

Consequence of less water availability on farming over three decades: A Case Study of Aligarh, Uttar Pradesh, India

Daya Shanlar Singh

daya.singhudai@gmail.com

University of Lucknow

Tanu Priya Gupta

University of Lucknow

Antara Gupta

Hemwati Nandan Bahuguna Garhwal University

Ajai Mishra

University of Lucknow

Pawan Kumar Gautam Gautam

Uttar Pradesh Remote Sensing Application Centre

Case Report

Keywords: Green Water, Blue Water, Water Footprint, Crop Shifting, Correlation matrix

Posted Date: March 6th, 2024

DOI: <https://doi.org/10.21203/rs.3.rs-4016824/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

This research delves into the relationship between water availability and crop yield. Availability of water for irrigation can be classified into two parts: surface water or ground water (Blue Water) and precipitated water (Green Water). Using data spanning three decades, we observed significant trends in crop production and cultivation influenced by less (Green) water availability and tells that farmers are changing the cropping pattern what they grow based on which water is available easily or cost effectively or low water footprint value. Notably, crops with high water footprint value, such as Barley and Sugarcane, have seen a decline, whereas crops requiring low water footprint value, like Potato and Rice, have shown an uptick. Employing advanced statistical methods, the Karl Pearson Correlation matrix, the study identifies distinct inverse relationships between crop groups; revealing differential water consumption metrics. Notably, crops groups that usually need a lot of water (blue and green or high water footprint value) are not growing as well anymore. On the other hand, types of crops that can survive with less water (blue or low water footprint value) are becoming more popular. This shows that farmers are growing drought-resistant crop varieties that is not because of water conservation, because of less water availability. This narrative underscores the urgent need for the adoption of water-efficient techniques and crop choices while highlighting the imperative of addressing the intricate interplay between water resources, and agricultural practices.

Introduction

The escalating demand for freshwater resources, as evidenced by a nearly sevenfold increase in global freshwater withdrawal over the last century, underscores the critical challenges facing water management worldwide (Aliyari et al. 2021). This surge in water usage is particularly pronounced in regions experiencing rapid population growth and economic development, where the allure of short-term gains often eclipses long-term sustainability considerations (Gleick 2000). The agricultural sector, being the largest consumer of freshwater, primarily for irrigation purposes, finds itself at the nexus of this complex water-energy-food nexus (Abera et al. 2024; Aggarwal and Kalra 1994).

Two primary sources cater to the irrigation needs of agriculture: blue water, derived from groundwater or surface water sources, and green water, sourced from precipitation. While blue water remains a dominant source of irrigation, accounting for approximately 85% of global groundwater consumption in agriculture (Shiklomanov 2000; Allen 1998; Manekar et al. 2024), the reliability of green water is becoming increasingly uncertain due to shifting climatic patterns. Decreasing trends in precipitation, which supplies green water, further exacerbate the challenges associated with water availability for agriculture.

As projections indicate a continued increase in water withdrawals in the foreseeable future (Rosegrant and Ringler 2000; Liu et al. 2008), the implications for the agricultural sector, particularly for farmers, are profound. The mounting pressure on water resources necessitates a paradigm shift in agricultural practices, prompting farmers to adopt water-efficient techniques and crop choices (Araya et al. 2015; Basso and Ritchie 2014, 2015). Faced with the escalating costs and uncertainties associated with water availability, farmers are increasingly inclined to cultivate crops that offer higher returns on investment while requiring minimal water inputs (Bootsma et al. 2005; Basso and Ritchie 2015). This economic imperative, coupled with environmental considerations, is driving a discernible shift in cropping patterns, with potentially far-reaching implications for

food security, rural livelihoods, and water resource management strategies (Boryan et al. 2014; Brown et al. 2014). Therefore, addressing the complex interplay between water, agriculture, and climate change is paramount to fostering sustainable development and resilience in the face of escalating water challenges (Solomon 2007).

Study Area:

Aligarh District, nestled in the heart of Uttar Pradesh, India, stands as a testament to the state's rich historical, cultural, and agricultural tapestry. Located strategically between the mighty Ganga and Yamuna rivers as shown in Fig. 1, the district's topography primarily comprises fertile plains that have been nurtured by these ancient rivers for millennia (Singh and Mishra 2021). The climate of Aligarh oscillates between extremes, with scorching summers where temperatures can soar to 45°C, giving way to fog-laden winters where the mercury plunges, often touching 5°C or lower. The region's lifeline, the southwest monsoon, brings much-needed respite and rainfall, averaging between 800-900 mm annually. This monsoonal bounty not only rejuvenates the parched land but also fuels the district's vibrant agricultural sector (Stanton et al. 2011). Traditional crops like wheat, rice, sugarcane, and mustard find their roots here, coexisting harmoniously with the emerging horticultural ventures that have started emphasizing fruits like mangoes, guavas, and citrus (Tao and Zhang 2010). However, the agricultural narrative is not without challenges. Water scarcity, soil degradation, and unpredictable weather patterns are constant concerns, demanding innovative solutions and sustainable farming practices (Smith and Wigley 2006; Tao and Zhang 2017). Despite these challenges, Aligarh District remains a beacon of agricultural prowess, contributing significantly to Uttar Pradesh's agrarian economy while preserving its rich heritage and cultural legacy.

Methodology

In this study, we meticulously designed a comprehensive methodology to ensure rigorous data collection, accurate analysis, and robust interpretation of findings through which we can find out the relation between crop production and rainfall.

Data Source: The crop production for Wheat, Potato, Sugarcane, Millet, Paddy, Pulses, Barley, and Maize has been collected from 1991 to 2021 in Metric tons as shown in Table 1. It has been collected from Jila Sankhyikiya Patrika while the rainfall data has been collected from the IMD website. Cropping area of these crops data has also been collected from 1992 – 2015 in hectares as shown in Table 2.

Data Analysis: To identify the most significant change (Crop Production) in the collected crop production data and its correlation with other crops, correlation matrix studies were done. Pearson correlation of the parameters is the standard method to identify the dependency of the parameters on the other parameters. This correlation has been calculated by the Factor analysis method with the help of SPSS and XL Stat Software. It is a multi-variable statistical method that shows the relationship between the measured variable/parameters (Dzotsi et al. 2015). By this method, the dependency of the resulting variable/parameters can be explained (Dlugokencky and Tans 2016). This analysis has been done with the 8 variables/parameters (crop) such as Wheat, Potato, Sugarcane, Millet, Paddy, Pulses, Barley, and Maize. Therefore, the Pearson correlation matrix was computed which shows the degree of a linear association between any two of the parameters, and measured by the degree of correlation as a coefficient (R). The coefficient value is used to identify the highly

correlated and interrelated crop that may influence the other crop (parameter). The value of R with a positive sign, or near to one indicates the strongest positive linear correlation between two compared crops, and the negative coefficient reveals the strongest negative linear correlation (Tilman et al. 2011). Thus, it indicates which crop is taking place to other crop production. Eventually, for the validation of this shifting, the crop production data and precipitation data have been validated by the graphical method.

Result And Discussion

The role of precipitation in shaping agricultural landscapes and influencing crop choices cannot be overstated (Chahal et al. 2007). Its fluctuating patterns have profound implications, driving farmers to continually recalibrate their strategies and choices (Cotterman et al. 2018; Dzotsi et al. 2015). Such adaptability, often manifested as crop shifting, stands as a testament to the resilience and adaptiveness inherent in agricultural practices (Cui et al. 2019; Dlugokencky and Tans 2016). This interplay between climatic variables and farming decisions becomes particularly evident in the study area under consideration (Van et al. 2014; Van et al. 2016).

From a myriad of crops cultivated in the region, eight pivotal ones namely Wheat, Potato, Sugarcane, Millet, Paddy, Pulses, Barley, and Maize have been meticulously analyzed for their production dynamics over the past three decades (Cure and Acock 1986; Xiao et al. 2017; Zhang et al. 2023). The findings reveal a dynamic landscape of production shifts (Ewaid et al. 2019). Notably, crops like Maize, Wheat, Millet, Potato, and Rice have demonstrated production growth rates of 93.94%, 67.08%, 41.91%, 10.76%, and 7.59%, respectively, over this period.

Conversely, Barley, Sugarcane, and Pulses have witnessed stark declines in production, registering reductions of 395.13%, 171.82%, and 250.65%, respectively, as delineated in Table 3. Intriguingly, even within these contrasting trajectories, there's a discernible pattern: the crops historically known for their higher water requirements are not exempt from production contractions (Fang, et al., 2018; Zhao, et al., 2023). For instance, while Rice production has marginally increased by 8%, this growth rate is significantly dwarfed when juxtaposed against the escalating population. Such disparities between production growth and population dynamics underscore the pressing challenges and complexities confronting modern agricultural systems (Fujino et al. 2006; Gleick 2000).

The notable fluctuations in crop production, characterized by significant increases and decreases, suggest the existence of underlying patterns (Grusson et al. 2021). Specifically, there appears to be a discernible trend wherein crops with high water requirements are witnessing a decline, while those with lower water needs are on the rise (Harding and Snyder 2012; Hu et al. 2016). To decipher and gain deeper insights into these observed patterns, the Karl Pearson Correlation matrix analysis method was employed, as delineated by Al-Harbi, M., et al. (2014). This analytical approach was systematically applied to the comprehensive dataset encompassing crop production records from 1991 to 2021 and corresponding cropping area data spanning from 1991 to 2016. A detailed overview and summary of the statistical findings derived from this analysis are meticulously presented in the accompanying tables 3 and 4.

By the Pearson correlation, matrix variables have been generated as shown in table 5 (for the Crop Production) and 6 (for the Cropping Area).

The correlation matrices pertaining to both Crop Production and cropping areas reveal a distinct inverse relationship between two clusters of crops: namely, Potato, Millet, and Rice as opposed to Wheat, Barley, Sugarcane, Maize, and Pulses as shown in Fig. 2. This observation underscores the differential water consumption patterns across various crop categories, as emphasized by Jones (1990).

There are mainly two sources for the irrigation water. One is from groundwater or surface water and another one is from precipitation (Kalra et al. 2007). Groundwater or surface water is known as blue water and precipitation water is known as green water. The agricultural sector accounts for about 85 % of global groundwater (blue water) consumption (Shiklomanov 2000; Kobata and Uemuki 2004). The intrinsic water footprints associated with different crops are not uniform; each crop type exhibits unique water consumption metrics. Seckler et al. (1998) embarked on a groundbreaking endeavor by presenting the inaugural global estimation of consumptive blue water utilization in agriculture, extrapolated down to national scales (Lansigan 2002). Delving deeper into this water-centric perspective, Mekonnen and Hoekstra 2011 and Mo (2009) provide a comprehensive breakdown of water footprint values for diverse crop varieties, elaborated in Table 7.

Intriguingly, a discernible pattern emerges wherein the green water footprint, indicative of rainwater usage, surpasses its blue water counterpart for the crops undergoing a shift in cultivation patterns (Liu et al. 2008; Mekonnen and Hoekstra 2011). This distinction underscores the pivotal role of water resource management in influencing agricultural choices and practices (Pannkuk et al. 1997; Pei et al. 2015).

Both the production and cropping areas have witnessed a decline in Wheat, Barley, Sugarcane, Maize, and Pulses. Specifically, there has been a 1.01%, 80.33%, 48.12%, 60.21%, and 71.34% reduction in the cultivation area for Wheat, Barley, Sugarcane, Maize, and Pulses, respectively. In terms of production, Barley has seen a decrease of 74.69%, Sugarcane by 41.80%, Maize by 6.45%, and Pulses by 60.10%. The decline in production and area for certain crops has been compensated by an increase in Potato, Millet, and Rice cultivation. There has been a 405.07% increase in the cultivation area for Potatoes, 71.22% for Millet, and 766.24% for Rice. Similarly, the production for these crops has seen an uptick, with Potato production rising by 829.34%, Millet by 138.60%, and Rice by 1218.00%. Additionally, Wheat production has also seen a 49.08% increase.

The changing dynamics of agricultural cropping patterns in recent years reflect a delicate balance between economic viability and environmental constraints (Qi 2002; Singh et al. 2020)). With dwindling precipitation levels, particularly affecting the availability of blue water resources, farmers are increasingly grappling with reduced yields and profitability in crops like sugarcane, barley, pulses, and maize (Riahi et al. 2007; Ritchie and Basso 2008).

This has prompted a discernible shift towards cultivating paddy, potato, wheat, and millets (Shroyer et al. 1996), which have lower water requirements and potentially offer better economic returns (Rosegrant and Ringler 2000). The evolving water footprint of these crops serves as a barometer for this transformation, underscoring the critical role of water availability in shaping agricultural practices (Rui et al. 2014; Shiklomanov 2000). Notably, while some crops may be inherently more resilient to water scarcity due to their physiological characteristics or market demand, the overarching driver for this shift remains the overarching challenge of reduced Blue Water resources, manifesting visibly in production graphs that correlate with changing precipitation patterns (Schlenker et al. 2009; Seckler 1998). The impact of this diminished

precipitation can be easily seen in the fig.3 where a certain group of crop production is increasing and decreasing with time and precipitation.

Conclusion

The intricate relationship between water availability, agricultural practices, and climatic patterns presents a compelling narrative. The surge in global freshwater demand, coupled with shifting precipitation patterns, places the agricultural sector at the forefront of water resource challenges. The crucial role of water both blue and green in irrigating crops is evident, with a predominant reliance on blue water sources despite increasing uncertainties in green water supply due to changing climatic conditions.

The analysis of crop production trends over the last three decades reveals a nuanced landscape. Crops with historically higher water requirements, such as Barley, Sugarcane, and Pulses, are experiencing significant declines, while those with lower water needs, like Potato, Millet, and Rice, are witnessing substantial increases. These shifts are not only economically driven but also underscore the imperative for sustainable water management in agriculture.

The use of statistical tools, including the Karl Pearson Correlation matrix, provides valuable insights into the inverse relationships between crop groups. The water footprints associated with different crops further emphasize the need for tailored water resource management strategies. The observed decline in the production and cropping area for certain crops is compensated by the rise of others, revealing the adaptive strategies employed by farmers in response to water availability challenges.

This narrative not only calls for the adoption of water-efficient techniques and crop choices but also emphasizes the urgency of addressing the complex interplay between water resources, agricultural practices, and climate change. In navigating these challenges lies the key to fostering sustainable development, ensuring food security, and preserving the delicate balance between human needs and environmental conservation.

Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have apparent to influence the work reported in this paper.

Acknowledgements:

I would like to thank to the Head, Department of Geology, University of Lucknow, Lucknow, for providing the necessary facilities to carry out this work.

Author Contribution:

DSS conceived the idea, designed the study, and wrote the manuscript. TPG contributed to statistical data analysis and interpretation. AG and PKG helped with the collection and tabulation of crop production and cultivation data. All the authors discussed the results and contributed to the final form of the manuscript.

Conflict of interest:

The authors declare that they have no conflict of interest

References

1. Abera, B., Desale, T., Asmare, M. et al. Impact of Climate Change on Irrigation Case Study on Wonji Shoa Sugar Plantation Estate. *Water Conserv Sci Eng* 9, 5 (2024). <https://doi.org/10.1007/s41101-024-00237-z>
2. Aggarwal P K, Kalra N (1994) Analyzing the limitations set by climatic factors, genotype, and water and nitrogen availability on productivity of wheat II. Climatically potential yields and management strategies. *Field Crops Research* 38(2): 93-103
3. Aliyari F, Bailey R T, Arabi M (2021) Appraising climate change impacts on future water resources and agricultural productivity in agro-urban river basins. *Science of the Total Environment* 788: 147717
4. Allen R G (1998) Crop Evapotranspiration-Guideline for computing crop water requirements. *Irrigation and drain* 56: 300
5. Araya A Hoogenboom G, Luedeling E, Hadgu K M, Kisekka I, Martorano L G (2015) Assessment of maize growth and yield using crop models under present and future climate in southwestern Ethiopia. *Agricultural and forest Meteorology* 214:252-265 <https://doi.org/10.1016/j.agrformet.2015.08.259>
6. Basso B, Ritchie J (2014) Temperature and drought effects on maize yield. *Nature Climate Change* 4(4) : 233-233
7. Basso B, Ritchie J T (2015) Simulating crop growth and biogeochemical fluxes in response to land management using the SALUS model 2015:252-274
8. Bootsma A, Gameda S, McKenney D W (2005) Potential impacts of climate change on corn, soybeans and barley yields in Atlantic Canada. *Canadian journal of soil science* 85(2):345-357 <https://doi.org/10.4141/S04-025>
9. Boryan C G, Yang Z, Willis P (2014) US geospatial crop frequency data layers. In 2014 The Third International Conference on Agro-Geoinformatics 1-5 <https://doi.org/10.1109/Agro-Geoinformatics.2014.6910657>
10. Brown H E, Huth N I, Holzworth D P et al (2014) Plant modelling framework: software for building and running crop models on the APSIM platform. *Environmental Modelling & Software* 62: 385-398
11. Chahal G B S, Sood A, Jalota S K et al (2007) Yield, evapotranspiration and water productivity of rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) system in Punjab (India) as influenced by transplanting date of rice and weather parameters. *Agricultural water management* 88(1-3): 14-22 <https://doi.org/10.1016/j.agwat.2006.08.007>
12. Cleophas T J, Zwinderman A H, Cleophas T et al (2018) Bayesian Pearson correlation analysis. *Modern Bayesian statistics in clinical research* 111-118
13. Cotterman K A, Kendall A D, Basso et al (2018) Groundwater depletion and climate change: future prospects of crop production in the Central High Plains Aquifer. *Climatic change* 146:187-200.
14. Cui J, Sui P, Wright D L, Wang D, Sun B, Ran M, Chen Y (2019) Carbon emission of maize-based cropping systems in the North China Plain. *Journal of Cleaner Production* 213: 300-308 <https://doi.org/10.1016/j.jclepro.2018.12.174>

15. Cure J D, Acock B (1986) Crop responses to carbon dioxide doubling: a literature survey. *Agricultural and forest meteorology* 38(1-3): 127-145 [https://doi.org/10.1016/0168-1923\(86\)90054-7](https://doi.org/10.1016/0168-1923(86)90054-7)
16. Deryng D, Elliott J, Folberth C, Müller C, Pugh T A et al (2016) Regional disparities in the beneficial effects of rising CO₂ concentrations on crop water productivity. *Nature Climate Change* 6(8): 786-790
17. Dlugokencky E, Tans P (2016) Trends in atmospheric carbon dioxide. NOAA/ESRL. Recuperado de www.esrl.noaa.gov/gmd/ccgg/trends.
18. Dzotsi K A, Basso B, Jones J W (2015) Parameter and uncertainty estimation for maize, peanut and cotton using the SALUS crop model. *Agricultural Systems* 135: 31-47 <https://doi.org/10.1016/j.agsy.2014.12.003>
19. Ewaid S H, Abed S A, Al-Ansari N. (2019) Crop water requirements and irrigation schedules for some major crops in Southern Iraq. *Water* 11(4): 756 <https://doi.org/10.3390/w11040756>
20. Fang Q, Zhang X, Shao L, Chen S, Sun H (2018) Assessing the performance of different irrigation systems on winter wheat under limited water supply. *Agricultural water management* 196: 133-143
21. Fujino J, Nair R, Kainuma M, Masuif T, Matsuokan Y (2006) Multi-gas mitigation analysis on stabilization scenarios using AIM global model. *The Energy Journal*, 27(2_suppl): 343-354 <https://doi.org/10.5547/ISSN0195-6574-EJ-VolSI2006-NoSI3-17>
22. Gleick P H (2000) A look at twenty-first century water resources development. *Water international*, 25(1): 127-138
23. Grusson Y, Wesström I, Svedberg E, Joel A (2021) Influence of climate change on water partitioning in agricultural watersheds: Examples from Sweden. *Agricultural Water Management* 249: 106766
24. Harding K J, Snyder P K (2012) Modeling the atmospheric response to irrigation in the Great Plains. Part I: General impacts on precipitation and the energy budget. *Journal of Hydrometeorology* 13(6): 1667-1686
25. Hu N, Wang B, Gu Z, Tao B, Zhang Z, Hu S, Meng Y (2016) Effects of different straw returning modes on greenhouse gas emissions and crop yields in a rice–wheat rotation system. *Agriculture, Ecosystems, Environment*, 223, 115-122. <https://doi.org/10.1016/j.agee.2016.02.027>
26. Jones C A (1990) Crop growth models. *Management of Farm Irrigated Systems*
27. Kalra N, Chander S, Pathak H, Aggarwal P K, Gupta N C, Sehgal M, Chakraborty D (2007) Impacts of climate change on agriculture. *Outlook on AGRICULTURE* 36(2): 109-118
28. Kobata T, Uemuki N (2004) High temperatures during the grain-filling period do not reduce the potential grain dry matter increase of rice. *Agronomy Journal* 96(2): 406-414
29. Lansigan F (2002) Assessing the impacts of climate variability on crop production and developing coping strategies in rainfed agriculture 1437:2019-5107
30. Liu J, Yang H, Savenije H H G (2008) China's move to higher-meat diet hits water security. *Nature* 454(7203): 397-397
31. Manekar, A., Jena, S. & Panda, R.K. Estimation of Groundwater Evapotranspiration and Extinction Depth Using Diurnal Water Table Fluctuation and Remote Sensing Observations: A Case Study in Agriculture-Dominated Watershed of Eastern India. *Water Conserv Sci Eng* 9, 4 (2024). <https://doi.org/10.1007/s41101-024-00236-0>
32. Mekonnen M M, Hoekstra A Y (2011) The green, blue and grey water footprint of crops and derived crop products. *Hydrology and Earth System Sciences* 15(5): 1577-1600

33. Mo X, Liu S, Lin Z, Guo R (2009) Regional crop yield, water consumption and water use efficiency and their responses to climate change in the North China Plain. *Agriculture, Ecosystems & Environment* 134(1-2) : 67-78
34. Pannkuk C D, Papendick R I, Saxton K E (1997) Fallow management effects on soil water storage and wheat yields in the Pacific Northwest. *Agronomy Journal* 89(3): 386-391
35. Pei H, Scanlon B R, Shen Y, Reedy R C, Long D, Liu C (2015) Impacts of varying agricultural intensification on crop yield and groundwater resources: Comparison of the North China Plain and US High Plains. *Environmental Research Letters* 10(4): 044013
36. Qi S, (2002) Classification of irrigated land using satellite imagery, the High Plains aquifer, nominal date 1992. US Department of the Interior, US Geological Survey 2: 4236
37. Riahi K, Grübler A, Nakicenovic N (2007) Scenarios of long-term socio-economic and environmental development under climate stabilization. *Technological forecasting and social change* 74(7): 887-935
38. Ritchie J T, Basso B (2008) Water use efficiency is not constant when crop water supply is adequate or fixed: The role of agronomic management. *European Journal of Agronomy* 28(3): 273-281
39. Rosegrant M W, Ringler C (2000) Impact on food security and rural development of transferring water out of agriculture. *Water Policy* 1(6): 567-586
40. Rui H, Teng B, Vollmer B, Mocko D, Lei G D (2014) NLDAS views of North American 2011 extreme events. *Remote Sensing of the Terrestrial Water Cycle* 407-426 <https://doi.org/10.1002/9781118872086.ch25>
41. Schlenker W, Roberts M J (2009) Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *Proceedings of the National Academy of sciences* 106(37): 15594-15598
42. Seckler D W (1998) World water demand and supply, 1990 to 2025: Scenarios and issues (19). Iwmi
43. Shiklomanov I A (2000) Appraisal and assessment of world water resources. *Water international* 25(1): 11-32
44. Shroyer J P, Thompson C, Brown R, Ohlenbach P D, Fjell D L, Staggenborg S, Kilgore G L (1996) Kansas crop planting guide. L-818. Manhattan, Kansas: Kansas State University Cooperative Extension Service
45. Singh D S, Mishra A (2021) Suitability of Groundwater Quality with Precipitation in the Western Part of Indo-Gangetic Plain, Uttar Pradesh. *Journal of the Geological Society of India* 97: 1422-1428
46. Singh D S, Singh R, Mishra A (2020) Determination of silt thickness in Durga Kund for its de-isolation at Varanasi UP India. *Water Science* 34(1): 13-17
47. Smith S. J, Wigley T M L (2006) Multi-gas forcing stabilization with Minicam. *The Energy Journal*, 27(2_suppl): 373-392
48. Solomon S D (2007) Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change 2007
49. Stanton J S, Qi S L, Ryter D W, Falk S E, Houston N A, Peterson S M, ... , Christenson S C (2011) Selected approaches to estimate water-budget components of the High Plains, 1940 through 1949 and 2000 through 2009. US Department of the Interior, US Geological Survey 2011
50. Tao F, Zhang Z (2010) Adaptation of maize production to climate change in North China Plain: quantify the relative contributions of adaptation options. *European Journal of Agronomy* 33(2): 103-116

51. Tao F, Xiao D, Zhang S, Zhang Z, Rötter R P (2017) Wheat yield benefited from increases in minimum temperature in the Huang-Huai-Hai Plain of China in the past three decades. *Agricultural and forest meteorology* 239: 1-14
52. Tilman D, Balzer C, Hill J, Befort B L (2011) Global food demand and the sustainable intensification of agriculture. *Proceedings of the national academy of sciences* 108(50): 20260-20264
53. Van Hoang T, Chou T Y, Basso B, Yeh M L, Chien C Y (2014) Climate change impact on agricultural productivity and environment influence based on simulation model. *Int. J. Adv. Remote Sens. GIS* 3: 642-659
54. Van Oort P A J, Wang G, Vos J et al (2016) Towards groundwater neutral cropping systems in the Alluvial Fans of the North China Plain. *Agricultural Water Management* 165: 131-140
55. Xiao D, Shen Y, Qi Y, Moiwo J P, Min L, Zhang Y, Pei H (2017) Impact of alternative cropping systems on groundwater use and grain yields in the North China Plain Region. *Agricultural Systems* 153: 109-117
56. Zhang D, Liu J, Li D, Batchelor W D, Wu D, Zhen X, Ju H (2023) Future climate change impacts on wheat grain yield and protein in the North China Region. *Science of the Total Environment* 902: 166147
57. Zhao Y, Tao H, He P, Yao X, Cheng T, Zhu Y, Tian Y (2023) Annual 30 m winter wheat yield mapping in the Huang-Huai-Hai plain using crop growth model and long-term satellite images. *Computers and Electronics in Agriculture* 214: 108335

Tables

Table 1: Crop Production in the study Area (Source: IMD Data & updes.up.nic.in)

Year	Wheat	Potato	Barley	Sugarcane	Millet	Maize	Rice	Pulses	Rainfall
	Production (M. Ton)								(mm)
1991-92	627173	84411	110233	819244	89066	46067	16643	31015	674.41
1992-93	618565	132267	95835	775348	120319	97971	20870	31148	839.30
1993-94	581153	92939	88651	728509	109165	76819	23089	29961	801.45
1994-95	738250	116653	122133	593500	123590	74199	30542	34553	641.64
1995-96	726722	124526	106405	739560	132059	75372	30948	27974	644.67
1996-97	602575	125252	89335	684170	126984	79125	18700	17307	800.70
1997-98	616108	75462	95194	598346	135408	96971	36571	13537	403.12
1998-99	629068	116886	78853	528025	87299	48294	35078	11738	912.10
1999-00	625621	184410	86773	574967	130908	72076	56313	11350	634.95
2000-01	709851	145737	82634	531201	137685	91441	68335	9459	595.32
2001-02	700120	158419	79766	577729	106726	89440	65137	7891	451.12
2002-03	718204	212532	66227	629505	116690	25491	45992	5880	413.08
2003-04	723449	193332	61643	614300	133287	50322	63262	4848	1084.30
2004-05	632775	246055	47549	466077	150165	53860	86432	3697	551.74
2005-06	653816	276841	38438	486316	143236	43920	91682	4819	651.85
2006-07	626981	319264	41629	576245	147698	42740	98179	3968	474.13
2007-08	716275	381020	37658	560043	171181	53143	94332	2601	485.58
2008-09	750861	415570	37618	501657	178992	67537	125464	2439	713.32
2009-10	717023	546116	26212	411410	152854	43233	115886	2667	391.45

2010-11	792957	571297	22603	445790	181120	44207	134380	5303	733.08
2011-12	830185	550998	33669	443736	175416	35683	187791	6196	873.43
2012-13	781641	603315	25917	422480	225969	47243	211928	5622	652.87
2013-14	775407	540470	27208	463114	277410	52633	201755	5126	694.87
2014-15	511138	675246	18865	402606	178140	42838	197104	3133	416.25
2015-16	709923	682442	16397	315556	199764	37725	205798	9019	588.57
2016-17	868289	653662	14428	264728	202911	47655	201328	18915	711.23
2017-18	961295	761370	18942	543375	206746	49395	222906	11369	587.42
2018-19	946190	918061	17925	685498	179183	35503	230780	8358	777.72
2019-20	921572	656713	34404	712510	196598	36282	242098	8615	491.45
2020-21	934986	784463	27898	476813	212508	49039	219354	12374	425.00

Table 2: Cropping Area in the study Area (Source: IMD Data & updes.up.nic.in)

Year	Wheat	Potato	Barley	Sugarcane	Millet	Maize	Rice	pulses
Cropping Area (Hectare)								
1991-92	222996	5146	38298	12960	13445	49281	10342	56323
1992-93	227412	5788	37527	12236	13310	45924	10051	56849
1993-94	239244	5832	36101	10820	12445	47826	11845	55698
1994-95	241363	4274	38109	9927	12158	41657	14677	57736
1995-96	245671	4295	38274	10537	11731	41302	18810	57893
1996-97	187794	4274	25743	11525	5560	39198	12827	40614
1997-98	190414	4295	26101	9501	5512	41728	16777	36677
1998-99	194670	5503	24335	8787	3608	25786	20961	33832
1999-00	205624	6801	23045	8010	5407	29830	30823	29374
2000-01	211652	5531	23674	8530	4500	28254	34116	27137
2001-02	213864	6059	21780	8566	3086	26694	33048	26743
2002-03	212456	8667	18698	9694	8437	27232	26027	25188
2003-04	219859	8583	17799	10107	6447	26694	30613	23242
2004-05	218709	8670	15473	8602	4986	27232	38254	25361
2005-06	216437	11901	14733	8608	4713	28254	43861	24074
2006-07	219466	13642	14658	8918	4937	26694	47543	21307
2007-08	222090	17856	11842	9438	2888	27232	47448	19770
2008-09	221651	18845	10929	8497	2271	20859	57411	17758
2009-10	224403	20117	8606	7122	15303	22093	67053	15413
2010-11	223816	23231	7649	7334	7003	20527	65742	17862
2011-12	220707	23861	9603	7334	4372	17588	86131	15525
2012-13	223574	21845	8042	6862	5502	17600	86444	16578
2013-14	223682	21683	8077	7601	5346	16935	89318	15605
2014-15	220742	25991	7535	6724	23021	19610	89587	16141

Table 3: Summary statistics for the Crop Production (M. Tons)

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Wheat	30	0	30	511138.00	961295.00	724939.10	115669.19
Potato	30	0	30	75462.000	918061.00	378190.96	257902.29
Barley	30	0	30	14428.000	122133.00	55034.73	33352.06
Sugarcane	30	0	30	264728.00	819244.00	552411.93	133060.35
Millet	30	0	30	87299.000	277410.00	157635.90	43616.28
Maize	30	0	30	25491.000	97971.000	56874.13	19994.90
Rice	30	0	30	16643.00	242098.00	112622.56	78273.60
Pulses	30	0	30	2439.000	34553.000	11696.067	9709.12

Table 4: Summary statistics for the Cropping Area Production (Hat.):

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Wheat	24	0	24	187794.00	245671.00	218679.00	14012.29
Potato	24	0	24	4274.00	25991.00	11778.75	7643.69
Barley	24	0	24	7535.00	38298.00	20276.29	10913.45
Sugarcane	24	0	24	6724.00	12960.00	9093.33	1665.47
Millet	24	0	24	2271.00	23021.00	7749.50	5017.76
Maize	24	0	24	16935.00	49281.00	29834.58	10065.33
Rice	24	0	24	10051.00	89587.00	41237.88	26960.25
Pulses	24	0	24	15413.00	57893.00	30529.17	15337.49

Table 5: Correlation matrix (Pearson) for the Crop Production

Variables	Wheat	Potato	Barley	Sugarcane	Millet	Maize	Rice	Pulses
Wheat	1	0.704	-0.510	-0.178	0.603	-0.386	0.703	-0.157
Potato	0.704	1	-0.890	-0.520	0.810	-0.624	0.960	-0.445
Barley	-0.510	-0.890	1	0.688	-0.782	0.681	-0.875	0.711
Sugarcane	-0.178	-0.520	0.688	1	-0.566	0.360	-0.551	0.553
Millet	0.603	0.810	-0.782	-0.566	1	-0.392	0.874	-0.433
Maize	-0.386	-0.624	0.681	0.360	-0.392	1	-0.585	0.475
Rice	0.703	0.960	-0.875	-0.551	0.874	-0.585	1	-0.475
Pulses	-0.157	-0.445	0.711	0.553	-0.433	0.475	-0.475	1

Table 6: Correlation matrix (Pearson) for the Cropping Area

Variables	Wheat	Potato	Barley	Sugarcane	Millet	Maize	Rice	Pulses
Wheat	1	0.192	0.172	0.055	0.427	0.119	0.131	0.265
Potato	0.192	1	-0.853	-0.731	0.087	-0.784	0.952	-0.758
Barley	0.172	-0.853	1	0.827	0.251	0.933	-0.874	0.977
Sugarcane	0.055	-0.731	0.827	1	0.144	0.884	-0.837	0.827
Millet	0.427	0.087	0.251	0.144	1	0.300	0.002	0.341
Maize	0.119	-0.784	0.933	0.884	0.300	1	-0.864	0.942
Rice	0.131	0.952	-0.874	-0.837	0.002	-0.864	1	-0.812
pulses	0.265	-0.758	0.977	0.827	0.341	0.942	-0.812	1

Table 7: Values of Water Footprint (Mekonnen, M.M. (2010))

Crops	Water Footprint (gm ³ /Year)	
	Green Water	Blue Water
Rice	2040	937
Wheat	527	906
Potato	244	28
Barley	706	682
Sugarcane	1107	455
Millet	3360	5
Maize	2188	58
Pulses	1464	351

Figures

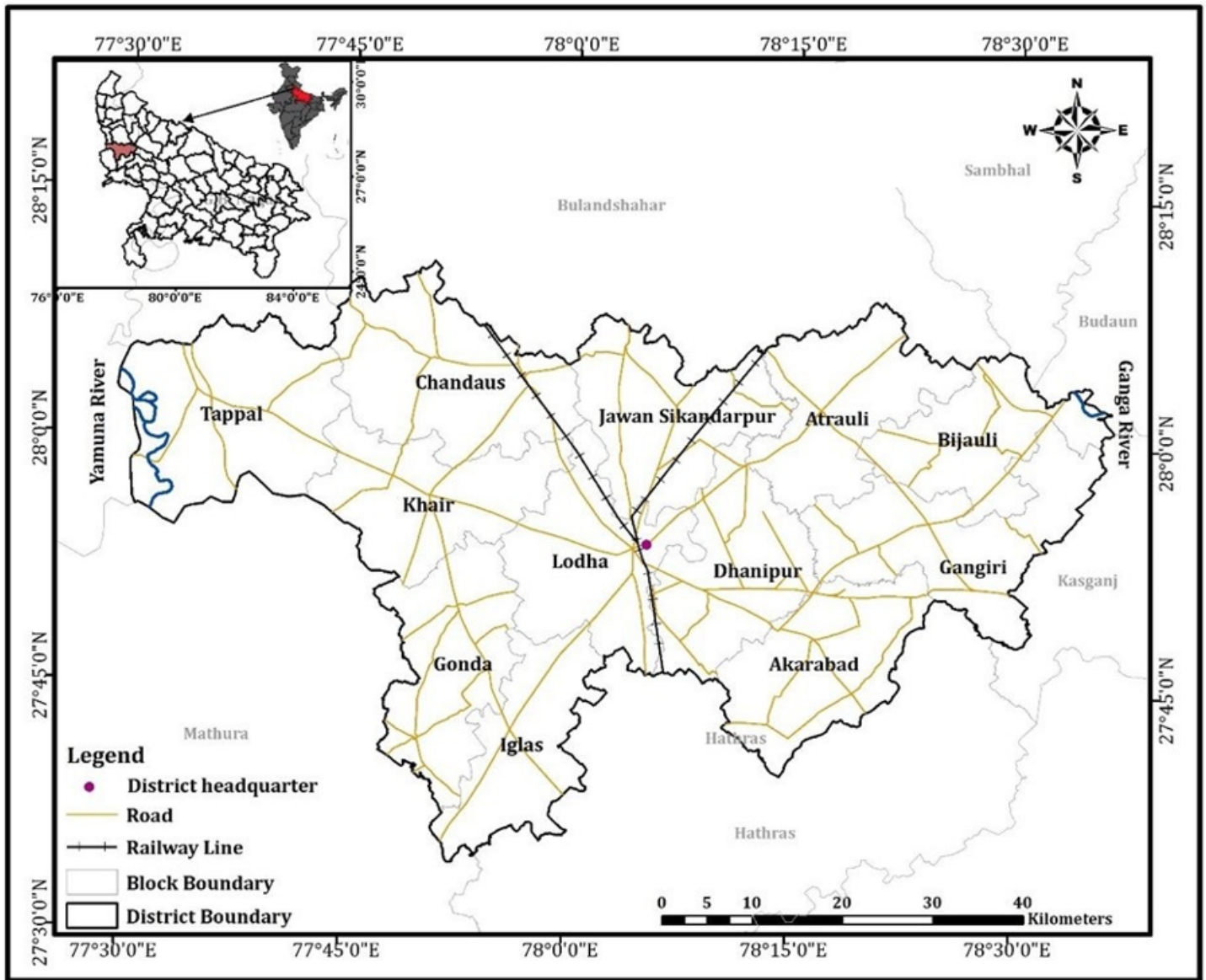


Figure 1

Location Map of the study area (Source: Survey of India, Toposheet)

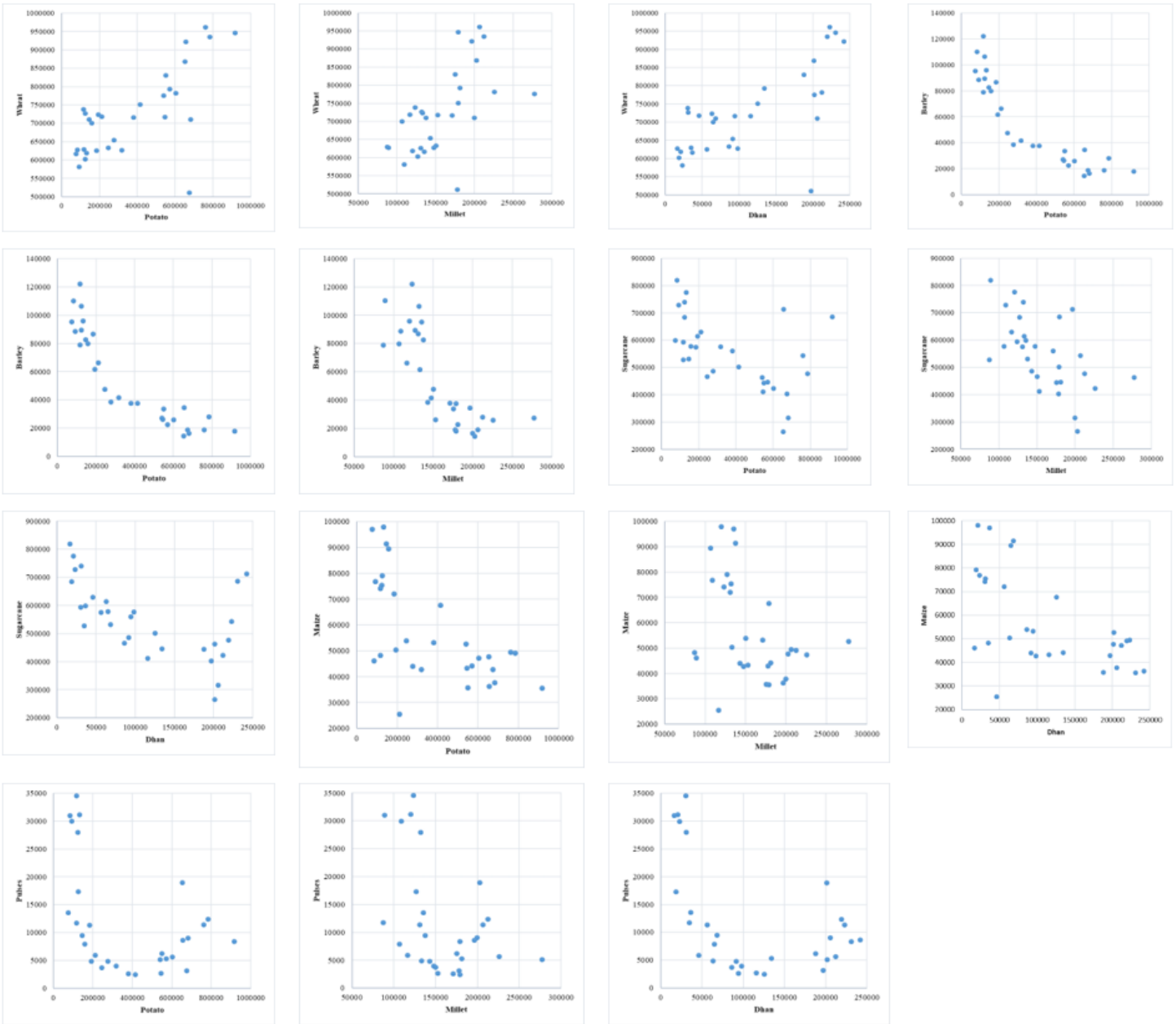


Figure 2

Production correlation of Crops (M. Tons)

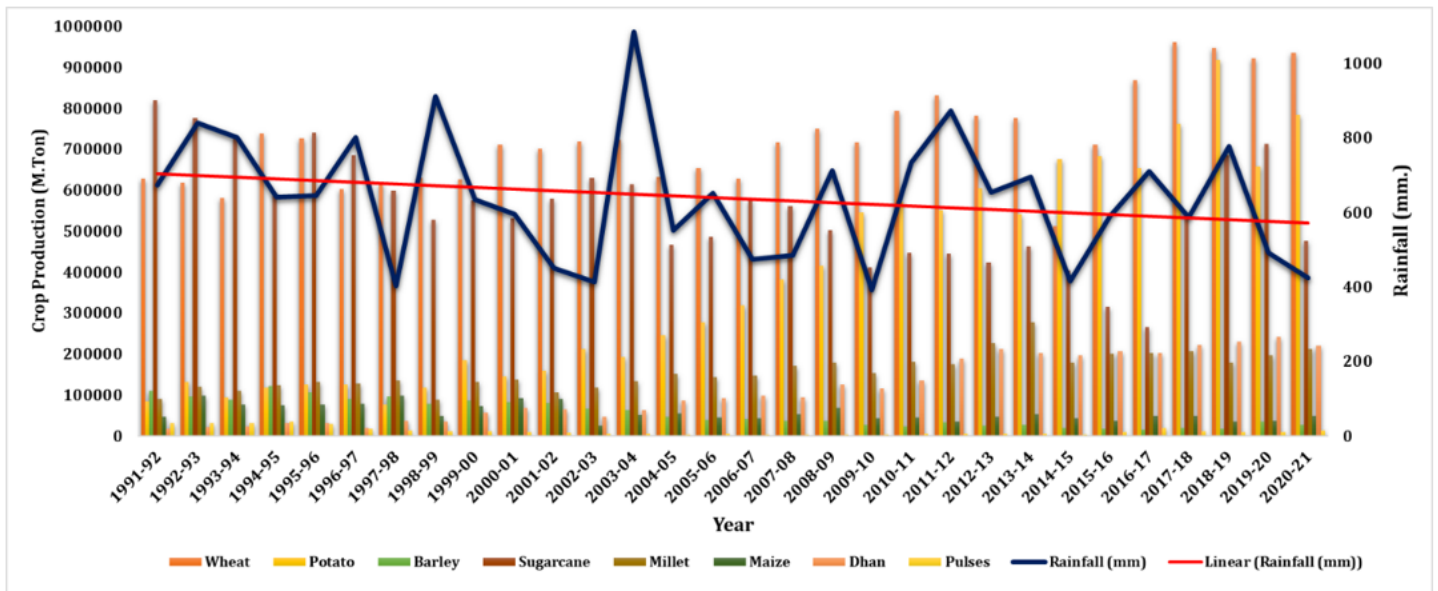


Figure 3

Production of Crops with the rainfall in different years (Source: IMD Data & updes.up.nic.in)