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Remote Sensing-Based Evaluation of Groundwater Influence on Agricultural Cropping Rotations: A case Study Bhuna Block (Fatehabad).

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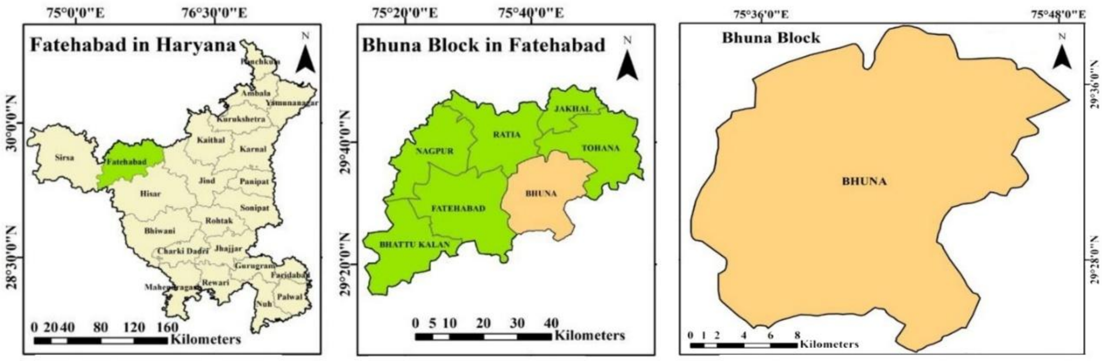
Abstract
This study explores the integration of Sentinel-2 satellite imagery with GIS-based spatial analysis to examine the relationship between groundwater depth and cropping patterns in Bhuna Block, Fatehabad District, and Haryana, India. Covering approximately 41,180 ha of alluvial terrain. Sentinel-2's Multi Spectral Instrument offers 13-band data at 10–60 m resolution with a 5-day revisit, ideal for high-resolution remote sensing applications in agriculture. The methodology involves band stacking to generate false-color composites, sub setting to the agro-delineated region, creation of an Agri-mask by digitizing and removing built-up areas, and unsupervised K-means classification to categorize land-use/land-cover. Groundwater depth was interpolated using the IDW method in ArcGIS, and ranking accuracy exceeded 80%, proven through Statistical Abstract of Haryana 2023-24 records and GPS-based field points. Assessment discloses that the Kharif season is intimidate by rice (14,225 ha) and cotton (10,907 ha), while the Rabi season is dominated by wheat (25,173 ha) and mustard (6,004 ha). A spatial overlay shows that surface groundwater areas (0–30 m) essentially support wheat–rice double-cropping, mid-depth zones (31–45 m) are suited for wheat–cotton and deeper zones (46–60 m) favor mustard–cotton rotations. Remote sensing and ground verification together disclose that differences in groundwater depth fundamentally drive the distribution and intensity of different cropping systems. The integrated approach offers a robust framework for informed crop planning and sustainable groundwater management—findings aligned with similar Sentinel-2-based agricultural studies.
Keywords: *Cropping Pattern, Groundwater Depth, Integration, Sentinel image, Union.*

I. INTRODUCTION

Studies highlight that the dominance of water-intensive rice–wheat rotations accelerate groundwater depletion in central Punjab, while adjoining districts experience rising water tables due to lateral water movement through paleo-channels (Sood et al., 2009).Remote sensing and GIS-based analyses provide critical insights into seasonal cropping patterns and crop rotation, supporting sustainable agricultural planning in Haryana, India (Bisht, Kumar, Yadav, Rawat, Sharma, & Hooda, 2014). Geospatial analysis using multi-date and multi-season IRS LISS-III satellite data with ISODATA classification and NDVI masking helps in accurate mapping of cropping systems and rotations in semi-arid areas like Sirsa district of Haryana, which helps in sustainable agricultural planning and resource management (Satyawan, Yadav, & Hooda, 2014). GIS-based spatial-temporal analysis using inverse distance weighted (IDW) interpolation has proven effective in monitoring changes in groundwater depth in Hisar district of Haryana during the period 1990–2014. This revealed distinct trends and spatial variations. The study highlights rising groundwater levels in the southern, eastern and north-eastern parts of the district, highlighting the importance of groundwater monitoring for sustainable water resource management in semi-arid areas (Rani and Chaudhary, 2016). This study effectively shows how increased irrigation and technology adoption have changed cropping patterns in Murshidabad district over a decade. It provides valuable insights into land-use transitions driven by agricultural modernization and demographic pressure (Dr. Md. Hasan Ali, 2018). Remote sensing and GIS-based spatial analysis using Sentinel-2A data effectively maps cropping patterns and crop area estimation, revealing dominant patterns such as Cotton–Wheat and Rice–Wheat in Sirsa District, Haryana, across Kharif and Rabi seasons (Kumar, Aashish, Manisha, Beniwal, & Rani, 2025). Satellite-based analysis using Sentinel-2 data combined with GIS and supervised classification effectively estimates crop area and distribution, revealing wheat as the dominant Rabi crop in Kaithal District, Haryana, and highlighting patterns of agricultural diversification (Aashish, Kumar, Devi, Bimla, & Rani, 2025). Digital image processing using Sentinel-2A satellite data combined with GIS enables accurate spatial estimation of Rabi crop areas, showing wheat as the predominant crop in Sirsa District, Haryana, and highlighting the effectiveness of remote sensing for agricultural monitoring (Kumar, Aashish, Devi, Rani, & Bimla, 2025). Remote sensing and GIS using Sentinel-2A imagery combined with supervised classification and ground truthing effectively map Rabi crop distribution in Hisar villages, showing wheat as the dominant crop and highlighting irrigation's impact on crop patterns (Manisha, Kumar, Aashish, Beniwal, & Sachin, 2025). Remote sensing and GIS technologies have been increasingly utilized to map crop rotation patterns, providing critical insights into spatial and temporal agricultural practices for sustainable resource management (Sharma & Kumar, 2025). Geospatial technologies, including remote sensing and GIS, have proven effective in analyzing cropping pattern dynamics, enabling accurate monitoring of spatial and temporal crop arrangements. Research highlights that such analyses help assess agricultural sustainability, crop diversification, and land-use efficiency in response to environmental and socio-economic factors (Rani, Kumar, & Dharamvir, 2025). Remote sensing and GIS technologies have become essential tools for flood mapping and agricultural damage assessment, allowing precise quantification of affected areas and crops. Studies indicate that integrating satellite data with GIS helps identify both natural and anthropogenic factors contributing to floods, thereby supporting effective flood management and mitigation strategies (Kuljeet, Manisha, & Ravinder, 2025).

II. STUDY AREA

Bhuna Block is an executive block that is placed in the Fatehabad district in Haryana, India. The entire topographical area of Bhuna Block is 41180 hectares. It's located between the Latitude of 29 ° 28" N to 29 ° 36" N and longitude 75 ° 36" E to 75 ° 48" E. This is positioned in Northern part of Fatehabad.



Map-1: Location Map of the study area.

The average periodic temperature in Bhuna Block is 22 degrees Celsius. Average annual rainfall is 373 mm to 395 mm. About 71 % periodic rainfalls get from South-West Monsoon. Soil type set up in Bhuna Block is alluvial soil, a direct consequence of its position within the rich Indo-Gangetic plains.

III. MATERIAL AND METHODOLOGY:

The study utilized Sentinel-2 satellite imagery (2A & 2B), which provides 10–60 m spatial resolution multispectral data captured through the MSI sensor across 13 spectral bands with a combined revisit time of 5 days, enabling detailed crop monitoring and LULC analysis due to its 290 km swath and sun-synchronous orbit at 786 km altitude. The preprocessing involved band stacking to generate False Color Composites (FCC), where near-infrared, red, and green bands were assigned to RGB to enhance vegetation detection.

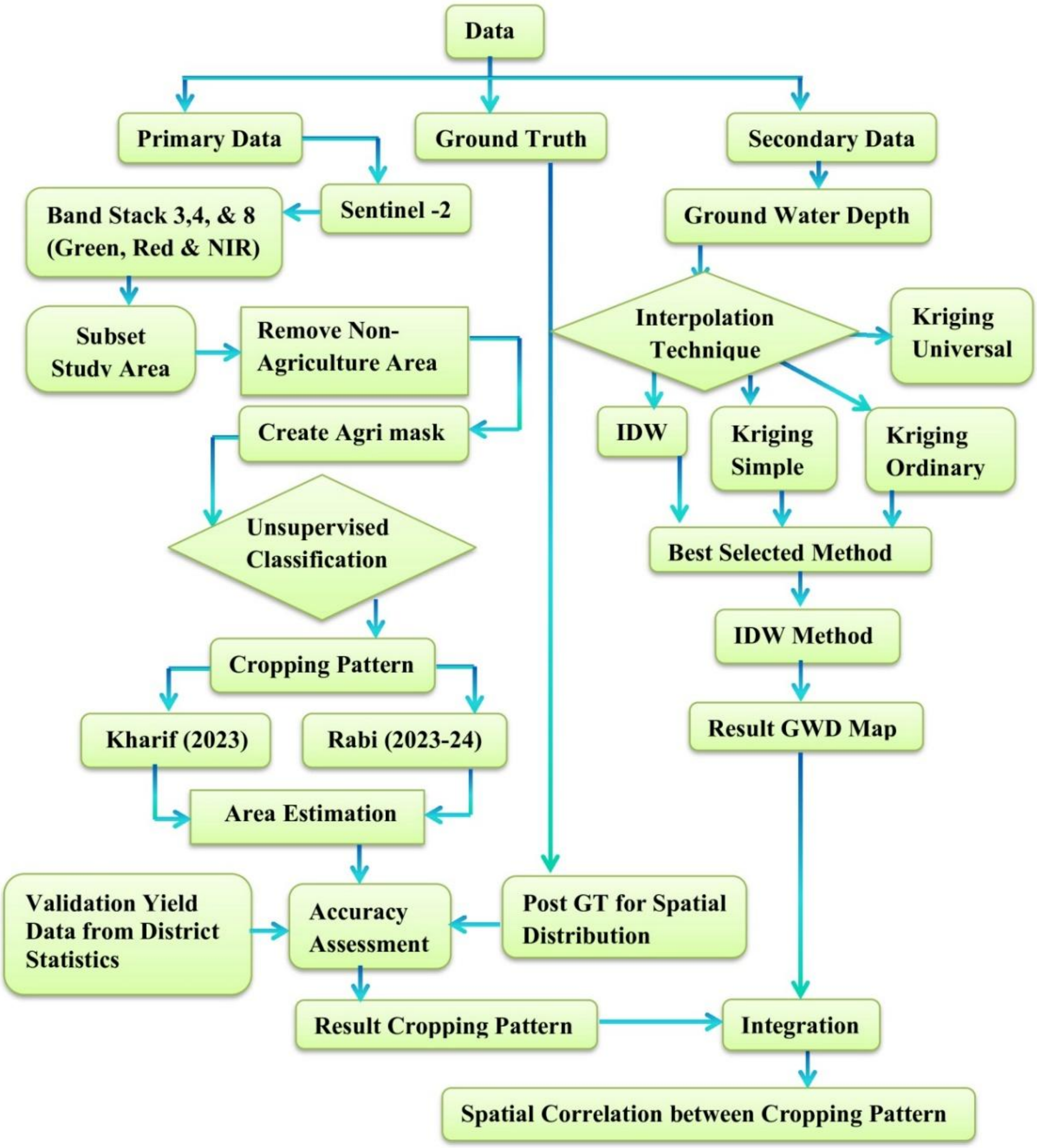


Fig-1: Flow diagram of the methodology.

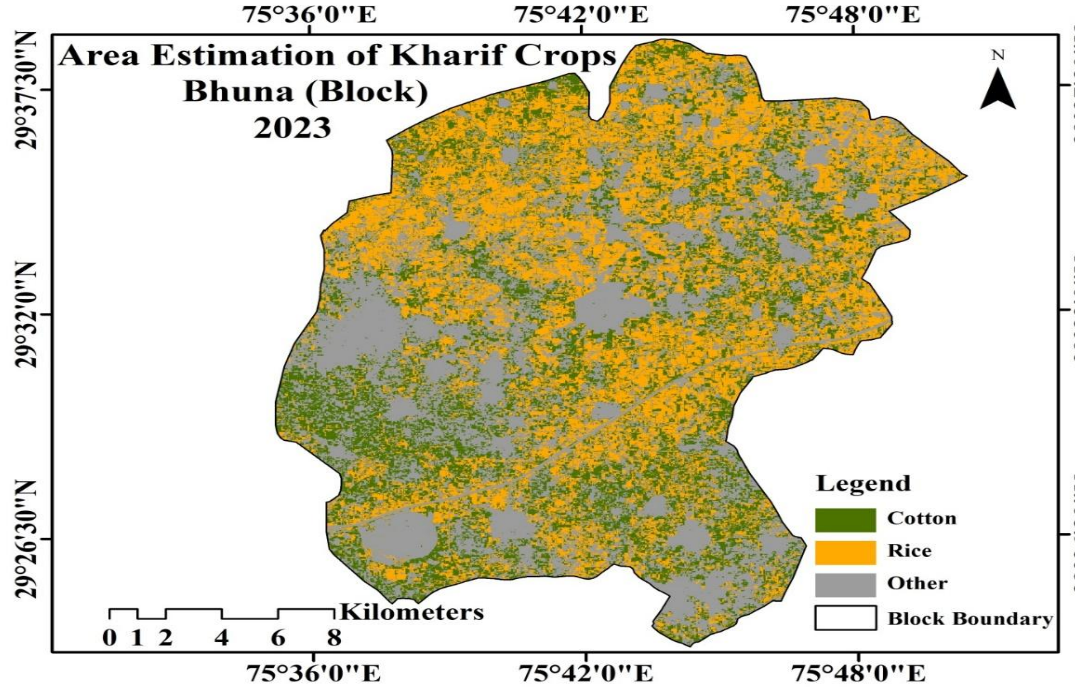
The imagery was then subsetted to extract the specific area of interest, followed by the creation of an agriculture mask by digitizing built-up areas and removing non-agricultural features such as settlements, ponds, and fallow land. Unsupervised classification using the K-means clustering algorithm was applied to categorize land features without training samples, suitable for rapid analysis. Accuracy assessment was performed using government land records and GPS-based ground truth data to validate the classification, achieving more than 80% accuracy. Cropping pattern analysis was conducted to understand the spatial distribution of various crops influenced by factors such as groundwater, soil, rainfall, and temperature. Groundwater depth surfaces were generated using Inverse Distance Weighting (IDW) interpolation, preferred for its lower RMSE among other methods. Finally, integration of interpolated groundwater depth with classified cropping patterns was carried out to examine their relationships and identify mismatches, such as water-scarce areas where water-intensive crops like rice are cultivated.

IV. RESULT AND DISICUSSION:

The analysis of Sentinel-2 imagery clearly revealed the spatial distribution of major land-use/land-cover classes across the study area, highlighting distinct patterns in vegetation, water bodies, and built-up surfaces.

Cropping Pattern of Bhuna Block:

Cropping Pattern refers to the proportion, arrangement, and sequence of different crops grown by farmers in a particular area during a specific agricultural year. It basically shows which crops are grown, how much area each crop occupies, and how crops are rotated over time.



Map-2: Area Estimation Map of Kharif Crops of Bhuna Block.

Spatial Distribution of Kharif Crops in Bhuna Block:

Map-2 shows the estimated area of Kharif season crops of Bhuna block. In which mainly two crops cotton (dark green) and rice (golden) are shown and other/non-agricultural (sky blue) area is shown. In this, cotton cultivation is mainly seen in the western and southern parts of the block and rice cultivation is mainly seen in the northern and eastern parts of the block.

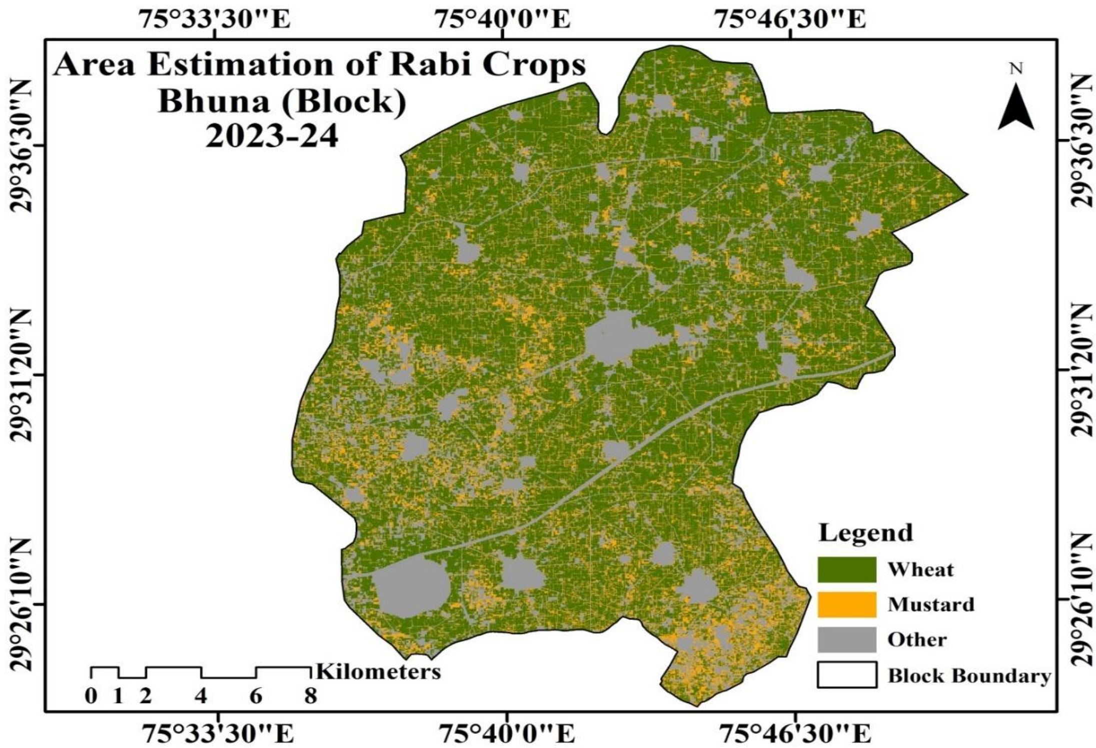
Table-1: Estimated Area of Kharif Crops 2023 of Bhuna Block.

Crop area Estimation of Bhuna Block 2023(Kharif season)			
Sr. No.	Crop Name	Area in hac.	Area in %
1	Cotton	10907.6	26.5
2	Rice	14225.4	34.5
3	Other	16047.7	39.0
Total		**41180.7**	**100**

Table 1 highlights the Kharif season crop area estimate for Bhuna block. In this table, crops are divided into three categories. The initial class is Cotton (10907.6 ha), second is Rice (14225.4 ha) and tertiary, whose area is 16047.7 ha. Properly. These data represent the Rice as the largest crop of Bhuna block.

Spatial Distribution of Rabi Crops in Bhuna Block:

Similarly, map-3 shows the estimated area of Rabi season crops of Bhuna block. In which mainly two crops wheat (dark green) and mustard (golden) are shown and other/non-agricultural (black) area is shown. In this, mustard cultivation is mainly seen in some part of western and southern parts of the block and wheat cultivation is mainly seen in the central, northern and eastern parts of the block.



Map-3: Area Estimation Map of Rabi Crops of Bhuna Block.

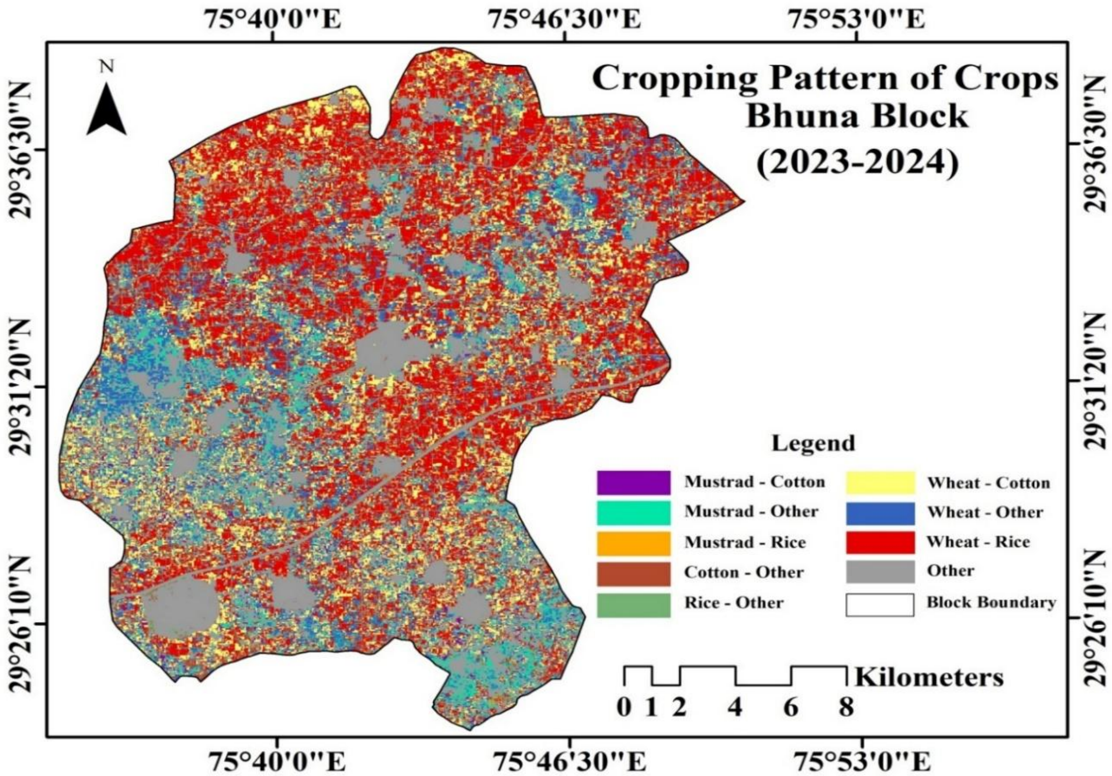
Table 2 highlights the Rabi season crop area estimate for Bhuna block. Crops are divided into three categories. The top-notch is Wheat (25173 ha), minor is Mustard (6003.9 ha) and third is Other, whose area is, 10003.8 ha correspondingly. The total area is 41180.7 ha. These data represent the Wheat as the largest crop of Bhuna block.

Table-2: Estimated Area of Rabi Crops 2023-24 of Bhuna Block

Crop area Estimation of Bhuna Block 2023-24(Rabi season)			
Sr. No.	Crop Name	Area in hac.	Area in %
1	Wheat	25173	61.1
2	Mustard	6003.9	14.6
3	Other	10003.8	24.3
Total		**41180.7**	**100**

Cropping Rotation of Bhuna Block:

Crop Rotation is the scientific practice of growing different crops in a planned sequence on the same field over different seasons or years**.** Crop Rotation is the systematic changing of crops on the same piece of land season after season to keep the soil healthy and productive.



Map-4: Area Estimation Map of Cropping Pattern of Kharif & Rabi Crops of Bhuna Block

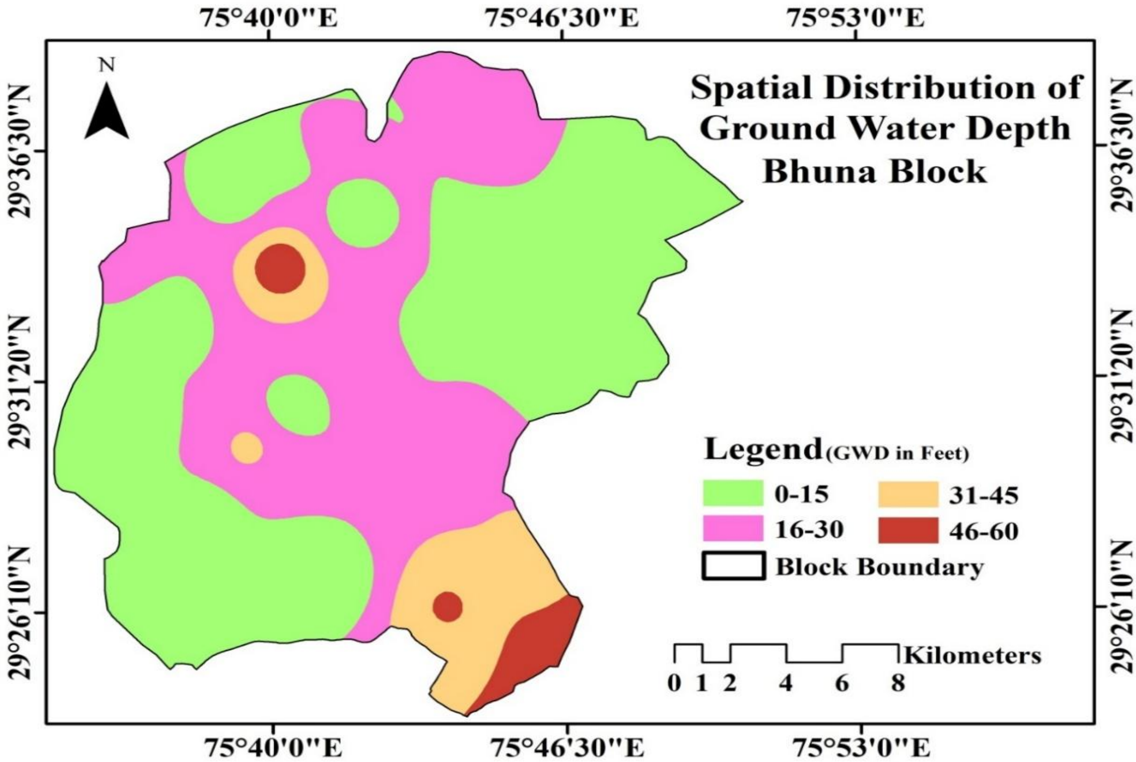
Map-4 highlights Bhuna block cropping pattern of Kharif & Rabi, showing mix wheat and rice(red) as the dominant crop, followed by wheat and cotton(yellow), mustard & cotton(purple), while mustard & rice (Sky blue) is cultivated in limited areas. The central, northern and eastern region favors wheat and rice and western and southern region favors wheat and cotton. The map clearly shows the spatial distribution of cropping pattern of all major crops.

Table-3: Cropping Pattern of Kharif & Rabi Crops 2023_24 of Bhuna Block.

Cropping Pattern of Bhuna Block (2023-2024)			
Sr. No.	Cropping Pattern	Area in hac.	Area in %
1	Wheat and Cotton	7691.5	18.7
2	Wheat and Rice	12560.5	30.5
3	Wheat and Other	4930.1	12
4	Mustard and Cotton	1886.7	4.6
5	Mustard and Rice	952.9	2.3
6	Mustard and Other	3163.4	7.7
7	Other and Cotton	1337.4	3.2
8	Other and Rice	703.8	1.7
9	Other and Other	7954.4	19.3
Total		**41180.7**	**100**

Table-3 highlights the Cropping Pattern of Karif & Rabi season crops of Bhuna block. Set out in the table, crops are split into diverse with different cropping pattern. The major category of cropping pattern is Wheat & Rice (12560.5 ha), second is Wheat & Cotton (7691.5 ha.) and third is Mustard & Cotton (1886.7 ha), similarly, next is Other whose area is (7954.4 ha.) respectively. These data represent the Wheat & Rice is the common cropping pattern of Bhuna block.

Ground Water Depth of Bhuna Block:
Spatial Distribution of Groundwater Depth refers to the variation in groundwater levels across different geographical locations within a study area. It shows how deep or shallow the water table is at different places**,** usually mapped using GIS, interpolation techniques, or well-data.



Map-5: Spatial Distribution of Ground Water Depth (feet) of Bhuna Block.

Map-5 shows the spatial distribution of groundwater depth in feet of Bhuna block the first category is divided into 0-15(green), the second category is divided into16-30(pink), the third category is divided into 31-45(mango) and the fourth category is divided into 46-60(red). In which we have presented different classes with different colors. We have presented the root mean square error (RMSE) of groundwater with the IDW method whose value is 20.86.

Table-4: Spatial Distribution of GWD (feet) of Bhuna Block

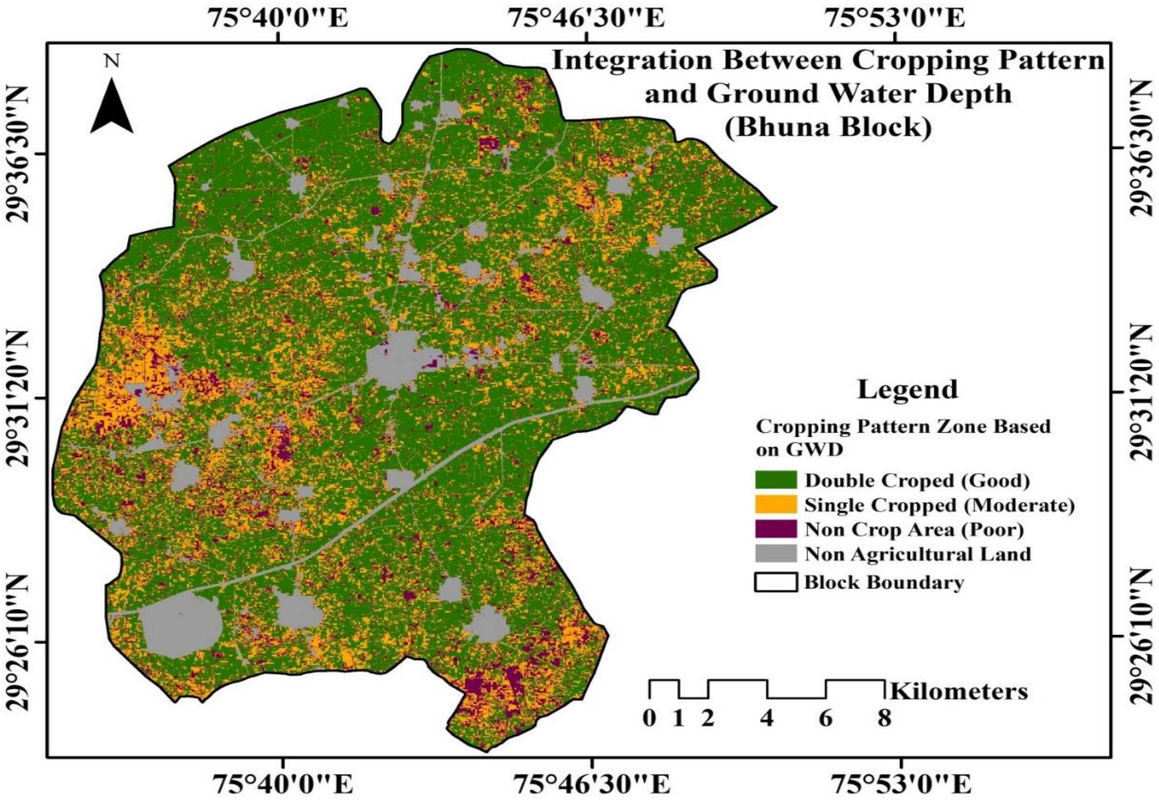
Ground Water Depth (Feet)			
Sr. No.	Classes	Area in hac.	Area in %
1	0-15	20893.2	50.7
2	16-30	15474.8	37.6
3	31-45	3638.2	8.8
4	46-60	1174.5	2.9
Total		41180.7	100

According to Table 4, we have divided the groundwater depth into four intervals. The first-class interval is between 0 to 15 which has an area of 20893.2 hectares, the second is between 16 to 30 which has an area of 15474.8 hectares, the third interval is between 31 to 45 which has an area of 3638.2 hectares, similarly the fourth interval is between 46 to 60 which covers 1174.4 hectares of the total block extent. The total area is 41180.6 hectares of the Bhuna block.

Evaluation of Groundwater Influence on Cropping Pattern:

Evaluation of groundwater influence on agriculture refers to the systematic assessment of how groundwater availability, depth, and quality affect agricultural practices, cropping patterns, crop productivity, and land-use decisions in a region.

The map-6 shows the spatial correlation between the cropping pattern and groundwater depth of the Bhuna block. In this map, the double-cropped pattern represents the good quality groundwater depth in dark green color.



Map-6: Spatial Correlation Map between Cropping Pattern of GWD of Bhuna Block.

Similarly, a single cropped pattern shows a moderate quality of GWD in golden color, and the non-cropped area represents poor quality in purple color. The majority of double cropping is in the northern, central, and eastern regions, while the western region shows the single-cropped area.

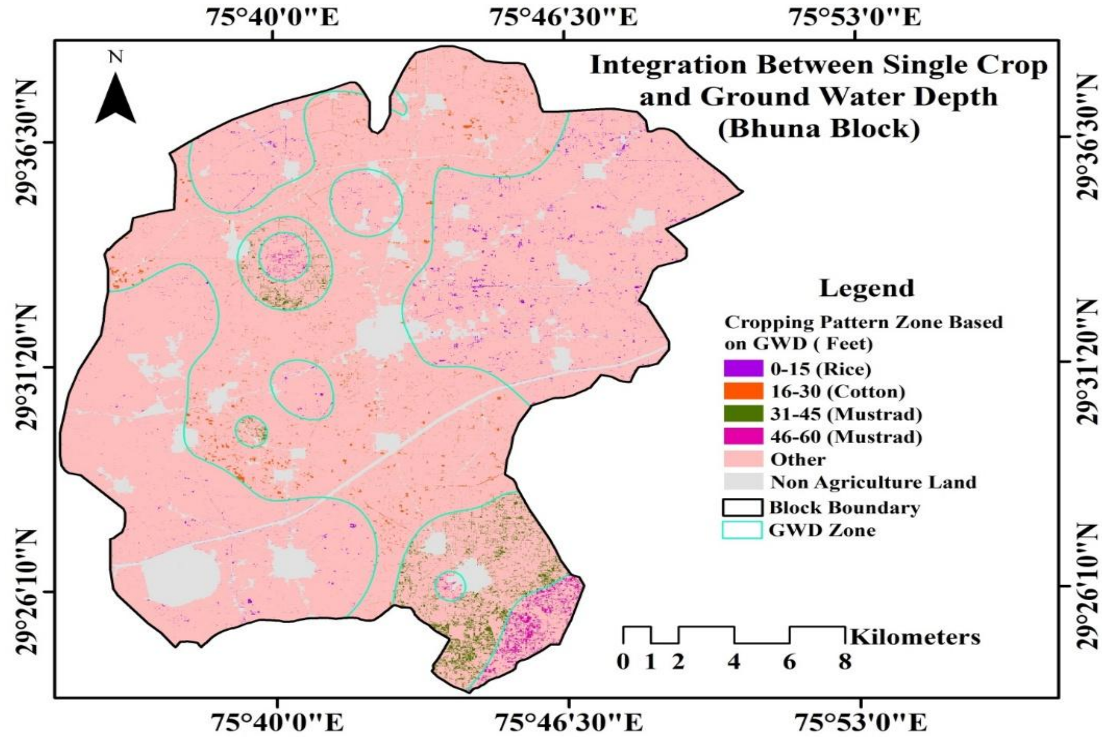
Table-5: Spatial Correlation between Cropping Pattern & GWD of Bhuna Block

Integration Between Cropping Pattern & GWD			
Sr. No.	Crops	Area in hac.	Area in %
1	Double Cropped (Good)	23073.7	56
2	Single Cropped (Moderate)	9887.7	24
3	Non-Crop Area (Poor)	4477.6	10.9
4	Non-Agricultural Land	3741.8	9.1
	Total	**41180.7**	**100**

Through this table-5, spatial correlation is shown between cropping pattern and ground water depth. According to this table, 56% of total study area falls under double crop pattern, which falls under good quality of groundwater depth. Whereas 24%-part falls under single crop pattern, which falls under moderate category and 10.9%-part falls under non crop area, which falls under poor quality of ground water depth.

Evaluation of Groundwater Influence on Single Crop:

Evaluating groundwater influence on a single crop means assessing how the depth, availability, and seasonal variation of groundwater directly affect the cultivation, growth, and spatial distribution of one particular crop—such as wheat, cotton, mustard and paddy within the study area.



Map-7: Integration between single crop and ground water depth of Bhuna block.

This map-7 shows us what kinds of crops grow best in different parts of the Bhuna Block based on how deep the groundwater is. If the groundwater is very close to the surface (0-15 units deep), it's a good spot for growing rice (golden). If the groundwater is a bit deeper (16-30 units), cotton (green) thrives there. For areas where the groundwater is even deeper (31-60 units), mustard (purple & yellow) is the best crop to grow. Besides farming areas, the map also shows non agriculture area (red). The majority of mustard crop is in the southern part of the area of specialization and rice is scattered in the entire study region.

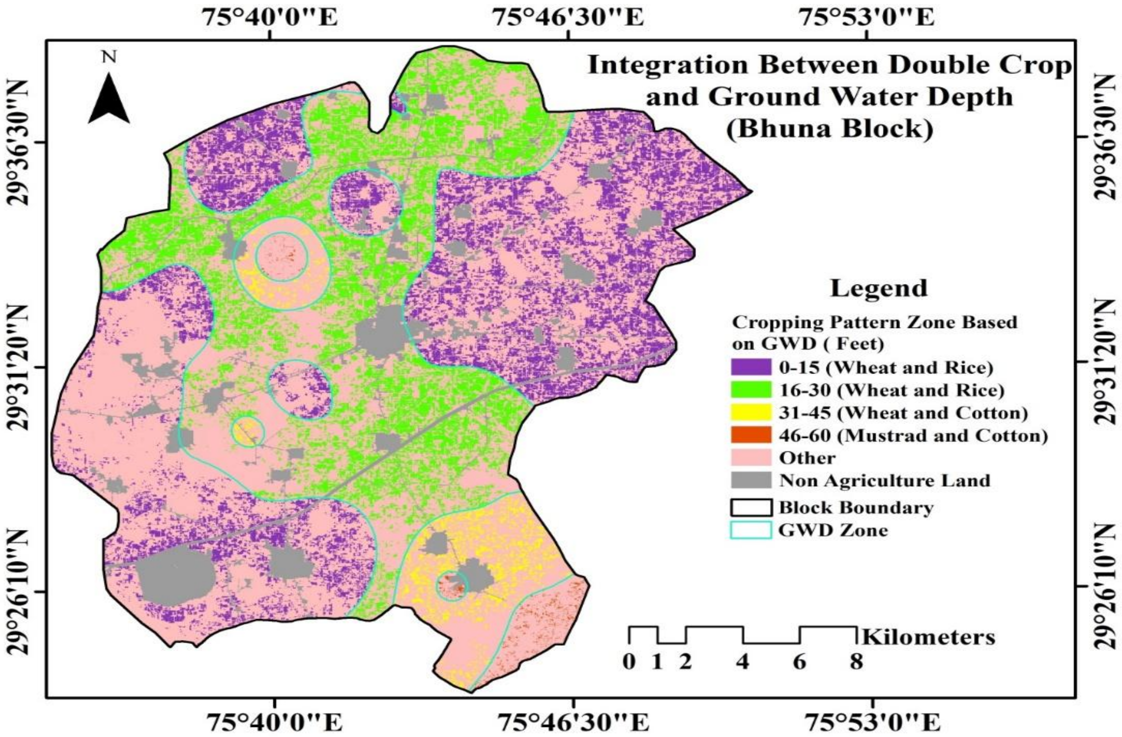
Table- 6: Spatial Correlation between Single Crops & GWD of Bhuna Block

Integration Between Single Crops & GWD			
Sr. No.	Crops	Area in hac.	Area in %
1	0-15 (Rice)	278.3	0.7
2	16-30 (Cotton)	352.4	0.9
3	31-45 (Mustard)	453.4	1.1
4	46-60 (Mustard)	191.2	0.4
5	Non-Agriculture Land	3741.8	9.1
6	Other	36163.5	87.8
Total		41180.7	100

Above table-6 shows us what kinds of crops grow best in different parts of the Bhuna Block based on how deep the groundwater is. If the groundwater is very close to the surface (0-15 units deep), it's a good spot for growing rice with 278.3 ha. If the groundwater is a bit deeper (16-30 units), cotton thrives there with 352.4 ha.. For areas where the groundwater is even deeper (31-45 and 46-60 units), mustard is the best crop to grow with 453.4 & 191.2 ha. Of total area. On the other hand, Non-Agriculture Land cover the 3741.8 ha.

Evaluation of Groundwater Influence on Double Crops:

Evaluation of groundwater influence on double crops refers to assessing how groundwater depth, availability, and seasonal variation affect a two-crop sequence grown on the same field within one agricultural year (for example: Wheat–Cotton, Wheat–Rice, Mustard–Bajra, Cotton–Mustard, etc.).



Map-8: Spatial Correlation Map between Double Crops of GWD of Bhuna Block.

Above map-8 help us understand which two crops grow best together in different parts of the Bhuna Block, depending on how deep the groundwater is. If the groundwater is shallow (0-15 & 16-30 units deep), farmers can successfully grow both wheat and rice(purple & dark green) in the same year . If the groundwater is a bit deeper (31-45 units) wheat and cotton (golden) make a good pair. And in areas with even deeper groundwater (46-60 units), mustard and cotton(dark pink) are the suitable double. The map also shows areas that aren't used for farming, as non agriculture land (red). In this, wheat & rice cultivation is mainly seen in some part of northern, central and eastern parts of the block and wheat & cotton cultivation is mainly seen in the southern parts of the block.

Table- 7: Spatial Correlation between Double Crops & GWD of Bhuna Block

Spatial Correlation Between Double Crops & GWD			
Sr. No.	**Crops**	**Area in hac.**	**Area in %**
1	0-15 (Wheat and Rice)	5898.5	14.3
2	16-30 (Wheat and Rice)	5745.7	14
3	31-45 (Wheat and Cotton)	706.6	1.7
4	46-60 (Mustard and Cotton)	91.3	0.2
5	Non-Agriculture Land	3741.8	9.1
6	Other	24996.8	60.7
Total		**41180.7**	**100**

Above table-7 highlights the spatial correlation between double crops and groundwater depth of the Bhuna Block. It helps us understand which two crops grow best together in different parts of the Bhuna Block, depending on how deep the groundwater is. If the groundwater is shallow (0-15 & 16-30 units deep), farmers can successfully grow both wheat and rice in the same year with 5898.5 & 5745.7 ha, of the total area . If the groundwater is a bit deeper (31-45 units) with 706.6 ha area of wheat and cotton make a good pair. And in areas with even deeper groundwater (46-60 units), mustard and cotton are the suitable double crops with total 91.3 ha. Of the total area of specialization. The map also shows areas that aren't used for farming, as non agriculture land with 24996.8 ha.

V. CONCLUSION:

Using high-resolution Sentinel-2 imagery (10–60 m, 5-day revisit) along with techniques like band stacking, false-color composites, unsupervised K-means classification, and IDW interpolation, this study effectively mapped groundwater depth and cropping patterns across Bhuna Block (~41,180 ha). An accuracy assessment using the Statistical Abstract of Haryana 2023-24 records and GPS-based field data confirmed >80% credibility. Results show a dominant wheat–rice double-cropping system supported by shallow groundwater (0–30 m), while mid-depth zones favor cotton and deeper zones are best suited to mustard. This integrated remote-sensing and ground-truth approach thus provides strong insights for optimized crop planning and sustainable groundwater management in Bhuna Block.

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