



Spatio-Temporal Transformation of Cropping Patterns in the Western Haryana Plains, India: A Five-Decade Analysis (1974-2022)

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Abstract: The increase in crop productivity resulting from the Green Revolution has had both positive and negative consequences for the natural environment, particularly with respect to water resources. Changes in cropping patterns have also increased the environmental risks associated with agricultural activities. The present study examines the long-term spatio-temporal changes in cropping patterns in the Western Haryana Plains of northern India during 1974 to 2022, with special emphasis on the expansion of wheat and paddy cultivation using geospatial data. Satellite data were used to analyse two major crops, wheat and paddy, grown during the rabi and kharif seasons, respectively. The expansion of irrigation facilities in the Western Haryana Plains has resulted in significant changes in crop distribution. The area under paddy increased from 0.74% in 1974 to 21.4% in 2022, while the area under wheat expanded from 9.5% to 55.1% of the total cultivable land during the same period. These changes in cropping patterns are largely attributable to improved irrigation infrastructure, which has facilitated the adoption of modern agricultural technologies. Furthermore, government policies introduced following the Green Revolution, aimed at achieving food security, have particularly promoted the cultivation of paddy and wheat. Consequently, large areas of land have been brought under the rice-wheat cropping system.

Key words: Cropping pattern, paddy, wheat, western Haryana plains, geospatial data.

Throughout the history, agricultural revolutions have brought significant advancements in plant domestication, land redistribution, and agricultural production. India's cropping patterns have expanded over the past two decades, with food grains such as paddy, wheat, mustard, and cotton emerging as the main crops. The Green Revolution in India has led to increased crop specialization and soil fertility changes. It has resulted

in major transformations in cropping patterns, food production, living conditions, economic growth, and national self-sufficiency. The shift in cropping patterns and agricultural output-driven by the introduction of high-yielding variety (HYV) seeds, chemical fertilizers, improved irrigation, and mechanization has paved the way for double cropping and expanded employment opportunities. Tube wells and improved irrigation systems have reshaped cropping patterns by promoting investment in high-yielding wheat and paddy, leading to increased yields and crop production while simultaneously accelerating groundwater depletion (Garg and Ali, 1998; Hassan and Inderjeet, 2000; Ghosh, 2011). Farmers have shifted to rotating wheat and paddy to maximize yields. Groundwater dependency has expanded due to farmers planting paddy crops well in advance of the rainy season. However, the rapid growth of paddy-wheat farming areas has led to overexploitation of shallow aquifers, affecting the overall agricultural landscape in Haryana (Singh *et al.*, 2010; Rawat and Bala, 2021, Rajput *et al.*, 2024).

Remote sensing with advancements in GPS and GIS is making easier to identify cropped areas over multiple time periods and are providing precision data on crop changes (Doraiswamy *et al.*, 2003; Casa *et al.*, 2009; Duro *et al.*, 2012; Li *et al.*, 2015; Khan *et al.*, 2016; Viskovic *et al.*, 2019). The investigation of classifying crops through mapping technology holds considerable importance in directing the cultivation of crops, devising policies for agriculture, and achieving sustainability in agriculture (Thenkabail, 2010; Atzberger, 2013, Taha *et al.*, 2025). Verma *et al.* (2011) used remote sensing and GIS technology to study wheat crop distribution in Karnal district of Haryana, revealing wheat crop dominance during the rabi season. Advancements in

remote sensing methods have made it possible to collect information on crop pattern changes (Sushma *et al.*, 2019; Arias *et al.*, 2020). Spectral signature of particular crop is a good way to classify and is often used for the selective crop demarcation (Nuarsa *et al.*, 2011; Latif *et al.*, 2019).

The study of crop diversification trends in the Haryana plains becomes more essential as more than 80% of the overall population is actively or indirectly involved in agriculture. Thus, the purpose of the study is to identify regional differences in diversification in the existing cropping patterns. The current work attempts to examine spatiotemporal variability in cropping patterns in Western Haryana Plains during the period 1974 to 2022 using multi-temporal satellite images combined with GIS tools. Spectral signature analysis is used in crop classification to identify key crops, especially the predominant paddy and wheat. Remote sensing-based mapping is used to assess changes in crops over time, as well as to investigate the relationship between irrigation expansion and adjustments in cropping patterns.

Materials and Methods

Study area

The study area, the Western Haryana Plains (WHP), lies between 28°22' N to 29°59' N latitudes and 74°27' E to 76°28' E longitudes, covering an area of approximately 15,646 km² with an average elevation of 232 m above mean sea level (amsl) (Fig. 1). The region is bounded by the sand dunes of the Thar Desert of Rajasthan in the west, Punjab in the north, and the remaining parts of Haryana in the south and east. Administratively, the WHP comprises 31 blocks distributed across four districts – Bhiwani, Hisar, Fatehabad, and Sirsa (Table 1). The Western Haryana Plains (WHP) constitute a major physiographic division of

Table 1. Different blocks of districts situated in Western Haryana Plains

Name of district	Name of block	No. of blocks	No. of villages
Bhiwani	Badhra, Bawani Khera, Bhiwani, Dadri-I, Dadri-II, Loharu, Kairu, Siwani, Tosham	09	436
Hisar	Adampur, Agroha, Barwala, Hansi-I, Hansi-II, Hisar-I, Hisar-II, Narnaund, Uklana	09	257
Fatehabad	Bhattu Kalan, Bhuna, Fatehabad, Jakhal, Ratia, Tohana	06	226
Sirsa	Baragudha, Dabwali, Ellenabad, Nathusari Chopta, Odhan, Rania, Sirsa	07	322

(Source: Director of Land Records; Panchkula, Haryana, <https://revenueharyana.gov.in>)

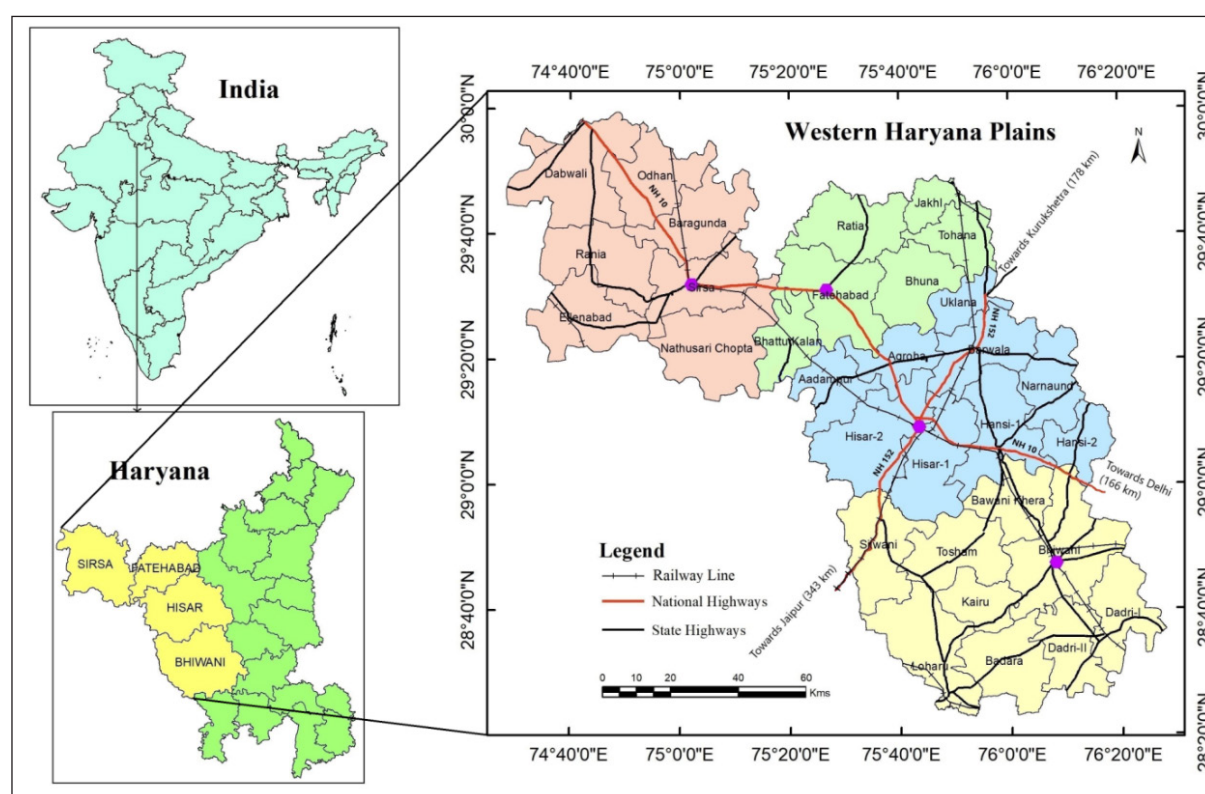


Fig. 1. Location map of the study area - the Western Haryana Plains.

Haryana and form part of the Indo-Gangetic alluvial plains. The area is frequently regarded as an agro-ecological and hydrological unit in regional planning and environmental studies due to its semi-arid climate, low relief, and extensive agricultural activity.

The region supports a population of nearly 5.6 m, with a population density of about 381 persons km⁻². Based on the occupational structure, agriculture remains the dominant economic activity, employing more than 60% of the total workforce (Table 2).

Table 2. Demographic characteristics of Western Haryana Plains

Details	WHP
Population (million)	5.6
Growth rate (Per decade)	15.5
Population density (person/sq. km)	381
Literacy rate (%)	71.2
Total Workers (lakh)	5.15
Cultivators	38.2
Agricultural laborers	23.4
Household/industry workers	2.2

(Source: District Census Handbook, 2011, <https://censusindia.gov.in/nada/index.php>)

The WHP experiences a semi-arid, tropical steppe-type climate, characterized by hot summers and cold winters. Annual rainfall varies from 318 mm in Sirsa to 420 mm in Bhiwani, with the south-west monsoon accounting for approximately 80% of the total precipitation. Temperatures range from 5°C in winter to 43°C in summer, with a mean annual temperature of about 26.5°C. The physiography of the region is dominated by aeolian sediments, loess, and sand dunes, which are primarily formed by wind action. These aeolian deposits, such as sands and dunes, have the potential to form excellent reservoirs; however, they are generally located above the regional groundwater table. The soils of the WHP consist mainly of coarse loam, sandy loam, loamy sand, and sandy textures. Irrigation in the region is primarily supported by a canal network fed by the Yamuna, Ghaggar, and Sutlej Rivers. Except for the seasonal runoff originating from the Aravalli relics, no perennial or seasonal rivers occur in the southern part of the study area. The region exhibits only limited natural drainage in the form of ephemeral inland channels, most of which dry up during the summer months. The absence of perennial drainage and natural

Table 3. Number of samples determined for rice and wheat crops for different years

Year	Crop	Training samples		Validation samples		Accuracy (%)
		No. of polygons	No. of pixels	No. of polygons	No. of pixels	
1974	Rice	3	50	3	45	90
	Wheat	45	2859	45	2608	91
1988	Rice	8	187	8	174	93
	Wheat	52	3578	52	3174	88
1998	Rice	15	2067	15	1877	90
	Wheat	60	3988	60	3578	89
2008	Rice	19	2569	19	2363	91
	Wheat	62	4016	60	3801	94
2022	Rice	24	3195	24	2923	91
	Wheat	65	4189	65	3899	93

water bodies highlights the predominantly arid conditions of the Western Haryana Plains.

The cropping patterns in the WHP during the rabi and kharif seasons were studied individually for wheat and paddy crops. The distribution of agricultural field sizes is an important factor that determines crop pattern accuracy. Landsat-2 MSS (1974), Landsat-5 TM (1988 and 1998), Landsat-7 ETM⁺ (2008) and IRS-P6 LISS IV (2022) data were utilized in identification of different crops. The methodology developed by Mahalanobis National Crop Forecast Centre of Dept. of Agricultural University, Haryana was used to demarcate wheat and paddy crops during rabi and kharif seasons, respectively (Kumar and Kumar, 2019). Landsat data was downloaded from the USGS Earth Explorer portal, while IRS data were obtained from Haryana Space Application Center (HARSAC), Hisar. All satellite images were georeferenced to a common map projection, namely the UTM WGS-84, Zone 43°N. The images were subset to cover only the study area. Temporal satellite images with less than 10% cloud cover, acquired between 1974 and 2022, were selected for analysis. Only the visible and near-infrared (NIR) bands were used in the study. Radiometric and atmospheric corrections were performed using standard digital image processing software. Landsat sensors provide a spatial resolution of 30 m, whereas the LISS-IV sensor has a spatial resolution of 5.8 m. To ensure uniformity, the Landsat imagery was resampled to match the spatial resolution of LISS-IV. The 30 m Landsat bands were sharpened to the 5.8 m LISS-IV pixel grid using the nearest-neighbour resampling technique, wherein neighbouring pixels with comparable

spectral information were used to derive appropriate spectral values (Gao *et al.*, 2006). Initially, a non-agricultural mask was applied to the study region. This mask included persistent water bodies, scrub vegetation, built-up areas, and wastelands, which were easily separable due to their distinct spectral signatures relative to agricultural land. Subsequently, all images were subjected to supervised classification. Training samples for wheat and paddy crops were selected carefully to maintain spatial and spectral uniformity. A supervised Maximum Likelihood Classification (MLC) technique was employed to delineate wheat and paddy crop areas. To capture surface changes at a fine spatial resolution and to assess temporal variations, spectrally similar neighbouring pixels were analyzed across different time periods. Although these pixels may exhibit slight spectral variations over time, they are valuable for detecting land-surface changes. Surface reflectance thresholds were directly applied to identify spectrally comparable pixels (Tariq *et al.*, 2023). The ground truth data was acquired from different locations utilizing GPS survey. This data is then used to generate spectral signatures for classification purposes. The mean reflectance spectra of wheat and paddy crops are found to be 0.706 and 0.789 μm , respectively. The peak value for wheat is observed at 0.850 μm , while for paddy, it is observed at 0.865 μm . Both crops demonstrate significant dispersion in NIR wavelength range and assimilation of chlorophyll in red band of image. The wheat and paddy crops manifest a vivid red tone in the NIR and red spectral bands (Dadhwal, 2005; Patel *et al.*, 2006; Ahmed *et al.*, 2017; Arvind, 2020). Figure 2 illustrates the methodology adopted in the

Table 4. Area under crops grown in rabi season in the study area during 1974-2022

Crop	1974		1988		1998		2008		2022	
	Area		Area		Area		Area		Area	
	sq. km	%	sq. km	%	sq. km	%	sq. km	%	sq. km	%
Wheat	1490	9.5	4920	31.5	6280	40.2	8590	54.9	8620	55.1
Gram	7600	48.6	4140	26.5	2840	18.2	1060	6.8	330	2.1
Mustard	1980	12.7	2170	13.9	2680	17.1	2960	18.9	3520	22.5
Sugarcane	120	0.8	40	0.3	60	0.4	60	0.4	70	0.4
Other crops	770	4.9	540	3.5	410	2.6	340	2.2	260	1.7

(Source: Directorate of Agriculture, Panchkula, Haryana)

present study, from satellite image acquisition to the generation of crop distribution maps. In addition to the use of satellite imagery, validation of the classified cropland areas was conducted using ground reference and ancillary data points. The range of validation points for each temporal image chosen was 45 to 2,923 for paddy and 2,608 to 3,989 for wheat. These reference points were used to assess classification accuracy through standard accuracy assessment procedures. The resulting overall classification accuracy found to be 90%, indicating a high level of agreement between the classified outputs and the reference data. The accuracy of crop identification was carried out to validate training samples (Table 3). The details of other crops of sugarcane, mustard, bajra and cotton were collected from Haryana Statistical Department for the study period. The

statistical results of Western Haryana Plains are given in Table 4. In the study, for statistical geographic analysis, ArcGIS 10.3 software was employed, and for digital image processing and classification, ERDAS Imagine 2014 software was used.

Results and Discussion

Cropping Pattern of Rabi Crops

Wheat, gram, mustard and sugarcane are among the principal rabi crops identified in the study area of Western Haryana Plains (Table 4). In 1974, gram recorded the major rabi crop being cultivated in the region followed by mustard and wheat. The gross cropped area under gram accounted for 7600 km² covering about 49% of the total cropped area (TCA). Mustard, which was the second most cultivated

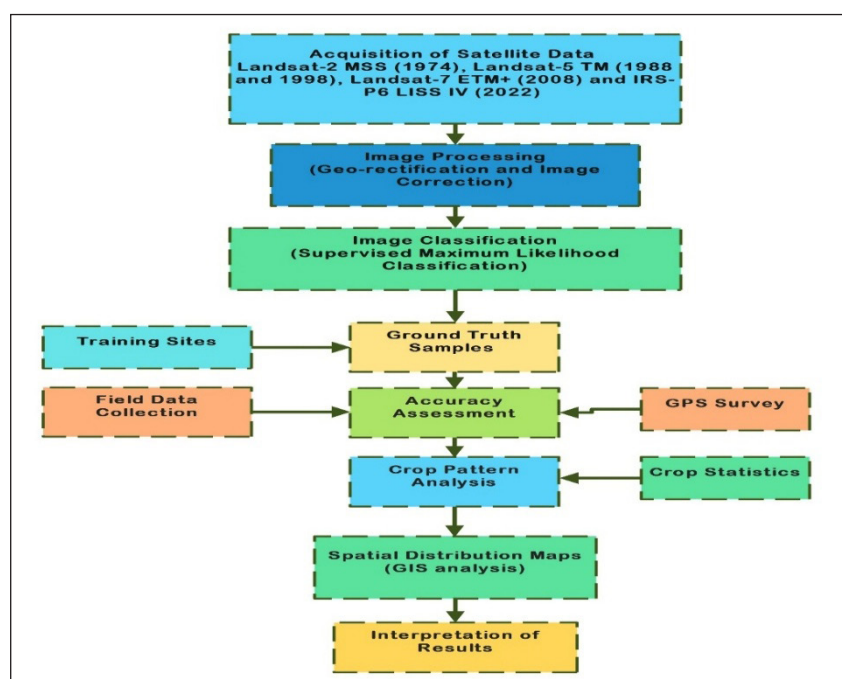


Fig. 2. Flow chart showing overall methodology.

rabi crop covered an area of 1970 km² with 13% followed by wheat (9%). Sugarcane was accounted for 120 km² whereas other crops namely barley, jowar, maize, sesame, and linseed, etc., cumulatively covered 770 km² (3%) of TCA. The availability of moisture during the winter months owing to western temperate cyclones helps these crops succeed. Irrigation technology advanced dramatically during 1974 with renewed focus on improving irrigation infrastructure (Shangari and Gupta, 1978). During 1988, wheat was being cultivated on a total area of 4920 km² (31.5%). The change in rabi crops to wheat as the primary crop grown in 1988 was noticeable. The area under wheat crop tripled between 1974 and 1988 covering 32% of TCA. This was the period following Green Revolution's second phase,

which began in the 1980s. Wheat cultivation is linked to the adoption of the Green Revolution technology and the introduction of HYV seeds and fertilizers. The substantial growth of wheat crop is clearly evident especially in northern and central parts of the study area (Fig. 3). The changes in the state cropping pattern were mostly due to increased irrigation infrastructure (Bhalla, 1989). Due to economical and assured returns than other rabi crops, wheat was gained more popularity for majority farmers. Gram covered nearly 27% which was reduced nearly half of the area cultivated in 1974. However, mustard farming noted a marginal increase than the previous decade. Similarly, an increase in sugarcane and other rabi crops were recorded in the time period. In 1998, the area under wheat cultivation

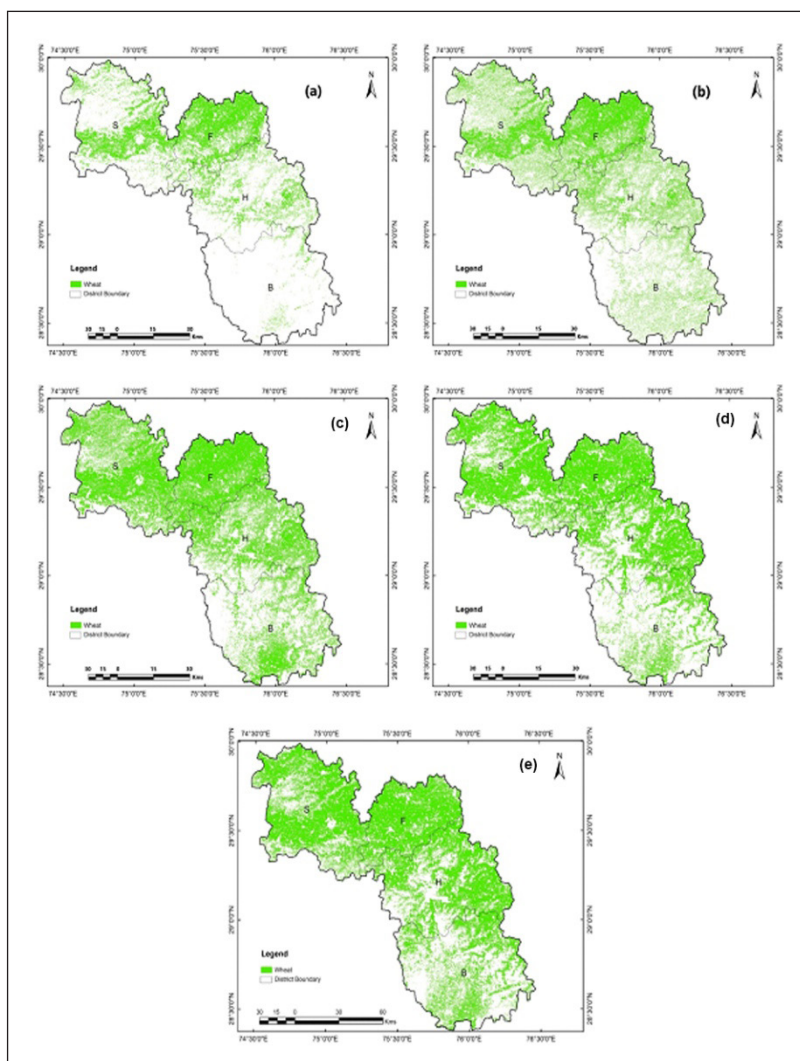


Fig. 3. Spatial distribution of the pattern of wheat crop in Sirsa (S), Fatehabad (F), Hisar (H) and Bhiwani (B) districts of WHP a) 1974 b) 1988 c) 1998 d) 2008 and e) 2022.

increased to 6280 sq. km which accounts for 40.2% of TCA of WHP. Apart from wheat, the crops grown were gram (18%), followed by mustard (17.1%), sugarcane (0.4%) and other crops (2.6%). The increased cropping of wheat clearly indicates the change in farmer's preference and the emergence of wheat as the major rabi crop (Matuschke *et al.*, 2007). Larger areas under mustard farming were noted in Bhiwani district, whereas wheat crop expanded to large areas of Sirsa and Fatehabad districts. Mustard was sown as a less water demanding crop where canal irrigation was not possible, only tube wells were the source of irrigation. During the Green Revolution, higher subsidies for agricultural inputs like chemical fertilizer, irrigation, and electricity for electric pump sets for tube wells were significantly responsible for the transformation (Nelson *et al.*, 2019). In 2008, wheat continued to be the major rabi crop that was cultivated on an area comprising of 8590 sq. km crossing more than fifty per cent of TCA.

This time period has noted drastic decline in area under gram cultivation limited to 1060 km² (6.8%) where it has more than halved as compared to 1998. Mustard was sown as the second major crop with 18.9% of TCA. The government support in the form of loan availability to farmers and agricultural input subsidies encouraged wheat production, which was perceived as providing better economical returns to farmers than other rabi crops (Sarkar *et al.*, 2009; Sangwan and Monika, 2017). While in 2022, the study area had witnessed marginal expansions of wheat (8620 sq. km) and mustard (3520 sq. km) with continuing decline of area under gram. Though, there has only been an addition of 30 ha to wheat cultivation between 2008 and 2022, it was found to be highly intense in Fatehabad followed by Sirsa and Hisar districts of WHP. On the other hand, area under mustard increased by 558 ha of land. Mustard farming has been very prominent in Bhiwani district where the availability of irrigation facilities has been comparatively lower than the other districts in the Western Haryana Plains. Gram farming was being done on only 331 ha of land during 2022 which has been reduced to cover only 2.12% of the total area. Other rabi crops cumulatively account for 4.44% of the total land area. The shift in rabi crop preferences between 2008

and 2022 demonstrates that the importance of wheat agriculture resulting in increased grain production in the region.

Changes in cropping pattern during 1974-2022

The wheat crop in rabi season dominate the cropping pattern by the areal extension of 1490 km² in 1974 to 8620 sq. km in 2022. Area under gram comprised of more than 50% of the total cropped area during 1974 that shrunk to covering less than 10% of the total cropped area during 2022. Clearly, the replacement of gram with wheat has been evident in the Western Haryana Plains. However, there has been an expansion of total cropped area under mustard as well which is generally intercropped with wheat for the sake of yield stability. The adoption of Green Revolution technology, which entails the introduction of high-yielding seed varieties and fertilizers, has been linked to the cultivation of wheat. The economic feasibility and guaranteed returns of wheat cultivation in comparison to other rabi crops have led to its widespread adoption by a significant number of farmers. In contrast, it can be observed that around 90% of the cultivated area allocated for gram cultivation underwent a decrease. The notable surge in wheat farming observed in the Sirsa and Fatehabad districts of the study area can be attributed to the abundant accessibility of canal networks and groundwater resources for canal and tubewell irrigation.

In addition to the adoption of irrigation methods, the arable alluvial terrain, especially in the level regions of the vicinity, demonstrated a remarkable propensity for the growth of wheat. The observable increase in the cultivation of wheat indicates a change in the inclinations of farmers and the emergence of wheat as the predominant crop for the winter season. The proliferation of wheat farming can be attributed to multiple factors, such as the quality of the soil, the accessibility of irrigation, the implementation of HYV seeds, and the heightened utilization of fertilizers. The Green Revolution was made possible through the provision of greater subsidies for agricultural inputs, including chemical fertilizers, irrigation, and electricity for electric pump sets utilized for tubewells. Further, the governmental allocation of loans to farmers and the provision

Table 5. Crops grown in kharif season in the study area during 1974-2022

Crop	1974		1988		1998		2008		2022	
	Area		Area		Area		Area		Area	
	sq. km	%	sq. km	%	sq. km	%	sq. km	%	sq. km	%
Paddy	120	0.8	630	4.0	1380	8.8	2590	16.6	3350	21.4
Cotton	3640	23.3	5250	33.6	5240	33.5	5010	32.0	5290	33.8
Bajra	4220	27.0	4450	28.5	3110	19.9	2460	15.7	1130	7.2
Sugarcane	120	0.8	40	0.3	60	0.4	60	0.4	70	0.4
Other crops	850	5.4	710	4.5	590	3.8	480	3.1	320	2.0

(Source: Directorate of Agriculture, Panchkula, Haryana)

of subsidies for agricultural inputs functioned as drivers for the growth of wheat cultivation.

Cropping pattern of kharif crops

The major kharif crops cultivated in the region include paddy, cotton, bajra, and sugarcane (Table 5). In 1974, bajra and cotton were the predominant kharif crops in the study area. Bajra occupied approximately 4,220 km², accounting for 27.0% of the total cropped area (TCA). Its dominance during this period can be attributed to its relatively short growing period and high tolerance to moisture stress, making it suitable for areas with limited and uncertain rainfall. Bajra can be cultivated under rainfed conditions and is particularly well adapted to low-rainfall environments. Cotton occupied approximately 3,640 km², representing 23.3% of the TCA, and was an important commercial crop in the region. Cotton is generally well adapted to warm climatic conditions and can be cultivated across a wide range of soil types. Although its total water requirement is considerably lower than that of water-intensive crops such as paddy and sugarcane, adequate and relatively consistent moisture availability during the growing season is important for optimum production (Singh and Benbi, 2021). The predominance of bajra and cotton in 1974 indicates that the kharif cropping pattern was strongly influenced by the prevailing moisture regime and the suitability of crops to relatively dry conditions. In contrast, paddy, which has a comparatively higher water requirement, occupied only a limited area during this period. Thus, the cropping pattern observed in 1974 reflects the adaptation of agricultural practices to the prevailing climatic and water-availability conditions of the study region.

The area under paddy and sugarcane crop comprised of 120 sq. km each in 1974. Although sugarcane is a summer crop, it can be grown

all year in warm to hot climates. The rise in productivity is due to the high yielding variety of sugarcane seeds. In 1988, the cotton was the major kharif crop being cultivated with a total area of 5250 km² accounting 33.6%. The area under bajra cultivation accounted for 28.5% with 4450 km² (1988) as compared to the year 1974, which was 27% of TCA. Therefore, it is evident that the study area during 1988 represented continued prominence of cotton and bajra as the major kharif crops on the other hand the area under paddy cultivation has noted signs of development. Due to favourable rates, this period saw a significant growth in the production of paddy in the entire region. When compared to the returns from other crops, paddy was by far the most profitable but it was limited to locations with irrigation water supplies since it required sufficient irrigation infrastructure (Fig. 4). During 1998, the cropping pattern of the study area was comprised of cotton being cropped 5240 km² (33.48%), bajra with an area of 3110 sq. km (19.85%) and paddy covering 1380 sq. km (8.81%) of TCA. Sugarcane cultivation has pretty much remained constant with marginal increase in area of 60 km² (0.37%). Other kharif crops were cultivated on a total area of 590 km² (3.8%). It has been recorded that paddy was the third most predominated kharif crop but area under paddy cultivation has doubled in between 1988 and 1998. The majority of paddy cultivating areas spread in the central parts of Sirsa and Fatehabad districts and eastern part of the Hisar and Bhiwani districts of the study area. The recorded growth in paddy crop was due to the fertile soils that were highly responsive to irrigation facilities. While tubewell irrigation benefits from a relatively shallow groundwater table, surface water irrigation in the region is predominantly provided by the Fatehabad Canal, a minor tributary of the Bhakra

Canal system. Water for irrigation in the region was supplied by both canal distributaries and tubewells. In 2008, the area was characterized by significant expansion of area under paddy crop along with corresponding decline of area under bajra. Also, there was marginal decline in cotton cultivated areas in 2008 but continued to be the major kharif crop in the region. The area under cotton cultivation was 5010 km² (32%) followed by paddy farming that expanded to cover 2590 km² (16.6%) of TCA. The area under bajra crop contracted to 15.7% in 2008. This period can easily be defined as the turning point in paddy crop preference. The new emergence of paddy growing belt is identified in the north and north-western parts of Sirsa and Fatehabad districts of the study area. The

increase in the market facilities for paddy in Sirsa boosted mainly in paddy production. In addition, the eastern areas of Hisar and isolated patches of Bhiwani districts are also noted for paddy crop distribution. Overall, it was noted major changes in the kharif cropping pattern in response to supportive policy and development in infrastructure along with more remunerative benefits attached to paddy crop. Extensive canal and tubewell irrigation have made paddy crop a very important crop of kharif season.

During 2022, paddy has continued to be the second most widely cultivated kharif crop covering 3350 sq. km with 21.4% of TCA followed to cotton cultivation (33.8%). The most significant feature of cropping pattern

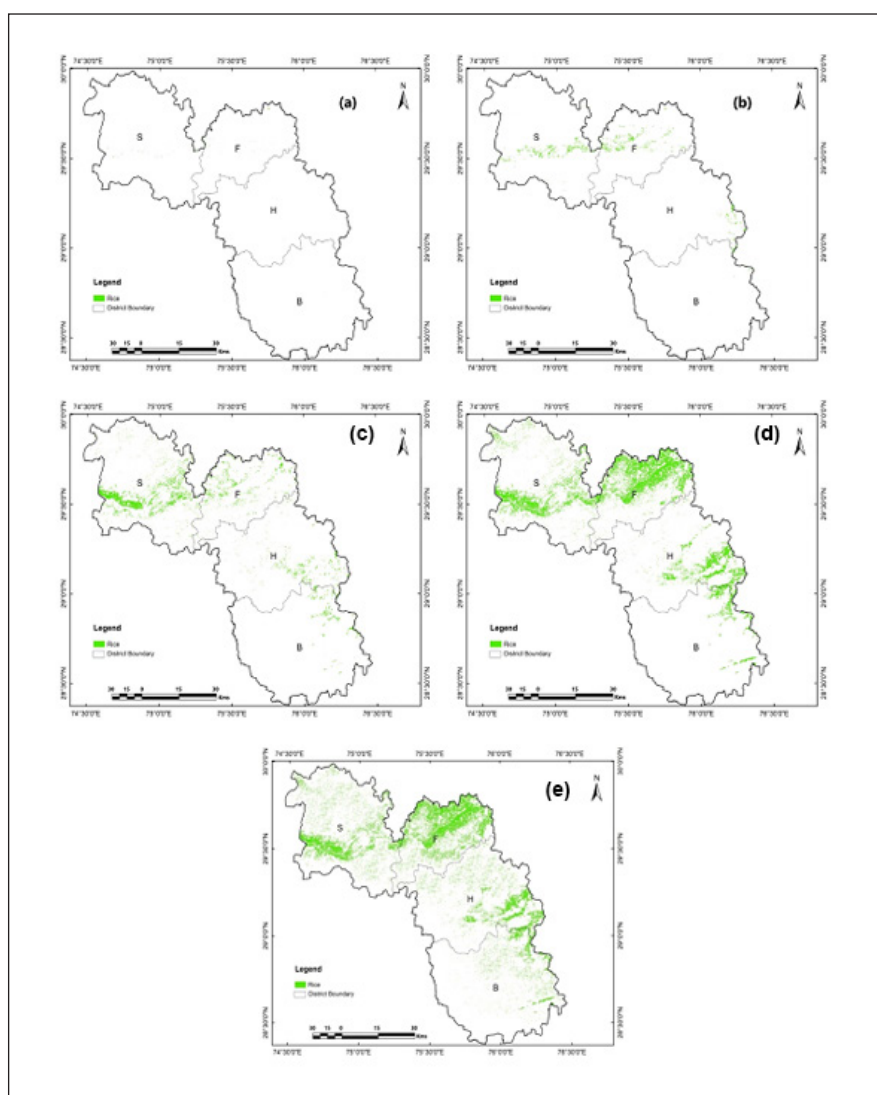


Fig. 4. Spatial distribution of pattern of paddy crop in Sirsa (S), Fatehabad (F), Hisar (H) and Bhiwani (B) districts of WHP a) 1974 b) 1988 c) 1998 d) 2008 e) 2022.

observed was the contraction of area under bajra crop 1130 sq. km (7.2%), which has halved in comparison to 2008. In 2022, the paddy crop began to be more visible in all the area of study area particularly in the central part of the Sirsa, northern part of the Fatehabad and eastern parts of the Bhiwani districts (Fig. 4). The northern regions of the study area have been recording widespread cultivation of paddy since 1988 with a gained momentum following 1998. However, in 2022 central and southern parts of the study area also recorded cultivation of paddy but the expansion has been limited to areas with constant supply of irrigation water which is an important requirement for paddy crop. Consequently, areas under cotton and bajra reduced, thus the highest impact was on the bajra crop. Cotton was still the major kharif crop widely cultivated in the study area. Corresponding to the increase in paddy farming, other kharif crops suffered a major hit. The area under other kharif crops covered 320 sq. km in 2022 which accounted only for 2% of the total area as compared to 3.1% in 2008.

Changes of cropping pattern during 1974-2022: Over the period of time between 1974 and 2022, the area under paddy cultivation has recorded expansion with major impacts on bajra farming (Fig. 4) in the Western Haryana Plains. The major crops grown in the study area were cotton (33.8%), and paddy (21.4%). Irrigation technologies have increased paddy production after the 1980s. The increased revenue from paddy was encouraged farmers to switch to this lucrative crop. Paddy replaced other crops as the second most cultivated kharif crop in 1998. Paddy farming is tied to Green Revolution technology, which introduces high yielding crop types and nutrients. However, bajra farming was decreased by four times and restricted to 7.2% (2022) from 27% (1974). The paddy was increased to 21.4% (2022) from just 0.8% in 1974. Canal networks and groundwater for canal and tube well irrigation have led to a paddy growing boom in northern regions of Sirsa and Fatehabad specifically and in the central and southern parts (Hisar and Bhiwani districts), particularly. In addition to irrigation, the alluvial land, notably in the flat areas, is most suitable to grow paddy well. Further, paddy growth is influenced by soil quality, irrigation, high-yield seed varieties, and nutrients. Subsidies for nutrients, irrigation,

and tubewell power pump sets made the Green Revolution feasible. Paddy output increased significantly and it has benefited largely from government debt and input support.

Conclusions

In the study area, Western Haryana Plains, irrigation and the use of modern inputs have helped to enhance wheat and paddy acreage in rabi and kharif seasons, respectively. The use of modern agricultural technology has led to decrease in the amount of land used to grow primary crops like gram, bajra, sugarcane, and other crops like maize, barley, and jowar. HYV seeds of paddy and wheat, in particular, have changed the region's subsistence agricultural environment. Western Haryana Plains are renowned for the cultivation of various important rabi crops. The predominant crops were grown in the region include gram, followed by mustard and wheat prior to Green Revolution. Wheat cultivation between 2008 and 2022 was found to be highly intense in Fatehabad followed by Sirsa and Hisar districts of WHP. The area has witnessed with the expansions of wheat (8620 sq. km) and mustard (3520 sq. km), cumulatively about 80% of cultivable land, with continuing decline of area under gram. However, it is noted that during kharif season, cotton continues to be the major crop with a cultivated area of 8620 sq. km accounting about 55% in 2022. Paddy is the second major kharif crop growing 22.5% of TCA, which continued to expand in cropping area while that of cotton has shrunk in 2022.

The cropping patterns in the region have varied greatly in general, particularly in Bhiwani district as compared to the other districts of Sirsa, Hisar, and Fatehabad. This is due to the irrigation options available, which include canal and tubewell irrigation. Irrigation has had a significant impact on the region agricultural landscape. The improvement in irrigation is significantly responsible for the expansion of cultivation to new areas, the optimization of cropping patterns on commercial lines, an increase in farm production, and the stabilization of agriculture in the area. A paradigm shift to paddy and wheat specialization has been quite evident post Green Revolution.

Declarations

The authors have no competing interests.

References

- Ahmed, O.S., Shemrock, A., Chabot, D., Dillon, C., Williams, G., Wasson, R. and Franklin, S. E. 2017. Hierarchical land cover and vegetation classification using multispectral data acquired from an unmanned aerial vehicle. *International Journal of Remote Sensing* 38: 2037-2052.
- Arias, M., Campo-Bescós, M.Á. and Álvarez-Mozos, J. 2020. Crop Classification Based on Temporal Signatures of Sentinel-1 Observations over Navarre Province, Spain. *Remote Sensing* 12: 278. doi:10.3390/rs12020278
- Arvind, Hooda, R.S., Sheoran, H.S., Kumar, D., Satyawar, A. and Bhardwaj, S. 2020. RS based regional crop identification and mapping: A case study of Barwala sub-branch of Western Yamuna canal in Haryana (India). *Indian Journal of Traditional Knowledge* 19(1): 182-186.
- Atzberger, C. 2013. Advances in remote sensing of agriculture: Context description, existing operational monitoring systems and major information needs. *Remote Sensing* 5: 949-981. doi:10.3390/rs5020949
- Bhalla, S. 1989. Technological change and women workers, evidence from the expansionary phase in Haryana agriculture. *Economic and Political Weekly* 24(43): 67-78.
- Casa, R., Rossi, M., Sappa, G. and Trotta, A. 2009. Assessing crop water demand by remote sensing and GIS for the Pontina Plain, Central Italy. *Water Resource Management* 23(9): 1685-1712.
- Dadhwal, V.K., Sehgal, V.K., Singh, R.P. and Rajak, D. R. 2005. Wheat yield modeling using satellite remote sensing with weather data: Recent Indian experience. *Mausam* 54: 253-262.
- Doraiswamy, P., Moulin, S., Cook, P. and Stern, A. 2003. Crop yield assessment from Remote Sensing. *Photogrammetric Engineering and Remote Sensing* 69: 665-674.
- Duro, D.C., Franklin, S.E. and Dubé, M. G. 2012. A comparison of pixel-based and object-based image analysis with selected machine learning algorithms for the classification of agricultural landscapes using SPOT-5 HRG imagery. *Remote Sensing Environment* 118: 259-272.
- Garg, N.K., and Ali, A. 1998. Two-level optimization model for Lower Indus Basin. *Agricultural Water Management* 36(1): 1-21.
- Gao, F. J., Masek, M., Schwaller, F., Hall, F. 2006. On the Blending of the Landsat and MODIS Surface Reflectance: Predicting Daily Landsat Surface Reflectance. *IEEE Transactions on Geoscience and Remote Sensing* 44(8): 2207-2218. doi:10.1109/TGRS.2006.872081.
- Ghosh, B.K. 2011. Determinants of the changes in cropping pattern in India: 1970-71 to 2006-07. *Bangladesh Development Studies* 34(2): 109-120.
- Hassan, M.I. and Inderjeet 2000. Canal irrigation and land degradation in Haryana. *Transactions of the Institute of Indian Geographers* 22(1): 51-61.
- Khan, A., Hansen, M.C. and Potapov, P. 2016. Landsat-based wheat mapping in the heterogeneous cropping system of Punjab, Pakistan. *International Journal Remote Sensing* 37: 1391-1410.
- Kumar, S. and Kumar, P. 2019. Area estimation of paddy crop in Haryana by different sensing platforms. *Journal of Emerging Technologies and Innovative Research (JETIR)* 6(3): 140-148.
- Latif, M.A. 2019. Multi-crop recognition using UAV-based high-resolution NDVI time-series. *Journal of Unmanned Vehicle Systems* 7: 207-218.
- Li, Q., Wang, C., Zhang, B. and Lu, L. 2015. Object-based crop classification with Landsat-MODIS enhanced time-series data. *Remote Sensing* 7: 16091-16107.
- Matuschke, I., Mishra, R.R. and Qaim, M. 2007. Adoption and impact of hybrid wheat in India. *World Development* 35(8): 1422-1435.
- Nelson, E., Ravichandran, A.R.L. and Antony, U. 2019. The impact of the green revolution on indigenous crops of India. *Journal of Ethnic Foods* 6(1):1-10.
- Nuarsa, W.I., Nishio, F. and Hongo, C. 2011. Spectral characteristics and mapping of rice plants using multi-temporal Landsat data. *Journal of Agricultural Science* 3(1): 54-67.
- Patel, N.R., Bhattacharjee, B., Mohammed, A.J., Tanupriya, B. and Saha, S.K. 2006. Remote sensing of regional yield assessment of wheat in Haryana, India. *International Journal of Remote Sensing* 19(10): 4071-4090.
- Rajput, J., Kushwaha, N. L., Sikka, A., Faiz Alam, M., Mahapatra, S., Sena, D. R., ... and Mani, I. 2024. Water accounting of groundwater over exploited districts in Haryana and Punjab states to analyse impacts of water conservation measures on water availability. *Water Supply* 24(9): 3093-3117.
- Rawat, S.D. and Bala, S. 2021. Changing cropping pattern in Haryana: A spatio-temporal analysis of major food crops. *International Journal of All Research Education and Scientific Methods (IJARESM)* 9(3): 212-217.
- Sangwan, B. and Monika 2017. Spatio-Temporal Trends in the Development of Irrigation in Haryana (1980-81 to 2010-11). *Amar: An Inter-Disciplinary Research Journal* 3(3): 80-88.
- Sarkar, A., Sen, S. and Kumar, A. 2009. Rice-wheat cropping cycle in Punjab: A comparative analysis of sustainability status in different irrigation systems. *Environment, Development and Sustainability* 11(4): 751-763.
- Singh, P., Saharan, J.P., Sharma, K. and Saharan, S. 2010. Physio-chemical and EDXRF Analysis

- of groundwater of Ambala, Haryana, India. *Researcher* 2(1): 68-75.
- Singh, P. and Benbi, D. K. 2021. Physical and chemical stabilization of soil organic matter in cropland ecosystems under rice-wheat, maize-wheat and cotton-wheat cropping systems in northwestern India. *Carbon Management* 12(6): 603-621.
- Sushma, B., Prawasi, R., Hooda, R.S., Yadav, M., and S. 2019. Mapping area under major rabi crops in Jhajjar district of Haryana using Geoinformatics. *International Journal of Current Microbiology Applied Science* 8(11): 1134-1140.
- Taha, M. F., Mao, H., Zhang, Z., Elmasry, G., Awad, M. A., Abdalla, A., Mousa, S., Elwakeel, A. E., and Elsherbiny, O. 2025. Emerging Technologies for Precision Crop Management Towards Agriculture 5.0: A Comprehensive Overview. *Agriculture* 15(6): 582.
- Tariq, A., Jianguo, Y., Alexandre, S.G., Khan, M.R. and Mumtaz, F. 2023 Mapping of cropland, cropping patterns and crop types by combining optical remote sensing images with decision tree classifier and random forest. *Geo-spatial Information Science* 26(3): 302-320. doi:10.1080/10095020.2022.2100287.
- Thenkabail, P.S. 2010. Global croplands and their importance for water and food security in the twenty-first century: Towards an ever green revolution that combines a second Green Revolution with a Blue Revolution. *Remote Sensing* 2: 2305-2312. doi:10.3390/rs2092305
- Verma, U., Dabas, D.S., Hooda, R.S., Kalubarme, M.H., Yadav, M., Grewal, M.S., Sharma, M.P. and Prawasi, R. 2011. Remote sensing based wheat acreage and spectral-trend agro-meteorological yield forecasting: factor analysis approach. *Statistics and Applications* 9(1-2): 1-13.
- Viskovic, L., Kosovic, I.N., Mastelic, T. 2019. Crop classification using multi-spectral and multitemporal satellite imagery with machine learning Inter pp. 1-5. National Conference on Software, Telecommunications and Computer Networks (SoftCOM), 1-5.

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