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Full Length Review Article

Analysis of Paddy Expansion on Topographically Unsuitable Land Using GIS: A Study of Sardulgarh Block

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Abstract:
Groundwater depletion has become a critical concern in the semi-arid regions of Punjab due to the expansion of water-intensive rice cultivation. This study analyzes the spatial and temporal relationship between groundwater decline and rice crop distribution in Sardulgarh block, Mansa district, using geospatial techniques. Multi-temporal datasets, including Digital Elevation Model (DEM), groundwater level data (2015 and 2023), and satellite imagery from AWiFS (2015) and Landsat (2025), were utilized. Unsupervised classification was applied to map rice cultivation, while change detection analysis was conducted to assess variations in groundwater levels and cropping patterns.
The results indicate a significant decline in groundwater levels, with a shift toward deeper water table categories across the study area. Despite this, rice cultivation has expanded considerably, including in topographically unsuitable areas identified through slope analysis. The findings reveal a clear mismatch between land suitability and cropping practices, highlighting unsustainable agricultural trends. The study emphasizes the urgent need for crop diversification and improved groundwater management strategies to ensure long-term sustainability in the region.

Keywords: *Groundwater depletion, Rice cultivation, GIS, Remote sensing, Unsupervised classification, Land suitability*

Introduction

A cropping pattern shows how different crops are grown on land in a region over a period of time. The choice of crops mainly depends on factors like water availability, soil conditions, climate, and economic benefits. In semi-arid regions, growing water-intensive crops such as rice requires proper planning because these crops need a large amount of water. If crops are grown without considering land suitability, it can lead to serious environmental problems, especially groundwater depletion.

Sardulgarh block in Mansa district, Punjab, is facing a similar issue. Even though groundwater levels are continuously declining and some areas are not suitable due to slope and land conditions, farmers are still growing rice. The region mainly follows a rice–wheat cropping system, which puts heavy pressure on groundwater resources. Government support policies like Minimum Support Price (MSP), along with irrigation facilities and traditional farming practices, encourage farmers to continue rice cultivation even in unsuitable areas.

Agriculture is the main source of income for most people in Punjab. Over time, farming has changed from traditional methods to modern, technology-based practices. The use of machines, improved seeds, and fertilizers has increased crop production, but it has also led to overuse of natural resources, especially groundwater (Rodell et al., 2009).

The Green Revolution played an important role in increasing food production in Punjab by promoting crops like wheat and rice. However, it also increased dependence on groundwater for irrigation. As a result, areas like Sardulgarh are now experiencing a rapid decline in groundwater levels, which is a serious concern for future agricultural sustainability.

Modern tools like Remote Sensing (RS) and Geographic Information Systems (GIS) are very useful for studying land use and groundwater changes (Jha et al., 2007). These technologies help in analyzing data over time and understanding patterns of resource use. Therefore, this study focuses on analyzing the relationship between groundwater depletion and the expansion of rice cultivation in Sardulgarh block using

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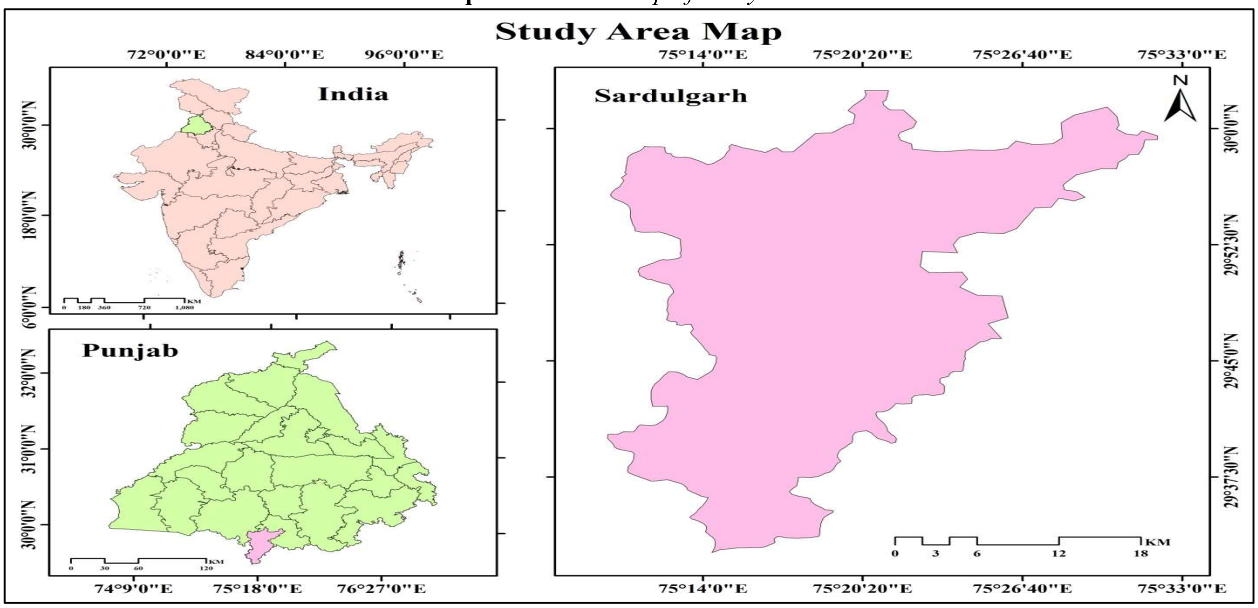
geospatial techniques, with the aim of identifying unsustainable farming practices.

Study Area

The selection of Sardulgarh Block as the study area is important because of its increasing dependence on groundwater and expansion of rice cultivation on topographically unsuitable land, which has significant environmental and agricultural implications.

Location: Sardulgarh block is located in the Mansa district of Punjab, India, in the southwestern part of the state. It lies approximately between 29°30′ to 30°00′ North latitude and 75°00′ to 75°30′ East longitude. The block consists of several rural settlements and plays an important role in the agricultural economy of the district. Its location in the semi-arid zone makes it highly dependent on groundwater resources for irrigation.

Map-1: *Location Map of Study Area.*



Source: Prepared by the author with the help of QGis from the data Administrative Boundary by Survey of India (SoI).

Climate

The study area experiences a semi-arid climate characterized by hot summers and cool winters. The summer season (April to June) is extremely hot, with temperatures often exceeding 40°C, while winters (December to February) are relatively mild. The region receives low to moderate rainfall, mainly during the monsoon season (July to September). Due to irregular rainfall, agriculture largely depends on irrigation from groundwater sources.

Soil Characteristics

The soils in Sardulgarh are predominantly alluvial in nature, which are generally suitable for agriculture. These soils vary from sandy to loamy textures, with moderate fertility levels. However, continuous cultivation of water-intensive crops like rice has affected soil health in some areas, leading to issues such as nutrient depletion and reduced productivity over time.

Topography (Relief and Slope)

Topographically Sardulgarh is mostly flat with slight variations in elevation. The slope derived from DEM data indicates that most areas fall under low slope categories, which are suitable for agriculture. However, certain patches show moderate slope, making them less suitable for water-intensive crops like rice due to reduced water holding capacity and higher runoff.

Land Use and Cropping Pattern

Agriculture is the dominant land use in Sardulgarh block. The region primarily follows a rice–wheat cropping system, which has become highly prevalent over the years. Despite declining groundwater levels, rice cultivation continues to expand due to economic incentives.

Groundwater Scenario

Groundwater is the main source of irrigation in the study area. Over the years, excessive extraction of groundwater for rice cultivation has led to a continuous decline in water levels. Many areas have shifted from shallow to deeper groundwater categories, indicating increasing water stress. This makes Sardulgarh a critical region for studying the impact of agricultural practices on groundwater resources.

Methodology:

The methodology of the study refers to the systematic procedure adopted to achieve the research objectives.

In the present study, a geospatial approach integrating Geographic Information System and Remote Sensing techniques was used to analyze groundwater depletion and rice cultivation on topographically unsuitable land in Sardulgarh Block. The methodology involved the collection, processing, and analysis of both spatial and non-spatial data from different sources.

Data Sources and Collection

The present study is focuses on the integration of multi-source geospatial datasets acquired from both primary and secondary sources.

The various datasets used for analyzing groundwater depletion and paddy cultivation in Sardulgarh Block. Different spatial and non-spatial data were collected from reliable sources to achieve the study objectives. The DEM (2025) obtained from the United States Geological Survey Earth Explorer was used for slope analysis and identification of suitable and unsuitable land for paddy cultivation. AWiFS imagery (2015) from Indian Space Research Organisation Resourcesat-2 was used to map land use/land cover and paddy cultivation areas for the base year. Landsat imagery (2025) sourced from the United States Geological Survey Landsat Program helped in recent land use classification and paddy area mapping.

Table-1: *Data Sources and Their Application in the Study.*

Sr. No.	Data Type	Year	Source	Usage in Study
1	DEM	2025	USGS Earth Explorer	Used for slope analysis to identify topographically suitable and unsuitable land for paddy cultivation
2	AWiFS	2015	ISRO – Resourcesat-2 AWiFS	Used to extract land use/land cover and identify paddy cultivation areas for the year 2015
3	Landsat	2025	USGS – Landsat Program	Used for recent land use/land cover classification and mapping of paddy area in 2025
4	GWD Data	2015 & 2023	Central Ground Water Board (CGWB)	Used to analyze groundwater level fluctuations and identify stress zones due to excessive irrigation

Source: Prepared by the author with the help of USGS website and Central Ground water board.

Groundwater data for 2015 and 2023 collected from the Central Ground Water Board (CGWB) were used to analyze groundwater fluctuations and stress zones. These datasets collectively supported the spatio-temporal assessment of groundwater conditions and agricultural land suitability in the study area.

Software Used

The study uses geospatial software for the processing, analysis, and interpretation of spatial data. QGIS is used for spatial analysis, map preparation, data visualization, and thematic map generation. It helps in overlay analysis, data management, and the preparation of land use and groundwater maps. ERDAS IMAGINE is used for satellite image processing, image classification, and extraction of land use/land cover information. The software also supports image enhancement and raster data analysis to identify paddy cultivation areas. The integration of these software tools enhances the accuracy and efficiency of spatial analysis in the study.

Fig-1: *Flow chart of Methodology*

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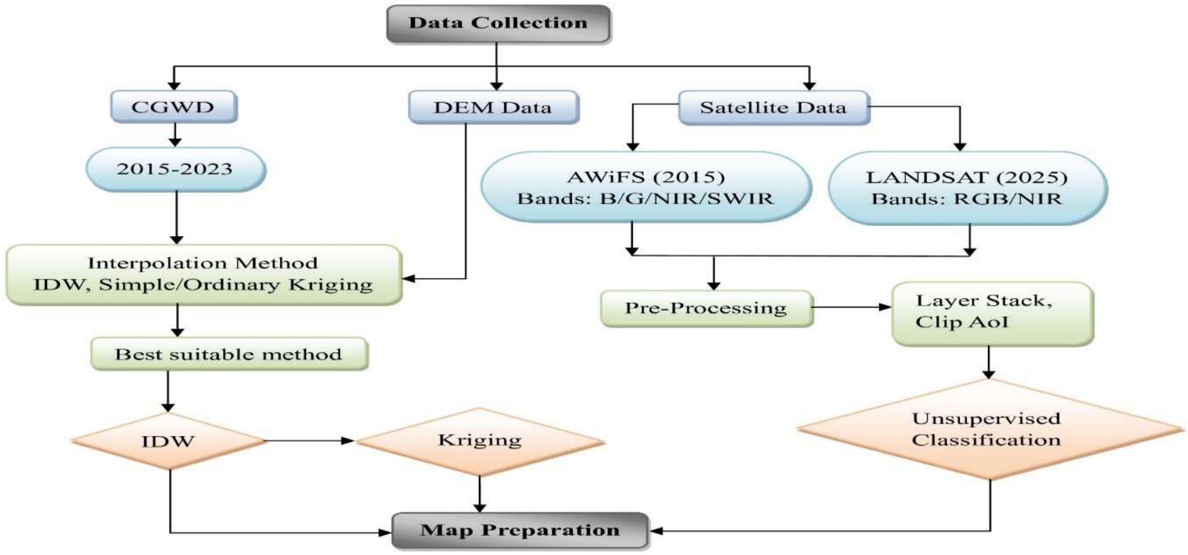

Data Pre-processing
All satellite datasets were pre-processed using Geo-spatial techniques. The DEM data were mosaicked to create a continuous elevation surface, while AWiFS (Green, Red, NIR, SWIR) and Landsat (Blue, Green, Red, NIR) bands were layer-stacked to generate multispectral images. Finally, all datasets were clipped to the Area of Interest (AoI) for effectual analysis.

Spatial Interpolation of Groundwater Data
To generate continuous spatial representations of groundwater depth, interpolation techniques were applied to the point-based CGWD dataset. Two widely recognized methods Inverse Distance Weighting (IDW) and Ordinary Kriging were employed. Both methods were implemented to ensure comparative evaluation.

Selection of the Most Suitable Interpolation Method
The performance of the applied interpolation techniques was critically evaluated based on their spatial accuracy, consistency, and representation of groundwater variability. The best method was selected for further analysis and for creating the final groundwater and DEM map.

Unsupervised Classification
The processed satellite imagery (AWiFS 2015 and LANDSAT 2025) was analyzed using **unsupervised classification techniques** to derive land use/land cover (LULC) information. The classification results facilitated the identification of agricultural land, with particular emphasis on rice cultivation areas across different time periods.

Map Prearation
The processed datasets were used to generate thematic maps using GIS techniques. A slope map was prepared from DEM data, while groundwater level change maps (2015–2025) were created using interpolated data. Rice crop distribution maps for 2015 and 2025 were derived from satellite imagery to analyze changes over time.
These maps were used to examine the relationship between terrain, groundwater conditions, and paddy cultivation.

Results and Discussion:
The results show a significant depletion of groundwater levels in the Sardulgarh region, with a noticeable shift toward deeper groundwater classes. This pattern indicates unsustainable extraction and declining recharge rates. The study underscores the urgency of implementing effective groundwater conservation and management strategies.
Slope Analysis: Slope map shows that most of the area has low to moderate slope, while higher elevation is found in the northern and eastern parts. The southern region appears relatively flat. Such conditions indicate that a large part of the area is suitable for agriculture, especially Rice cultivation, which requires flat land for water retention.
The table-2 shows the distribution of area according to elevation classes measured in meters above sea level (m a.s.l.) in Sardulgarh Block. The total geographical area covered under the study is 88,392.07 hectares, which is divided into four elevation categories. The 210–214 m a.s.l. elevation class occupies the largest area, covering 32,972.51 hectares, indicating that a major part of the study area lies within moderate elevation.

Table-2: Slope/Elevation Class-wise Distribution of Area in the Study Region

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Sr. No.	Class (m a.s.l.)	Area in hec.
1	186-210	18076.93
2	210-214	32972.51
3	214-218	24046.28
4	218-260	13296.36
Total		**88392.07**

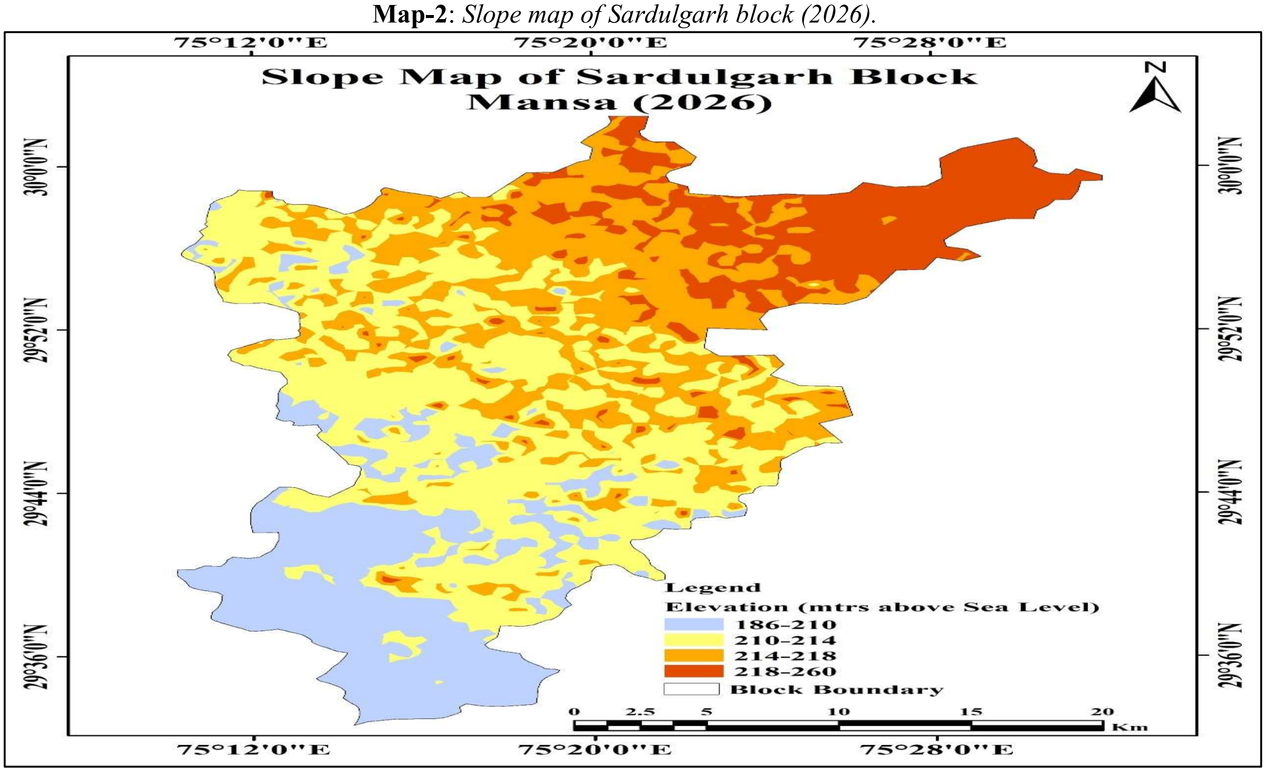
Source: Area estimation from prepared map-2 with the help of Q-Gis.

This is followed by the 214–218 m a.s.l. class, which covers 24,046.28 hectares. The 186–210 m a.s.l. elevation range occupies 18,076.93 hectares, while the 218–260 m a.s.l. category covers the smallest area of 13,296.36 hectares. The analysis reveals that the study area is predominantly characterized by low to moderate elevation, which influences drainage patterns, agricultural suitability, and groundwater availability in the region.

The map-2 represents the spatial distribution of slope/elevation classes in Sardulgarh Block, Mansa for the year 2026**,** categorized into different elevation ranges measured in meters above sea level (m a.s.l.). The terrain of the study area is classified into four elevation classes: 186–210 m, 210–214 m, 214–218 m, and 218–260 m, showing variations in topography across the block.

The 210–214m elevation class occupies the largest portion of the study area and is mainly distributed across the central and western regions, indicating relatively moderate and uniform terrain. The 214–218m class is spread over several parts of the block, particularly in the northern and eastern regions, representing slightly elevated landforms. The 186–210 m elevation class**,** which represents comparatively lower elevation areas, is mainly concentrated in the southern and southwestern parts of the block. In contrast, the 218–260 m class, representing relatively higher elevation zones, is predominantly observed in the northeastern region with scattered patches in other areas.

Map-2: *Slope map of Sardulgarh block (2026).*



Source: Prepared by the author with the help of QGis from the data NASA SRTM DEM (Space Shuttle Endeavour Mission, 2000).

Groundwater Level Distribution:

According to the present study, groundwater level distribution shows differences in water levels across the area. Some places have deeper groundwater due to more use, while others have shallow levels because of

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better recharge. These changes indicate increasing pressure on groundwater resources and the need for proper management.

Table-3: *Spatio-Temporal Changes in Groundwater Depth Classes in Sardulgarh Block (2015–2023)*

Sr. No.	Class (m)	Area in hec.(2015)	Area in hec.(2023)	Change in GWD
1	0-5	4296.13	7380.82	3084.68 (Increase)
2	5-10	65725.35	32592.11	33133.23 (Decrease)
3	10-15	18532.11	34610.34	16078.23 (Increase)
4	15-20	0	12005.61	12005.61 (Increase)
5	20-25	0	1801.88	1801.88 (Increase)
Total		**88553.59**	**88390.76**	

Source: Area estimation from prepared map-3 and 4 with the help of Q-Gis.

Table 3 shows changes in groundwater depth (GWD) from 2015 to 2023. Shallow depth (0–5 m) slightly increased, while the 5–10 m category declined significantly. Deeper classes (10–25 m) expanded, with some appearing only in 2023. Overall, it indicates a shift towards deeper groundwater levels, suggesting increasing groundwater depletion.

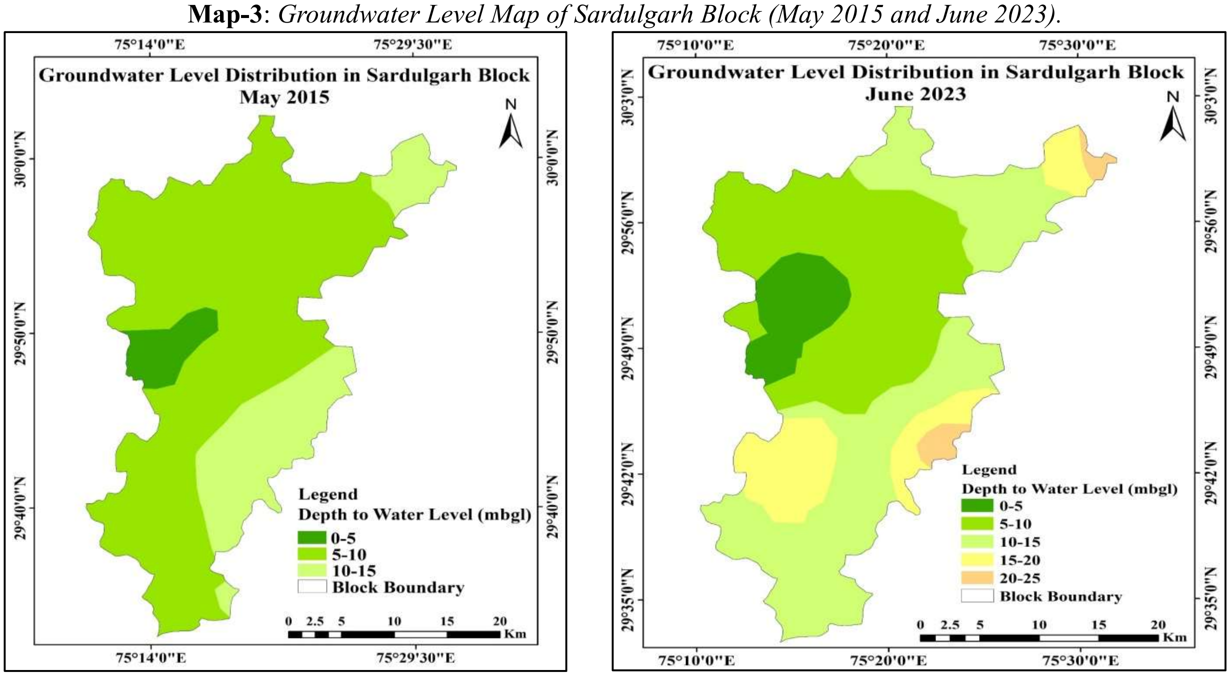
Spatial Distribution Groundwater Level

The map-3 illustrates the spatial distribution of groundwater levels in Sardulgarh Block for May 2015 and June 2023, showing noticeable changes in groundwater depth over time. The groundwater depth is categorized into different classes measured in meters below ground level (mbgl), which helps in understanding groundwater availability and depletion patterns across the block.

In 2015, the majority of Sardulgarh Block falls under the 5–10 m groundwater depth category, indicating relatively shallow groundwater availability in most parts of the study area. A small portion in the western-central region records 0–5 m depth, suggesting comparatively higher groundwater availability. Meanwhile, some southeastern areas fall within the 10–15 m class, indicating relatively deeper groundwater levels in limited locations.

By 2023, a significant spatial shift in groundwater distribution becomes visible. Although the 5–10 m category still covers a major portion of the block, the area under 10–15 m depth expands considerably, particularly in the southern and eastern regions, reflecting groundwater decline.

Map-3: *Groundwater Level Map of Sardulgarh Block (May 2015 and June 2023).*



Source: Prepared by the author with the help of QGis from the data Central Ground Water Board (CGWB), Government of India.

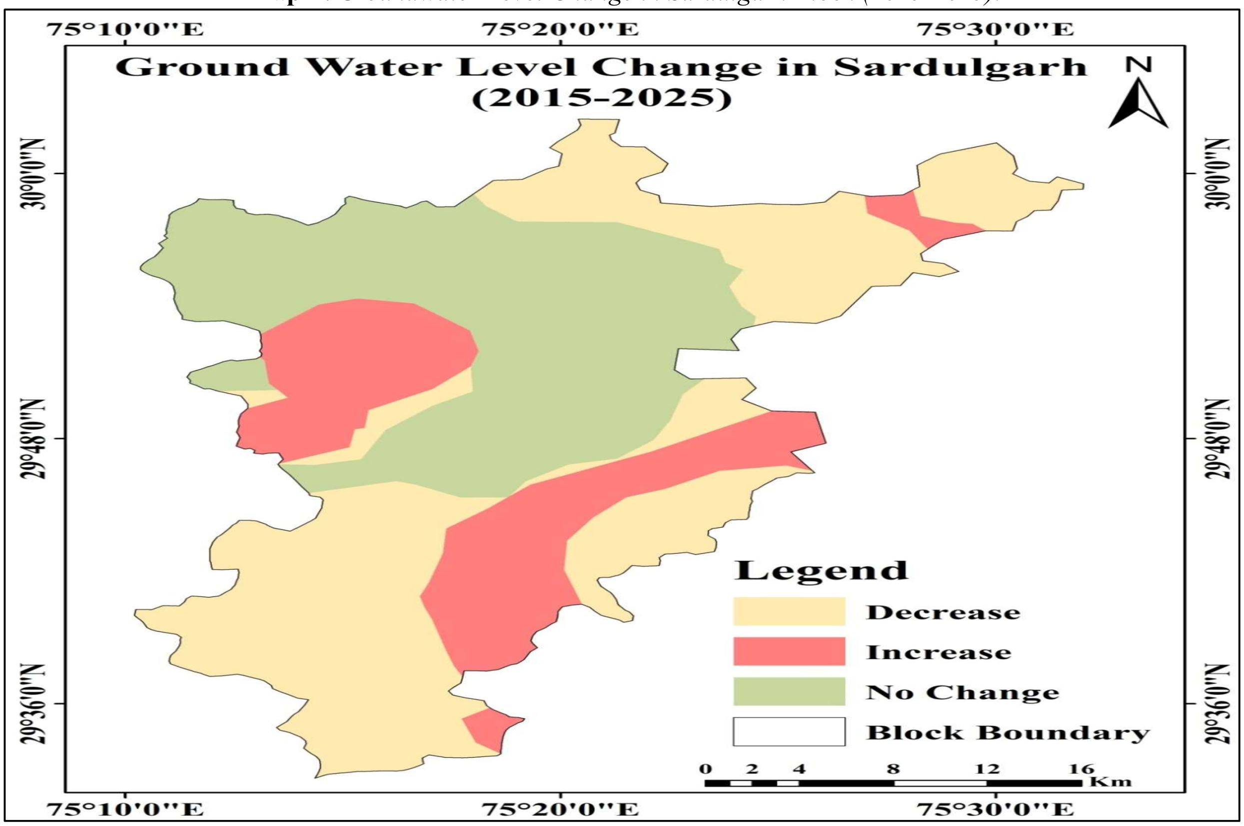
More importantly, the emergence of deeper groundwater classes such as 15–20 m and 20–25 m in certain areas indicates increasing groundwater stress and lowering water tables. These deeper zones are mainly observed in localized pockets, suggesting excessive groundwater extraction.

Groundwater Level Change (2015–2025)

The comparative analysis of both maps reveals a clear trend of groundwater depletion between 2015 and 2023. The expansion of deeper groundwater depth categories indicates increased dependence on groundwater for irrigation, particularly due to water-intensive paddy cultivation. This changing groundwater pattern highlights the growing pressure on water resources and emphasizes the need for sustainable groundwater management practices in Sardulgarh Block.

Map 4 shows the spatial variation in groundwater level changes over time, indicating areas of decline, rise, and stability. It reflects the combined impact of groundwater extraction, recharge, and hydrogeological conditions, and highlights an overall declining trend in the region. The maps clearly indicate a declining groundwater trend in Sardulgarh Block, highlighting increasing pressure on water resources over time.

Map-4: *Groundwater Level Change in Sardulgarh Block (2015-2025).*



Source: Prepared by the author with the help of QGis from the data Central Ground Water Board (CGWB), Government of India.

Spatial Distribution of Rice Crop:

The spatial distribution of rice crop in Sardulgarh Block shows the pattern and extent of paddy cultivation across different parts of the study area. Rice cultivation is mainly concentrated in agriculturally productive areas with suitable irrigation facilities and fertile soils. The distribution pattern varies according to land suitability, water availability, and farming practices followed in different regions of the block.

Table-4: *Temporal Change in Rice Sown Area in Sardulgarh Block (2015–2025).*

Sr. No.	Year	Rice Sown Area (ha)
1	2015	28962.84
2	2025	40233.69

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Source: Area estimation from prepared map-5 and 6 with the help of Q-Gis.

In 2015, rice cultivation is distributed over a comparatively smaller area, mainly concentrated in suitable agricultural zones. By 2025, the spatial extent of rice cultivation expands significantly, covering a larger geographical area of the block. This expansion indicates an increasing preference for paddy cultivation due to its economic returns and market demand

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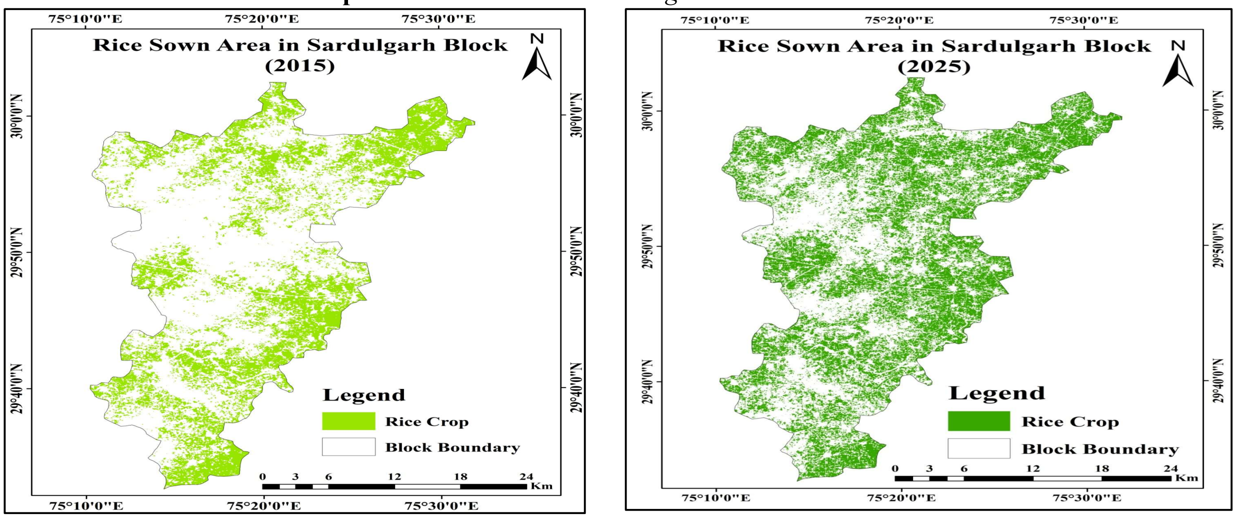
Map-5: *Rice Sown area in Sardulgarh block 2015and 2025.*



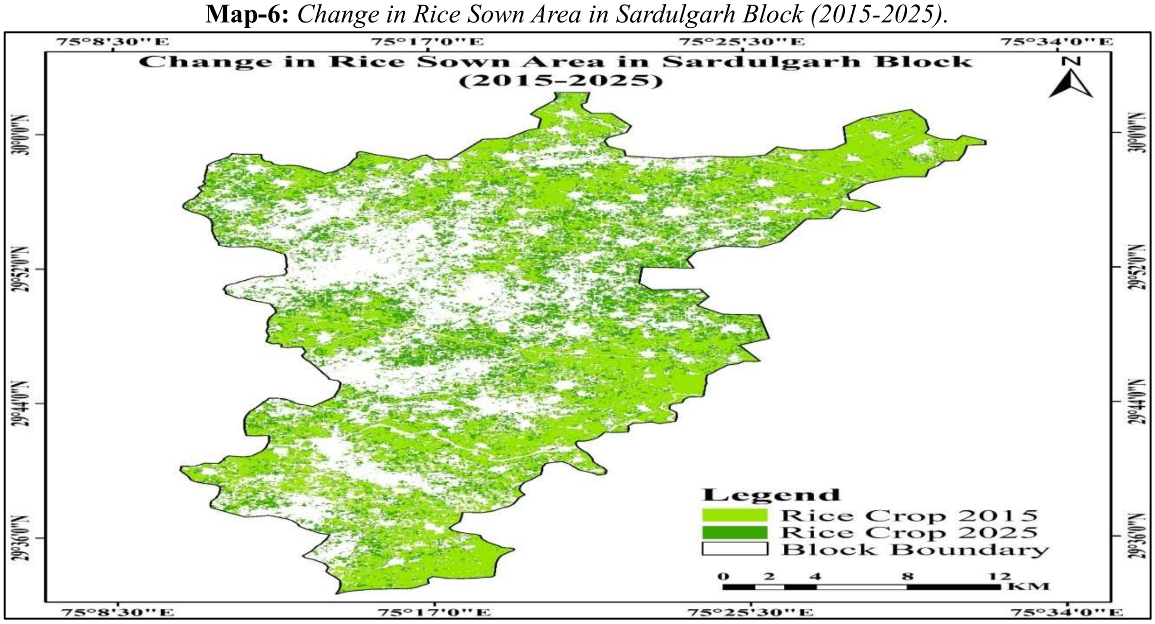
Source: Prepared by the author with the help of QGis from the data Resourcesat AWiFS data (2015) and Sentinel-2 satellite imagery (2025)

The table-4 presents the change in rice sown area in Sardulgarh Block between 2015 and 2025**.** It shows a significant increase in the area under rice cultivation during the study period. In 2015, the total rice sown area is 28,962.84 hectares, which increases to 40,233.69 hectares in 2025**.** This indicates an overall increase of 11,270.85 hectares in rice cultivation over ten years.

Change Analysis in Rice Crop area (2015-2025).

The map-6 illustrates the spatial distribution and temporal change in rice sown area in Sardulgarh Block between 2015 and 2025. It highlights the extent of rice cultivation and its expansion over the ten-year period. Based on the given table-4, the total rice sown area increases significantly from 28,962.84 hectares in 2015 to 40,233.69 hectares in 2025, indicating an overall increase of 11,270.85 hectares under paddy cultivation.

Map-6: *Change in Rice Sown Area in Sardulgarh Block (2015-2025).*



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Source: Prepared by the author with the help of QGis from the data Resourcesat AWiFS data (2015) and Sentinel-2 satellite imagery (2025)

Spatially, in 2015, rice cultivation is distributed in scattered and comparatively limited areas across the block. The concentration of rice fields is mainly observed in agricultural zones with favorable irrigation conditions. However, by 2025, the map shows a noticeable expansion of rice cultivation across a larger geographical area. The increase is more prominent in the northern, eastern, southern, and central parts of the block, where paddy cultivation becomes denser and more widespread.

Discussions:

The analysis of paddy expansion on topographically unsuitable land in Sardulgarh Block is carried out using Geographic Information System (GIS) techniques by integrating slope/elevation and rice sown area datasets. The study examines the relationship between the spatial expansion of rice cultivation and land suitability based on topographic conditions between 2015 and 2025. Since paddy is a water-intensive crop, its cultivation on unsuitable terrain can increase irrigation demand and put pressure on groundwater resources.

The slope/elevation analysis reveals that Sardulgarh Block consists of different elevation classes ranging from 186–210 m to 218–260 m above sea level**.** The 210–214 m elevation class occupies the largest geographical area and is generally more suitable for agriculture due to relatively favorable terrain conditions. However, higher elevation zones, particularly areas within the 214–218 m and 218–260 m classes, are considered comparatively less suitable for intensive paddy cultivation because of their topographic characteristics and lower groundwater recharge potential.

The spatial distribution maps of rice cultivation indicate a significant increase in rice sown area from 28,962.84 hectares in 2015 to 40,233.69 hectares in 2025, showing an expansion of 11,270.85 hectares. GIS-based overlay analysis of rice crop maps with the slope/elevation map demonstrates that paddy cultivation expands not only in suitable agricultural zones but also into moderately and highly elevated areas that are topographically less suitable. The expansion is particularly visible in northern, eastern, and some central parts of the block where rice cultivation spreads into higher elevation classes.

Therefore, GIS-based analysis highlights a clear spatial relationship between paddy expansion and topographic suitability in Sardulgarh Block. The findings indicate that the rapid increase in paddy cultivation on unsuitable land may intensify groundwater stress and reduce long-term agricultural sustainability. This emphasizes the need for crop diversification, efficient irrigation practices, and sustainable land-use planning to reduce environmental pressure and conserve groundwater resources.

Conclusion:

The present study examines the spatio-temporal relationship between groundwater depletion and rice cultivation on topographically unsuitable land in Sardulgarh Block, Mansa, using GIS and Remote Sensing techniques. The findings reveal a substantial increase in rice cultivation between 2015 and 2025, where the rice sown area increases from 28,962.84 hectares to 40,233.69 hectares**,** indicating a rapid expansion of paddy cultivation in the block. The spatial distribution maps further show that rice cultivation spreads extensively into new agricultural areas over time.

The topographic analysis based on DEM and slope/elevation data indicates that Sardulgarh Block is characterized by varying elevation classes ranging from 186–210 m to 218–260 m above sea level. GIS overlay analysis demonstrates that paddy cultivation is not only confined to suitable agricultural land but also expands into moderately and highly elevated areas that are comparatively unsuitable for water-intensive crops. The increasing cultivation of rice on such land raises concerns regarding land suitability and sustainable agricultural practices.

The groundwater analysis between 2015 and 2023 reveals a declining trend in groundwater availability. The reduction in shallow groundwater zones and the emergence of deeper groundwater categories such as 15–20 m and 20–25 m indicate increasing groundwater stress in the region. The study suggests that the expansion of paddy cultivation, particularly on unsuitable land, contributes significantly to excessive groundwater extraction due to the high water requirement of rice cultivation.

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