Using GIS for Spatio-temporal Assessment of Gross Irrigated Area in Punjab, India

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Abstract

Agricultural production during the Green Revolution occurred mainly through a healthy combination of institutional and technological factors. This significantly increased crop production and productivity, especially wheat and rice in India where Punjab, Haryana, and Uttar Pradesh were the best-performing states. The rice-wheat rotation requires intensive irrigation, leading to excessive groundwater pumping due to government-subsidized electricity. Long-term unsustainable water supplies have deepened aquifers in much of Punjab. The depletion of groundwater resources led to acute shortages in some areas while higher water levels constitute the problem of waterlogging and salinity. This paper focuses on the spatial and temporal assessment of the Gross Irrigated Area of Punjab and the mapping of water table depth in the state using secondary data sources and Geospatial Information Technology

Keywords: Green Revolution, Gross Irrigated Area, Ground Water level, Geospatial Technology

Introduction

Irrigation, an important land management activity, accounts for about 70%of all water withdrawals globally, irrigating only 20 percent of total agricultural land. In terms of irrigation capacity, Asia, with 38 per cent of the cultivated area, has the largest area equipped with irrigation i.e. 70 per cent of the world total, led by India and China, followed by the US(16 percent) and Europe(8 per cent). (FAO, 2022). Agriculture continues to be a very important sector of the Indian economy as it provides food security to more than 1.5 billion people in India and abroad. It employs about 54 per cent of the country's workforce (census, 2011) and about 17 per cent to total value added (Central Bureau of Statistics). India accounts for 11 per cent of the world's arable land and has about 180 million hectares of land of which nearly 18 per cent is irrigated (Statistical Abstract, 2019). Following the post-independence food crises, various initiatives were taken to improve agricultural

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output and productivity. The Green Revolution of the late 1960s brought enormous success to Indian agriculture through the adoption of improved seed, and irrigation systems and increased use of unconventional inputs such as fertilizers, new machinery, pesticides and technology. In 1950, only 18 per cent of the area was irrigated, but the adoption of canal and tubewell irrigation increased the irrigated area to 48 per cent till 2019-2020.(Jain et. al., 2019).

Punjab stands out as the most successful region in te Green Revolution belt in terms of agricultural production, which increased by about 100 per cent, and the irrigated area expanded from 48 per cent to 80 per cent between 1960 to 1980(Bhalla et. al., 1990). Although Punjab constitutes only 1.5 per cent of the country’s total geographical area, it now contributes 13-14 per cent to the nation's total foodgrain production. Pull factors, such as the pre existing irrigation facilities and the ease of accessing water resources, facilitated the state’s rapid adoption of technological package. A supportive policy environment also played a crucial role in Punjab’s agricultural development.

In the post-independence period, a significant change in irrigation patterns have been observed. The expansion of irrigated acreage has been substantial in Punjab, as well as in other parts of India. Furthermore, the sources and techniques of irrigation have improved in efficiency and reliability. Projects like the Indira Gandhi Canal, along with the use of pumping sets and tube wells, have significantly enhanced agricultural land resources and farm production. However, the groundwater levels in several regions of the country indicate that the availability of good quality water will become a challenge for future development (Manivannan et al., 2017). Several biogeological issues, such as reduced soil fertility, increased salinity, lower groundwater levels, and soil and water pollution due to fertilizer and pesticide use have occurred due to unsustainable exploitation of land and water resources.

Description of the Study Area: Punjab

Punjab is situated between North Latitudes 29° 32' and 32° 28' and east longitudes 73° 50' and 77° 00', covering a total area of 50,362 km sq.

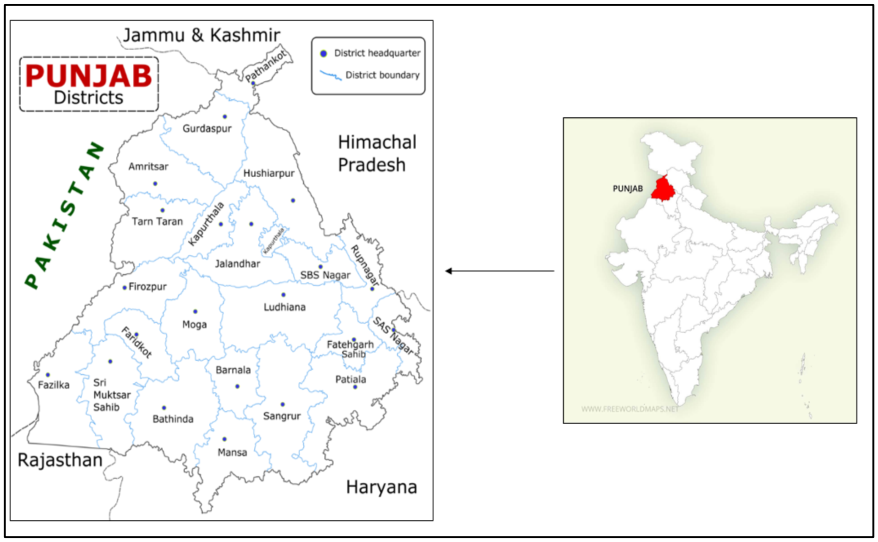

Figure 1Study area
Source- Maps of India

It is bordered by Himachal Pradesh to the northeast, Jammu and Kashmir to the north, and Haryana and Rajasthan to the south and sout west, respectively. The state is divide into four main divisions: Jalandhar, Patiala, Ferozpur and Faridkot, which are further subdivided into 22 districts, 77 sub-divisions/tehsils, and 146 community development blocks. Chandigarh, a Union territory, serves as the capital of both Punjab and Haryana.

Punjab is drained by perennial rivers such as the Sutlej, Beas, and Ravi, as well as the ephemeral river Ghaggar, and has an extensive canal system. The introduction of these canals transformed the fertile land into green fields, leading to significant achievements in agricultural production

The state is divided into three physio-geographic regions based on the drainage basin: Majha, Doaba and Malwa. The Malwa region, covering the southern part of the state, includes cities like Ludhiana, Patiala, Sangarur, Bhatinda and Mohali. The Majha region is located north of the Beas River and South of the Ravi River, drained by its tributaries, with main districts including Amritsar, Gurdaspur, and Tarn Taran. The Doaba region, between the Sutlej and Beas rivers, is one of the most fertile areas and was the center of the Green Revolution in Punjab, comprising cities like Jalandhar, Kapurthala, Hoshiarpur, Nawanshahr and Phagwara.

Punjab's economy is primarily agararian with low industrial output. The scarcity of basic minerals, including fuels, hampers the industrial progress. Other important economic activities include livestock, textile industry and tourism

Objective

The study aims at presenting an overview of irrigation in Punjab and its impact on underground water level through:

- Spatial and temporal assessment of Gross Irrigated Area in Punjab
- Depth of groundwater level in the state.

Data Source and Methodology

The present study is primarily based on the secondary data collected from government reports published under government departments like Statistical Abstract 2021 published by the Economic and Statistical Organization, Punjab and various research articles, journals etc. The information gathered from various archived have been very helpful during the study.

Datasets gathered from the Statistical Anstract, Pnjab have been used to show the spatio temporal analysis of Gross irrigated area in Punjab using graphs and Map. The overlay map created to sho the spatial analysis is created using ArcGIS software, the technique used in foreground of the main map is a proportional circle, representing the district wise Gross Irrigated Area. Whereas, the dataset to show the depth of underground water is obtained from Central Ground Water Board and Statistical Abstract, 2021. The overlaid map which shows the groundwater level over different regions has been created in ArcGIS by digitizing the map obtained from a secondary source.

Gross Irrigated Area

The gross irrigated area denotes the total land that receives water through various artificial irrigation methods, essential for boosting agricultural productivity globally. The area includes fields irrigated by surface water, groundwater or other sources, representing human efforts to manage water resources for sustaining agricultural production, particularly in regions with inadequate or unpredictable rainfall. According to Jal Shakti Ministry, Government of India, Indi's gross irrigated area stands at about 96 million hectares, incorporating both suface and groundwater sources. The method of irrigation vary significantly: well irrigation is predominantly found in northern alluvial plains and southern alluvial regionsof Karnataka and Tamil Nadu. Canals are a crucial irrigation source in extensive plains with perennial rivers, natable in the North Indian Plains of Punjab, Uttar Pradesh and eastern Rajasthan. Conversely, tank irrigation is primarily utilized in areas with irregular and highly seasonal rainfall, such as Eastern Madhya Pradesh, Chattisgarh, Odisha, interior Tamil Nadu, and certain parts of Andra Pradesh.

Temporal status of Gross Irrigated Area

Over the past forty years, the Gross Irrigated area in Punjab has seen an increase, particularly favoring crops popularized during the Green Revolution. Rice, which requires a significant amount of water, has experienced the most substantial rise in gross irrigated area, with an increase of 200 percent during this time. This surge is attributed to 26 per cent annual growth in agrcltural land dedicated to rice from 1980 to 2016. Wheat, a staple crop in Punjab, has maintained the largest irrigated area since 1980-81, expanding to 3.5 million hectares by 2015-16, reflecting a 71 percent increase. As notes in the Statistical Abstract of 2021, 82 percent of Punjab's total gross irrigated area(7.757 million hectares) is occupied by rice and wheat cultivation. The shift in cropping patterns towards rice and the increase in wheat cultivation after the green revolution have led to a decline in the irrigated area for other food and non-food crops, resulting in much lower and slightly decreasing gross irrigated area for these crops compared to wheat and rice.

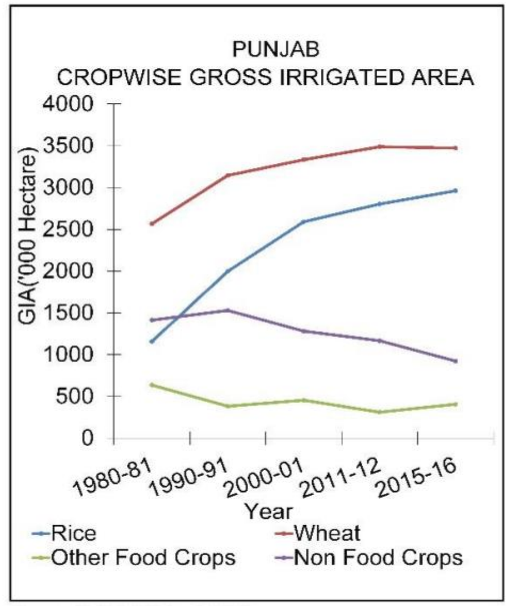

Figure 2 Gross Irrigated Area
Source- Statistical Abstract, 2020

Spatial pattern of Gross Irrigated Area and its Impact on ground water level.

The introduction of high yielding variety seeds for rice and wheat, driven by the Green Revolution, necessitated substantial water use due to wter intensive commercial cropping pattern. This resulted in a 150 percent increase in rice cultivation and 23 percent rise in wheat cultivation, causing extensive groundwater extraction via tubewells and canals. Currently, Punjab faces India's most critical groundwater situation, with 80 percent of monitored wells classified as overexploited (Central Ground Water Board, 2012). Groundwater levels steadily fall across the state, with depletion rates ranging from 0.7 to 1.2 meters yearly (World Bank, 2010).

Districts such as Pathankot, Faridkot and Rupnagar which have lower gross irrigated areas, mainly relatively better groundwater levels. Conversely, districts like Amritsar, Fatehgarh Sahib, Jalandhar, Kapurthala, Mansa, Ludhiana, Moga, SBS Nagar, Patiala and Sangarur see high levels of groundwater extraction, leading to significant depletion. These areas characterized by intensive use for crops, have a gross irrigated area of over 500,000 hectares in 2020. In about 70 percent of Punjab, groundwater depths have surpassed 10 meters, raising serious concerns about water scarcity and sustainability. Additionally, regions with higher groundwater tables face waterlogging issues.

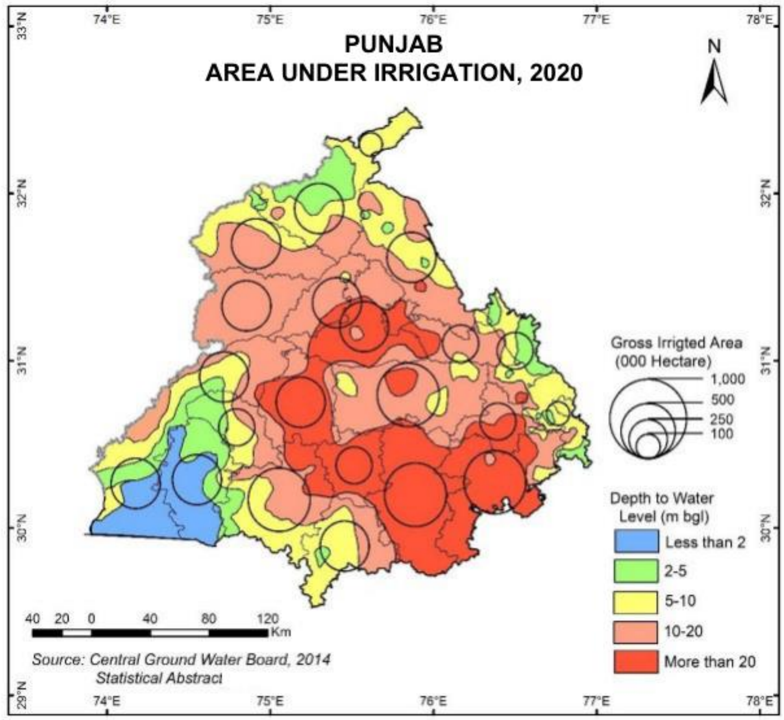

Figure 3 Gross Irrigated Area and Depth of ground Water Level, Punjab

In the past two decades, the water table in districts like Muktsar and Firozpur has risen over by 10 meters. Groundwater in roughly a quarter of southwestern districts in saline and unsuitable for irrigation. Areas irrigated by the Sirhind Canal and its extensive network are experiencing severe waterlogging and soil salinity problem. The Rajasthan feeder and Shrihind feeder canals, in their linings. Inadequate or poorly maintained surface drainage systems further aggravate waterlogging. These factors collectively degrade agricultural land, making it challenging for farm labourers to achieve productivity.

Experts from CGWB’s Northwestern region recommend strategies to manage water level fluctuations, such as restoring groundwater levels in the northern and southern districts and addressing waterlogging in the southern districts.

Reasons for groundwater depletion

- Water intensive cropping pattern: The green revolution promoted the cultivation of high-yielding variety seeds of rice and wheat, which are highly water-intensive crops. This led to an increase in paddy cultivation from 28 per cent net sown area in 1980 to 75 per cent in 2019-20. The shifting of the cropping pattern also affected the cropping intensity from 116 percent in 1970 to more than 191 percent in 2011- 2012. Which ultimately resulted in excessive groundwater extraction to meet irrigation demands.
- Lack of efficient irrigation techniques: Traditional flood irrigation methods were used which are less efficient and result in significant water wastage as the paddy crops required heavy and timely irrigation. The canal systems were primarily built to cater to the demand of irrigation in the state. Indira Gandhi Canal with a length of 650 km covers Rajasthan, Punjab and Haryana through main canals and feeder canals. The southern districts of Punjab where the feeder canal passes through are dominated by canal irrigation.
- Free/ Subsidised power: The socialist policies during the Green Revolution provided farmers with electricity subsidies to shift from rain-fed agriculture to irrigation-led agriculture. The high amount of electricity subsidy adversely influenced the cropping pattern and unsustainable use of water resources. People started installing pumps on their farms and extracted groundwater resulting in groundwater table depletion and fiscal pressure on DISCOMs.(Sharma, 2012)
- Climate Change and Variability: Changes in weather patterns, including reduced and untimely rainfall and increased temperatures, have contributed to lower groundwater recharge rates, further exacerbating the depletion problem.

Conclusion

Punjab stands out among Indian states for its exceptional achievements in the agricultural department. Several factors contributed to this success, including the agrarian economy, landholding consolidation, reclamation of new agricultural lands irrigation development, and the use of biochemical inputs such as high-yielding variety seeds, chemical fertilizers, insecticides and mechanical tools. Significant developments in irrigation patterns have been noted since independence. The introduction of high-yielding variety seeds during the Green Revolution led to a significant increase in the gross irrigated area for wheat and rice, often at the expense of other crops. However meeting the irrigation demands of rice and wheat resulted in excessive groundwater use, causing water table depletion of some areas and waterlogging and salinization in others. These factors have collectively degraded agricultural land making it challenging for farm labourers to maintain efficient and adequate productivity. To ensure long-term sustainability of the agro-ecosystem, it is crucial to halt further water table depletion by promoting water conservation techniques, micro-irrigation methods, and changes in cropping patterns.

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