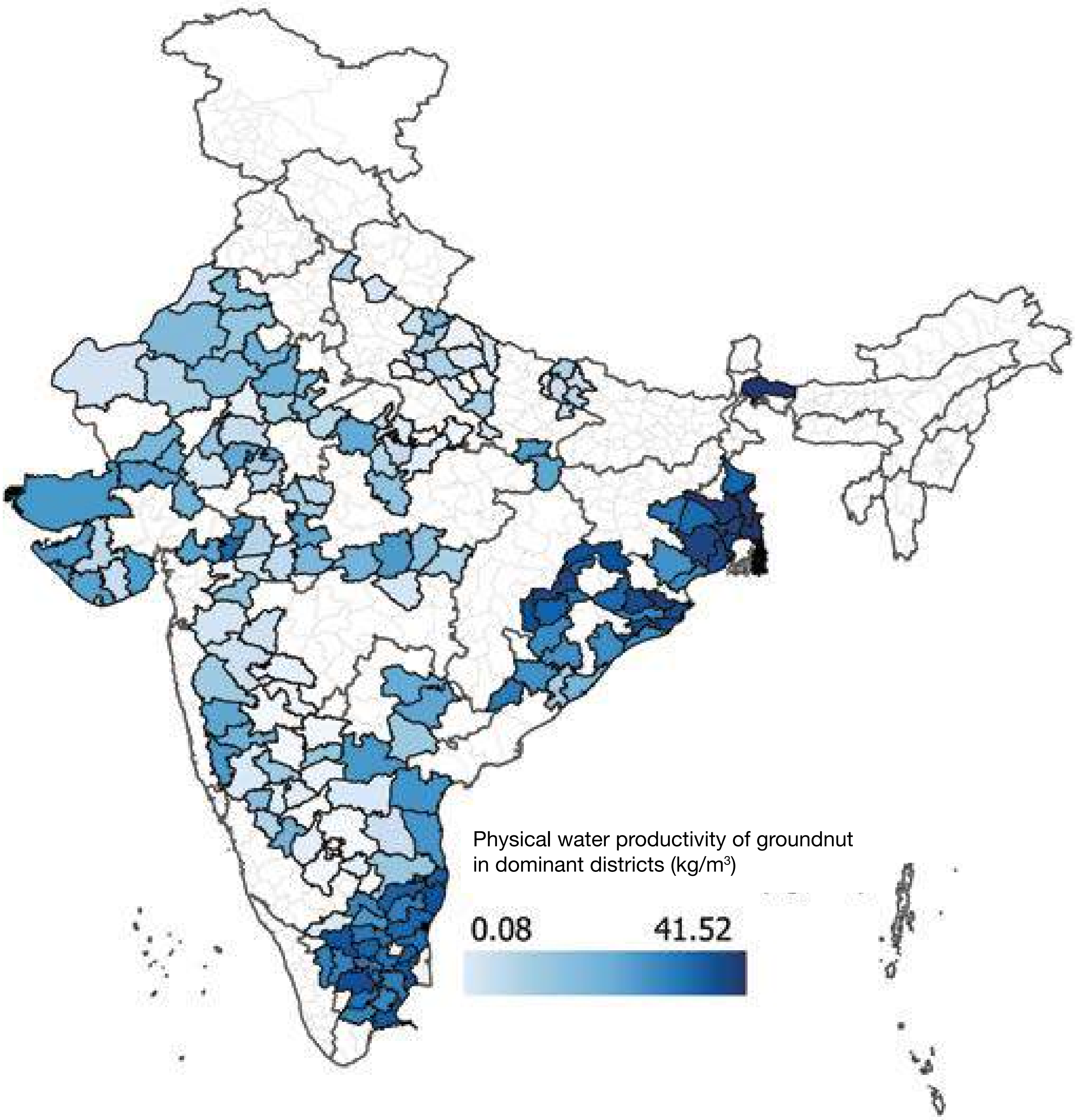
This study estimated that the total water consumed for all the groundnut cultivation area in India is 16.01 km^3 (16.01 BCM), while for the dominant districts, this figure is estimated at 15.55 km^3, which is more than 97 per cent of the total water consumed. Total Consumptive Water Use and Physical Water Productivity for the five groundnut production groups are given in Table 32.

Table 32

Total consumptive water use and physical water productivity in the five production groups of the dominant groundnut production districts in India

Production wise groups	Total Consumptive Water Use(TCWU) (km^3)	Percent TCWU	Physical Water Productivity (kg/m^3)
0-20 per cent	2.87	18.46	0.435
20-40 per cent	2.81	18.06	0.442
40-60 per cent	2.89	18.57	0.454
60-80 per cent	4.47	28.75	0.288
80-100 per cent	2.51	16.16	0.539
Total/Average	15.55	100	0.415

The distribution of total water consumption is evenly distributed among the production-wise groups. The only anomaly is the second last group (60-80 per cent), which has much higher TCWU figure. The share of total water consumed follows the same pattern as share of area under each group thus suggesting that water consumption is mostly a function of total area under groundnut cultivation. The pattern of PWP values across groups is similar to productivity pattern. The values for the first three groups are very comparable among



Map 24. Variation in physical water productivity across dominant groundnut districts of India

each other while the PWP value for the second last group drops significantly. The top group (80-100 per cent) demonstrates the higher PWP values.

Spatial variation of Physical Water Productivity across the dominant groundnut production districts is shown in Map 24. State wise estimates of the Total Consumptive Water Use and Physical Water Productivity are shown in Table 33.

Table 33

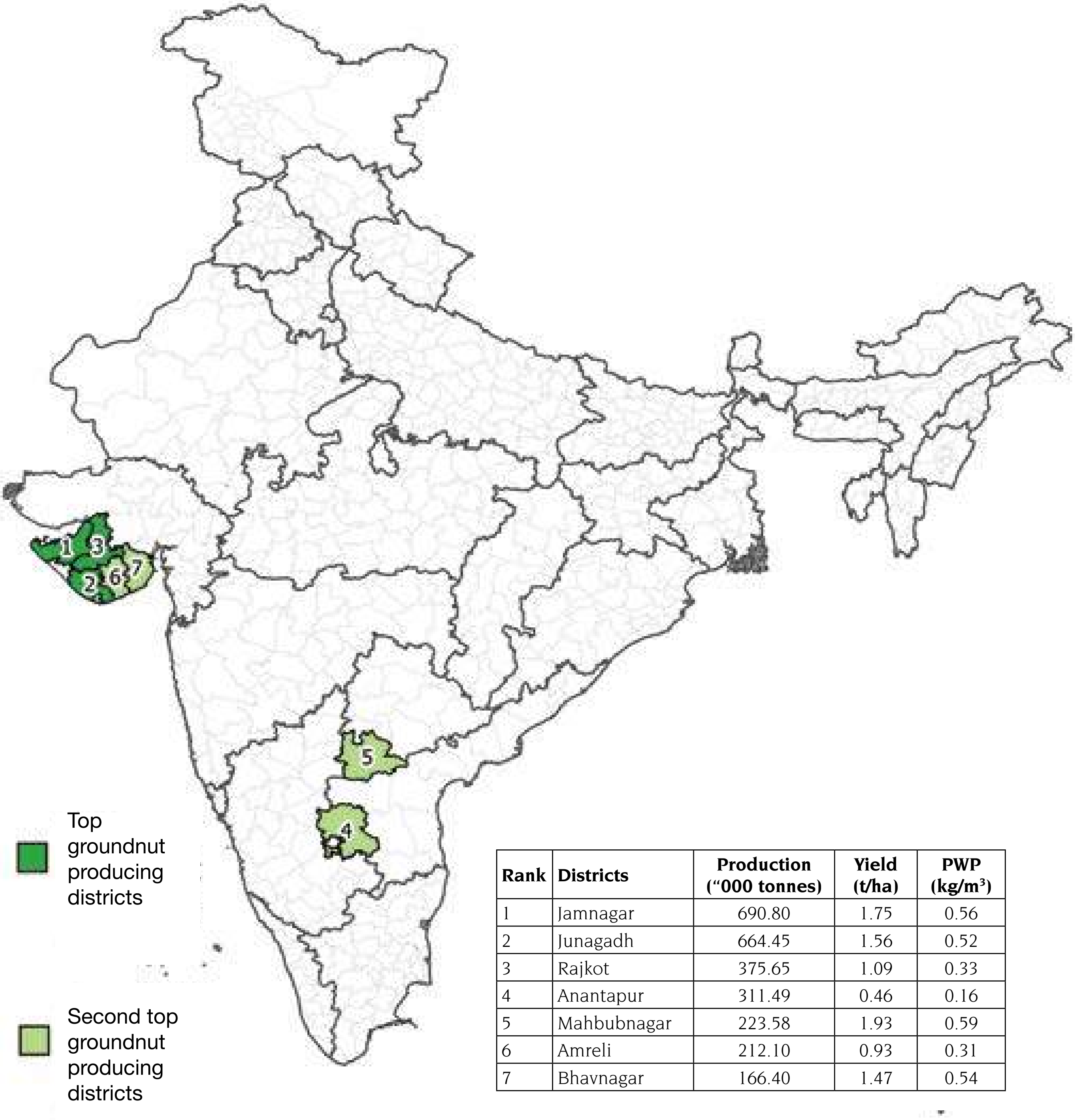
Total consumptive water use and physical water productivity of groundnut in the dominant groundnut production states of India

States	Total Consumptive Water Use (km^3)	Percent TCWU	Physical Water Productivity (kg/m^3)
West Bengal	0.03	0.21	3.30
Odisha	0.05	0.32	1.74
Tamil Nadu	0.59	3.79	1.48
Gujarat	5.54	35.65	0.46
Madhya Pradesh	0.6	3.88	0.45
Maharashtra	0.73	4.7	0.41
Rajasthan	1.25	8.05	0.40
Andhra Pradesh	4.13	26.6	0.28
Uttar Pradesh	0.26	1.68	0.27
Karnataka	2.35	15.14	0.22
Total/Average	15.55	100	0.41

Total water consumption for groundnut at the state level almost mirrors the total share of area under groundnut in the respective states. But when it comes to water productivity, the top producing states lag far behind states like West Bengal, Odisha, and Tamil Nadu. West Bengal has the least share of area among the states and produces less than two per cent of the total production. But its water use efficiency value is many times higher than the top producing states of Gujarat, Andhra Pradesh, and Karnataka because it mainly produces the irrigated groundnut. Water productivity is also high in Tamil Nadu and Odisha. Production, yield and physical water productivity in the seven top groundnut producing districts in India is shown in Map 25. Out of the top seven districts, five districts (Jamnagar, Junagarh, Rajkot, Amreli, and Bhavnagar) are in Saurashtra region of Gujarat and have high yield levels. Anantapur district in Andhra Pradesh- a drought prone district, has high total production due to large area but with a poor yield and water productivity. Availability of even limited amount of water can significantly improve the yield and water productivity.

The correlation analysis of all the production and water use factors (Table 34) indicates that:

i. Greater area under groundnut cultivation leads to more production and water consumption. But higher production of groundnut at the district level is not due to higher yield.



Rank	Districts	Production ("000 tonnes)	Yield (t/ha)	PWP (kg/m³)
1	Jamnagar	690.80	1.75	0.56
2	Junagadh	664.45	1.56	0.52
3	Rajkot	375.65	1.09	0.33
4	Anantapur	311.49	0.46	0.16
5	Mahbubnagar	223.58	1.93	0.59
6	Amreli	212.10	0.93	0.31
7	Bhavnagar	166.40	1.47	0.54

Map 25. Production, yield and physical water productivity in top seven groundnut districts in India (Together these seven districts produce 40 per cent of the total groundnut production in India)

ii. High productivity for groundnut is observed in districts where irrigation water is applied and they use the available water more effectively.

iii. A distinction needs to be made between total water availability and irrigation water. Higher consumption of water does not result in higher productivity or higher water-use efficiency. But in districts where water needed for growing groundnut is applied through irrigation, it results in higher yield and PWP. This suggests that if timely irrigation water is applied in districts which are the top producers, the total production due to higher efficiency of water can be even greater.

Table 34

Correlation analysis of production and water-use factors for the dominant 175 groundnut production districts in India

Variables	Area	Production	Yield	TCWU	PWP	Percent irrigated
Area	1	.859**	-.062	.994**	-.074	-.132
Production	.859**	1	.133	.871**	-.057	-.088
Yield	-.062	.133	1	-.071	.229**	.438**
TCWU	.994**	.871**	-.071	1	-.083	-.120
PWP	-.074	-.057	.229**	-.083	1	.198**
Percent Irrigated	-.132	-.088	.438**	-.120	.198**	1

8.3.2.2 Economic water productivity

Among the large groundnut states, Tamil Nadu has a high Economic Water Productivity of Rs 45.08/m^3 indicating that it makes a good economic sense to allocate irrigation water to rain fed groundnut crop in the

Table 35

Production, farm harvest price, economic value and economic water productivity in the dominant groundnut production states of India

States	Production (m t)	TCWU (km^3)	Farm Harvest Price, (Rs/100 kg)	Total economic value (Rs crore)	Economic value share	Economic Water Productivity (Rs/m^3)
Andhra Pradesh	1.16	4.13	2810	3264.49	18.57	7.90
Gujarat	2.57	5.54	2725	7004.98	39.86	12.64
Karnataka	0.51	2.35	2770	1411.42	8.03	6.00
Madhya Pradesh	0.27	0.60	2510	677.92	3.86	11.24
Maharashtra	0.30	0.73	2090	627.77	3.57	8.60
Odisha	0.09	0.05	2140	192.48	1.10	39.06
Rajasthan	0.51	1.25	2640	1348.59	7.67	10.78
Tamil Nadu	0.87	0.59	2950	2652.43	15.09	45.08
Uttar Pradesh	0.07	0.26	2870	201.22	1.14	7.71
West Bengal	0.11	0.03	1770	194.50	1.11	60.73
Total/Average	6.44	15.55	2730	17575.80	100	20.97

state (Table 35). Among the smaller states, West Bengal and Odisha, in spite of the very low farm harvest price for the crop has high Economic Water Productivity indicating that farmers should invest in irrigation and the state government must ensure to provide a reasonable farm harvest price for the cash crop. Andhra Pradesh, Karnataka and Maharashtra have large areas under the crop but poor Economic Water Productivity. Both water and non-water issues need to be addressed for improving the land, water and economic water productivity in these states.

8.4 Conclusions

Ground nut is being cultivated in an area of around 5.5 million ha. However, groundnut being primarily a kharif crop (85 per cent share in Kharif season) has irrigation cover of only about one-fourth of its cultivated area. Hence groundnut production in India is highly vulnerable to rainfall deviations and displays huge fluctuations. Physical water productivity of groundnut was found to be highest in West Bengal, followed by Odisha and Tamil Nadu. Thus with respect to the total consumptive water use, these states emerged more efficient in groundnut production than Gujarat, Andhra Pradesh and Karnataka. In terms of EWP per unit of TCWU, West Bengal (Rs 60.73/m^3), Tamil Nadu (Rs 45.08/m^3) and Odisha (Rs 39.06/m^3) top the list. Improved, timely and efficient water use is required to ensure better yield of crop in the top producing states like Gujarat, where the irrigation coverage is only 12.4 per cent of total area under crop. Groundnut being a less water consuming crop is ideal for cultivation in water scarce regions. However, with the prices of groundnut falling below Minimum Support Price, farmers resort to distress sale limiting the expansion of area under the crop.

In terms of EWP per unit of TCWU, West Bengal (Rs 60.73/m^3), Tamil Nadu (Rs 45.08/m^3) and Odisha (Rs 39.06/m^3) top the list.

9

Rapeseed-mustard[17]

[17] In the text the terms Rapeseed/Mustard/ Rapeseed-Mustard have been used interchangeably and pertains to the Rapeseed- Mustard group of crop.

9.1 Rapeseed-mustard in the world

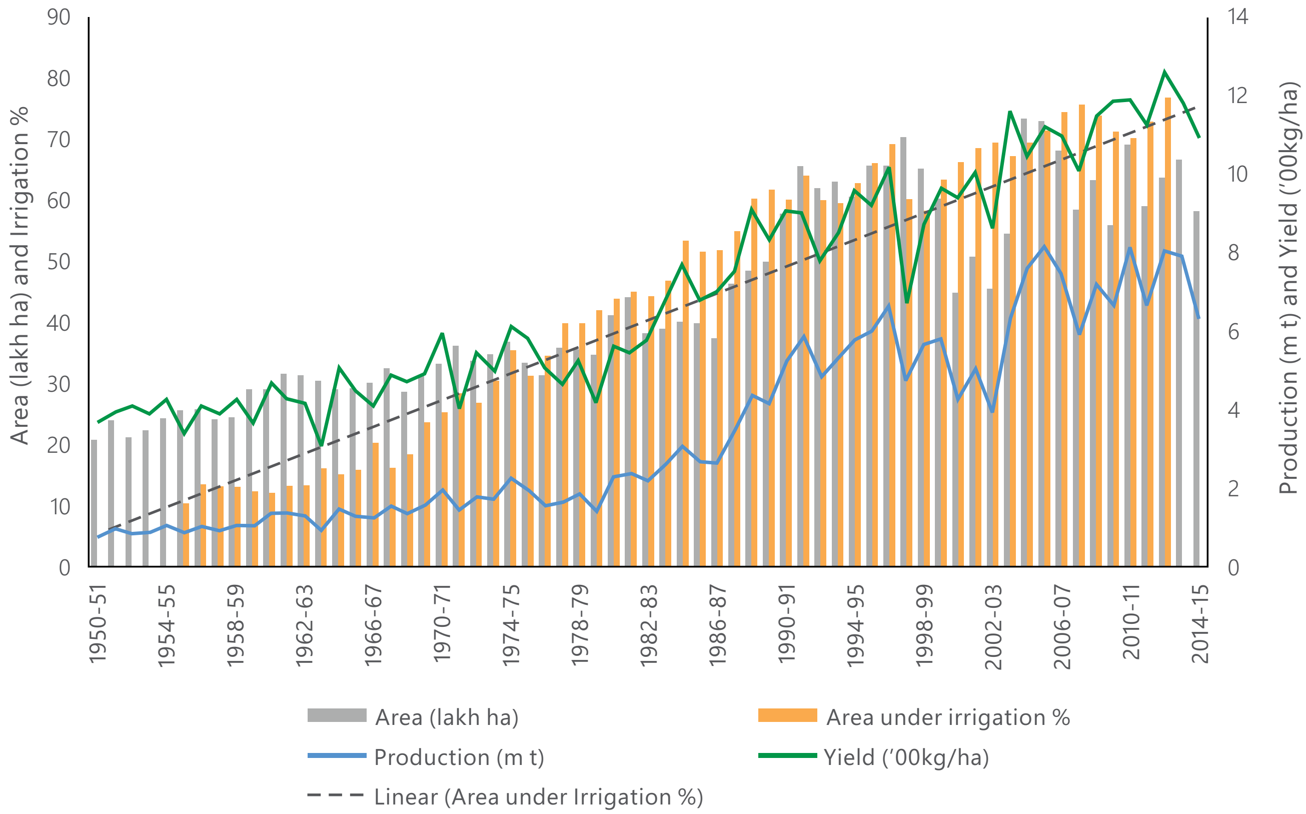
Rapeseed-mustard (B*rassica juncea* and other species) is the third important oilseed crop in the world after soybean and palm oil. The group broadly includes Indian mustard, yellow *sarson*, brown *sarson*, *raya* and *toria*. It is widely grown in majority of the continents with largest area of 8.3 mha in Canada, followed by China (7.3 mha), European Union (6.75 mha) and India (5.76 mha) with global area at 35.5 mha (2015-16). As against the world average of 2144 kg/ha, highest productivity of 3640 kg/ha of European Union, 1881 kg/ha in China, the Indian average yield was only 1151 kg/ha during the triennium ending 2015-16. Besides better agronomic management, longer crop duration and high carbon content in the soils are the major factors attributing to high productivity in the western world.

9.2 Rapeseed-mustard in India

Rapeseed-mustard is cultivated across the country, pre-dominantly in North, North-Western and North-Eastern region of the country over an area of about 6.6 mha. India produces around 7 million tonnes of rapeseed-mustard next to China (11-12 mt) and European Union (10-13mt) with significant contribution in the world rapeseed-mustard industry. Among the major oilseeds, irrigated area under mustard has increased more rapidly from 10 per cent in 1955-56 to 77 per cent in 2013-14. This is reflected through a rising trend in productivity (Figure 23). However, the area coverage under the crop largely depends upon the late kharif rains. The years of low rainfall and drought like 2002-03, 2008-09, and 2012-13 have seen large decline in productivity and production as the crop meets large part of the water requirements through residual soil moisture of the *kharif* season. Rajasthan, Madhya Pradesh, Haryana, Uttar Pradesh and West Bengal contribute more than 81 per cent area 86 percent production of rapeseed-mustard in the country.

Rajasthan, Madhya Pradesh, Haryana, Uttar Pradesh, and West Bengal contribute more than 81 per cent area and 86 per cent production of rapeseed-mustard in the country.

Among the major rapeseed-mustard producing countries, an average (TE 2015-16) yield of 1151 kg/ ha of India as against the world average of 2144 kg/ha indicates a large gap of 85 per cent. Even Front Line Demonstrations (FLDs) of mustard conducted by ICAR during rabi 2013-14 indicate an average yield gap of 44 per cent (MoA&FW, 2017). It is unfortunate that Indian rapeseed area has not expanded (Figure 23) in the same way as the major producers in the world, despite high prices. The Indian solution is to import vegetable oil, even though rapeseed-mustard is well suited to satisfy the rising oil demand and good prices. This opportunity needs to be availed by utilizing a part of an area of 8 mha of rice fallows in the eastern states of Assam, Bihar, Chhattisgarh, Jharkhand, Odisha and West Bengal (OFI, 2016)

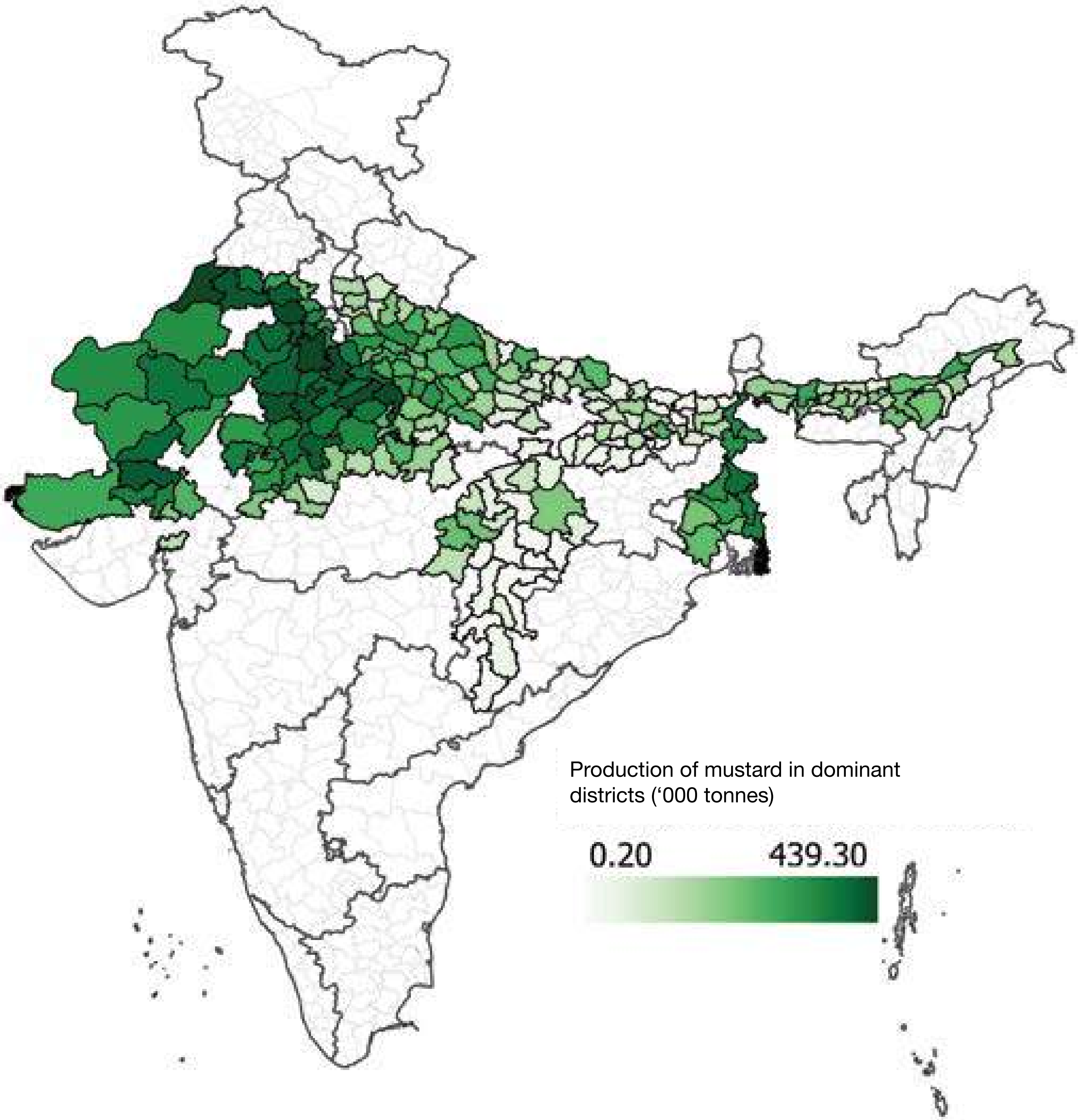


Source: (DES, 2016)

Figure 23. All India trend in cultivated area, total production, average yield and the area under irrigation for the rapeseed-mustard crop since 1950

9.3 Dominant districts for rapeseed-mustard

Rapeseed-mustard (R&M) is one of the primary oilseeds grown in most parts of India. District level data for 2009-10 and 2010-11 indicate that mustard is cultivated across 465 districts spread over 21 states. The total area under mustard is around 5.39 mha and with the average yield of 1.3 t/ha, a total of 7.02 million tonnes are produced. With the application of dominant state and dominant district criterion, the study identified 201 districts spread over nine states. The total area under R&M in these districts is 5.05 mha (94.3 per cent of the



Map 26. Variation in total production of rapeseed-mustard in dominant rapeseed-mustard districts of India

total area) and the total production is 6.7 mt (95.4 per cent of the total production) while the average yield is 1.32 t/ha. Spatial distribution of these dominant districts across the states of India is shown in Map 26. As can be seen there is a contiguous region in Rajasthan, Haryana and Madhya Pradesh which makes the largest production of rapeseed-mustard.

The distribution of districts among the five production groups of 20 per cent each indicates that almost 90 per cent of the districts (179 out of 201 districts) are in the lowest two groups (Group 1 and 2) and they contribute just 40 per cent of the production (Table 36). The highest producing top 2 groups (Group 4 and 5) have only 11 districts and also contribute 40 per cent of the total production. The top producing 11 districts occupy more than 35 per cent of the total area under mustard whereas the bottom 159 districts cumulatively cover less than 30 per cent of the area. The difference in average yield between the top (1.65 t/ha.) and bottom group (0.89 t/ha.) is almost two times and this presents a large unexploited opportunity for improving the rapeseed-mustard yields in the country. One can also observe that as one moves from the first to the last group; there is an incremental increase in yield value. Clustering pattern of groups of the dominant districts is shown in Figure 24.

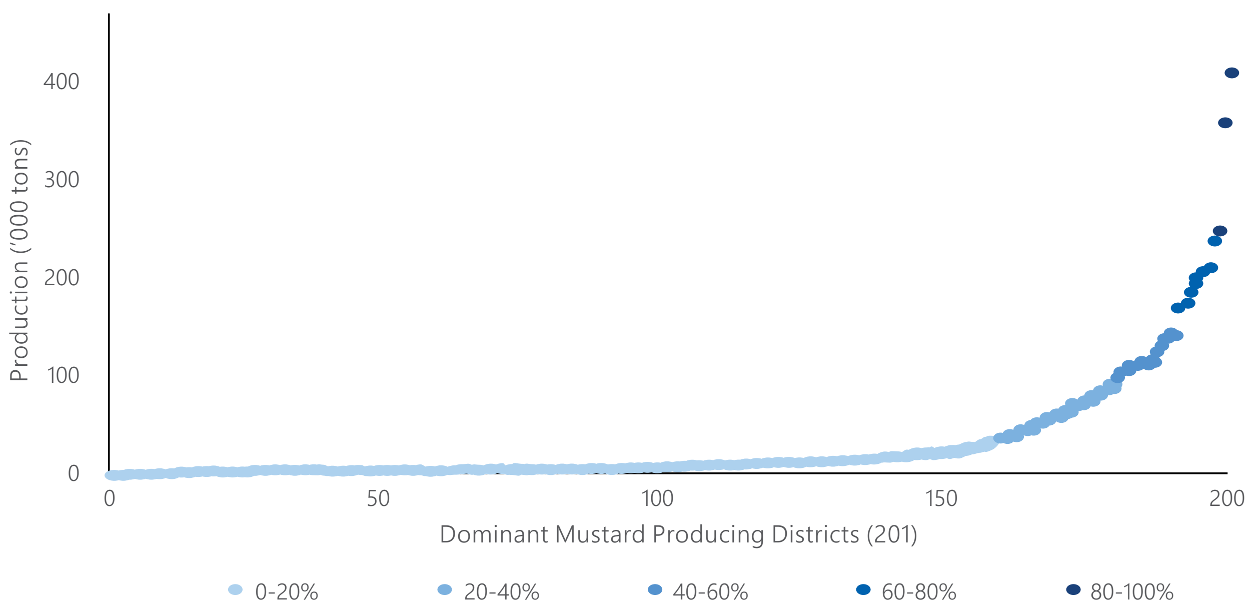


Figure 24. Clustering pattern of the five dominant rapeseed-mustard production groups in India

Table 36
Distribution of production-wise groups and variation in yield of the dominant rapeseed-mustard districts of India

Production wise groups	Number of districts	Percent of districts	Area (m ha.)	Percent area	Production (m t)	Yield (kg/ha.)	Percent irrigated
0-20 per cent	159	79.1	1.44	28.3	1.28	893	59.5
20-40 per cent	20	10.0	0.96	19.0	1.26	1305	81.6
40-60 per cent	11	5.5	0.88	17.4	1.31	1488	79.6
60-80 per cent	7	3.5	0.92	18.0	1.39	1515	70.5
80-100 per cent	4	2.0	0.88	17.3	1.46	1657	76.7
Total/Average	201	100	5.08	100	6.70	1319	72.2

9.4 Water use in rapeseed-mustard

9.4.1 Water use and irrigation requirement of rapeseed-mustard

Rapeseed-mustard is mostly grown under temperate climate and is reported to tolerate annual precipitation of 500 to 4200 mm. The crop has efficient photosynthetic response at 15-20°C temperature. Rapeseed-mustard has a low water requirement of 240-400 mm. Irrigation is very important for getting the optimum productivity potential of mustard. A substantial rapeseed-mustard area in Rajasthan (82.5 per cent), Gujarat (98 per cent), Haryana (76 per cent) and Punjab (93 per cent) is covered under irrigation. Generally, two irrigations, one at flowering stage and another at silique formation can increase the seed yield by 28 per cent over rain fed conditions (Shekhawat et al., 2012). However, water-use efficiency was highest with one irrigation at 45 days after sowing. Single irrigation given at vegetative stage is found to be most critical, as irrigation at this stage produces the highest seed yield.

9.4.2 Water Productivity of Rapeseed-Mustard

9.4.2.1 Physical Water Productivity

This study estimated that Total Consumptive Water Use for mustard cultivation in India was 8.21 km^3 (8.21 BCM). For the dominant districts, TCWU was 7.91 km^3 (96.3 per cent of the total). Variation in water consumption across districts can be seen in Table 37. The smaller 159 districts (~80 per cent) in the first group consume 23.5 per cent of the total water while the top 4 districts (2 per cent) consume 17.5 per cent of water. The relation between production and water consumption is also positive. Since the production is more or less evenly distributed across the groups, the TCWU figures are not very dissimilar. As water requirements for the crop are small, Physical Water Productivity for mustard follows the same trend as seen for land productivity. As one moves from first to last group, the PWP values increase incrementally with the large districts having 1.5 times the PWP value compared to the smaller districts.

Table 37

Variation in total consumptive water use and physical water productivity across the major rapeseed-mustard production groups in India

Production wise groups	Total Consumptive Water Use (km^3)	Percent TCWU	Physical Water Productivity (kg/m^3)
0-20 per cent	1.86	23.5	0.69
20-40 per cent	1.62	20.5	0.78
40-60 per cent	1.52	19.1	0.87
60-80 per cent	1.53	19.4	0.90
80-100 per cent	1.38	17.5	1.05
Total/Average	7.91	100	0.85

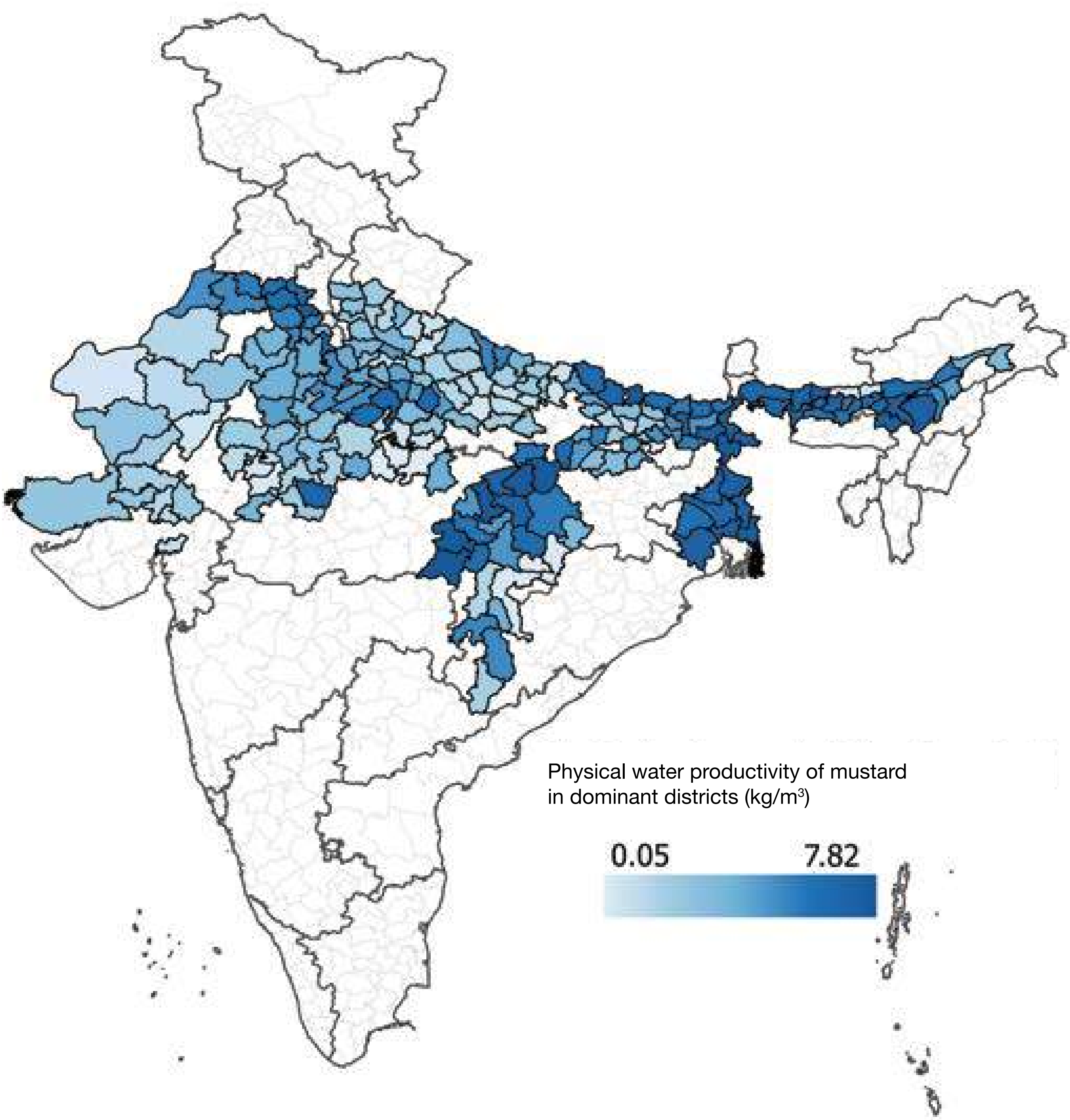
In the second phase of the analysis, state wise consideration is made. In the state level data, top performing state is Rajasthan. The state has close to 45 per cent of the total area of mustard and about half of India's mustard production comes from Rajasthan alone (Table 38). The other production wise top states include Haryana, Madhya Pradesh and Uttar Pradesh. These four states produce more than 85 per cent of the mustard. In terms of productivity, Haryana has the highest productivity of 1.86 t/ha, followed by Gujarat (1.58 t/ha) and Rajasthan (1.45 t/ha). Lower percentage of irrigated area under mustard was reflected in the lower yield in the states of Assam, Bihar and Chhattisgarh and Madhya Pradesh.

Table 38

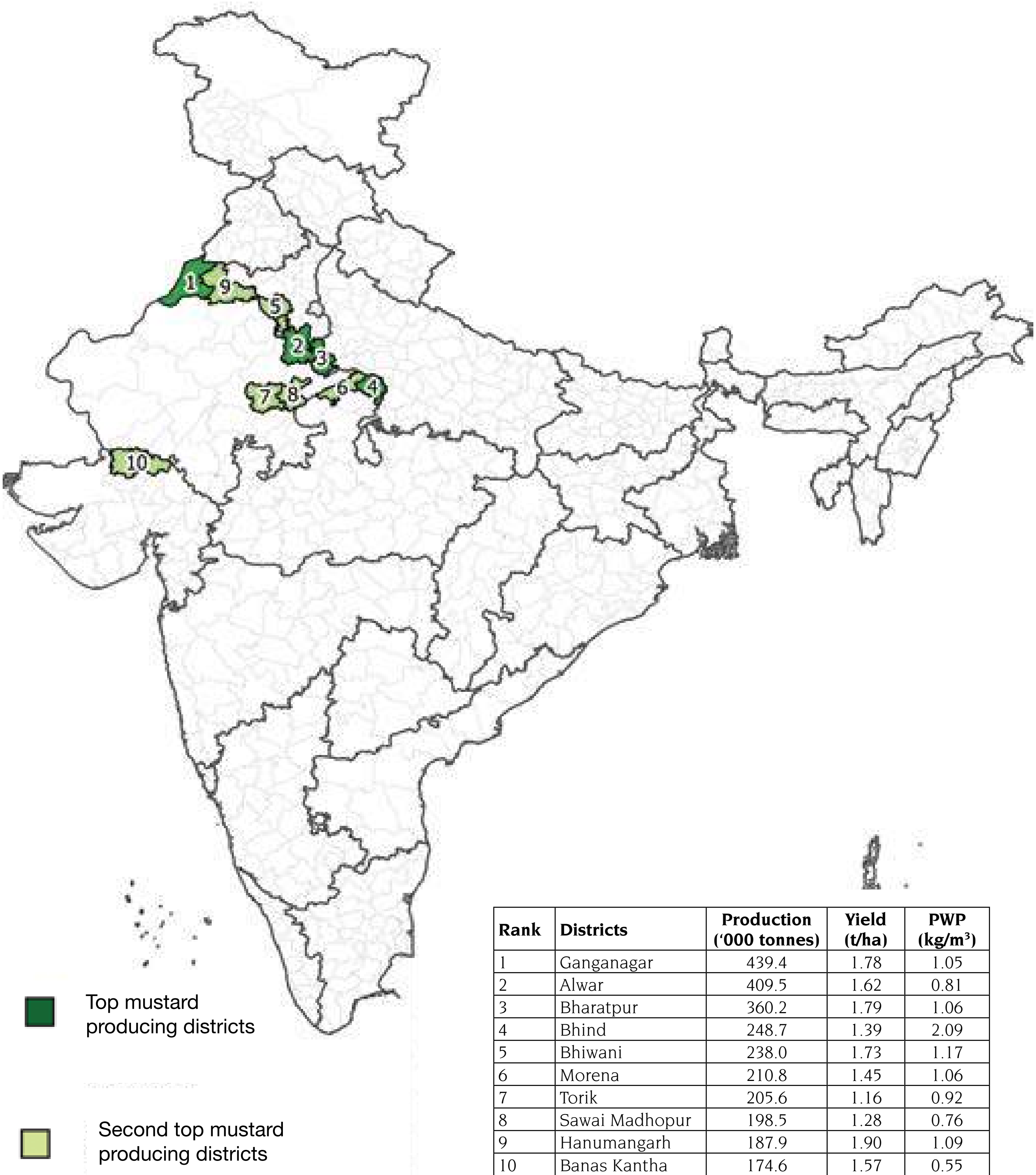
Cultivated area, production, yield, total consumptive water use and physical water productivity of mustard across major rapeseed-mustard producing states of India

States	Area (m ha)	Production (m t)	Yield (t/ha)	Total Consumptive Water Use, km^3	Percent TCWU	Physical Water Productivity (kg/m^3)
Assam	0.24	0.13	0.56	0.143	1.80	0.93
Bihar	0.09	0.09	1.07	0.096	1.21	0.95
Chhattisgarh	0.05	0.02	0.41	0.025	0.32	0.82
Gujarat	0.21	0.33	1.58	0.601	7.59	0.56
Haryana	0.49	0.92	1.86	0.767	9.69	1.20
Madhya Pradesh	0.73	0.80	1.10	0.891	11.26	0.90
Rajasthan	2.28	3.30	1.45	4.228	53.44	0.78
Uttar Pradesh	0.59	0.68	1.16	1.003	12.68	0.68
West Bengal	0.40	0.42	1.05	0.160	2.02	2.62
Total/Average	5.08	6.70	1.32	7.912	100	0.85

Due to lighter soils and comparatively warmer day temperatures, 45 per cent of the cropped area consumes a disproportionately higher 53.5 per cent of the total water. Gujarat and Uttar Pradesh also fall in this group. On the other end, among the large state Madhya Pradesh (14.3 per cent of area and 11.2 per cent of water



Map 27. Variation in physical water productivity across dominant rapeseed-mustard districts of India



Rank	Districts	Production ('000 tonnes)	Yield (t/ha)	PWP (kg/m³)
1	Ganganagar	439.4	1.78	1.05
2	Alwar	409.5	1.62	0.81
3	Bharatpur	360.2	1.79	1.06
4	Bhind	248.7	1.39	2.09
5	Bhiwani	238.0	1.73	1.17
6	Morena	210.8	1.45	1.06
7	Torik	205.6	1.16	0.92
8	Sawai Madhopur	198.5	1.28	0.76
9	Hanumangarh	187.9	1.90	1.09
10	Banas Kantha	174.6	1.57	0.55
11	Mahendragarh	171.0	1.91	1.09

Map 28. Yield and physical water productivity of top rapeseed-mustard in 11 rapeseed-mustard districts of India

consumed) leads the group and it is followed by West Bengal, Assam, and Haryana. Greater consumption of water doesn't always translate into effective use of water. This is proven by the latter states, which have higher Physical Water Productivity values than the states in the former group. West Bengal has the highest PWP value of about 2.6 kg/m^3 (Map 27). Haryana also has high PWP value of 1.2 kg/m^3. Rest of the states have PWP values less than 1 kg/m^3 .The state level data for rapeseed-mustard indicates that higher water productivity value is not necessarily a function of irrigated area. West Bengal and Haryana have high PWP values suggesting that they use water more efficiently. Average PWP for the rapeseed-mustard crop in India is 0.85 kg/m^3 which is quite good for a high value oilseed crop. This suggests that the small water needs of the crop should be fully met by converting all the rain fed areas into irrigated area and the fields receiving only one irrigation may be equipped to receive 2-3 small irrigations.

Yield and Physical Water Productivity of the top 11 rapeseed-mustard producing districts of India is shown in Map 28. Among these, Sri Ganganagar district of Rajasthan records the highest production (0.44 million tonnes) and Mahendragarh district of Haryana records highest crop yield (1.91 t/ha).However these districts recorded comparatively lower PWP values. Bhind district of Madhya Pradesh recorded the highest PWP of 2.09kg/m^3, almost double that of Sri Ganganagar and Mahendragarh.

9.4.2.2 Economic Water Productivity

Based on the parameters of Farm Harvest Price offered by the state, consumptive water used and the Physical Water Productivity, the Economic Water Productivity was the highest at Rs 65.5/m^3 in West Bengal, followed by Rs 29/m^3 in Haryana (Table 39). Chhattisgarh government is also encouraging farmers to grow mustard by offering a farm harvest price of Rs 33.15/ kg.

EWP was the highest at Rs 65.5/m^3 in West Bengal, followed by Rs 29/m^3 in Haryana.

The other large states like Rajasthan, Madhya Pradesh, and Uttar Pradesh all produce less than Rs 20 per m^3 of water. But since half of India's mustard comes from Rajasthan, half of total monetary value gained from selling the crop in the market also comes from the state.

Correlation of all the production and water use related factors for rapeseed-mustard are presented in Table 40. Important outcomes from this analysis are given below:

Table 39

Production, farm harvest price and economic water productivity of rapeseed-mustard in the dominant rapeseed-mustard producing states of India

States	Area (m ha.)	Production (m t)	Percent irrigation	Farm Harvest Price, Rs/ 100 kg	Share of economic value, Rs Crore	Economic Water Productivity (Rs/m^3)
Assam	0.24	0.13	0.0	2424	2.1	22.6
Bihar	0.09	0.09	48.4	2545	1.5	24.3
Chhattisgarh	0.05	0.02	6.4	3115	0.4	25.6
Gujarat	0.21	0.33	95.2	2232	4.8	12.4
Haryana	0.49	0.92	79.0	2413	14.3	29.0
Madhya Pradesh	0.73	0.80	47.7	2196	11.3	19.7
Rajasthan	2.28	3.30	81.5	2330	49.5	18.2
Uttar Pradesh	0.59	0.68	80.9	2158	9.5	14.7
West Bengal	0.40	0.42	86.0	2498	6.7	65.5
Total/Average	5.08	6.70	72.2	2435	100	25.8

Table 40

Correlation analysis for factors of production, water use and water productivity for the dominant rapeseed-mustard production districts of India

Variable	Area	Production	Yield	TCWU	PWP	Percent Irrigated
Area	1	.979**	.406**	.935**	-.036	.213**
Production	.979**	1	.479**	.938**	-.043	.238**
Yield	.406**	.479**	1	.444**	-.088	.621**
TCWU	.935**	.938**	.444**	1	-.174*	.305**
PWP	-.036	-.043	-.088	-.174*	1	-.420**
Percent Irrigated	.213**	.238**	.621**	.305**	-.420**	1

i. Production of rapeseed-mustard has positive and highly significant relation to total area and total water consumption. The coefficients are close to one suggesting that districts with more area and consuming more water are producing the most amount of mustard in India. Production is also positively associated with yield and percentage area under irrigation. The relationship with yield is understandable. As mustard is sensitive to water availability, the results suggest that districts having more area under irrigation do produce more of mustard. The relationship between water productivity and production is not significant.

ii. The productivity of rapeseed-mustard at the district level is positively and significantly associated with all the variables except physical water productivity. This indicates that districts with higher yield not necessarily use water most effectively, which is a cause for concern. Thus availability of water for mustard should be monitored to optimize water use inefficiency.

iii. Physical water productivity and its relation with the other variables suggest that it only has significant and negative relation with TCWU and percent area under irrigation. As the crop has very limited but critical water requirements, mere availability of water does not yield higher water efficiency and large irrigated areas may not use water effectively.

9.5 Conclusions

Rapeseed-mustard is the third important oilseed crop in the world and the second most produced oilseed crop in India after soybean. Almost 77 per cent of the crop area (6.0 million ha) is under irrigation cover, which has played a significant role in bringing up the yield levels of the crop. Analysis also indicates that yield and area irrigated are significantly and positively correlated to each other. The total consumptive water use (TCWU) of rapeseed-mustard in India is 7.91km^{3,} almost half that of groundnut crop (16km^3). Rajasthan which contributes to about 49 per cent of the country's rapeseed-mustard production has a PWP (0.78kg/m^3) lower than the average PWP of the country (0.85kg/m^3). West Bengal and Haryana record the highest PWP across the top rapeseed-mustard producing states. Among the top 11 rapeseed-mustard producing districts of the country, Bhind district of Madhya Pradesh displayed the highest PWP (2.09 kg/m^3). In Rajasthan which produces almost half of the rapeseed-mustard in the country, focus needs to be laid upon efficient water use in order to achieve a higher level of PWP. Haryana state which stands second in production, reports a higher level of PWP (1.20kg/m^3). In Rajasthan, districts like Hanumangarh and Sri Ganganagar report higher yield as well as higher PWP than the state average value. Lessons can be learned from these districts for improvement of yield from the water perspective.

Rajasthan which produces almost half of the rapeseed-mustard in the country, needs to focus on efficient water use in order to achieve a higher level of PWP.

Lessons can be learned from Hanumangarh and Sri Ganganagar districts in the state.

10

Sugarcane

10.1 Sugarcane in the world

Sugarcane (*Saccharum officinarum*) is an important cash crop which produces 78 per cent of sugar worldwide. The crop also contributes to energy demands by co-generation and alcohol production; and other high value products besides providing livelihoods to millions of farmers and industrial workers. Sugarcane is a tall, erect perennial plant growing up to 5-6 m with multiple stems. Brazil (736.11 mt), India (352.14 mt), China (126.15 mt), Thailand (103.69 mt), Pakistan (62.83 mt), Mexico (56.67 mt), Colombia (36.51 mt), Australia (30.52 mt), Indonesia (28.60 mt), and United States of America (27.60 mt) are the top ten sugarcane producing countries in the world. Among these countries, Colombia has the highest yield of sugarcane (126 t/ha) (FAO[18]). Sugarcane is a water-intensive long duration crop with 11 to 18 month duration, with the ratoon crop up to three or more years.

10.2 Sugarcane in India

Sugarcane occupies about 3 per cent of the total cultivated area in India and by adding about 7.5 percent (US$ 8.61 billion) of the gross value of agricultural production, it is among the top 5 crops by economic value (FLA, 2012). Broadly, there are two distinct agro-climatic regions of sugarcane cultivation in India- tropical and sub-tropical. Tropical region (Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka, Gujarat and Madhya Pradesh) shares about 42 per cent of total sugarcane area and 47 per cent of the production in the country with an average productivity of 76 t/ha (2015-16). Sub-tropical region (Uttar Pradesh, Uttarakhand, Bihar, Haryana and Punjab) accounted for about 55 per cent of total area and 51 per cent of production with an average productivity of 66 t/ha. In the tropical zone, Maharashtra is the major growing state (9.9 lakh ha) with production of 72.26 mt whereas Tamil Nadu has the highest productivity (102.9 t/ha). Uttar Pradesh in the Gangetic Plains is the highest sugarcane producing state (21.77 lakh ha) in the sub-tropical zone with production of 145.3 mt whereas Punjab has the highest productivity. Higher cane yields and sugar recovery in the tropical region are attributed to a long-duration crop, high-yielding disease resistant variety for seeds, favourable climatic conditions, better irrigation facilities, and good quality heavy soils. Sugarcane takes about one year to mature in sub-tropics and is called "E*ksali*", and in some tropical states (Andhra Pradesh, Maharashtra,

Sugarcane takes about one year to mature in sub-tropics and is called "E*ksali*", and in some tropical states (Andhra Pradesh, Maharashtra, Karnataka) the crop matures in 14-17 months and is called "*Adsali*".

[18] http://www.fao.org/faostat/en/#data/QC

Karnataka) the crop matures in 14-17 months and is called "*Adsali*". In Karnataka and Tamil Nadu sugarcane planting and harvesting continues throughout the year, except for few months. Average sugar recovery rate in Maharashtra was 11.32 per cent and was way above that of UP at 9.16 per cent and all India level of 10.2 per cent. Duration of crop growth season has implications for cane productivity and water requirements and needs to be given due consideration.

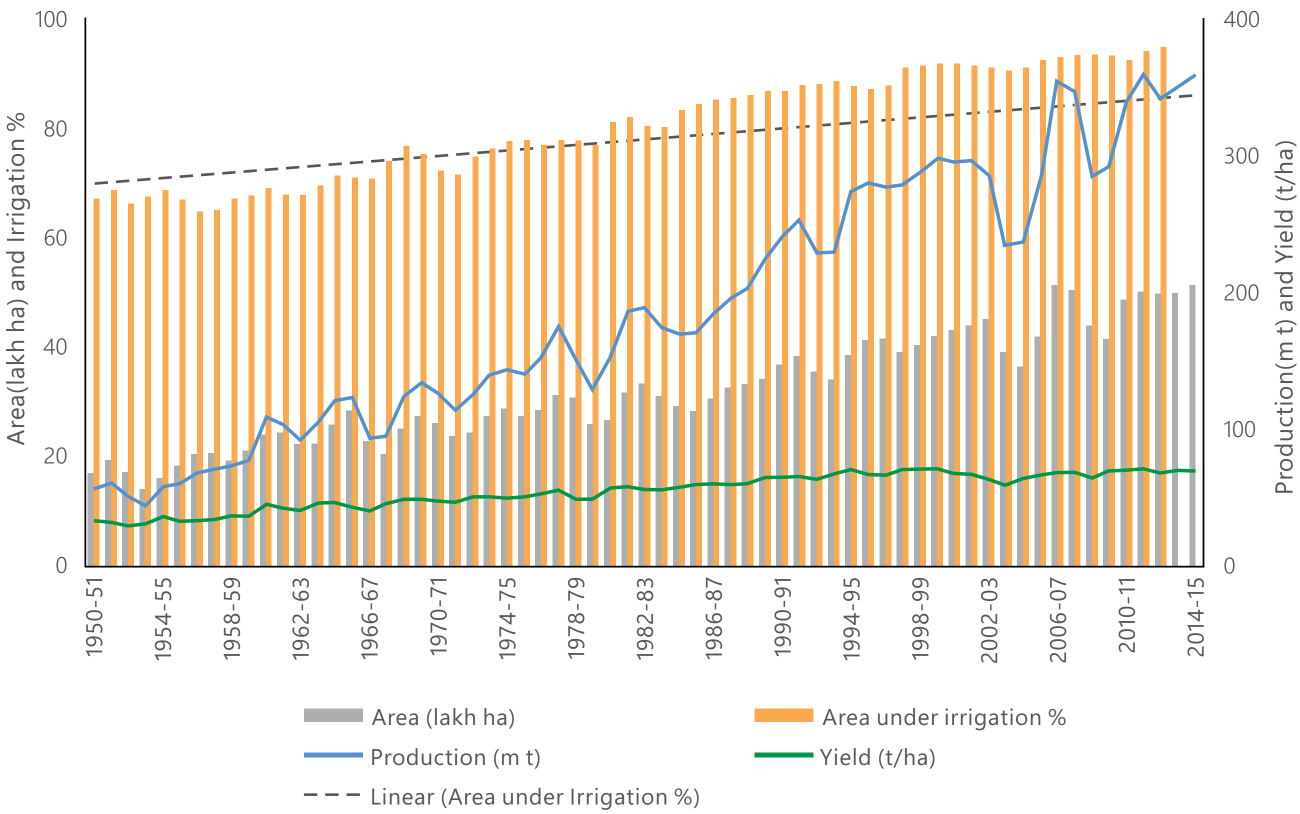


Figure 25. Variation in production, yield, cropped area and area under irrigation of the sugarcane crop in India since 1950

At the national level, area under the crop has witnessed a steady increase and has stabilized around 5 m ha. Now more than 95 per cent of the sugarcane crop is under irrigation (Figure 25). Yield of the sugarcane crop has not witnessed any large improvements and the national average yields are around 71 t/ha. Highest production of 362 million tonnes was achieved during 2014-15. As monsoon rains satisfy the large water requirements during grand growth period of the crop, the years of deficient rainfall has seen huge shortfalls in production and productivity: in 2003-04 the cane production was 233.9 mt with a productivity of 59.5 t/

ha, and in 2008-09 the cane production was 285.03 mt with a productivity of 64.48 t/ha. This indicates that irrigation provided to crop is only supplemental in nature and not capable of meeting full water needs during the years of low rainfall.

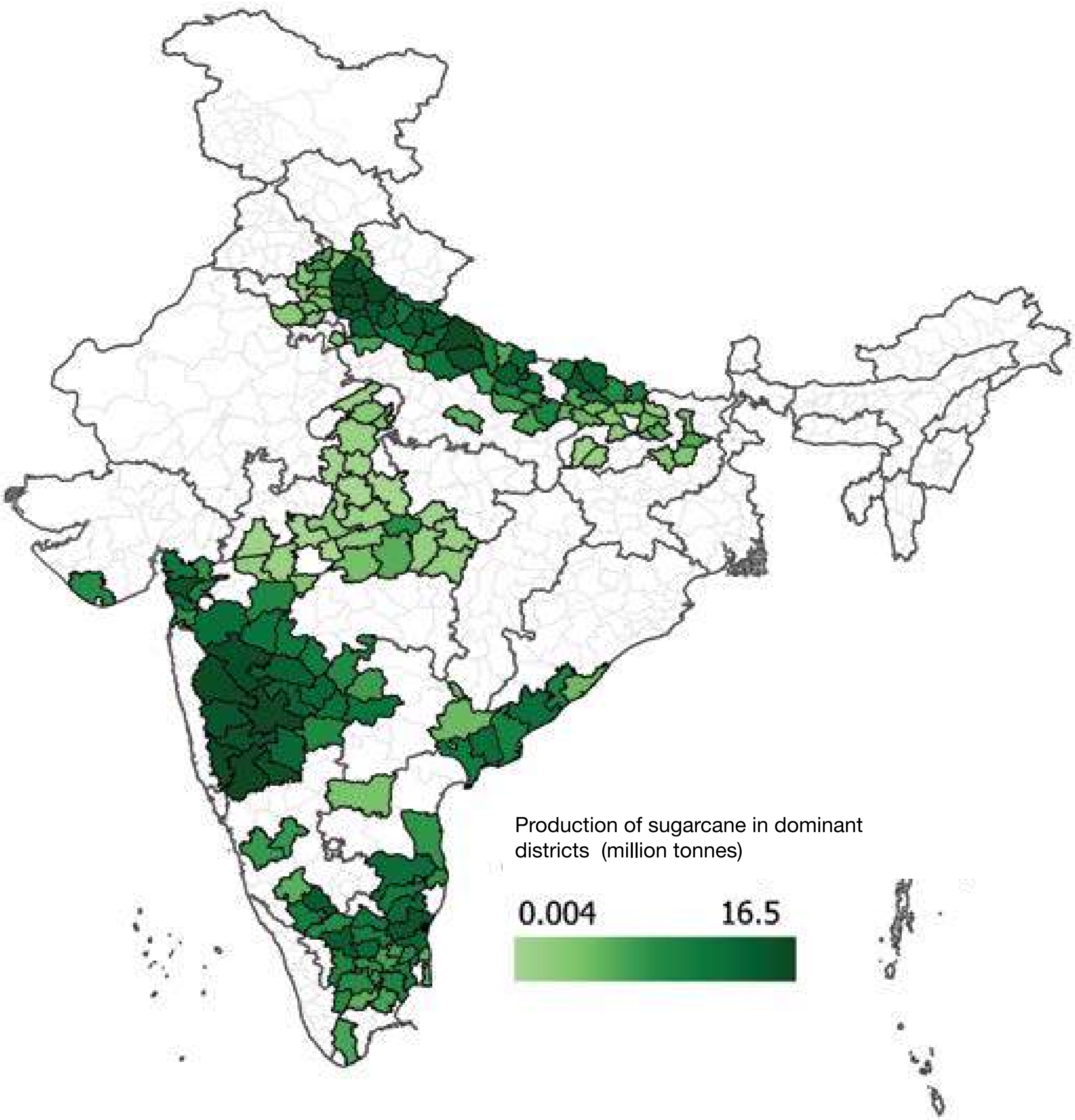
10.2.1 Dominant Districts for Sugarcane Cultivation in India

Sugarcane is one of the most important commercial crop of India and cultivated in fertile regions of both northern and southern states. The government data for 2009-10 and 2010-11 on sugarcane indicate that this crop is cultivated in 500 districts that are spread across 26 states. The cumulative area under sugarcane is around 4.45 mha and at an average yield of 70.25 t/ha the total production amounts to 312.54 mt. For the purpose of this study, we apply few filters on the larger data set to arrive at areas that represent dominant districts where sugarcane is grown. On application of the criterion, we are left with 161 districts spread over 10 states. The total sugarcane area in these dominant districts is 4.23 mha and with the average yield of 70.9 t/ha, the total production is 299.75 mt.

In the first step of the analysis, the dominant 161 districts are arranged in production wise ascending order so as to divide them into 5 groups of each contributing about 20 per cent of the total production (Table 41). The stark skew even among the dominant districts can be observed from the data where the bottom 140 districts (Group I, II) or 87 per cent of the districts contribute only 40 per cent of sugarcane. In contrast, the top two groups (Group IV, V) containing just 10 districts or 6.2 per cent of dominant districts also produce 40 per cent of the total sugarcane in India. These districts predominantly belong to Uttar Pradesh and Maharashtra. The share of area in each of the groups indicates that the districts in the top groups also have significant amount of area under them. The average yield per hectare in the top 10 districts is also almost 10 t/ha higher than bottom districts, thus contributing to the difference in production share.

Table 41
Variation in area, production and yield of sugarcane under different production groups in dominant sugarcane districts of India

Production wise groups	Count of district	Percent of districts	Area (m Ha)	Percent Area	Production (m t)	Yield (t/ha)	Percent Irrigation
I. 0-20 per cent	118	73.3	0.92	21.78	59.26	64.4	95.33
II. 20-40 per cent	22	13.7	0.95	22.43	62.53	66.0	95.38
III. 40-60 per cent	11	6.8	0.80	18.83	61.10	76.8	97.11
IV. 60-80 per cent	6	3.7	0.80	19.03	59.06	73.4	97.11
V. 80-100 per cent	4	2.5	0.76	17.94	57.80	76.2	97.06
Total/Average	161	100.0	4.23	100.00	299.75	70.9	96.32



Map 29. Variation in total sugarcane production in dominant sugarcane districts of India

Variation in total production among the dominant districts is shown in Map 29 and their clustering pattern is shown in Figure 26.

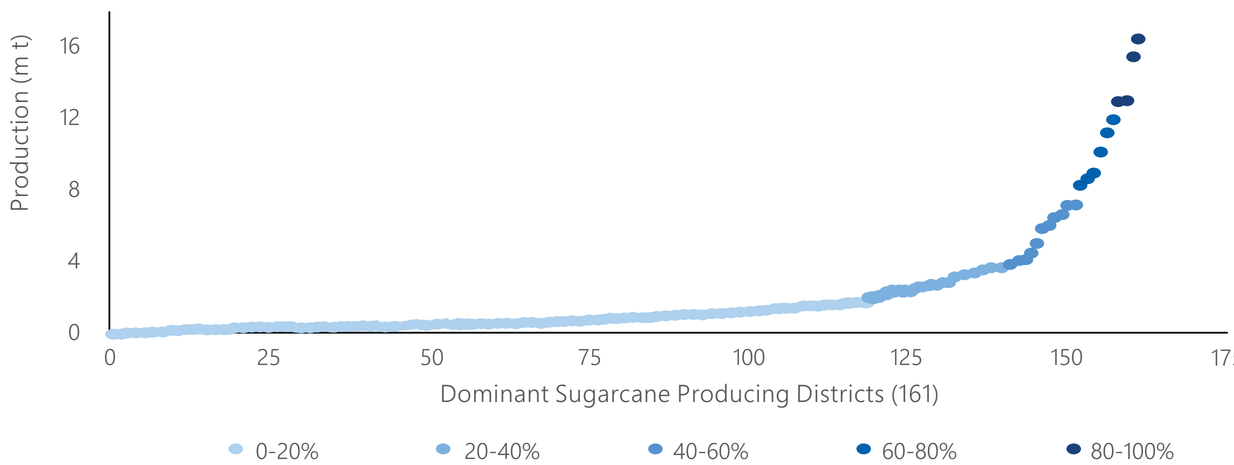


Figure 26. Clustering of the dominant sugarcane districts under five production groups

There is not much variation in the per cent area under irrigation under different groups as it varies in the narrow range of 95.33 to 97.11 per cent. However, experience shows that the variation is in the quality and sufficiency of irrigation. Though small farmers in Bihar, Uttar Pradesh, and Madhya Pradesh do apply some irrigation but economize heavily on irrigation due to high cost of diesel-pump based irrigation; and inadequacy and uncertainty of rural electricity and canal based irrigation.

10.3 Water use in sugarcane

10.3.1 Water use and irrigation water requirement in sugarcane

Sugarcane is a water-intensive crop due to its long duration and accumulation of the largest biomass among all the agricultural crops. Maintenance of optimum soil moisture during all stages of crop growth is one of the essential pre-requisites for obtaining high cane yield (Teixeria et. al., 2016). Under field conditions, water requirements are met by effective rainfall, contribution from shallow water table and irrigation. It is estimated that about 80 per cent of the irrigation requirements of sugarcane in India are met through groundwater sources. Frequent light irrigations, each of 40 to 50 mm, adjusted to suit growing period of the crop and to the prevalent weather conditions are very useful. Water requirement is least in ripening stage when accumulation of sucrose starts, and just before harvest irrigation is withheld for about a month. It has been estimated that the irrigation water requirement for sugarcane crop in India, ranges between 37.5 cm (Bihar) to 297 cm (Tamil Nadu)or about 5 - 40 irrigations of 7.5 cm each per hectare during its crop growth ((CACP, 2015-16)). However, there are variations between the tropical and sub-tropical regions due to variations in crop duration, growing season, soil type and the targeted yield levels (Table 42).

Table 42
Average water requirements in the major sugarcane growing states of India

Region/ State	Water requirement (cm)	Number of irrigations (of 7.5 cm depth)
Sub-tropical India		
Bihar	37.5	5
Uttar Pradesh/ Uttarakhand	57.2	8
Tropical India		
Andhra Pradesh	202.5	27
Tamil Nadu	297.0	40
Karnataka	256.0	34
Maharashtra (Pre-Seasonal crop)	206.3	28
Maharashtra (Adsali Crop)	243.8	33

Source: CACP, 2015-16.

In northern India as the summer is hotter and drier than in southern India, the crop needs water more frequently. In central and western Uttar Pradesh about 8 irrigations are given which help crop to tide over summer. In eastern Gangetic plains cane subsists almost entirely on subsoil moisture and rainfall and receives around 5 irrigations at the most. The flat crop is irrigated by flooding, the crop on ridges/ after earthing-up receives irrigation through furrows. In initial stages, the crop can also be irrigated with sprinklers. Farmers in Maharashtra, Andhra Pradesh, Tamil Nadu and Karnataka have also adopted micro/ drip irrigation to economize on water application and achieve higher productivity and water- and fertilizer-use efficiency.

10.3.2 Water Productivity of Sugarcane

Sugarcane is one of the most water intensive crops. This fact is evident from the fact that on average more than 96 per cent of the land under sugarcane is irrigated and in many states like Maharashtra, Karnataka, Tamil Nadu, Haryana, and Madhya Pradesh irrigation coverage is 100 per cent or approaching it. Studies of Indian Sugar Mills Association (ISMA, 2013) estimated that total water requirement for sugarcane in India is 80-100 BCM/ year and growing at ~ 1.2 per cent CAGR. On an average sugarcane requires 1500- 2000 mm of water / year to produce 100 tonnes of millable cane (150-200 lakh litre/ annum/ ha in full season). This translates to an average of about 88 kg water/ kg of cane and 884 kg of water/ kg of sugar for a fresh planted crop, and about 118 kg water/ kg of cane or 1157 kg water/ kg of sugar for a ratoon crop; but with wide variations among states and regions. Considerable efforts are now being made in the tropical region for saving irrigation water through cultivation of sugarcane on raised beds and irrigating either all or the alternate furrows. In recent years, sugarcane farmers in Maharashtra, Tamil Nadu and Karnataka are also adopting drip irrigation for saving the irrigation water and achieve higher yields of sugarcane.

10.3.2.1. Physical Water Productivity

Our results show that total volume of water actually consumed through evapo-transpiration by sugarcane crop in India is 60.43 km^3 (60.43 BCM) and this figure is about 57.42 km^3 for dominant sugarcane producing districts. As seen in the data below (Table 43), share of water consumed is close to 20 per cent for all the groups. The bottom groups have slightly lower water productivity compared to the average water productivity level of 5.22 kg/m^3. Average water productivity level in India is better than the global average of 4.80 kg/m^3 but lower than water-efficient sugarcane production in South Africa (5.8- 7.8 kg/m^3) and Thailand (5.8-6.5 kg/m^3) (Chooyok et al., 2013). The magnitude of difference among the groups is smaller for Physical Water Productivity. This suggests that the top sugarcane producing districts do not necessarily use the water most efficiently. Increase in water productivity in these districts, which are mainly located in the water stressed states of Maharashtra, Tamil Nadu and western Uttar Pradesh can make them the true leaders in sugarcane production.

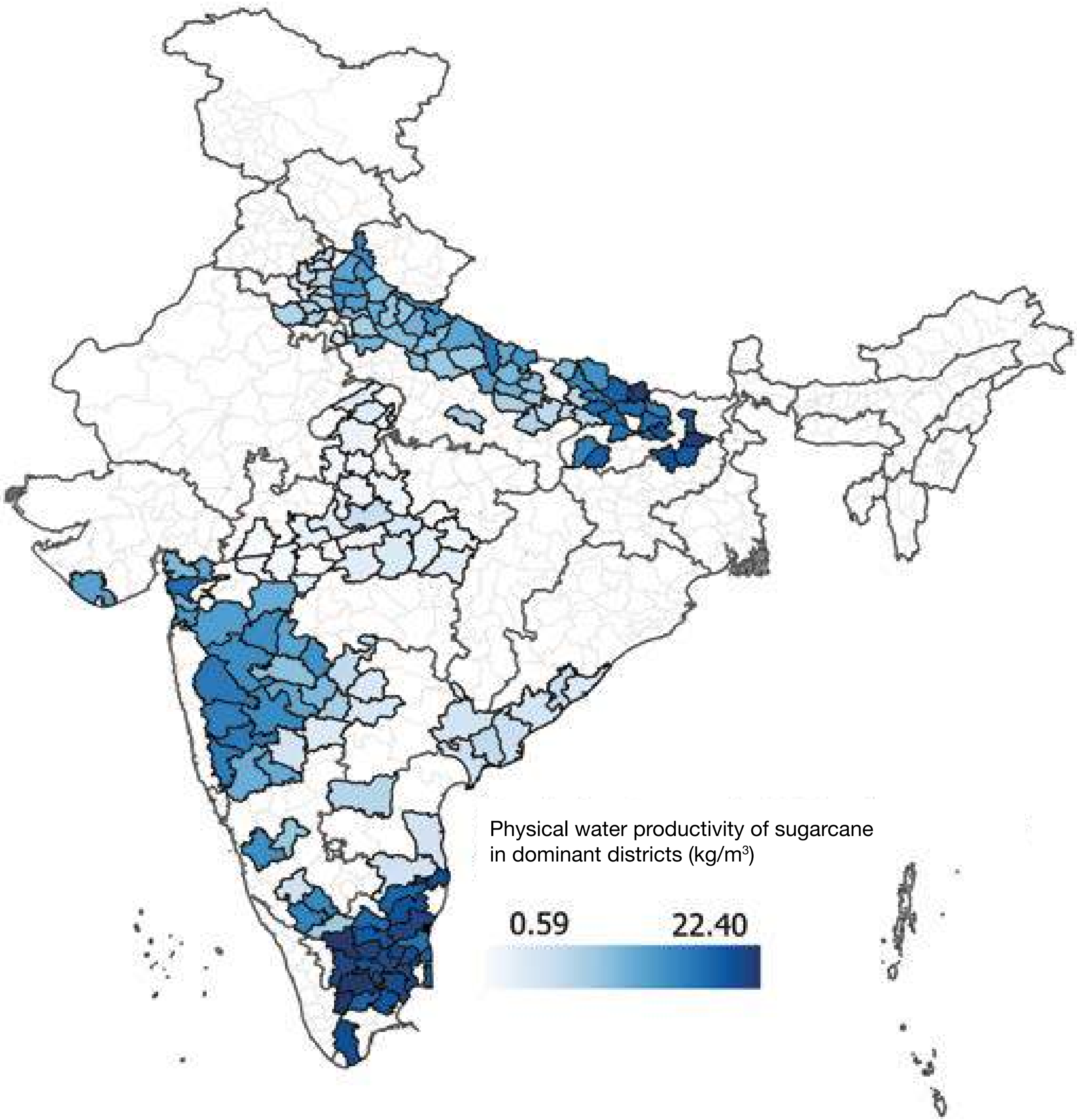
Table 43

Total consumptive water use and physical water productivity of sugarcane in the five production-wise groups for the dominant sugarcane producing districts of India

Production wise groups	Total consumptive water use (BCM)	Percent total consumptive water use	Physical Water Productivity (kg/m^3)
I. 0-20 per cent	12.92	22.49	4.59
II. 20-40 per cent	12.64	22.02	4.95
III. 40-60 per cent	10.21	17.78	5.99
IV. 60-80 per cent	10.65	18.54	5.55
V. 80-100 per cent	11.01	19.17	5.25
Total/Average	57.42	100.00	5.22

Variation in Physical Water Productivity at the district level is presented at Map 30. Most of the sugarcane producing districts in Madhya Pradesh, coastal Andhra Pradesh, and eastern Uttar Pradesh have low levels of Physical Water Productivity.

Next part of the analysis studies the sugarcane data at the state level. There is a marked difference in the distribution of area among the states. Uttar Pradesh has the most land under sugarcane (almost 2 mha, 47.2 per cent of the total area) among the dominant states followed by Maharashtra. Such magnitude in difference is also reflected in the production but due to low yield, U.P contributes less than proportion to India's sugarcane production (Table 44). As discussed above, sugarcane is a water intensive crop and hence all the states with 100 per cent irrigation (Karnataka, Maharashtra, and Tamil Nadu) demonstrate high yield and contribute more than their area proportion. Bihar has the least percentage of area under irrigation, has the lowest yield among states and as a result contributes much less than its area proportion. Physical Water Productivity map of sugarcane is shown in Map 30.



Map 30. Variation in the physical water productivity of sugarcane in the dominant districts/ states of India—Water Productivity Map of Sugarcane in India

Table 44

Variation in cultivated area, production, yield and percent area under irrigation for the sugarcane crop in the dominant sugarcane producing states of India

States	Area (Mha)	Percent area	Production (m t)	Production share, per cent	Yield (t/ha)	Percent irrigation
Andhra Pradesh	0.17	4.00	12.86	4.29	75.96	95.10
Bihar	0.16	3.74	7.45	2.49	47.18	76.60
Gujarat	0.18	4.31	13.00	4.34	71.38	94.50
Haryana	0.08	1.88	2.28	0.76	71.65	99.70
Karnataka	0.37	8.87	36.25	12.09	96.70	100.00
Madhya Pradesh	0.05	1.08	1.87	0.62	40.87	99.40
Maharashtra	0.83	19.64	72.85	24.30	87.75	100.00
Tamil Nadu	0.29	6.96	30.99	10.34	105.30	100.00
Uttar Pradesh	2.00	47.23	116.29	38.80	58.24	95.10
Uttarakhand	0.10	2.30	5.91	1.97	60.82	98.20
Total/Average	4.23	100.00	299.75	100.00	70.90	96.32

Total water consumed for growing sugarcane (based on evapo-transpiration estimation) is proportional to the area under the crop with more than 40 per cent of the water consumed in U.P. It is followed by Maharashtra and Karnataka. Consuming more water doesn't necessarily mean effective use of water. The data indicates that Tamil Nadu is leader among the states in physical water productivity (Table 45). Its PWP is almost 2 times greater than Bihar, which comes second. Top sugarcane producing states of Uttar Pradesh, Maharashtra, and Karnataka have much lower levels of PWP values. Sugarcane crop has an additional variable of crop duration as its average varies from a low of 9.6 months in Uttar Pradesh to a high of 13.5 months in Maharashtra.

Table 45

Variation in production, total consumptive water use, physical water productivity, crop duration and normalized water productivity of sugarcane in the dominant sugarcane producing states of India

States	Production (mt)	Total consumptive water use (km^3)	Percent total consumptive water use	Physical Water Productivity (kg/m^3)	Crop duration (month)
Andhra Pradesh	12.86	4.41	7.68	2.91	10.9
Bihar	7.45	0.96	1.68	7.74	12.0
Gujarat	13.00	2.53	4.41	5.13	13.0
Haryana	2.28	0.91	1.59	2.50	11.0
Karnataka	36.25	8.00	13.93	4.53	13.1
Madhya Pradesh	1.87	0.99	1.72	1.88	12.0
Maharashtra	72.85	12.26	21.35	5.94	13.5
Tamil Nadu	30.99	2.21	3.85	14.01	10.8
Uttar Pradesh	116.29	24.02	41.83	4.84	9.6
Uttarakhand	5.91	1.12	1.95	5.28	9.6
Total/Average	299.75	57.42	100.00	5.22	11.55

The correlation analysis for the production, water use and water productivity for sugarcane is given below in Table 46.

Table 46

Correlation analysis of production and water-use factors for sugarcane

	Area	Prod	Yield	TCWU	PWP	Percent Irrigated
Area	1	.959**	.142	.957**	-.035	.071
Prod	.959**	1	.272**	.963**	.029	.130
Yield	.142	.272**	1	.185*	.622**	.191*
TCWU	.957**	.963**	.185*	1	-.114	.120
PWP	-.035	.029	.622**	-.114	1	-.248**
Percent Irrigated	.071	.130	.191*	.120	-.248**	1

Important findings from the correlation analysis are:

i. High production is associated with more area under sugarcane, high yield, and high water consumption. But interestingly districts with high sugarcane production don't use water efficiently and not necessarily are fully irrigated.

ii. Being a water intensive crop, high sugarcane yield comes mainly due to water consumption, efficient use of that water and higher levels of irrigation.

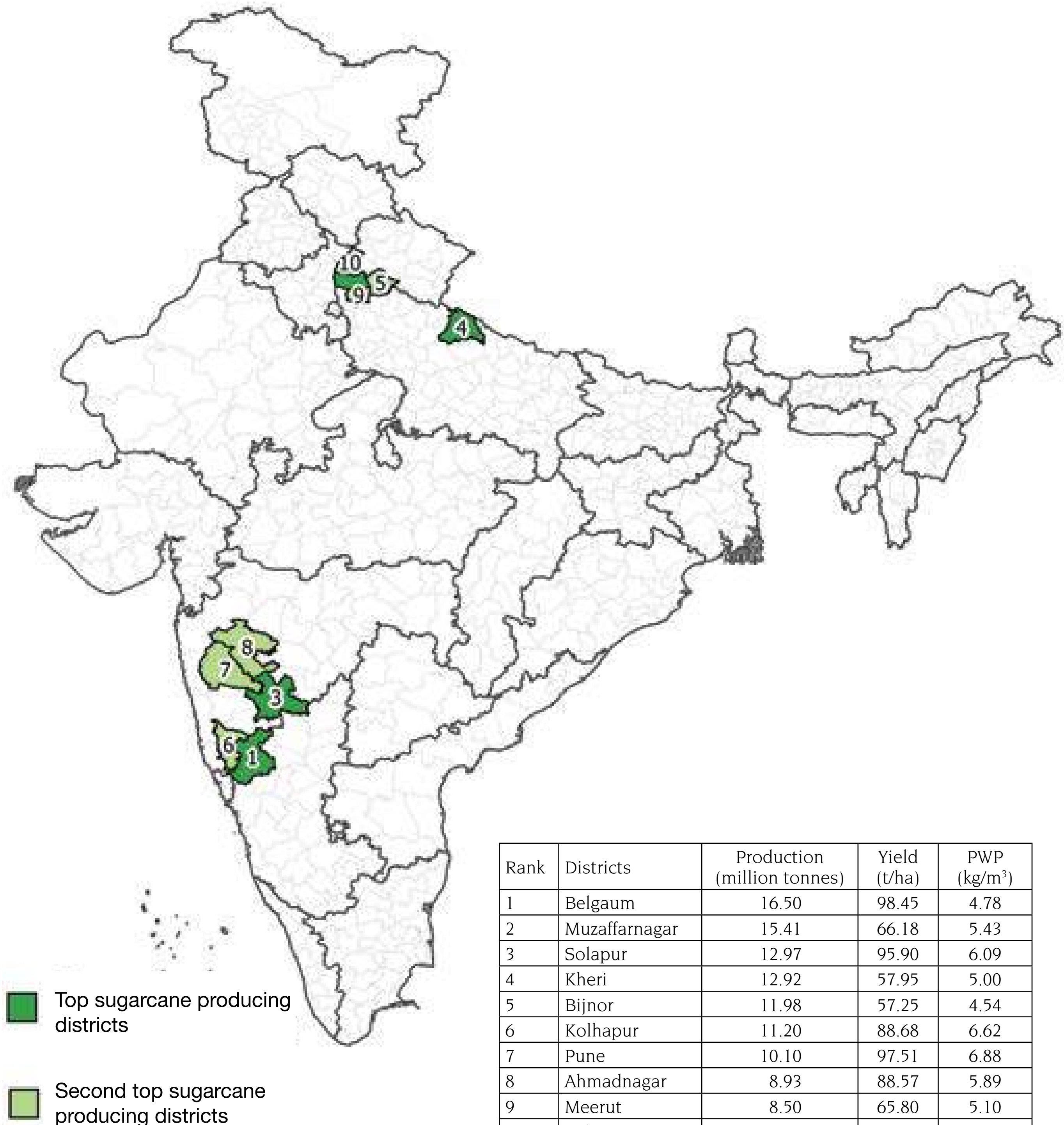
iii. Water for sugarcane cultivation in India is not used most efficiently as it is clear from the non-significant coefficient between TCWU and PWP.

iv. One of the most interesting findings is that water availability through irrigation doesn't lead to efficient water use as the coefficient between PWP and percent irrigated area is negative and highly significant.

Top 10 sugarcane producing districts in the country and their Physical Water Productivity is shown in Map 31. These constitute only 6.2 per cent of the total sugarcane producing districts but cover 37 per cent of the total sugarcane area and produce about 39 per cent of the total sugarcane production in the country- *the real sugar-bowl of India*. With the exception of Belgaum in Karnataka, all the top sugarcane producing districts are located in western Uttar Pradesh and western Maharashtra.

10.3.2.2. Irrigation Water Productivity

As mentioned in the case of rice, being a water guzzler crop, irrigation water productivity gives a more realistic picture of efficient water use in case of sugarcane also. Irrigation water requirements vary due to the climatic conditions of the state/ region. Generally, states in the northern sub-tropical region have higher rainfall, cooler winters and shorter growing season and thus lower irrigation water requirements. We find that Irrigation Water Productivity is high in the states of Bihar, Uttar Pradesh and Uttarakhand (Table 47). Each unit of applied irrigation water in these states produce more output as compared to the tropical region states of Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu. Bihar and Uttar Pradesh need to invest both



Rank	Districts	Production (million tonnes)	Yield (t/ha)	PWP (kg/m^3)
1	Belgaum	16.50	98.45	4.78
2	Muzaffarnagar	15.41	66.18	5.43
3	Solapur	12.97	95.90	6.09
4	Kheri	12.92	57.95	5.00
5	Bijnor	11.98	57.25	4.54
6	Kolhapur	11.20	88.68	6.62
7	Pune	10.10	97.51	6.88
8	Ahmadnagar	8.93	88.57	5.89
9	Meerut	8.50	65.80	5.10
10	Sahararipur	8.36	61.72	5.01

Map 31. Yield and physical water productivity of top 10 sugar districts of India

on improving the coverage under irrigation and quality of irrigation so as to ensure sufficiency of moisture during the entire crop season. On the contrary, each unit of applied irrigation water in the water-stressed states of Maharashtra, Tamil Nadu, Andhra Pradesh and Karnataka is only about one-third of the irrigation water productivity in Bihar and Uttar Pradesh. These results are comparable to earlier findings of CACP (CACP, 2012) which also concluded that while UP seemed inefficient in sugarcane yields, Maharashtra is inefficient by 175 per cent when productivity per unit of water application is considered. Similarly, Bihar and terai regions of Uttarakhand in the sub-tropical region have high irrigation water productivity as compared to states of Maharashtra, Karnataka, and Tamil Nadu in the tropical region. Madhya Pradesh in the central region due to high temperatures, high irrigation requirements and low yields has the lowest irrigation water productivity.

Table 47
Irrigation water requirements and irrigation water productivity of sugarcane in the major sugarcane growing states of India

States	Yield, kg/ha	Irrigation water requirement, m^3	Crop duration, months	Recovery rate	Irrigation Water Productivity, kg/m^3
Andhra Pradesh	75963	20200	10.9	9.52	3.76
Bihar	47177	3800	12	9.40	12.42
Gujarat	71375	18000	13	10.26	3.97
Haryana	28762	10500	11	9.19	2.74
Karnataka	96699	25600	13.1	10.79	3.78
Madhya Pradesh	40874	15000	12	9.38	2.72
Maharashtra	87747	19600	13.5	11.39	4.48
Tamil Nadu	105302	29700	10.8	9.02	3.55
Uttar Pradesh	58238	5700	9.6	9.14	10.22
Uttarakhand	60822	5700	9.6	9.27	10.67
Average	67296	15380	11.55	10.19	4.38

10.3.2.3 Economic Water Productivity

Sugarcane crop, except in some districts of eastern Uttar Pradesh and Bihar, is completely raised on irrigation water supplied through surface canals and groundwater pumps. This water has a real economic value (cost of water to society) which is distorted to various degrees through a variety of water and energy subsidies. Further, the farm harvest prices of sugarcane vary considerably among the states as sugarcane producers have a strong political lobby in several states, states tend to announce bonuses etc. and each year the prices are regulated through State Administered/Advised Prices (SAP) for sugarcane.

In our study, we have estimated the economic water productivity of sugarcane with respect to the total consumptive water use and the irrigation water applied. Figure 27 present the EWP of irrigation water as well as the EWP with respect to TCWU in the major sugarcane producing states of India. As irrigation water requirements are small owing to comparatively shorter duration of the crop, each unit of applied irrigation water produces much larger gains in Bihar, Uttar Pradesh and terai districts of Uttarakhand. Thus Economic

Irrigation Water Productivity for applied irrigation water for the growing season is much higher in these states as compared to the tropical states of Maharashtra, Andhra Pradesh, Tamil Nadu and Karnataka. The EWP-TCWU is found to be highest for Tamil Nadu (Rs 26.6/m^3) indicating that in terms of the existing evapo-transpiration rate (climatic condition) and the FHP, Tamil Nadu is optimum for sugarcane cultivation from water use perspective. However owing to the injudicious level of irrigation water use, the EWP of irrigation water applied (Rs 6.7/m^3) is low in Tamil Nadu. Hence there is a need to use efficient irrigation water management practices in Tamil Nadu to improve the EWP with respect to irrigation water applied. Lowest economic irrigation water productivity is observed in Haryana as the state has low rainfall and due to high temperature the irrigation requirements are large.

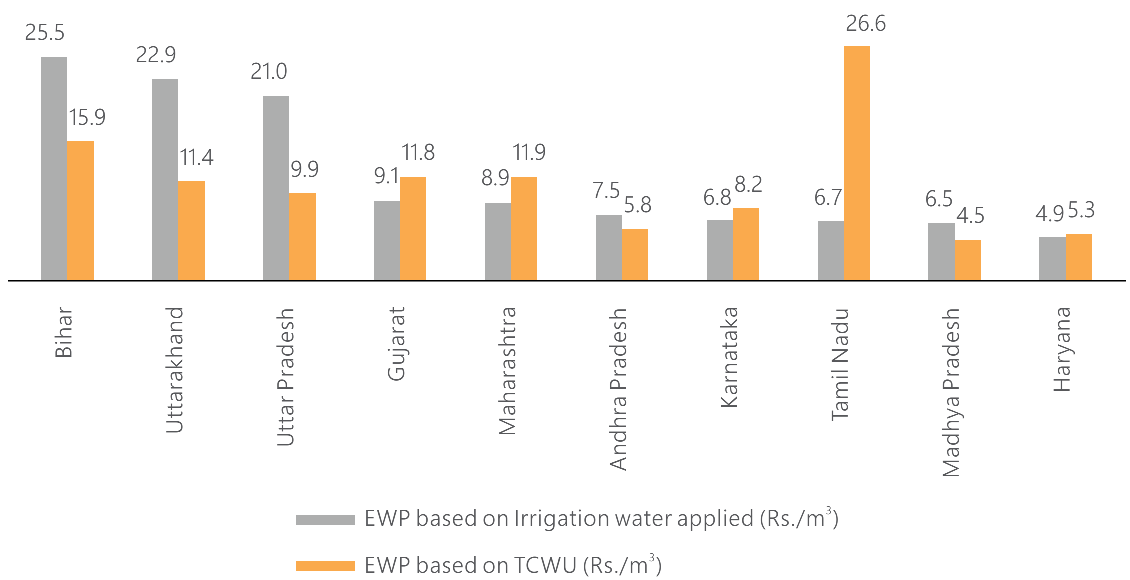


Figure 27. Economic water productivity of sugarcane across major states

10.4 Conclusions

Sugarcane is an important cash crop and from about three percent of total cultivated area, it generates about 7.5 per cent (US$ 8.61 billion) of the gross value of the agricultural production. India occupies second position globally in terms of total production of 352 million tonnes. It is a water-intensive crop and national average yield is around 70 t/ha with water requirements ranging between 37 to 297 cm per hectare during the crop cycle.

Highest PWP of 14.01kg/m^3 was observed in Tamil Nadu and lowest in the hot states Madhya Pradesh (1.88kg/m^3), Haryana (2.50kg/m^3) and Andhra Pradesh (2.91kg/m^3).

The tropical belts of Uttarakhand, Uttar Pradesh (both with IWP of 10.22 kg/m^3) and Bihar (IWP =12.4 kg/m^3) report higher levels of IWP but lower levels of land productivity.

Following are the important conclusions and recommendations based on the water productivity analysis for the sugarcane crop in India:

i. Broadly, there are two distinct agro-climatic regions of sugarcane cultivation in India- tropical and sub-tropical with area under cultivation in the ratio of 45:55, and production in the ratio of 55:45 due to variations in a number of climatic factors and management practices. More than 96 per cent of the crop receives some form of irrigation with lower irrigation levels and quality in the sub-tropical region. Average crop duration also varies from 9.6 to 13.5 months with longer duration in the tropical region.

ii. Sugarcane is cultivated in about 500 districts spread across 26 states. But 161 districts spread over 10 states contribute over 95 per cent of the area and production and are designated 'dominant sugarcane producing districts'. This forms the universe for this study.

iii. There is wide variation in production among these districts and when arranged in ascending order of production, the bottom 87 per cent of the districts (140 districts) contribute 40 per cent to total production. The top 6.2 per cent districts (just 10 districts in UP and Maharashtra) also contribute 40 per cent to the total production.

iv. This study estimates that total water annually consumed by sugarcane crop in India is 60.43 km^3 (60.43 BCM).

v. Average Physical Water Productivity of sugarcane in India is 5.22 kg/m^3 with a wide variation of 0.59 to 22.4 kg/m^3 with larger number of districts at the lower level. These values are better than the global average of 5.8 kg of sugarcane/m^3 of consumed water. Highest Physical Water Productivity of 14.01kg/m^3 was observed in Tamil Nadu and lowest in the hot states Madhya Pradesh (1.88kg/m^3), Haryana (2.50kg/m^3) and Andhra Pradesh (2.91kg/m^3). These states should seriously consider reducing the area under sugarcane and diversify to more water efficient crops.

vi. As in the case of rice, one observes somewhat perverse relation between land productivity and IWP in sugarcane also. The tropical belts of Uttarakhand, Uttar Pradesh (both with IWP of 10.22 kg/m^3) and Bihar (IWP =12.4 kg/m^3) report higher levels of IWP but lower levels of land productivity. At the same time, the sub tropical belts of Maharashtra Karnataka, Andhra Pradesh and Tamil Nadu have high land productivity but lower levels of IWP values ranging between 3.55 to 4.48 kg/m^3. Thus there exists a major mismatch between the IWP and the cropping pattern of sugarcane based on its land productivity across major states. This needs correction by suitably adjusting the price of power and irrigation water, and by promoting more efficient technologies (such as drip) for irrigating sugarcane crop in these regions. It may be worth mentioning that historically, Bihar and eastern Uttar Pradesh were the centres of sugarcane belt, which were in line with the water resource endowment of the region, and that is where IWP is the highest. But over time, preference for cooperatives took the sugarcane belt to Maharashtra, Karnataka and Tamil Nadu, which do not have that type of water resource endowment.

vii. Economic Irrigation Water Productivity for the growing season is much higher in Bihar, Uttar Pradesh and Uttarakhand when compared to the tropical states of Maharashtra, Andhra Pradesh, Tamil Nadu and Karnataka. Lowest economic irrigation water productivity is observed in Haryana as the state has low rainfall and due to high temperature the irrigation requirements are large. The EWP based on TCWU is highest in Tamil Nadu, but the EWP based on irrigation water applied is relatively low indicating the inefficiency in irrigation water application in the state. Adoption of efficient irrigation water management techniques may aid in improving the EWP based on irrigation water applied in Tamil Nadu.

It may be worth mentioning that Bihar and eastern UP which report high IWP, historically comprised a significant section of the sugarcane belt, in line with the water resource endowment of the region.

11

Cotton

11.1 Introduction

Cotton crop (*Gossypium spp*.) is cultivated by about 80 countries across the world. On average cotton was planted in an area of 295.8 lakh ha[19] in 2016-17. Of the total area in the world, about 75 percent is contributed by six countries of India (36.7 per cent), China (9.8 per cent), USA (13.0 per cent), Pakistan (8.1 per cent), Uzbekistan (3.9 per cent) and Brazil (3.2 per cent). Several countries in Africa also grow cotton. China has a high productivity of 1708 kg lint/ha against 542 kg lint/ha in India. World average production of cotton during the last decade (2006-2016) was 1482.9 lakh bales with an average cotton lint yield of 765 kg/ha. It is estimated that average global green-blue water footprint for cotton cultivation was 3589 m^3/tonne with the total global green-blue water footprint of 207 BCM (Menkonen and Hoekstra, 2014).

11.2 Cotton in India

Cotton is the second largest *kharif* crop of India, after rice contributing to 6-7 per cent of net sown area. India is the largest producer of cotton in the world accounting for about 25 per cent of the world cotton production. It has the distinction of having the largest area and production of cotton in the world. The yield per hectare is, however, only 542 kg lint/ha which is substantially lower than the world average of 784 kg lint/ha (USDA, 2016-17).

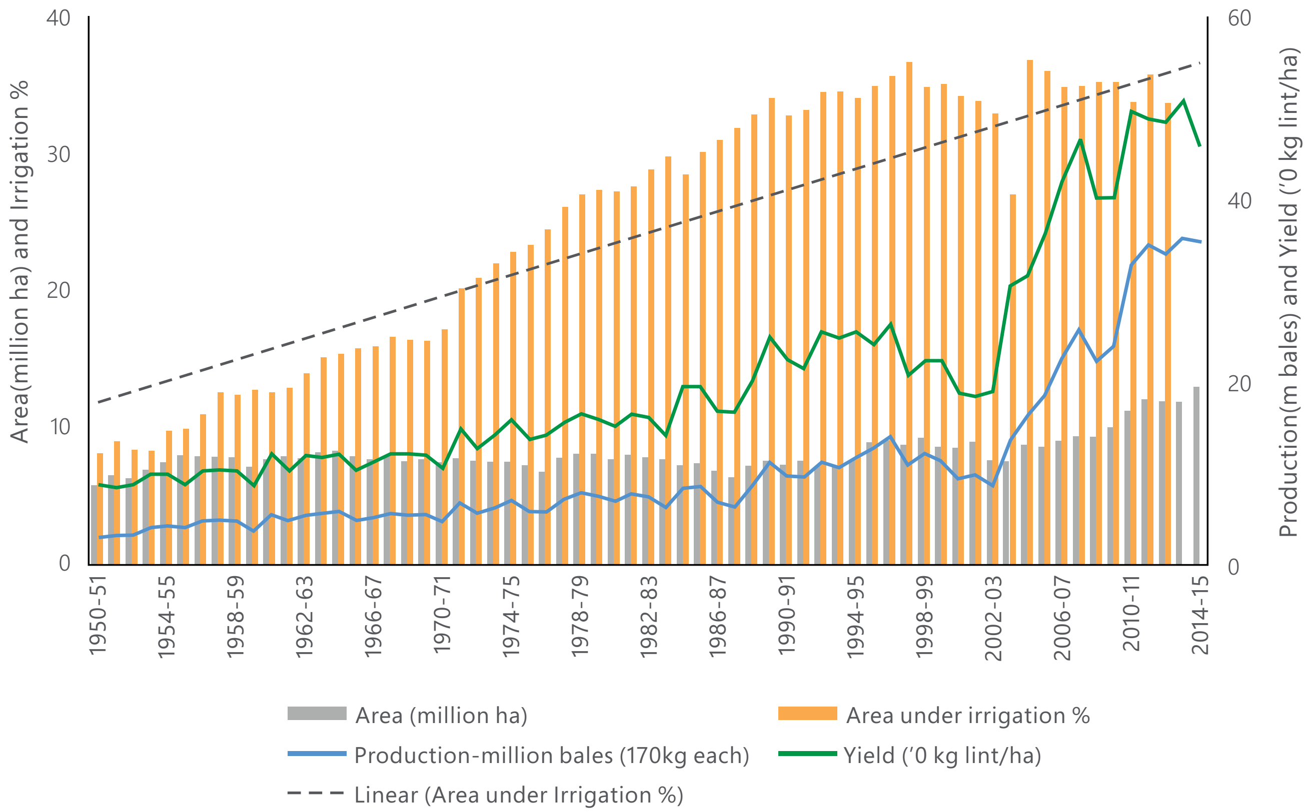
Over the years, country has achieved significant quantitative increase in cotton production and the country has become self-sufficient in cotton production. The yield per hectare which was stagnant at about 300 kg/ha for so many years, jumped to 472 kg in the year 2005-06 and now it reached to the level of 504 kg to 566 kg per hectare (Figure 28). Bringing more area under irrigation (presently around 35 percent) and adoption of hybrids and genetically modified Bt Cotton on an extensive scale have the potential to take the current productivity level near to the world average in the near future.

The current land productivity of cotton cultivation in India can climb closer to the world average of 784 kg lint/ha if more crop area (than the current 35 per cent) is brought under irrigation and hybrids and genetically modified Bt Cotton are adopted on widely.

11.2.1 Dominant districts for cotton cultivation in India

The government data for 2009-10 and 2010-11 suggest that 264 districts across 19 states cultivated cotton. The total area under these districts is

[19] https://apps.fas.usda.gov/psdonline/circulars/cotton.pdf

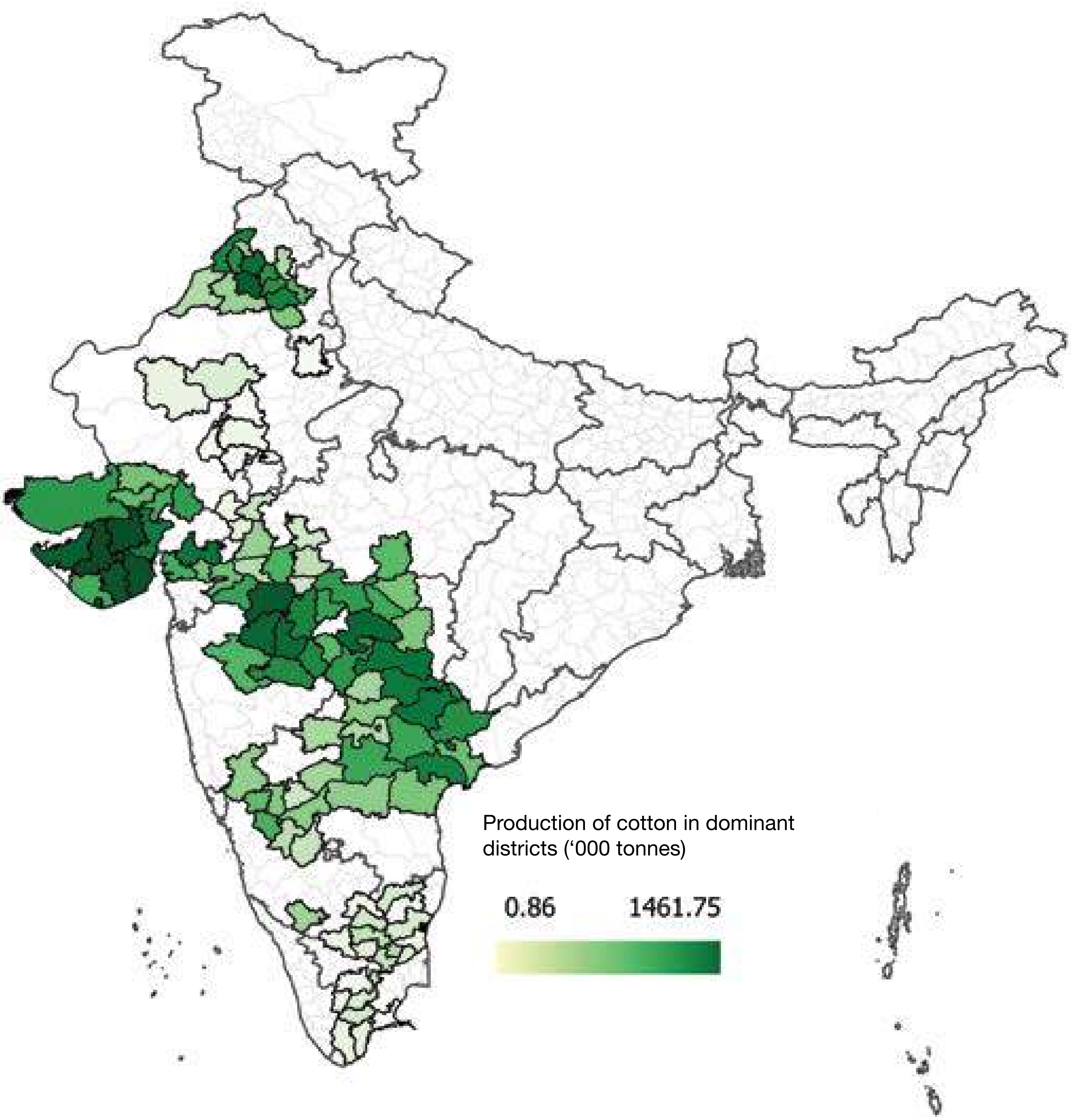


Note: Significant improvements in production and productivity since the year 2002 onwards when Bt Cotton was introduced in India.

Figure 28. Changes in cropped area, production, yield and area under irrigation for cotton cultivation in India during 1950 to 2015

close to 10.44 million hectares and at an average seed cotton yield of 2.3 t/ha; the total production was around 24.07 million tonnes. With the application of criterion for selection of dominant states and dominant districts 9 states and 105 districts were selected for the study. These districts in the dominant states cover more than 95 per cent of the total cotton area and production of India. The total area in the dominant districts is around 10.09 mha and they cumulatively produce 23.3 million tonnes with an average seed-cotton yield of 2.31 t/ha. Spatial distribution of these districts and variation in production across the districts is shown in Map 32.

In the first part of the district level analysis, the dominant districts are arranged in ascending order into 5 production wise percentage groups where each group contributes approximately 20 per cent of the production. These groups are presented in Table 48 below. The skew in production among these groups is clearly noticeable with almost 69 per cent of the districts falling in the first group with almost 30 per cent of the area while contributing only 20 per cent of production. The last two groups only have 10 districts or less than 10 per cent of the dominant districts covering 32 per cent of the cotton area and contributing 40 per cent of production. The average yield values across the groups suggest the middle groups are similar while



Map 32. Variation in production of cotton across dominant cotton districts of India

Table 48
Variation in area, production, yield and percent area irrigated across the production-wise groups of dominant cotton cultivating districts of India

Production wise groups	Number of districts	Percent of districts	Area (m ha.)	Percent area	Production (m t)	Avg. seed cotton yield (t/ha.)	Percent irrigated
0-20 per cent	72	68.57	2.97	29.41	4.77	1.61	38.46
20-40 per cent	14	13.33	2.10	20.82	4.63	2.20	22.13
40-60 per cent	9	8.57	1.79	17.72	4.69	2.62	47.64
60-80 per cent	6	5.71	1.87	18.55	4.37	2.33	19.98
80-100 per cent	4	3.81	1.36	13.50	4.83	3.55	69.32
Total/Average	105	100	10.09	100.00	23.30	2.31	37.42

the yield of the top group (80-100 per cent) is more than double that of the bottom group (0-20 per cent). This difference might be caused by the extent of irrigation applied across them. Clustering pattern of these dominant districts production groups is shown in Figure 29.

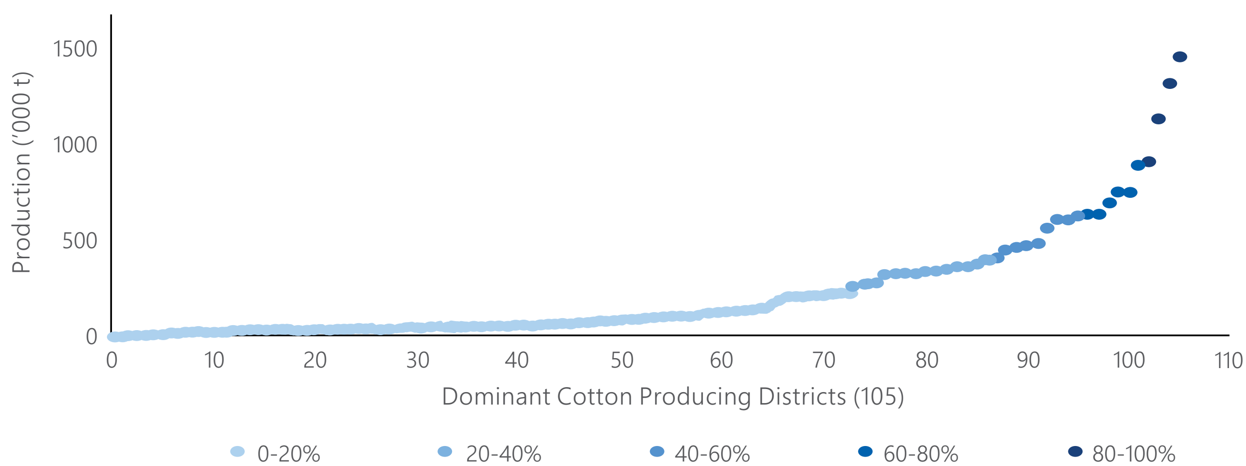


Figure 29. Clustering pattern of the dominant cotton production districts in India

11.3 Water use in cotton

Nearly 64 per cent of the cotton area is rain fed mainly in the Central Zone (Maharashtra-97 per cent, Madhya Pradesh- 60 per cent, Gujarat- 64 per cent) and Southern Zone (Telangana, Andhra Pradesh- 80 per cent, Karnataka-75 per cent, Tamil Nadu-65 per cent). Rain fed cotton requires a minimum rainfall of 500 mm, with favourable distribution for good cotton yields which generally is not available and leads to crop failures or very low yields.

Cotton requires four to six irrigations, depending upon soil type and seasonal rainfall. First irrigation should be given 4 to 6 weeks after sowing and subsequent at 2-3 weeks interval. Sowing of cotton on ridges and irrigation in furrows save considerable amount of applied water. The crop must not be allowed to suffer water stress during flowering and fruiting stage, otherwise a lot of shedding of flowers and bolls will take place resulting in low cotton yield. To hasten boll opening, last irrigation may be given by end of September. Cultivating cotton under drip irrigation has a lot of benefits- reducing the cost of irrigation by 50 per cent and water savings by 45 per cent, and improving the cotton productivity by 114 per cent as compared to flood irrigation. Adoption of drip irrigation is economically viable with the capital cost repayment period of just one year (Narayanmoorthy, 2008)

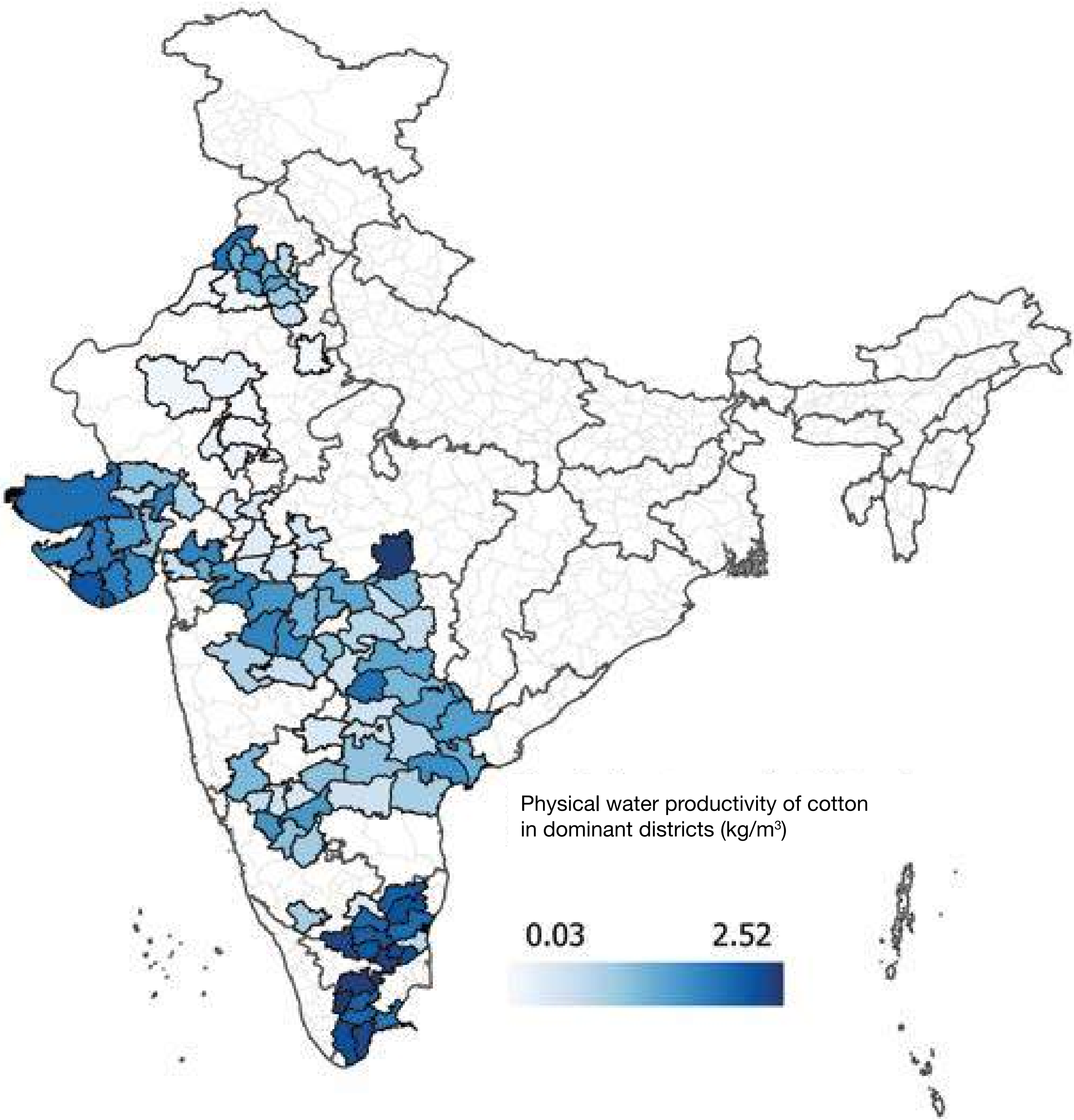
11.3.1 Water Use and Water Productivity of Cotton in India

11.3.1.1 Physical Water Productivity

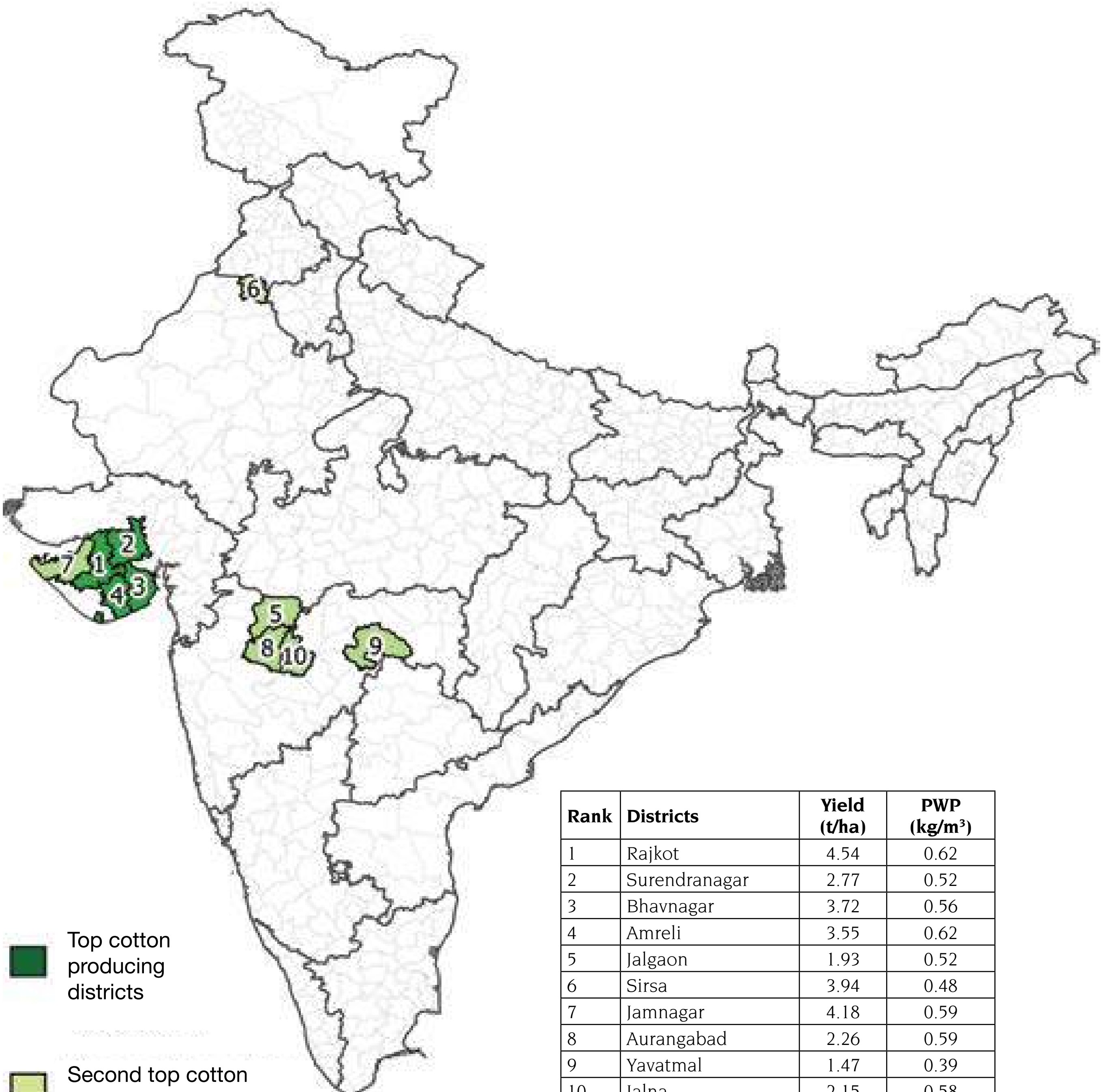
The study estimated that Total Consumptive Water Use for cultivation of cotton in India was 52.82 km^3 (52.82 BCM) (25.5 per cent of global consumption), while the dominant districts consumed 51.11km^3 (96.7 per cent of the total). Total water consumption for any crop is largely determined by the area cultivated under that crop. As mentioned above, the bottom group occupies close to 30 per cent of the area and it also consumes proportional amount of water. The following groups also consume proportional volume of water but that is not the case of the top group (80-100 per cent) (Table 49). This group consumes more than its proportional share of water with highest percent of irrigation. Physical Water Productivity values also indicate incremental increase in its values as one move from the bottom group to the top group. The variation is 0.33 to 0.57 kg/m^3 with the national average value of 0.46 kg/m^3 .The top group's PWP is more than 1.5 times than that of bottom group. This suggests that the top cotton producing districts have more area under them; they enjoy more productivity and are also more efficient in utilizing water. Variation in Physical Water Productivity across the dominant cotton growing districts of India is shown in Map 33. Productivity and Physical Water Productivity of top performing 11 districts for cotton production in India are shown in Map 34.

Table 49
Variation in total consumptive water use and physical water productivity across the five production-wise groups of cotton in India

Production wise groups	Total Consumptive Water Use (km^3)	Percent TCWU	Physical Water Productivity (kg/m^3)
0-20 per cent	14.54	28.45	0.33
20-40 per cent	10.10	19.76	0.46
40-60 per cent	9.57	18.71	0.49
60-80 per cent	8.47	16.58	0.52
80-100 per cent	8.44	16.50	0.57
Total/Average	51.11	100.00	0.46



Map 33. Variation in physical water productivity across dominant cotton districts of India



Rank	Districts	Yield (t/ha)	PWP (kg/m³)
1	Rajkot	4.54	0.62
2	Surendranagar	2.77	0.52
3	Bhavnagar	3.72	0.56
4	Amreli	3.55	0.62
5	Jalgaon	1.93	0.52
6	Sirsa	3.94	0.48
7	Jamnagar	4.18	0.59
8	Aurangabad	2.26	0.59
9	Yavatmal	1.47	0.39
10	Jalna	2.15	0.58

Map 34. Yield and physical water productivity of the top 10 cotton districts of India (Rajkot district in Gujarat has the highest yield and water productivity)

State level analysis indicates that cotton is broadly cultivated in three zones- northern, central-western and southern. Most of the area under cotton is located in the western parts of the country with Maharashtra and Gujarat as the leading states. Almost 60 per cent of the area under cotton cultivation falls in these two states and they are also the leading producers. It is important to point out that though Maharashtra's area under cotton is higher by one million hectare compared to Gujarat's area; the latter's production is higher by 2.27 million tonnes primarily due to high productivity (Table 50). However, the highest productivity of cotton is in Punjab where above 90 per cent of the crop is irrigated. In Maharashtra, only 3 per cent of the crop is irrigated and is one of the major reasons for continued farmers' distress.

These differences in crop irrigated area are also reflected in the Total Consumptive Water Use figures with Gujarat consuming almost 30 per cent of all the water used for cotton in India. Tamil Nadu has the highest Physical Water Productivity of 0.87 kg/ $m^{3.}$ Other states that also perform well in terms of water productivity include Gujarat, Punjab, and Andhra Pradesh. Madhya Pradesh with 0.20 kg/m^3 and Rajasthan with just 0.06 kg/ m^3 have very low value than the average water productivity of 0.46 kg/ m^3 indicating that from water use perspective these states are not suitable for cultivation of the cotton crop.

Table 50
State level variation in area, production, yield, total consumptive water use and physical water productivity of cotton production in India

States	Area (m ha.)	Production (mt)	Avg. Yield (t/ha.)	Percent Irrigated	TCWU (km^3)	Percent TCWU	PWP (kg/m^3)
Andhra Pradesh	1.58	3.47	2.20	15.97	7.42	14.52	0.47
Gujarat	2.46	8.34	3.38	71.87	15.20	29.74	0.55
Haryana	0.48	1.80	3.70	99.91	3.97	7.77	0.45
Karnataka	0.47	0.84	1.81	18.14	2.08	4.07	0.41
Madhya Pradesh	0.60	0.57	0.95	47.02	2.91	5.68	0.20
Maharashtra	3.54	6.07	1.71	3.00	13.32	26.06	0.46
Punjab	0.48	1.84	3.84	88.00	3.53	6.91	0.52
Rajasthan	0.38	0.15	0.39	92.99	2.42	4.74	0.06
Tamil Nadu	0.11	0.23	2.08	24.72	0.26	0.51	0.87
Total/Average	10.09	23.30	2.31	37.42	51.11	100.00	0.46

11.3.1.2 Economic Water Productivity

Economic Water Productivity is a function of the production, water use and the Farm Harvest Price realised by the farmers in the state. Due to higher physical water productivity and better farm harvest prices offered by the state, Tamil Nadu (Rs 26.17 /m^3) followed by Haryana (Rs 24.13/m^3) and Punjab (Rs 24.13/ m^3) have high economic water productivity (Table 51). Average Economic Water Productivity for cotton in India is Rs 16.27/ m^3, while states like Madhya Pradesh and Rajasthan have very low economic water productivity.

Table 51

State level variation in area, production, yield, total consumptive water use, physical water productivity and economic water productivity of cotton production in India

States	Production (mt)	Farm Harvest Price (Rs/kg)	Share of economic value (per cent)	Economic Water Productivity (Rs/m^3)
Andhra Pradesh	3.47	35.7	14.88	16.67
Gujarat	8.34	34.0	34.05	18.63
Haryana	1.80	53.3	11.52	24.13
Karnataka	0.84	36.0	3.65	14.59
Madhya Pradesh	0.57	36.3	2.47	7.08
Maharashtra	6.07	30.2	22.07	13.78
Punjab	1.84	44.7	9.89	23.30
Rajasthan	0.15	35.9	0.63	2.16
Tamil Nadu	0.23	30.1	0.83	26.17
Total/Average	23.30	35.0	100.00	16.27

11.4 Conclusions

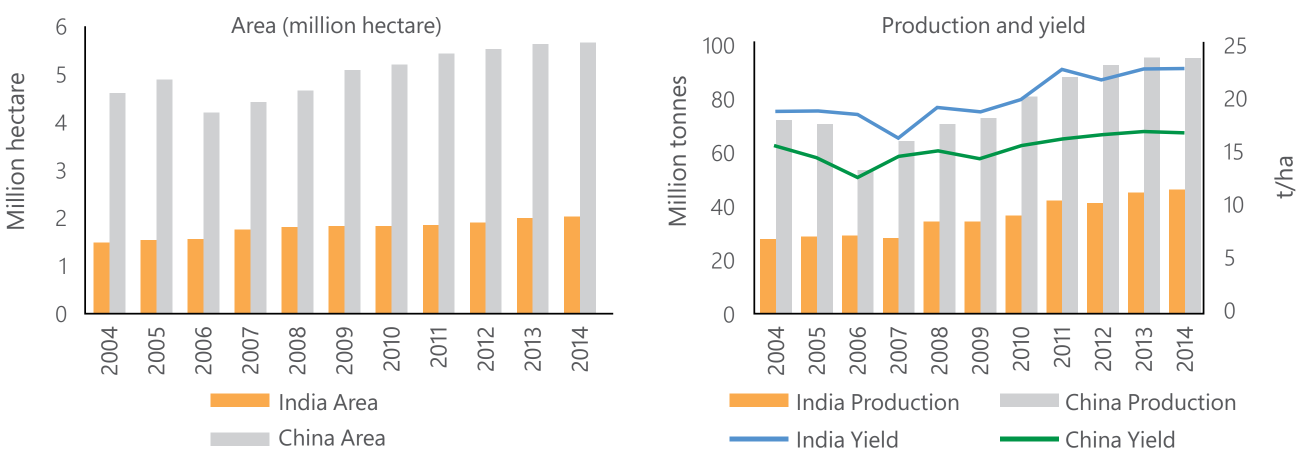
Cotton is the third most important commercial crop being cultivated in about 11 million ha, with an irrigation cover of about 37 percent. Total water consumed, based on ET, in cotton production in India is 51.11 $km^{3.}$ Gujarat and Maharashtra are the major cotton producing states of India, but the Physical Water Productivity of cotton in the two states is lower than Tamil Nadu. Tamil Nadu with a higher yield value of 2.08t/ha reports highest physical water productivity of cotton (0.87 kg/m^3). But the share of cotton area and production in Tamil Nadu is only close to 1 per cent of the country's total. In Maharashtra, the yield of cotton crop is almost half that in Gujarat, mainly owing to the low levels of irrigation given to the crop. Though the crop has a major share of cropped area in the state (19 per cent), it occupies only 3 per cent of the total irrigated area in the state. Increasing irrigation coverage and improving efficiency of irrigation in states like Maharashtra will increase production and productivity of the cotton. In states like Punjab, Haryana and Tamil Nadu if area under cotton crop is increased by replacing water guzzling paddy crop and introducing efficient water use practices, cotton productivity in India can be increased to match the global levels.

12

Potato

12.1 Potato in the world

The decadal growth of world-wide production in potato was recorded at the rate of 1.3 per cent per annum between 2004 and 2014. The world production of potato for the triennial ending 2014 was recorded as 375 million tonnes, with China, India and Russia being the top three producers, producing 25 per cent, 12 per cent and 8 per cent of the total production (FAO[20]). Though there has been considerable improvement in the yield of the crop over the years, yet it was the increase in area under the crop that led to the substantial increase in production (Figure 30). In India, the potato crop is mainly grown in the winter season across the Indo-Gangetic plains while in China it is mainly grown in the interior highlands as a summer crop under rain-fed condition (Bowen, 2003). With the increasing demand for fresh as well as processed potato, added with the decreasing land availability for area expansion, there is a need to focus upon ways to increase the yield of the crop. Being a heat and water sensitive crop, adequate and efficient water use will be a critical input for achieving increased yield in potato.



Source: FAO

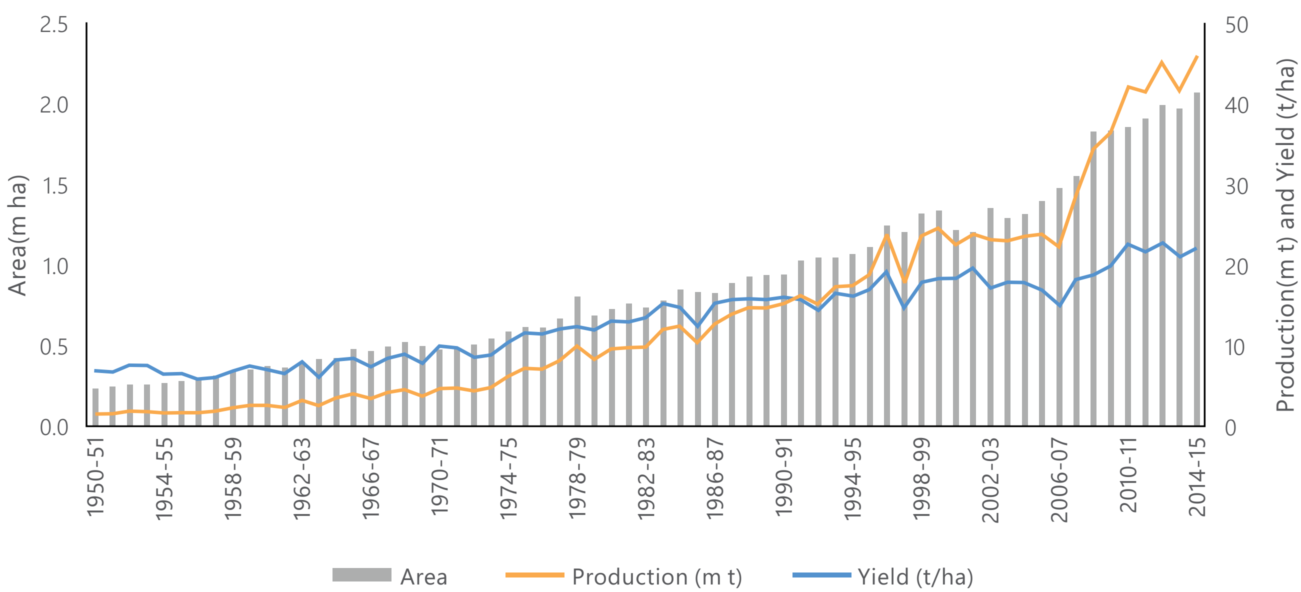
Figure 30. Area, production and yield of potato in India and China

12.2 Potato in India

Broadly the potato growing zones in India could be classified into the northern hills, the northern plains, the eastern hills, the plateau region and the southern hills. The growing season in the northern hills is the kharif season with long days. Almost 85-90 per cent of the crop is cultivated during the winter (Rabi) season (between October and February–March) under irrigated condition in the northern parts of Indo-Gangetic plains extending from Punjab in the west to West Bengal in the east. Kharif potato cultivation is mostly taken up in Karnataka, Maharashtra, Himachal Pradesh and Uttarakhand and the summer crop is cultivated in the hills of Uttarakhand, Himachal Pradesh and Gujarat (MoA&FW, 2015).

[20] http://www.fao.org/faostat/en/#data/QC

In 2014-15, India produced 48 million tonnes of potato from 2.08 million hectare area under the crop. The major producing states include Uttar Pradesh and West Bengal which contribute almost 82 per cent of the total share in production. Between 1950 and 2014, the area, yield and the production of the crop recorded an annual growth of 3.4, 5.3 and 1.8 per cent respectively (Figure 31).



Source: (DES, 2015)

Figure 31. Area, production and productivity trends of potato crop in India for the period 1950-2015

12.2.1 Dominant districts for potato production in India

In 2009-10 and 2010-11, potato was cultivated in 428 districts across 19 states and one union territory in India[21]. It covered an area of 1.54 million hectare, producing an output of 34.11 million tonnes with an average yield of 13.28 t/ha. To narrow down the focus of our study on the dominant potato producing districts in India, we have applied filters in two stages. The first filter is applied at the state level where only the states that contribute at least 1 per cent of the total potato cropped area in India are considered. There are 10 major potato producing states in India (Table 52). In the selected states, the second filter is applied to identify top districts that cumulatively contribute at least 95 per cent of the total area under potato in the respective states and also produce at least 95 per cent of the total potato production in the state (Map 35). After this stage, the study arrives at a total of 199 districts that cover 1.42 million hectare and produce 32.43 million tonnes with an average yield of 15.32 t/ha.

[21] http://aps.dac.gov.in/APY/Public_Report1.aspx

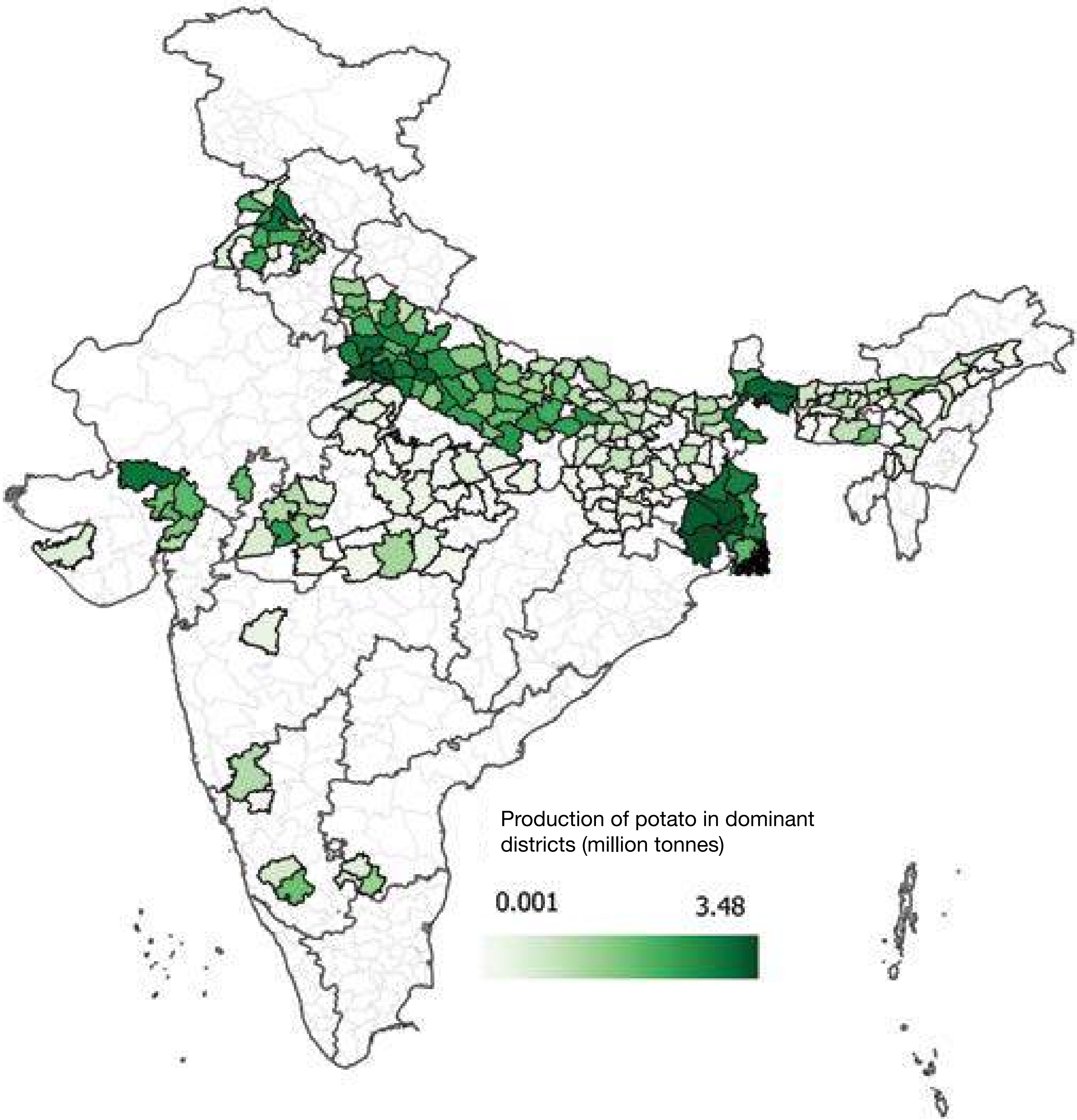
Table 52

Area, production and productivity of potato in dominant states of India

States	Area (mha)	Area share (per cent)	Production (m t)	Production share (per cent)	Average yield (t/ha.)
Uttar Pradesh	0.54	37.71	13.18	40.62	24.63
West Bengal	0.39	27.30	13.33	41.10	34.42
Bihar	0.15	10.24	0.91	2.79	6.24
Assam	0.08	5.76	0.61	1.88	7.46
Punjab	0.08	5.75	2.06	6.35	25.25
Madhya Pradesh	0.07	4.67	0.68	2.09	10.20
Gujarat	0.05	3.50	1.10	3.40	22.20
Karnataka	0.04	2.63	0.31	0.96	8.37
Jharkhand	0.02	1.24	0.10	0.31	5.77
Meghalaya	0.02	1.22	0.16	0.50	9.32
Total/Average	1.42	100	32.43	100	22.86

Following the filtering process on the area, production, and yield data, we included district wise 'total consumptive water use' data (TCWU) for potato with it. Using the production and TCWU data we calculate physical water productivity (PWP), which indicates the quantity of potato produced per cubic meter of water. Further, detailed district wise analysis for production, productivity, and physical- , and economic-water productivity is worked out.

In the detailed analysis of the dominant districts, they are first arranged in production-wise ascending order and then divided into 5 groups so that each group roughly contributes 20 per cent of the total production. Some of the key variables for these groups are presented in the Table below (Table 53). The first group has almost 80 per cent of the dominant districts indicating that most of them have smaller area under potato cultivation compared to other districts. This is validated by the total share of land in this group which is 37.3 per cent (0.53 mha). These districts not only have small area under potato, they also have lower than average yield of 12.6 t/ha. All other groups have higher productivity than the average yield for the dominant districts. In contrast, the last two groups have just 6 districts (< 3 per cent of all dominant districts) and they contribute almost 38 per cent of the production while occupying about 25 per cent of the total area under potato. These districts not only have significant area of potato cultivation in them, but also have much high yield levels. The average yield for these six districts is close to 34 t/ha, which is almost twice that of the total average yield. If one considers the last 3 groups, 15 districts alone contribute almost three-fifth of the potato production in the country. Hence, these are the leading districts from which lessons can be learnt by the lagging districts.



Map 35. Variation in production of potato in dominant potato districts of India

Table 53

Main characteristics of the five production clusters of the dominant potato production districts in India

Production wise groups	Number of districts	Percent districts	Area (mha)	Per cent area	Production (mt)	Per cent production	Average Yield (t/ha)
0-20 per cent	158	79.40	0.53	37.31	6.67	20.57	12.6
20-40 per cent	26	13.07	0.28	19.58	6.64	20.47	23.9
40-60 per cent	9	4.52	0.26	18.38	6.89	21.46	26.4
60-80 per cent	4	2.01	0.19	13.48	6.29	19.39	32.9
80-100 per cent	2	1.01	0.16	11.24	5.95	18.35	37.3
Total/Average	199	100.00	1.42	100.00	32.43	100	15.3

The 199 dominant potato producing districts spread over 10 states in the country which cover 92 per cent of the potato cropped area and contribute to 95 per cent of the total production (Figure 32). Rest of the 229 districts (53.5 per cent of the total) have very small area under the crop and just contribute 8 per cent of the total production. Thus, for any future potato improvement program these 199 districts should receive priority attention. The clustering trend of all the dominant potato production districts is shown in Figure 32 which shows a large flat base and few districts in the top ranks. Fifteen districts (7.5 per cent) with 0.61 million hectare area (43 per cent) alone contribute almost three-fifth of the potato production in the country with an average yield of about 31 t/ha.

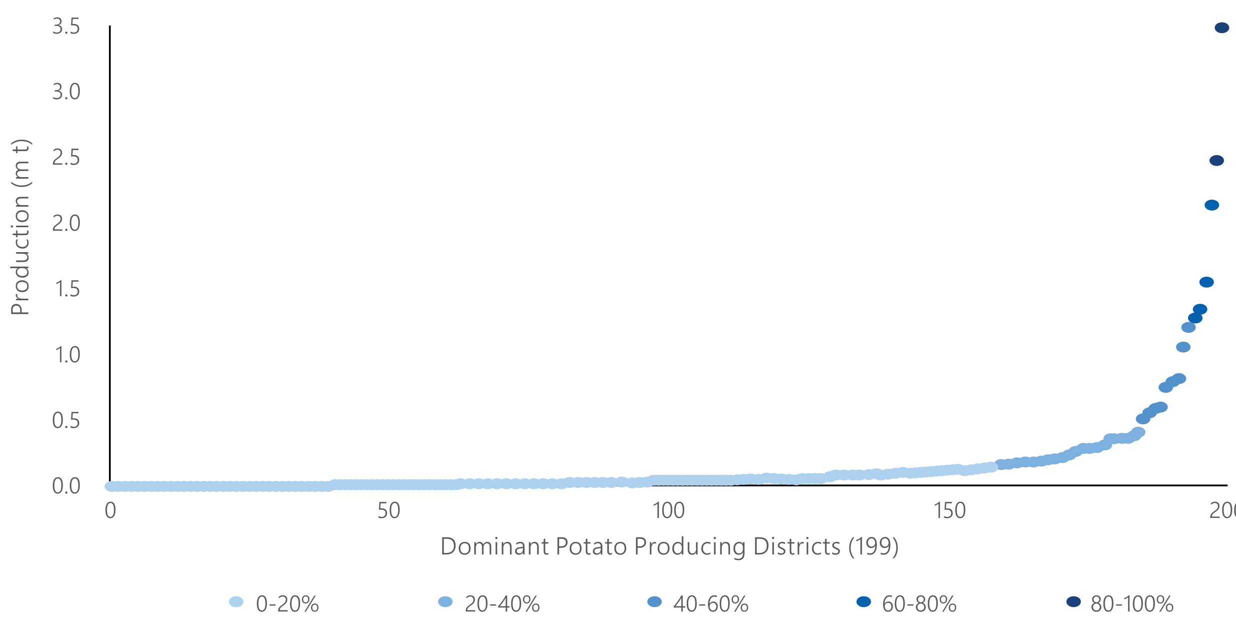


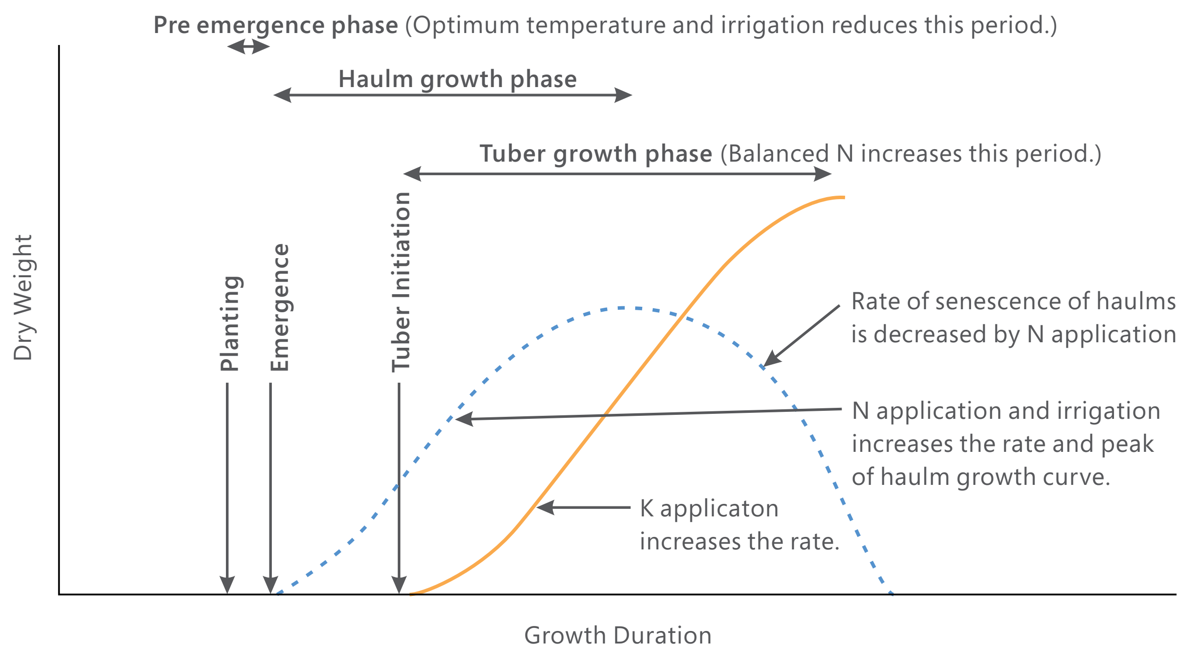
Figure 32. Production-wise percentage groups for dominant potato cultivating districts

12.3 Water use in potato

12.3.1 Water use and irrigation requirements for potato

As per the agricultural census 2010-11, about 86 per cent of the total area under potato crop is under irrigation cover in India. Being a heat and water sensitive crop, irrigation water is a critical input for potato crop. Potato has sparse root system which makes it highly sensitive to water stress and drought. In the Indo-Gangetic plains potato is cultivated majorly in the rabi season which receives negligible rainfall. Hence method of irrigation and scheduling of irrigation is very important for potato.

In general, the irrigation requirement of potato is around 50 cm of water per crop season. As per the Central Potato Research Institute, irrigation is scheduled at an interval of 8-10 days initially when the temperatures are warm and later the interval is increased to 12-15 days as the winter sets in and the temperatures cool down. Irrigation on the basis of cumulative pan evaporation has also been advocated in potato. In this case irrigation scheduling when the cumulative pan evaporation reaches 20 mm is recommended. Surface irrigation method is largely practiced in potato at an application rate of 50 mm water per irrigation. Micro irrigation practices like sprinkler and drip irrigation, where the depth of irrigation can be reduced and conveyance losses are minimal when compared to surface irrigation method, also turn out to be profitable irrigation method in potato. However the investment cost for micro irrigation system are high especially in case drip system owing to close spacing of the crop necessitating the increased requirement for laterals and emitters.



Source: CPRI

Figure 33 Growth stages of potato

The growth stages in potato and the impact of irrigation and temperature on them are displayed in Figure 33. It can be seen that proper irrigation application ensures quick emergence and increases the rate of vegetative growth.

12.3.2 Water Productivity of Potato

12.3.2.1 Physical water productivity

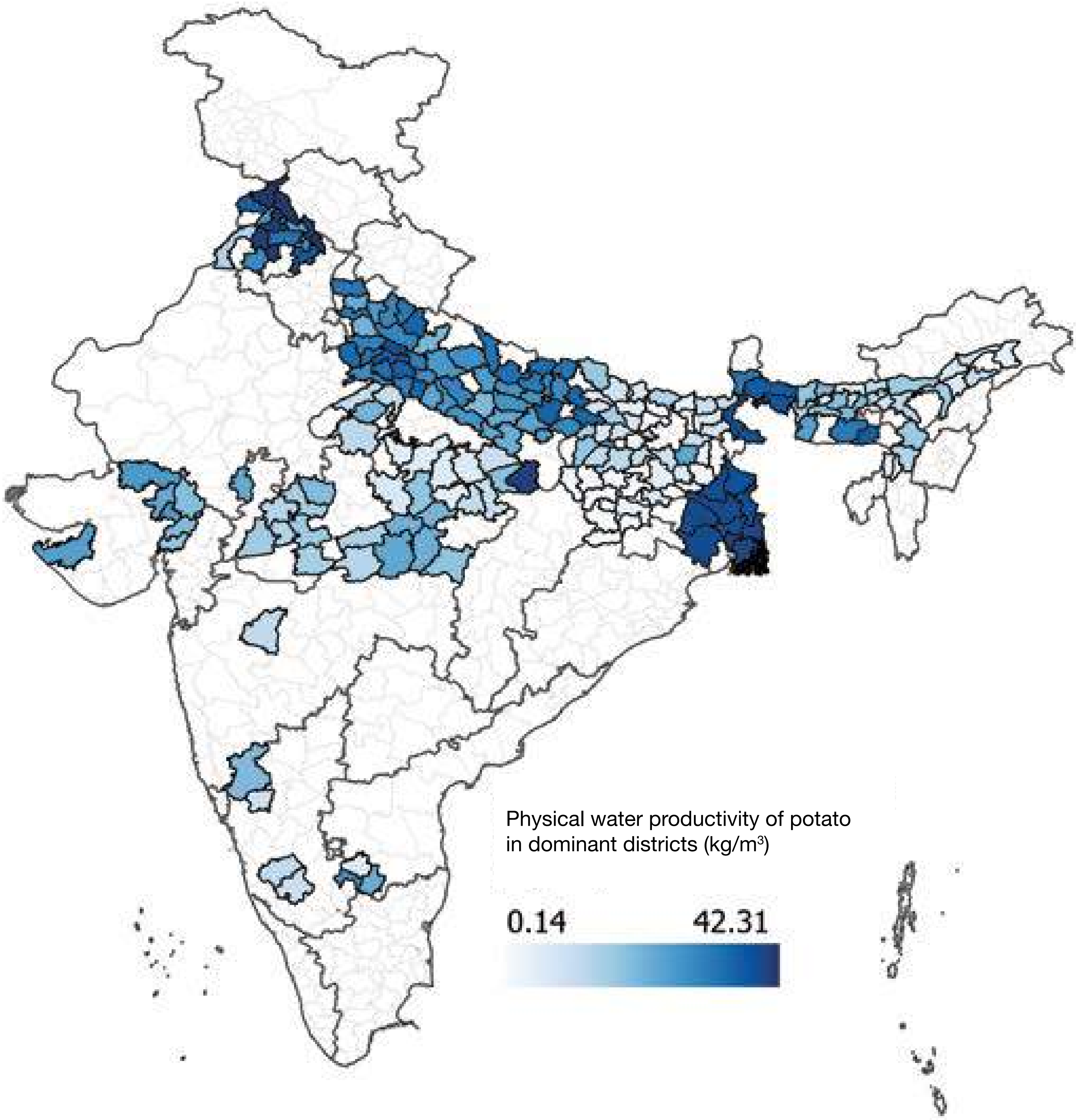
Based on the area, crop growth stages, climatic factors and other variables, this study estimated the total consumptive water use (TCWU, km^3) by potato crop in each of the dominant districts in India. Using the district-wise data on potato production and TCWU, the water productivity of the crop (kg/m^3) for each of the district was estimated. The total amount of water consumed to produce 31 million tonnes of potato in India was 6.53 km^3 (6.53 BCM). Average physical water productivity (PWP) of potato crop was 5.39 kg/m^3 but with a huge variation of 0.14 to 42.31 kg/m^3 across the districts. Data in Table 54 presents the variation of TCWU, water productivity and PWP across different production clusters in India. The lowest group consumed about 37 per cent of total water (2.23 km^3), to produce 21 per cent of total production with a PWP of 2.99 kg/m^3, the highest group consumed only 9.61 per cent of TCWU to produce the same amount of production with the highest PWP of 10.29 kg/m^3. Hoshiarpur district in Punjab had the highest physical water productivity of 42.31kg/m^3, followed by Gurdaspur district of Punjab with PWP of 29.30 kg/m^3 (Map 36).

Table 54

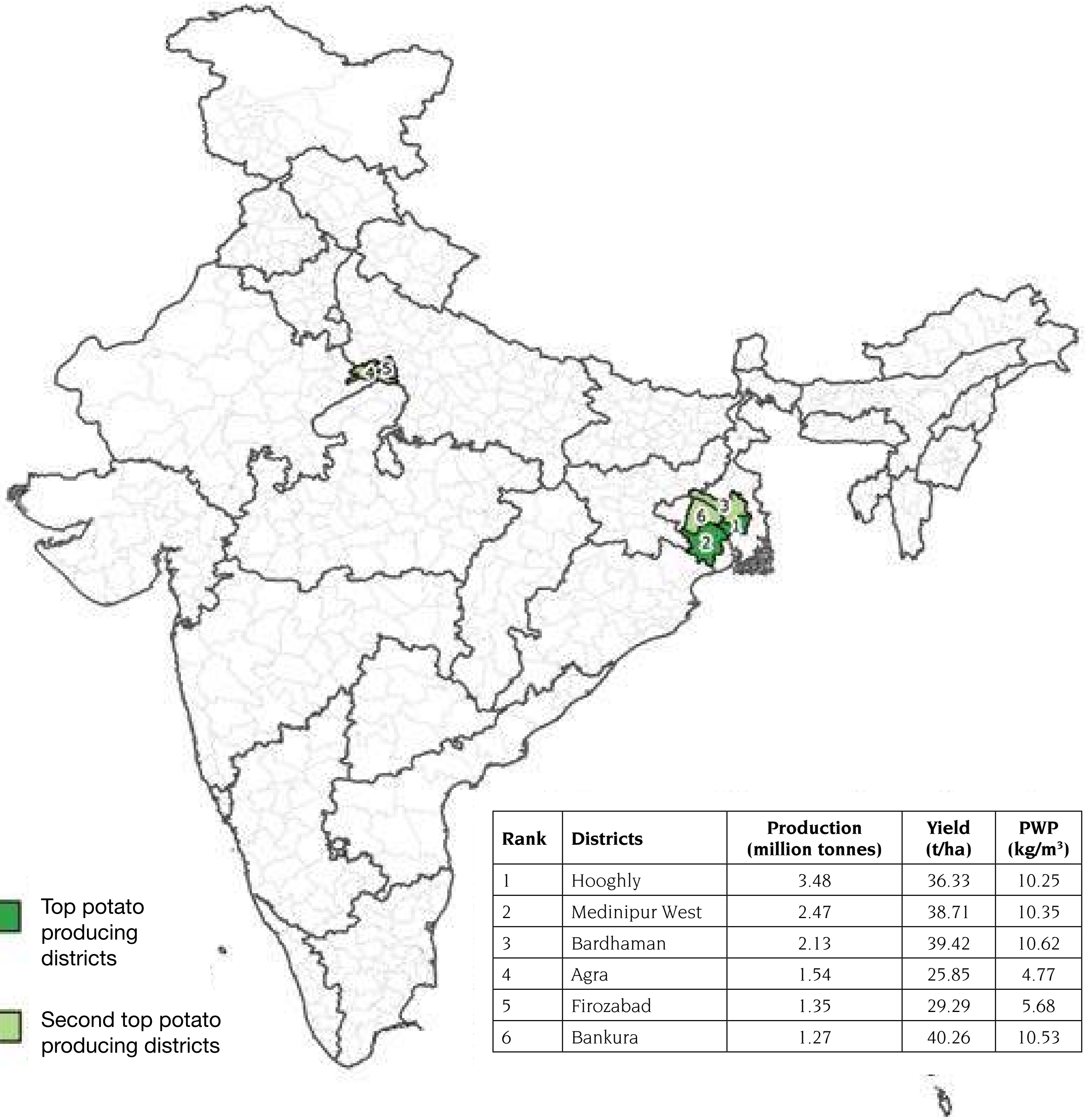
Total consumptive water use and physical water productivity of potato in major production groups

Production wise groups	Total Consumptive Water Use (km^3)	Per cent TCWU	Physical Water Productivity (kg/m^3)
0-20 per cent	2.23	37.08	2.99
20-40 per cent	1.17	19.49	5.66
40-60 per cent	1.15	19.16	5.98
60-80 per cent	0.88	14.66	7.14
80-100 per cent	0.58	9.61	10.29
Total/Average	6.02	100.00	5.39

Among the top six potato producing districts in India exhibited in Map 37, the three districts belonging to West Bengal namely Hooghly, Medinipur West and Bankura have higher physical water productivity compared to the other three districts belonging to Uttar Pradesh. This indicates that in Uttar Pradesh, though the production is high, yet it is at the expense of the scarce water resource resulting from inefficient irrigation water use (Table 55).



Map 36. Physical water productivity for potato across dominant potato districts of India



Rank	Districts	Production (million tonnes)	Yield (t/ha)	PWP (kg/m^3)
1	Hooghly	3.48	36.33	10.25
2	Medinipur West	2.47	38.71	10.35
3	Bardhaman	2.13	39.42	10.62
4	Agra	1.54	25.85	4.77
5	Firozabad	1.35	29.29	5.68
6	Bankura	1.27	40.26	10.53

Map 37. Top six potato producing districts

Table 55

State level variation in area, production, yield, total consumptive water use and physical water productivity of potato production in India

States	Area (m ha.)	Percent Area	Production (m t)	Percent production	Yield (t/ha.)	TCWU (km^3)	Percent TCWU	PWP (kg/m^3)
Assam	81686	5.76	0.61	1.88	7.46	0.30	4.94	2.05
Bihar	145248	10.24	0.91	2.79	6.24	0.59	9.73	1.55
Gujarat	49650	3.50	1.10	3.40	22.20	0.27	4.51	4.06
Jharkhand	17593	1.24	0.10	0.31	5.77	0.15	2.50	0.67
Karnataka	37285	2.63	0.31	0.96	8.37	0.14	2.35	2.21
Madhya Pradesh	66307	4.67	0.68	2.09	10.20	0.31	5.09	2.21
Meghalaya	17289	1.22	0.16	0.50	9.32	0.03	0.44	6.09
Punjab	81526	5.75	2.06	6.35	25.25	0.24	3.95	8.67
Uttar Pradesh	535039	37.71	13.18	40.62	24.63	2.61	43.38	5.05
West Bengal	387312	27.30	13.33	41.10	34.42	1.39	23.10	9.59
Total/Average	1418933	100.00	32.43	100.00	22.86	6.02	100.00	5.39

Analysis at the production wise group level indicated that share of water consumption closely mirrors share of area under each group. We find the similar trend for most of the states except for West Bengal and Uttar Pradesh, the two highest potato producing states. Uttar Pradesh has 43.5 per cent of area but consumes

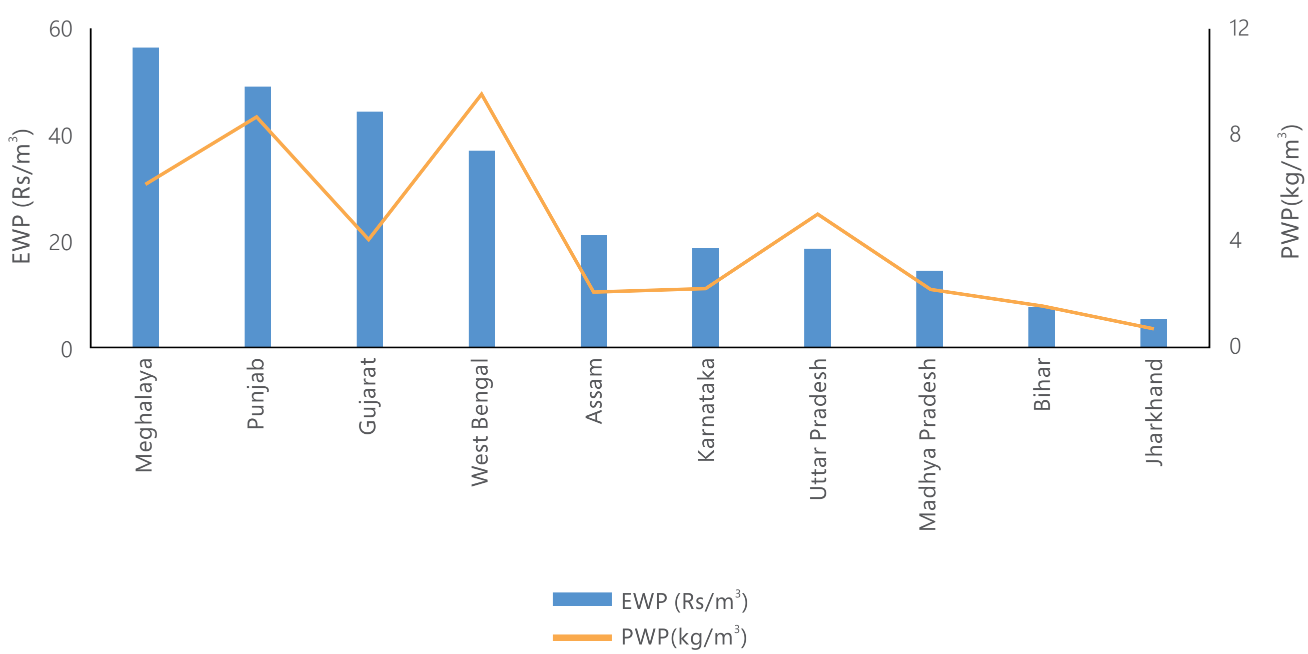


Figure 34. Physical and economic water productivity of potato in major states

proportionally higher share of water (almost 49 per cent of TCWU). On the other hand, West Bengal has 31.5 per cent of the area but consumes only 26 per cent of TCWU. In other words, though Uttar Pradesh and West Bengal produce almost similar quantity of potato, the former consumes almost twice the amount of water compared to the former. This fact also gets reflected in their PWP values. West Bengal has the highest water productivity value while U.P's value is almost half of West Bengal. It is also partly due to western and Central UP region where potato is cultivated and has a higher thermal regime.

12.3.2.2 Economic Water Productivity

The average of farm harvest price (FHP) of potato across the states is used to convert the physical water productivity to monetary terms. As listed in the table below, the FHP received by the farmers in Uttar Pradesh and West Bengal are the lowest compared to the other states owing to the higher levels of potato production in these states. Even then, West Bengal has a higher EWP value of Rs 43.5 per cubic metre of water used while UP has low EWP value of Rs 21.5 per cubic metre of water (Figure 34). The low PWP and EWP values of Uttar Pradesh suggest that the state does not utilize its irrigation water most efficiently. Gujarat, Punjab and West Bengal thus emerge as the leaders in terms of EWP. Meghalaya has higher EWP value but has very small share of area and thus is not considered significant.

12.4 Conclusions

In India potato is majorly cultivated in rabi season. As per the agriculture census 2010-11, it is cultivated in an area of 1.2 million hectare with almost 86 per cent area covered under irrigation. The study shows that though Uttar Pradesh and West Bengal are the top producers of potato, contributing almost 82 per cent to the country's total potato production, yet in terms of water utilization, Uttar Pradesh lags far behind. This indicates that efficient water use strategies need to be adopted by Uttar Pradesh from West Bengal to improve its production in a water sustainable way. The dominant districts of Gujarat and Punjab reflect higher EWP values in comparison to Uttar Pradesh and even West Bengal. However owing to the lower share of potato cultivated area in these state, their share in country's production is low. Thus, there is a scope to increase area under potato cultivation in these states.

13

Conclusions and Recommendations

Agriculture is the largest freshwater user and its global consumption from precipitation and irrigation is expected to increase at 0.7 per cent per year from its estimated level of 6400 BCM/year in 2000 to 9600 BCM/year in 2050 (Rosegrant et al., 2009). Growing water scarcity is already evident in many parts of the world, including India. Raising water productivity in agriculture, "more crop or value per drop", can contribute to reducing the pressure on global or national freshwater resources besides developing the strategies for targeted and hydrologically sustainable crop productivity, improved crop quality and favourable energy policies.

In the current study, water productivity (crop output per unit of total consumptive water use and irrigation water applied) of 10 major crops in India (covering 63 per cent of gross cropped area) has been studied and compared across dominant states and districts to understand the sustainable water use in improving agricultural production.

Table 56

Summary of dominant states, districts, area, production, productivity and yield of major crops studied (biennium ending 2010-11).

Crops	Number of dominant states	Number of dominant districts	Number of districts which produce 20 to 40* per cent of total production	Total Area (lakh ha)	Total Production, lakh tonnes	Average Yield (t/ha)	Percentage of crop area irrigated (per cent)
Rice	16	325	16	395.2	861.0	2.0	54.6
Wheat*	9	255	15	260.4	787.4	2.7	94.7
Maize*	13	239	25*	59.8	146.3	2.4	30.1
Chickpea	9	157	20*	75.6	68.0	0.9	32.5
Tur	7	167	13*	31.9	21.1	0.7	4.3
Groundnut	10	175	7*	54.6	64.4	1.2	19.3
Rapeseed-Mustard	9	201	11*	50.8	67.0	1.3	72.2
Cotton	9	105	10*	100.9	233.0	2.3	37.4
Sugarcane	10	161	10*	42.3	2997.5	70.9	96.3
Potato	10	199	6*	14.2	324.3	26.6	85.9@

**Data on TCWU for Himachal Pradesh is not available. Hence the state is not included among the dominant states even though it satisfies the 1per cent criteria.

@ Percentage irrigated area under potato is calculated based on the data as published in Agriculture census 2010-11. The total area under potato cultivation is given as 12.02 lakh ha (different from 14.2 lakh ha as calculated from APY data given by Directorate of Economics and Statistics, MoA&FW for 2009-10 & 2010-11) and irrigated area as 10.32 lakh ha.

Table 56 summarises and compares some important factors that influence production relating to major crops in the study. Figure 35 also gives the area under these crops as well as their irrigation coverage. As can be seen from the data among the crops considered, rice is the major crop cultivated over 44 million ha across the country with almost 60 percent irrigation cover (2013-14) (Figure 34). However, 325 districts together produce roughly 95 per cent of production in the country (Table 56). Wheat the second most important cereal crop in India after rice, cultivated on roughly 30 million ha of land with an irrigation cover of as high

Amongst rice, wheat and cotton, which together account for about 86.6 million ha (43 per cent) of cropped area in India (2013-14), wheat has the highest irrigation cover (94 per cent).

as 94 percent (Figure 34).It is cultivated dominantly in 9 major states, spread across 255 districts mostly in the northern and north-western and central parts of India. Cotton is the third most important commercial crop being cultivated in about 11 million ha, with an irrigation cover of about 37 percent. About 105 districts together produce 95 per cent of cotton, indicating that cotton production is concentrated in fewer districts, unlike rice or wheat. In fact just ten dominant districts concentrated in Gujarat and Maharashtra alone produce almost 40 per cent of cotton in the country. Amongst rice, wheat and cotton, which together account for about 86.6 million ha (43 per cent) of cropped area in India (2013-14), wheat has the highest irrigation cover (94 percent) as it is a *rabi* crop when rainfall is scanty and therefore much of its water requirement has to be met through irrigation sources. But rice and cotton being *kharif* crops, they meet a part of their water requirement from rainfall during the south-west monsoon, while remaining comes from irrigation sources.

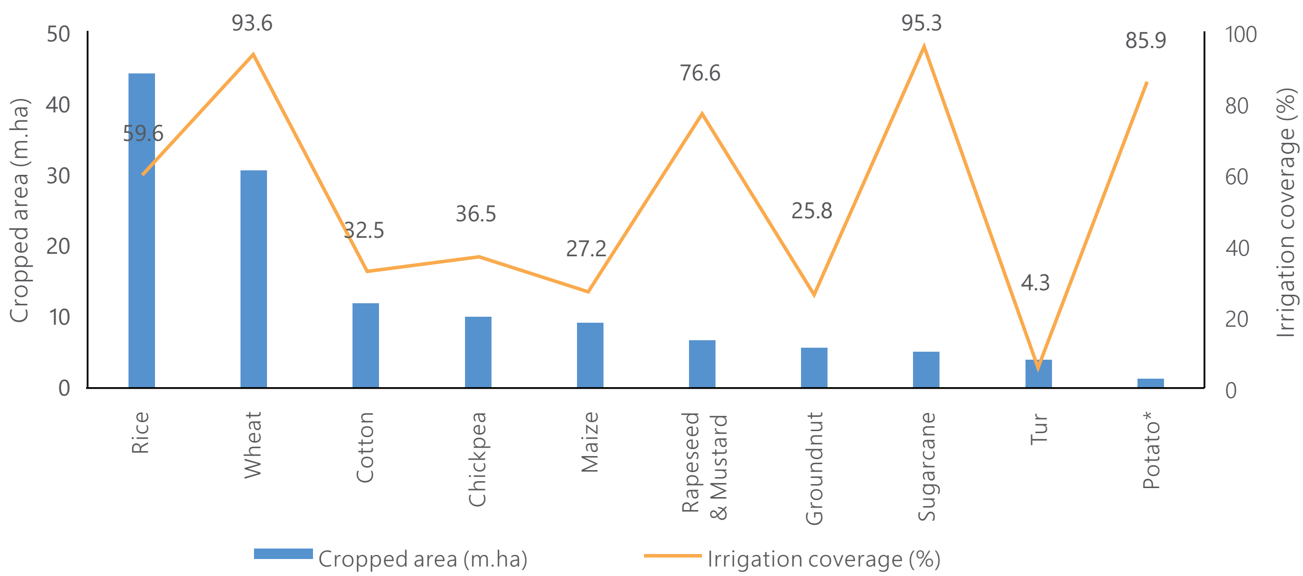
Maize is yet another cereal crop cultivated widely on 9 million ha in India. It has an irrigation cover of around 27 percent. Much of maize (more than 75 percent) is used for poultry feed and starch and less than 25 percent of it goes for direct human consumption. Out of the 239 districts spread across 13 states cultivating maize, 25 districts alone contribute towards 40 per cent of maize production. Most of these districts are spread in Karnataka, Andhra Pradesh Maharashtra, Rajasthan and Bihar states.

Amongst pulses, chickpea is the most dominant pulse being grown in almost 10 million ha with about one third of it under irrigation cover. Almost 40 per cent of chickpea production comes from 20 districts located mainly in Madhya Pradesh and Rajasthan indicating that there is a shift from northern states to central India and parts of western and southern India. Tur crop has irrigation coverage of 4.3 percent in India, which makes its yield lower than world average yield. In 2016-17, almost 0.7 million tonnes of tur was imported to India, which was almost 1.5 times more than the preceding year's import. Correlation analysis carried out in the study reveals a positive relation between crop yield and irrigation coverage for all the crops studied.

Groundnut and rapeseed-mustard are important oilseed crops, with rapeseed-mustard being grown on 6.6 million ha and groundnut on 5.5 million ha. However, groundnut being a kharif crop has irrigation cover of only about one-fourth of its cultivated area while rapeseed-mustard has over three-fourths of its area under irrigation (Figure 35). Gujarat alone produces 40 per cent of groundnut in India. But the yield level of the crop in the state is only 1.42t/ha, which can be attributed to its low irrigation coverage (10.5 per cent) (Table 56). There has been a significant increase in the yield of rapeseed-mustard (R&M) over the last few years, owing to the increase in irrigation coverage. However in comparison to the world average, a yield gap of almost 85 per cent was recorded in R&M in India in TE 2015-16.

Sugarcane occupies about 5 million ha area in the country, and is largely irrigated (about 95 percent) crop. Though the share of crop in gross cropped area of the country is only about 3 percent, its irrigation coverage is even more than wheat crop. Rice, wheat and sugarcane are the major water consuming crops in India, whereas pulse crops are the least irrigated crops. Oilseeds like groundnut, rapeseed- mustard and pulse crops which require very low quantity of irrigation water for growth, display significantly higher productivity when provided with timely irrigation facility.

In India, potato is mainly grown in *rabi* season under irrigated condition. As per the agriculture census 2010-11, potato is cultivated in an area of 1.2 million hectare, out of which almost 86 per cent area is under irrigation coverage. Six districts of West Bengal together constitute almost 38 per cent of potato production in India. Being a heat and water sensitive crop, efficient water use is an important pre-requisite for increasing potato yield in the country.



Note: The latest data on crop-wise irrigation coverage to total cultivated area is available only up to 2013-14. Hence the year considered for plotting the graph is 2013-14.
*The data of potato pertains to Agriculture Census, 2010-11.

Figure 35. Cropped area under major crops and their irrigation coverage (2013-14)

Once the dominant states and districts are identified for each of the studied crops, analysis of water productivity of these crops can help better understand the issue of sustainability of the crop in that area with respect to available water resource. In Table 57 the total water consumed and physical water productivity of studied crops is presented. For rice, wheat and sugarcane, which together consume more than 80 per cent of the irrigation water of the country, we have also estimated irrigation water productivity.

Table 57

Summary of water productivity: Total consumptive water use, average physical water productivity, average irrigation water productivity and average economic water productivity of major crops studied

Crops	Total TCWU (km^3)	Average PWP (kg/m^3)	Average EWP (Rs/m^3 of TCWU)	Average IWP(kg/m^3)	Average EWP (Rs/m^3 of applied irrigation water)
Rice	206.2	0.4	6.0	0.4	5.4
Wheat	82.7	0.9	11.6	0.8	9.7
Maize	18.0	0.8	19.9	-	
Chickpea	10.7	0.6	21.1	-	
Tur	9.8	0.2	8.1	-	
Groundnut	15.5	0.4	20.9	-	
Rapeseed-Mustard	7.9	0.9	25.8	-	
Cotton	51.1	0.5	16.3	-	
Sugarcane	57.4	5.2	11.1	4.4	11.98
Potato	6.0	5.4	31.9	-	

Note: The PWP is estimated taking the average PWP of dominant districts in dominant states, while IWP and EWP are averaged from the dominant states.

The key findings of the study are listed below:

- Rice, wheat and sugarcane, which together are spread over 85 million ha (about 43 percent) of total gross cropped area of 198 million ha, consume almost 80 per cent of freshwater available for irrigation. This has led to large inequity in irrigation water availability for other crops, leaving most of them being grown under rain fed conditions, and therefore making them risky with high volatility in their yields.
- In addition to this inequity, it is worth noting that these water guzzler crops are concentrated in some of the most water scarce regions of the country. Classic example is the case of rice in north-west India (Punjab and Haryana), which is leading to massive depletion of groundwater in these states, and sugarcane crop in sub tropical belts, mainly Maharashtra.
- Comparing the physical water productivity as well as irrigation water productivity of rice, wheat and sugarcane with their corresponding land productivity across major states, one finds significant misalignment in the cropping patterns and available water resource. This is clearly visible in the case of sugarcane and rice showing almost a perverse relation between land productivity and irrigation water productivity. For example, Punjab shows the highest land productivity of 4t/ha. However its irrigation water productivity is very low (see Figure 35). It is interesting to observe that its PWP still remains quite high even when IWP is low. Almost similar results follow in most of other states for rice, with high land and

PWP, but low IWP. It may be worth noting that the concept of PWP is used by water experts and hydrologists to express the crop productivity with respect to the total water consumed by the crop, considering evapo-transpiration rate of water in the region. However, this concept of PWP can be closer to IWP at field situation, especially for water guzzler crops (that are largely cultivated under assured irrigated), only when the application efficiency of irrigation water is also high. In Punjab and Haryana, the PWP is high to the tune of 0.57 kg/m^3 and 0.4 kg/m^3 respectively. However the IWP in these states is found to be relatively low at 0.22 kg/m^3, indicating the inefficient irrigation water use. The existing almost free electricity policy in agriculture in Punjab and Haryana has led to indiscriminate groundwater exploitation and non-judicious water use in agriculture. The high land productivity owing to assured irrigation, added with effective and assured procurement policy for paddy further encourage farmers to cultivate this crop despite serious sustainability issues getting manifested in alarming rate of depleting water table (almost 70 cms/year during 2008-12, as per NASA study). In contrast to Punjab and Haryana, states like Chhattisgarh and Jharkhand which display high irrigation water productivity have low irrigation coverage (32 per cent and 3 per cent respectively) and subsequently lower land productivity. The under developed procurement policy for paddy and low power supplies to agriculture in these states has further resulted in lower profitability levels of rice cultivation in these states, despite the hydrological suitability of the region. Thus there exists a serious misalignment in rice cropping patterns with respect to the water resource availability in India, which needs to be corrected with effective demand side as well as supply side policies.

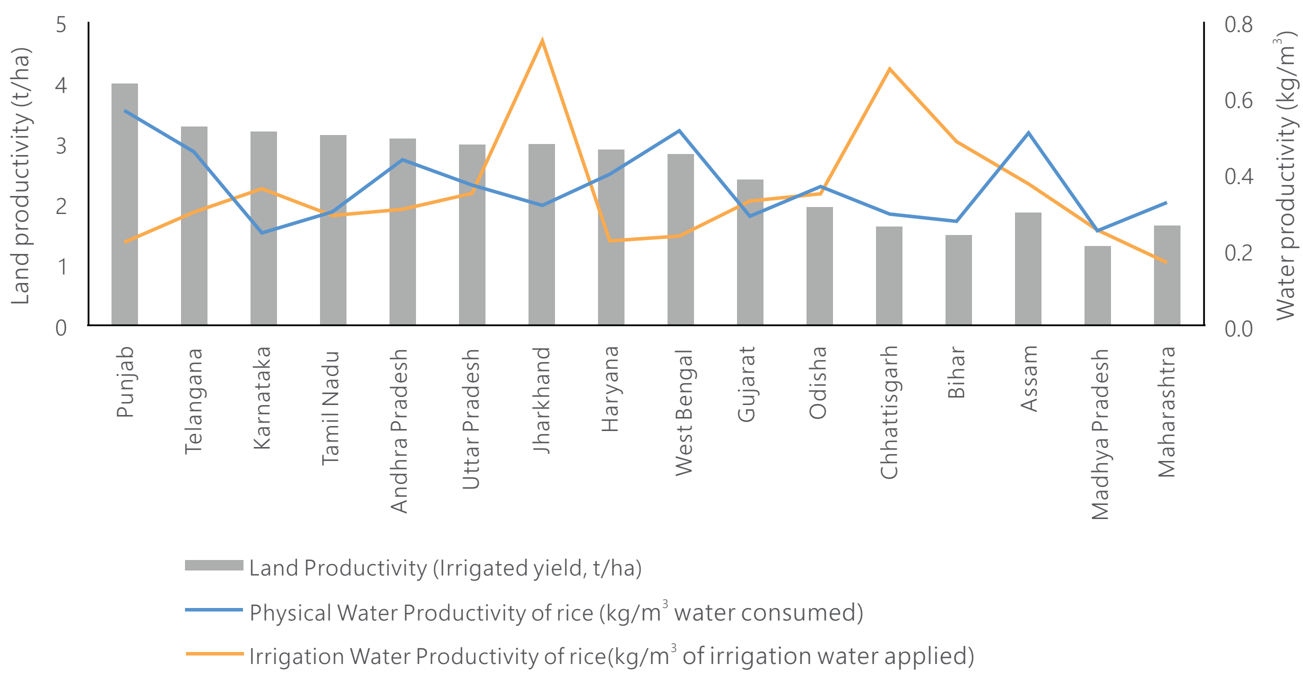


Figure 36. Comparison of land and water productivity of rice across major producing states

- In case of wheat, it can be seen that the land productivity is almost in line with the water productivity (both PWP as well as IWP). Punjab (4.6 t/ha) and Haryana (4.4 t/ha) top the list of land productivity, as well as PWP (1.88 and 1.57 kg/m^3 respectively) and irrigation water productivity (1.23 and 1.05 kg/m^3 respectively) (Figure 37). Uttarakhand also reports high levels of PWP (1.27 kg/m^3) as well as IWP (1.04 kg/m^3) values, but the land productivity (2.3t/ha) is almost half that of Punjab and Haryana. Thus in case of wheat crop there is no major misalignment in cropping pattern and hydrological suitability.

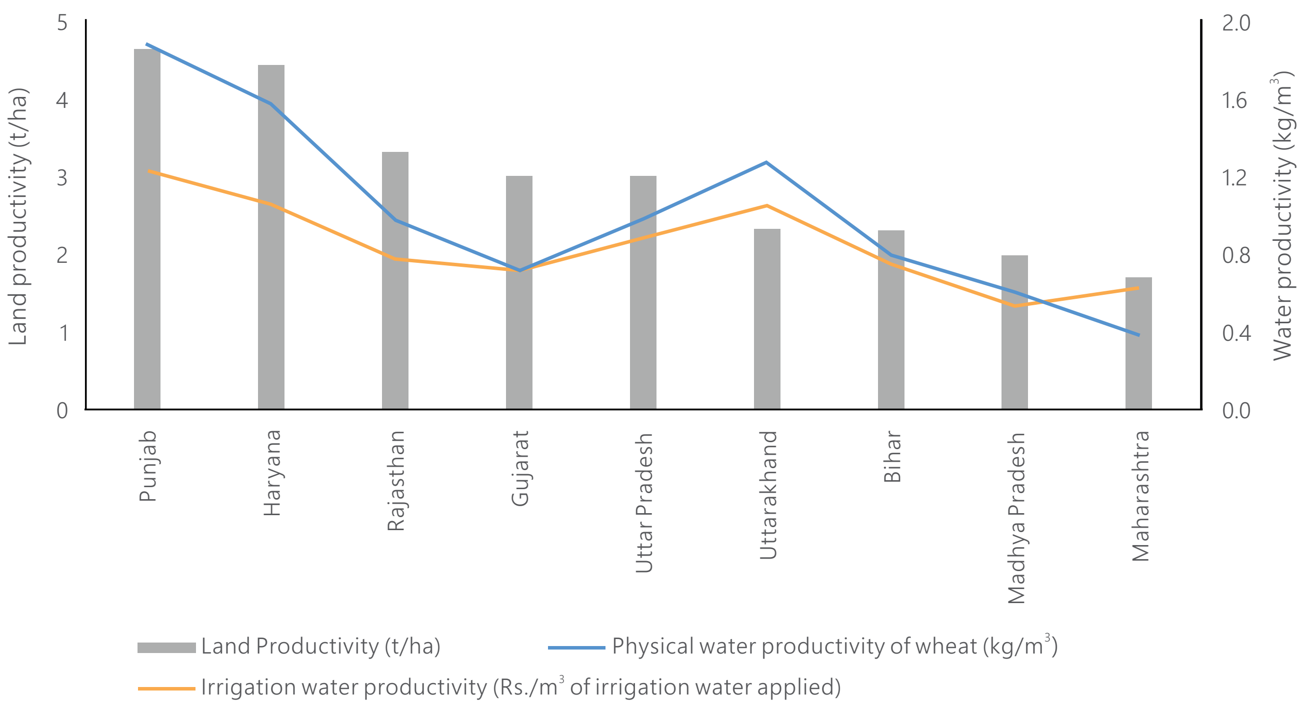


Figure 37. Comparison of land and water productivity of wheat across major producing states

- For sugarcane, Tamil Nadu reports the highest level of land productivity (105.3 t/ha) as well as PWP (14.01 kg/m^3). As in the case of rice, one observes somewhat perverse relation between land productivity and IWP in sugarcane also. The tropical belts of Uttarkhand, Uttar Pradesh and Bihar report higher levels of IWP but lower levels of land productivity (Figure 38). At the same time, the sub tropical belts of Tamil Nadu, Karnataka, Maharashtra and Andhra Pradesh have high land productivity but lower levels of IWP values. What all this indicates is that quite a bit of sugarcane is being grown in such regions where water resources are scarce (Tamil Nadu, Karnataka, and Maharashtra), and IWP of sugarcane is low. This needs correction by suitably adjusting the price of power and irrigation water, and by promoting more efficient technologies (such as drip) for irrigating sugarcane crop in these regions. It may be worth mentioning that historically, Bihar and eastern Uttar Pradesh were the centres of sugarcane belt, which were in line with the water resource endowment of the region, and that is where IWP is the highest. But over time, preference for cooperatives took the sugarcane belt to Maharashtra, Karnataka and Tamil Nadu, which do not have that type of water resource endowment.

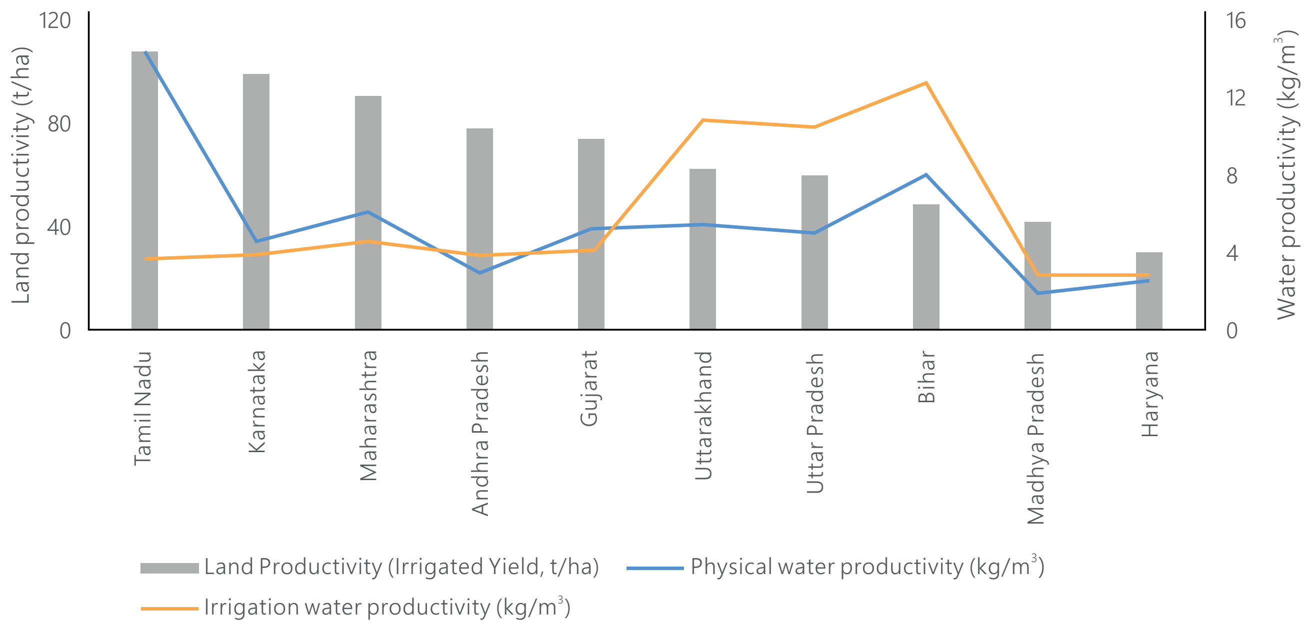


Figure 38. Comparison of land and water productivity of sugarcane across major producing states

Hence at the present level of water stress existing in the country there is need to realign the cropping patterns in line with their IWP (particularly for water guzzler crops like rice and sugarcane), and not remain obsessed with only their land productivity. Else, country will be moving towards unsustainable agriculture from water availability point of view, raising risks for the farmers, and promoting extreme inequity in the use for scarce water resources.

Strategic Policy Options

There are a number of strategic policy options, both in terms of price and procurement policies as well as in terms of water technologies and institutions governing irrigation water supplies that can be adopted with a view to improve water productivity in general and IWP in particular. These can be broadly grouped into four thematic areas as shown in **Figure 39**.

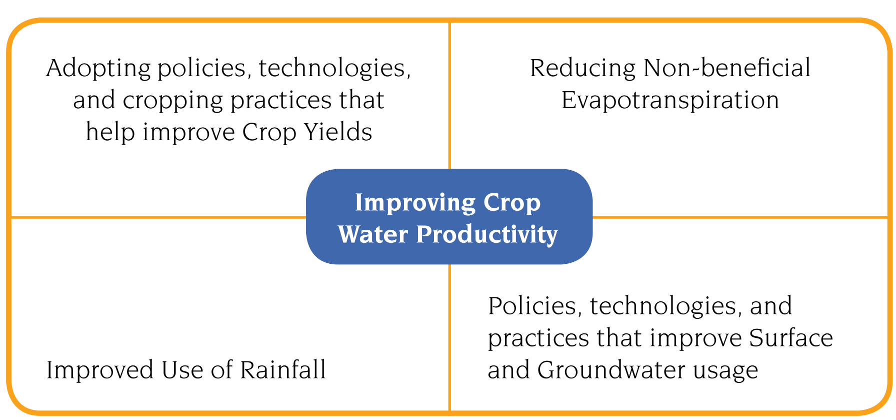


Figure 39. Matrix showing strategies for improving crop water productivity

Specific policies, technologies, and best practices for implementation of these strategies are given in Table 58.

Table 58

Policies, technologies and practices for improved agricultural water productivity

Strategies	Policies, technologies, and Practices
Improving crop yield	Improve incentives structures for water efficient crops through price and procurement policies; price water, power and fertilizers to recover their full costs; Input subsidies be given to all farmers directly in their accounts on per ha basis, and let farmers decide which crops they want to grow.
	Breeding of superior crop varieties with higher yield, stress and disease tolerance
	Precision irrigation: synchronising water application with crop water demand
	Soil fertility management-rotation, tillage, targeted application of nutrients
	Disease, pest and weed management
Reducing non-beneficial evapo- transpiration	Improved canopy architecture through agronomy and breeding
	Zero and minimum tillage to reduce evaporation
	Enhanced use of micro-irrigation- drips, micro-sprinklers, sprinklers
	Use of plastic and residue mulches, weed control; boundary plantations
	Avoid hot season planting, transplanting
Improved use of rainfall	In-situ, on-farm and catchment water harvesting for supplemental irrigation
	Synchronising crop planting, transplanting with on-set of monsoons
	Improved water retention through mulches, composts; drainage of excess rainfall
	Agro-met advisory services, crop insurance; drought and flood management
Improved use of Irrigation (surface and groundwater)	Laser land levelling of fields, optimum size of basins
	Furrows, raised beds, conveyance pipes, underground distribution system
	Proper canal schedules, irrigation schedules, well-maintained distribution networks
	Water user associations, community tubewells
	Pricing of water and power to recover their full costs (as suggested above); Replacing diesel pumps by solar pump sets through easy availability of long term credit, and allowing excess solar power to be fed back into the grid.
	Water quality, control of pollution, safe use of wastewater

A. Specific policy implications emerging from study

1. Re-aligning cropping pattern with water resource endowments

The hydrological suitability of water-intensive paddy and sugarcane crop (using more than 60 per cent of irrigation water available in the country) is found to be somewhat perverse with sizeable production of these crops taking place in water scarce regions. For example, rice in Punjab-Haryana belt and sugarcane in Maharashtra, Karnataka and Tamil Nadu. With the help of this water productivity report, cropping patterns (using 10 major crops under study) across states can be improved and re-aligned with water availability considering the quantity and value of crop output produced per cubic metre of available water (total consumptive water used and/ or irrigation water applied) using suitable demand-side and supply-side policy interventions further listed below.

One of the activities supported by the "Farm Sector Promotion Fund" of NABARD is creation of awareness among farmers on improving water use efficiency and sensitizing them to avoid cultivation of water intensive crops in water scarce regions. The water productivity report developed for the 10 major crops can act as a blue print to identify suitable state and district wise cropping pattern based on water use and streamline the fund accordingly.

2. Price policy reforms

The root cause responsible for the misalignment between cropping patterns and water resource availability can be attributed to imperfect water and power pricing, which are highly subsidised (almost free) and assured procurement policies (for rice and sugarcane) existing in these states. This is topped by highly subsidised fertilizers, which are used in large quantities in these two crops compared to nitrogen fixing oilseeds and pulses, which incidentally also need much less water. So the first and biggest reform that is needed is in pricing policies of inputs and procurement of outputs.

i. Price Reforms

Water pricing is inefficient in the country with water charges for surface irrigation not recovering even 20 percent of O&M expenses of canal networks, not to speak of capital costs, which are deemed sunk forever. Water charges need to be raised to indicate its scarcity value and must be synced with better and timely irrigation services, so that at least the operation and maintenance cost of surface irrigation is recovered fully.

In case of groundwater extraction for irrigation, electricity rates are highly subsidised in most states (almost 75 to 90 percent subsidy). Agricultural power supplies are free of cost in several of the water scarce states- Punjab, Karnataka, Andhra Pradesh and the latest declaration of

Higher water charges to indicate its scarcity value must be synced with better and timely irrigation services, so that at least the operation and maintenance cost of surface irrigation is recovered fully.

Telangana to supply 24x7 free supply. This has led to overexploitation of groundwater for irrigation, resulting in negative externalities to the natural resource. Thus, like surface irrigation, the power sector also needs price policy reforms to recover the full costs of power supplies. But no price policy reform will succeed unless it is carried out in sync with improvement in quality and timely electricity supply. This needs to be done gradually, and most of the farmers have shown willingness to pay higher charges provided they get power in time and of good quality. The reason is simple that farmers otherwise have to rely on diesel, which is at least three to four times more expensive than full cost power supplies. The real issue is earning the trust of farmers by supplying them timely, good quality, and adequate power when they need it the most. Any subsidization policy should be through income policy, i.e, giving an 'aggregate input subsidy' directly to their accounts, and then charging full cost for these inputs, be it power, water, or fertilizers. It may be noted that groundwater costs are much higher in the water-abundant eastern states as they do not get enough power supplies and rely mainly on diesel. So, they are forced to go for either less water intensive crops or rely on uncertain rainfall. Improved policy prescriptions are pre-requisite for improving the water productivity for most crops and other uses.

ii. Procurement Policy

Input pricing and output marketing incentive structures which favour water intensive crops, need to make way for crop neutral incentives that promote better water use.

Reducing the market (price) risk of less water consuming crops like oilseeds and pulses is essential to promote crop diversification away from water intensive crops like rice and sugarcane. This is especially so in regions facing water scarcity. For instance, in Punjab where water table is receding, much of rice production is assured to be bought by the state procurement agencies for FCI. This reduces the market risk of paddy farmers in Punjab almost to zero. But this type of incentive environment locks them to water intensive crops. Farmers realise the damage that is happening to water table, and our interaction with farmers confirmed this, and also that farmers are willing to switch to other crops such as maize or pulses, which use much less water, provided their market risk is covered by the state. So, it is the skewed incentive structures, both from pricing of inputs as well as marketing of outputs, which today are favouring water intensive crops, which need to be made crop neutral if one has to promote better use of water. On the other hand the eastern states like West Bengal, Assam and Bihar, and Chhattisgarh, which have high Irrigation Water Productivity and are major producers and consumers of rice but lack an effective procurement policy. The paddy prices in these states often go 10-25 percent below MSP, depriving the farmers from comparable profits like the Punjab-Haryana farmers. There is a need to strengthen the rice procurement policy in these eastern states to improve the profitability of the farmers as well as to ensure the shift of rice crop from the water scarce Punjab and Haryana belt to the eastern belt of the country. Same is true for sugarcane, where mills assure a market for the cane at a pre-announced price, which is at least the Fair and Remunerative Price (FRP) announced by the Centre, or the State Advised price (SAP). But for most of all other crops, ranging from perishables like potato, onion, tomatoes, etc to oilseeds and pulses, in most of the years in most of the states, there is no assured price guarantee backed by effective procurement. So the market risk remains high for the cultivators of these crops.

By financing and supporting producer organizations through the dedicated "Producers Organisation Development Fund" of NABARD or "Agriculture Market Infrastructure Projects Refinanced" by NABARD, crop-specific market interventions as well as marketing opportunities can be created across states based on the crop-water productivity rather than just looking at the crop-land productivity. This will encourage farmers to cultivate crops based on the hydrological suitability of the region.

iii. Direct Benefit Transfer (DBT)

One of the ways to contain the adverse impact of low pricing of water and power, and fertilizers, on inefficient use of water is to move from price policy of heavily subsidizing inputs to income policy to directly give money into the accounts of the farmers on per ha basis. This direct benefit transfer of input subsidies will increase the purchasing power of farmers, stop much of leakages of those precious inputs and give right signals for their efficient use. This shift will enable the Government to raise the water and electricity price for irrigation to recover at least the O&M charges, and delivery better service, and at the same time will help the farmers to afford the increased input charges. With water and power being appropriately priced, it is expected that farmers will use these inputs more judiciously. The success in Chinese experience of separating subsidies from prices and moving to the concept of '*general input subsidy*' which is the largest payment to farmers (> US$35 billion/annum) from price policy towards income policy can come in handy in improving the irrigation infrastructure and water productivity.

That the provision of highly subsidised water, power, and fertilisers leads to inefficient water use indicates the need to move away from input subsidies to direct benefit transfers to farmers based on the size of land.

Judicious water use in agriculture may also be promoted by rationing irrigation water supplies, akin to the warabandi system of canal irrigation in Punjab.

iv. Rationing of irrigation water

If price reforms in inputs, coupled with DBT of aggregate input subsidy, cannot be carried out, the second best option is to ration irrigation water supplies, more like a warabandi system in canals in Punjab. Similar rationing will have to do be done of power supplies to regulate groundwater supplies. Farmers cultivating water guzzler crops like paddy and sugarcane will have to purchase extra requirement of water from the farmers cultivating less water intensive crops like pulses. Thus the farmers cultivating more water intensive crops get incentivised for using less water in raising their crops.

3. Lessons from model districts may be implemented on larger scale with proper investments

Financial institutions like NABARD in collaboration with respective state governments can focus on creating and implementing sustainable crop-water use projects in the identified model districts on pilot basis.

The study revealed that agricultural production though scattered all over India, is highly fragile due to a very narrow base as about 20-40 per cent of the production for each crop is concentrated in just a handful of the districts. Clustering patterns for most of the crops demonstrated that invariably there exists a large base of low production districts with a small number of 'bright spot' districts having high land and water productivity. Such identified and mapped districts in the study can serve as 'model districts' for a given crop and the enabling practices and policies need to be documented to put the large number of 'laggard districts' on the take-off trajectory. Financial institutions like NABARD in collaboration with respective state Governments can focus on creating and implementing sustainable crop-water use projects in the identified model districts on pilot basis. These projects after thorough evaluation may be scaled up to other laggard districts, if found feasible.

B. Other supporting policies

1. Improving irrigation efficiency

i. Improving conveyance efficiency of surface irrigation

Freshwater resources are finite and even by allocation of large funds for ambitious programs, the development of new public water resources is happening at a very slow pace. Farmers dependent on rainfall or private sources cannot wait any further. In cases where the development of water resources is not happening any time soon, the states and the centre can at least take steps/ interventions to cover larger areas with the already created irrigation potential. This is possible through improved distribution and conveyance pipes, underground distribution systems, affordable and reliable energy to lift water from shallow depths and innovative and differentiated energy policies both for the 'north-west and south', and more importantly for 'east and the northeast'.

Setting up piped water facilities to connect dams/canals and micro-irrigation system can reduce water loss and increase the overall water use efficiency up to 90 per cent. At present, considering the conveyance loss of surface irrigation and application loss due to flood irrigation, only about 40 per cent of irrigation water actually reached the farmer's field from the source dam. Thus the investments need to be made not only to increase creation of irrigation potential, but must be channelized to make them more efficient.

The Infrastructure development funds and Long term irrigation funds raised by NABARD can focus on creating structures to improve conveyance efficiency of the canal system as well.

The Rural Infrastructure Development Fund and Long Term Irrigation Fund of NABARD can focus on creating structures to improve conveyance efficiency of the canal system as well.

ii. Improving application efficiency of irrigation

Micro-irrigation (drips, sprinklers, micro-sprinklers, tapes, guns) is a suitable option to enhance the coverage under irrigation, improve land and water productivity and quality of the produce. In case of commonly practiced flood irrigation method the rate of water application loss is around 35 per cent, while in micro irrigation techniques the application loss is only 10-15 per cent. Adoption of these techniques will help to save water and thereby increase the area under irrigation by diverting the saved water to other non-irrigated fields. Instead of promoting micro irrigation as just a water saving technique, it should be popularised among the farmers as an yield enhancing and input cost saving method, considering the incremental yield and electricity and fertiliser saving associated with the technique.

Micro irrigation funds raised by NABARD must be disbursed and allocated to states looking into the nature of state-wise and district-wise crop-water productivity and extent of water scarcity of the region.

Micro irrigation funds raised by NABARD must be disbursed and allocated to states and districts based on their crop-water productivity and the extent of water scarcity.

iii. Solar irrigation

Solar irrigation system needs to be further promoted to ensure assured and timely irrigation water availability in electricity deprived interior

Dovetailing solar pumps with micro irrigation systems and developing the concept of "Solar power as the third crop" in the farmers' fields can be an innovative step.

villages particularly in the eastern region. Solar pumps shall turn out to be a boon promising timely availability of power for lifting groundwater and water from ponds, lakes and depressions for irrigation, helping farmers to get rid of the costly diesel pumps. These can be further coupled with efficient application methods for higher water productivity. Dovetailing solar pumps with micro irrigation system and developing the concept of "Solar as third crop" in the farmers' field can be an innovative step towards this. Solar panels may be installed at a height of about 15 feet from the ground in the farmers' cropped fields. This model helps in saving on agriculture land from getting diverted solely for setting up solar panels. Assured grid connection must also be provided to the farmers to encourage them to divert the excess solar power generated in fields to the state grids, thereby ensuring the judicious use of solar power for groundwater extraction. This will also serve as additional income to farmers and act insurance in case if there is occurrence of crop failure. The Solar Pump Irrigators'' Cooperative E*nterprise* (SPICE) in Gujarat is yet another worthwhile models that can be followed and scaled up. Successful models such as S*olar Power as Second Remunerative Crop* (SPaRC) at Dhundi are working and can be scaled up by NABARD. Such projects may be capital intensive at the initial stages and government will have to figure out smarter ways like feed-in-tariff (FIT) to mobilise the funds.

2. Infrastructure development for water management

i. Rainwater harvested in farm structures has the highest value when applied in small quantities to provide supplemental/ deficit/ critical irrigation and helps in achieving the highest water productivity. NABARD may help in formulating targeted programs for the identified 'dominant districts' to start with the pulse, oilseed and cotton crops.

ii. Artificial groundwater recharge: The impact assessment surveys on artificial groundwater recharge conducted across states by Central Groundwater Board (CGWB) have recorded positive results. Such projects must be encouraged with proper financial support to solve the issue of depleting groundwater resource in the country. IWMI has successfully demonstrated the concept of "U*nderground Taming of Floods for Irrigation* (UTFI)" where surplus flood waters can be conveniently used to recharge the groundwater in the selected river basins.

3. Encourage Participatory Irrigation Management through WUAs, FPO and Corporate Farming Ventures

i. Handing over the irrigation management activities to the Water Users Association (WUA) helps the government agencies to reduce their pressure of timely and adequate water delivery, recording of irrigated area, revenue collection and even conflict management. Government of India and various state Governments in their water policies have emphasised the role of WUAs in the operation and maintenance of canals. The WUA may typically be farmer's organisations capable of undertaking responsibilities of operation and maintenance of the canal water sources. They are mostly self-financed entity. The WUAs have success stories across states like Maharashtra, Gujarat, Andhra Pradesh and Uttar Pradesh. However, till the WUA achieve its full potential of lessening the gap between the irrigation potential created and utilised, they may need extra funds and hand-holding to achieve the desired objectives.

ii. In spite of good overall production levels in several crops, land productivity and water productivity values in India are much below the world averages and even the comparable agro-ecologies necessitating that we cultivate '*too much land and apply too much water*', rather inefficiently. This is because only 48 per cent of the lands are irrigated (with huge variation among the crops and the states) and 65 per cent of the holdings are not suitable for mechanisation. The marginal farmers lack funds to invest in any of these and thus shall continue to have low and uncertain yields. Well-designed Farmer Producer Organisations (FPOs) or the Corporate Farming Ventures (CFVs) are the win-win propositions which benefit farmers and increase land and water productivity. Presently, these cover less than 3 per cent of the arable land and may be enhanced to 10 per cent by end of this decade through suitable legislative and policy reforms.

Well-designed Farmer Producer Organisations (FPOs) or Corporate Farming Ventures (CFVs) are win-win propositions which benefit farmers and increase land and water productivity.

4. Best Water Management Practices across the World

i. Israel's state water policy and water management technique

As per Israel's water law, all water in the country is common property resource. The Government accounts for every drop of water used and thus has maintained a healthy water governance in the country. The water pricing in Israel is such that it reflects the scarcity of resource. Water deficit states of India need to learn relevant lessons from such a water scarce country which despite having less than 200 m^3 per capita water availability emerges as one of the leading agriculture nation in the world. Efficient water management through micro irrigation has been one of the historical interventions of Israel in agriculture water management. Recently, the country has looked beyond and aims at reducing the use of its fresh water resource for agriculture. At present, more than 60 per cent of the irrigation water used in Israel comes from recycled waste water. The country aims at reducing the reliance on potable water for irrigation to 26 per cent by 2050[22]. China has also been able to save irrigation water, reduce the cultivated area and still improve productivity of most of the crops. Like Israel and China, India can also adopt best water management practices, policies and technologies to substantially improve the water productivity.

Based on the best water management techniques available across the world and within the country, state governments can prepare suitable innovation projects for agriculture water management techniques and seek financial assistance from the National Adaptation Fund for Climate Change (NAFCC) of NABARD

Based on the best water management techniques available across the world and within the country, state Governments can prepare suitable innovation projects for agriculture water management techniques and seek for financial assistance from National Adaptation Fund for Climate Change (NAFCC) of NABARD.

ii. Supplemental irrigation

Supplemental irrigation (SI), which entails harvesting rainwater run-off, storing it in ponds, tanks or small dams, and applying it during critical crop growth stages has emerged as the promising option for increasing both land and water productivity particularly in the rain fed irrigated zones. A suitable example to illustrate the effective result of supplemental irrigation can be drawn from the dry areas of North Africa and West Asia and the model watersheds of ICRISAT/ CRIDA in Andhra Pradesh and Karnataka. The water productivity in these region ranged from about 0.35 to 1 kg of wheat grain for every cubic metre of water. ICARDA/ ICRISAT/ CRIDA in its research found that, supplemental irrigation and along with good management practices resulted in same amount of water producing 2.5 kg of grain. The improvement is mainly attributed to the effectiveness of a small amount of water in alleviating severe moisture stress. In India, where still more than half of the agriculture is rain fed, there is scope for adoption of supplemental irrigation, provided there is scope for increased investments on rainwater harvesting structures, particularly in rain fed agriculture zones.

22 http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/2012/24-The-State-of-Israel-National-Water-Efficiency-Report.pdf

iii. Precision technology

Precision irrigation technology involving drones, sensor networks and data analytics are adopted in most of the developed countries to promote irrigation water management in agriculture. China has developed the concept of trace irrigation system based on capillary force principle. The water control tap buried near the root zone of the crops can sense the change in water level and supply water to the crops accordingly. The supply of water stops once the plant water requirement is met. Indian agriculture can definitely benefit from such advanced precision technologies but there needs to be well directed investment to be made for these.

iv. Virtual water trade

Trade barriers are often directed to encourage domestic production and protect local markets from international competition. However, studies reveal that trade policies can even help reducing virtual water export and encouraging virtual water import in water scarce countries. Nations or states that import or export a product also import or export the water used in production of the product, known as the virtual water. The existing picture of agri-trade of India is such that India is the largest exporter of rice in the world with an export volume of more than 10 million tonnes per year. One kg of rice inherently needs about 5000 litres of water for irrigation in a region like Punjab-Haryana, and about 3000 litres in water abundant regions. Taking an average of say 4000 litres per kg of rice, export of 10 million tonnes amounts to exporting 40 billion cubic metres of water. On the other hand our largest agri-import is of edible oils and pulses. Oilseeds and pulses are water saving, except oil palm which needs high rainfall and moisture. Overall, our agri-trade structure is turning out to be hydrologically and economically unsustainable with low productivity of water resources. These trends need to be reversed for creating a water positive agriculture.

One kg of rice inherently needs about 5000 litres of water for irrigation in a region like Punjab-Haryana, and about 3000 litres in water abundant regions. Taking an average of say 4000 litres per kg of rice, export of 10 million tonnes amounts to exporting 40 billion cubic metres of water.

Thus, India needs to work on its policies and programmes involving technologies, and farm practices, to optimise the use of its limited water resource. And to do that, the first step is to change the mind set from maximising land productivity to productivity per unit of water with the help of suitable financial support from institutions like NABARD. That has been precisely the subject of research in this report.

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