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Spatiotemporal Dynamics of Urban Sprawl and Its Impact on Agricultural Land: A Case Study of the Jauharabad–Khushab Twin Cities, Pakistan (2000–2025)

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ABSTRACT

Rapid urbanization is a characteristic of the current land use change in developing nations, frequently at the cost of quality agricultural lands. The object of this research is the spatiotemporal dynamics of the urban sprawl phenomenon in Jauharabad-Khushab twin cities of Punjab, Pakistan during a time span of 25 years (2000 – 2025). The classification of Landsat satellite maps, reclassification using supervised classifiers and the assessment of the accuracy through confusion matrices allowed the quantification of the land use class transition. The results reveal a dramatic 384% increase in built-up area, from 5.1 km^2 in 2000 to 24.7 km^2 in 2025. Agricultural land-wise the losses were 56%, coverage of water bodies 275% and other land cover losses were 53%. The greatest periods of urbanization were in 2005–2010 and 2020–2025, which are related to housing societies and commercial corridors. Results of the overall classification was high with high accuracy (above 85%) and Kappa coefficient of 0.82. The results of this work reflect many urgent questions around the balance of urban development and food security and clearly point to the need for sustainable land use planning.

Introduction

Urbanization is a worldwide trend but has the greatest impact and intensity in fast-industrializing areas in South Asia (United Nations, 2019). In particular, unplanned urban growth has led to fertile agricultural land being lost and fragmented in Pakistan (Qureshi & Breuste, 2010; Hassan et al., 2016; Riaz et al 2024). This dichotomy of development over sustainable development is shown in the twin cities of Jauharabad and Khushab in the Punjab province. The landscape of this predominantly agricultural landscape has undergone an urban renewal in the past 20 years, bringing a surge of new road networks, housing development, and population growth (Farooq et al 2024; Punjab Development Statistics 2023).

Little research, however, has attempted to quantify the extent of this sprawl or the direct effects this sprawl has on agriculture spatially or temporally. Researches conducted so far have been focused on major cities and urban concentrations like Lahore, Karachi, Islamabad and Sargodha (Ali et al, 2019; Ahmed & Ahmad, 2018; Riaz et al 2017), and small yet growing urban centers are not well-researched. To fill that void, this paper has attempted to present a sat-based and longitudinal study of land use change between 2000 and 2025. Built-up areas are extracted from the remote sensing image, based on the expansion of these areas the corresponding area loss of agriculture, water bodies and barren areas are assessed using Geographic Information Systems (GIS) (Jensen, 2015; Lillesand et al., 2015).

The specific objectives are: (1)To map the land use/land cover (LULC) changes in Jauharabad-Khushab at six different time periods of 2000, 2005, 2010, 2015, 2020 and 2025, (2)To extract and analyze Built-up area growth from reclassification, (3)To assess the accuracy of classification by constructing error matrices, and (4)To discuss the socio-environmental implications of the conversion of agricultural land.

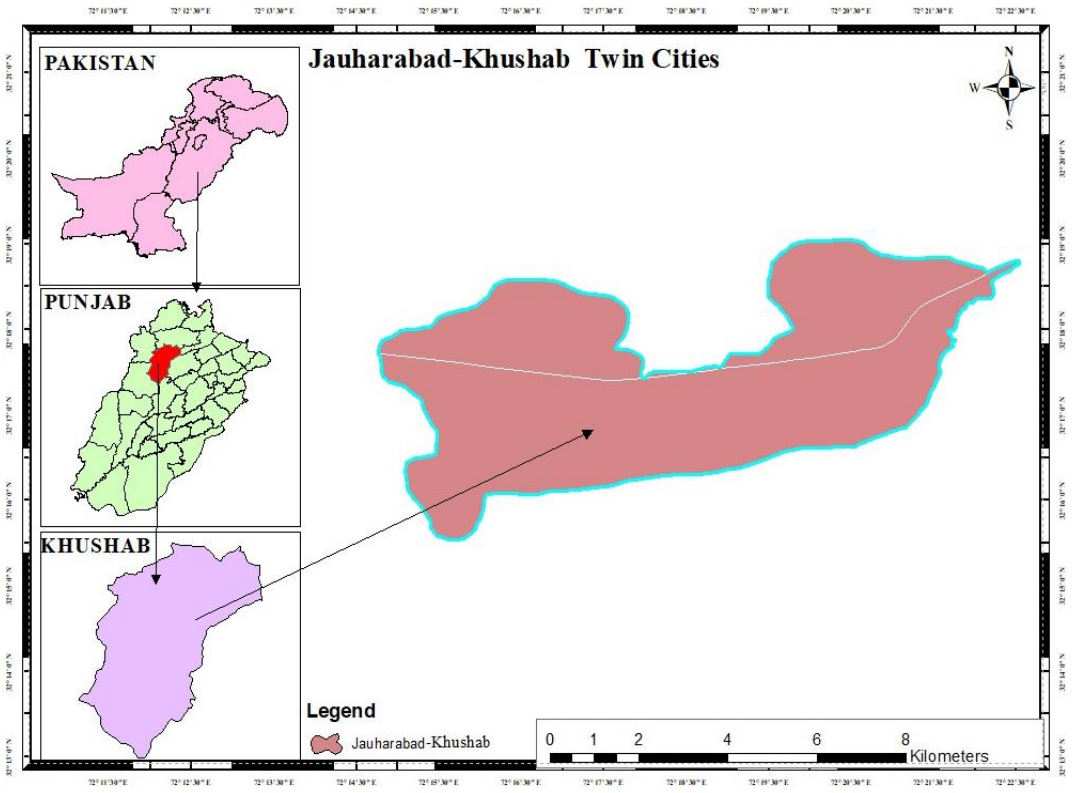

Figure: 1 Map of Study area

Study Area

Jauharabad and Khushab are twin cities lying between 31°50' to 32°30' N latitude and 71°40' to 72°30' E longitude in Khushab District, Punjab, Pakistan. The geographical areas in this study are 39.71 km^2. The city of Khushab is the district headquarters while the planned city Jauharabad dates to the 1950s. It has a semi-arid climate with most of the farming depending on the Jhelum River and canal system. The principal crops produced are wheat, sugarcane and rice.

The twin cities were traditionally agricultural and grew at an accelerated pace since the construction of highway from Sargodha to Mianwali turning the road into a commercial artery. The Pakistan Ordnance Factories (POF) in Wah with related industrial units of Khushab have also created migration and housing demand. As a result, farming land around the outskirts is constantly undergoing a process of fragmentation where residential colonies, housing societies and investment plots are forming. The spatial dynamics of this sprawl is an important aspect for sustainable regional planning.

Materials and Methodology

Data Sources

USGS Earth Explorer satellite imagery dates back to Landsat 5 TM from 2000, 2005 and 2010, to Landsat 8 OLI from 2015, 2020 and 2025. Spatial resolution of all images was 30 m and were taken in the dry season (known as the period of minimal cloud-cover and seasonal agricultural variation, (April-June). To provide reference, topographic sheets and field measured Ground Control Points (GCPs) through GPS were taken.

Image Preprocessing

All satellite data has been geometrically corrected to the Universal Transverse Mercator (UTM) coordinate system, Zone 42N and referenced to the topographic map. All data were subset to the same spatial boundaries in this study that were provided in a common boundary vector file. To account for inter-year variations in atmospheric differences, radiometric calibration was used. (Jensen, 2005).

Land Use Classification Scheme

Visual interpretation and digital interpretation were followed by classification of four land use categories:

- Urban/Built-up Land: Residentially, industrially, commercially, for transportation and communication.
- Agricultural Land: All rainfed and irrigated arable land, all permanent crop and all orchards.
- Surface Waters: ponds, lakes, springs, fountains, streams, and any other body of water.
- Other Land: Unclassified Surfaces, Fallow Areas, Barren Land.

Maximum Likelihood algorithm supervised classification was carried out in the GIS software (ArcGIS 10.8). Training samples were chosen based on their spectral signature and checked by using Google Earth historical imagery and field GPS point checks (Shaikh and Gotoh, 2006).

Reclassification for Built-up Area Extraction

A reclassification process was used to isolate built up land. Secondary classes (agriculture, and water, others) were lumped into a background value rather than a new built-up thematic value; built-up pixels were assigned to a new theme. Over time this bi-layer system enabled the calculation of “Net Urban Gain”. The reclassification was based on differences in spectral reflectance: urban materials (concrete, asphalt and brick surfaces) have higher shortwave (SWIR) reflectance than vegetation and water.

Accuracy Assessment

Accuracy assessment was done using the following error matrix (confusion matrix) approach. Twenty pairs of reference points were chosen using a random sampling scheme each time period. These reference data were retrieved from the topographical maps, Google Earth Pro and field GCPs. These four statistics were calculated:

- **Overall Accuracy:** percentage of pixels (those correctly classified/those in the reference file).
- **Producer's Accuracy:** chance that a real pixel matches the classification made in the production system.
- **User’s Accuracy:** Probability the classified pixel is equal to the reference.
- **Kappa Index of Agreement (KIA):** measures agreement beyond chance (Jensen, 2005).

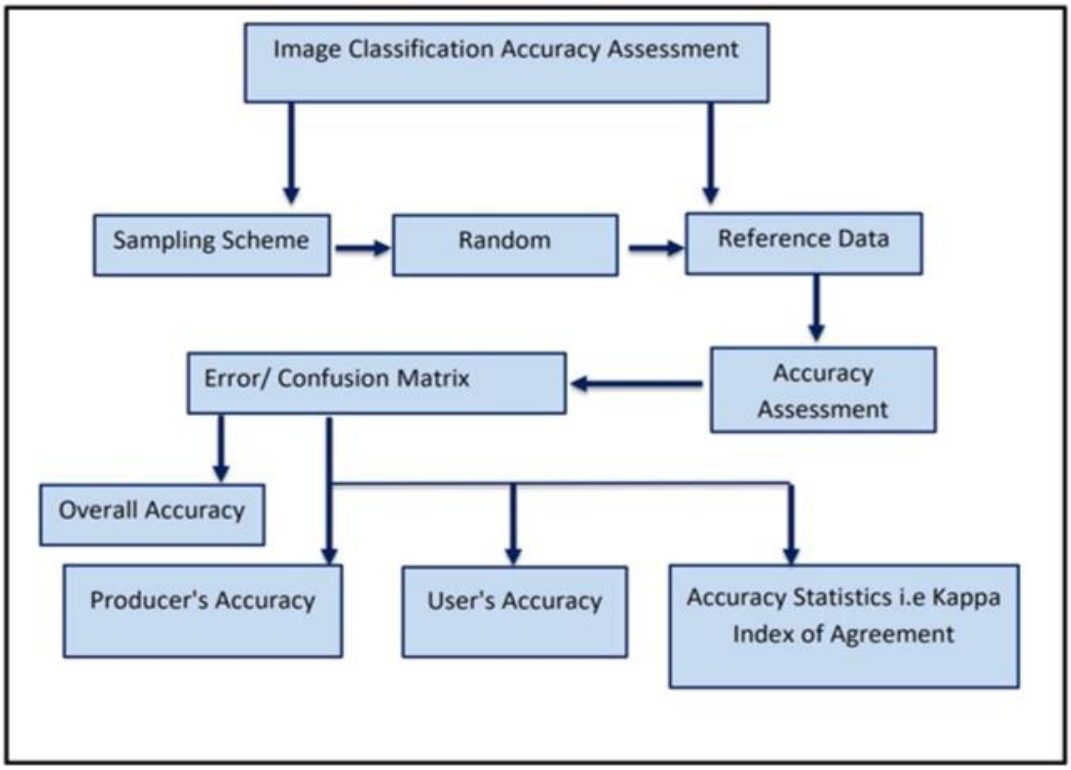

Figure: 2 The methodology flow is summarized in 2000

Results and Discussion

Land Use Change (2000–2025)

The quantitative changes in the LULC are shown in Table 5.1. Built-up land increased from 5.1 km^2 (12.8% of total area) in 2000 to 24.7 km^2 (62.2%) in 2025, a staggering 384% increase. Agricultural land declined from 16.01 km^2 to 7.1 km^2 (56%), water bodies from 3.6 km^2 to 0.9 km^2 (275%), and other land from 15 km^2 to 7.01 km^2 (53%). The total area did not change, being 39.71 km^2.

Table 1: Land Use Area (km^2) in Jauharabad-Khushab Twin Cities (2000–2025)

Category	2000 km^2	2005 km^2	2010 km^2	2015 km^2	2020 km^2	2025 km^2	Increase/decrease Since 2000
Built-up Land	5.1	8.16	13.4	16.78	19.36	24.7	**384%**
Agriculture Land	16.01	14.63	12.26	11.03	10.34	7.1	**-56%**
Water Bodies	3.6	2.9	2.5	2	1.3	0.9	**-275%**
Others	15	14.02	11.55	9.9	8.71	7.01	**-53%**
Total Area	**39.71**	**39.71**	**39.71**	**39.71**	**39.71**	**39.71**	**0%**

Built-up Growth Trajectory

The highest increases are seen periodically (see Table 5.2). Between 2000 and 2005, built-up area expanded by 3.06 km^2 (60% cumulative growth). This was the first such significant pulse with an increase of 5.24 km^2 (162%) in the period 2005-2010. After a slight slowdown during 2010–2015 (+3.38 km^2, 229% cumulative) and 2015–2020 (+2.58 km^2, 279% cumulative), the second major pulse occurred between 2020 and 2025 (+5.34 km^2, 384% cumulative).

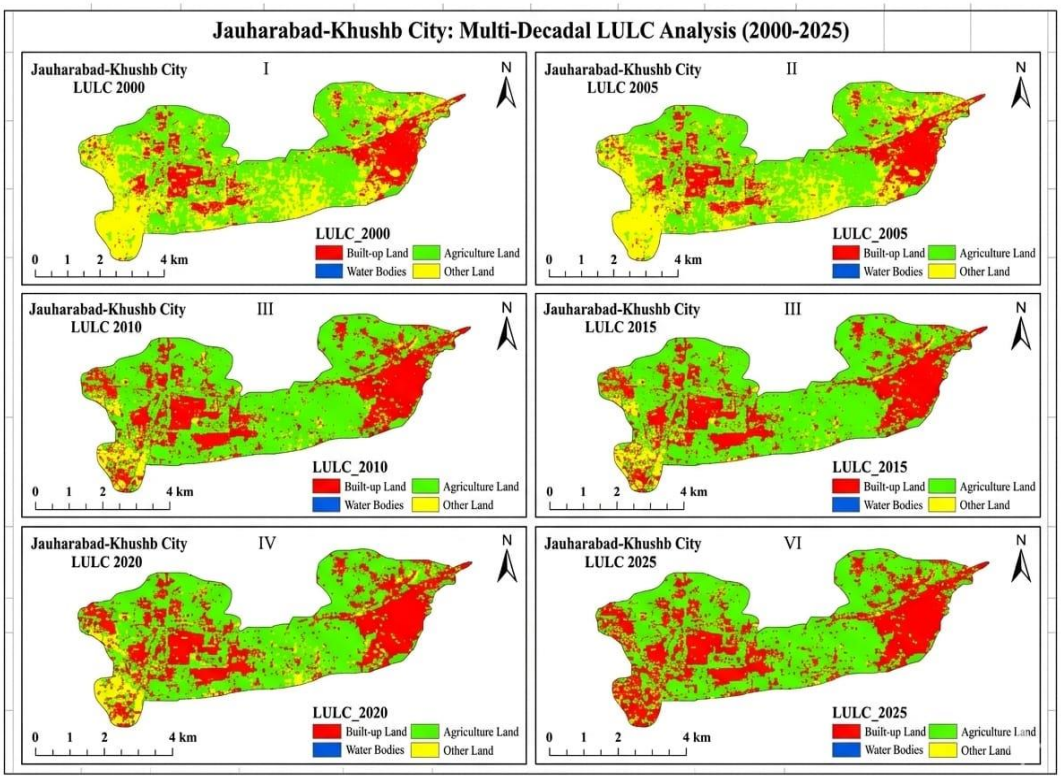

Figure: 2 Multi-Decadal LULC Analysis (2000-2005)

Drivers of the 384% Surge

The two spurts of aggressiveness are associated with recognizable socio-economic triggers. The pulse between 2005-2010 falls during the time of initiation of various private housing schemes (Khushab City Housing Scheme, Al-Noor Town) and better road connectivity through the widening of Sargodha-Mianwali Road. These later years in the 2020-2025 are an indication of real estate speculation since COVID-19, peri-urban commercial strip projects and Government Infrastructure work such as bypass construction. These pulses are a form of leapfrog sprawl, or discontinuous, low-density development which uses agricultural land inefficiently (Sudhira et al., 2004).

Agricultural Land Loss and Food Security

The significant decrease of 56% in agricultural land is alarming. The grain district of Khushab is a net exporter of wheat production so further change of land use could lead to loss of food self-sufficiency in the area. In addition, the decrease in water bodies (−275%) indicates that the region may either have experienced water shortages or is being actively filled and built-up: a typical trend in peri-urban regions of Pakistan (Hassan, 2017). A reduction in 'Other Land' (barren areas) suggests the importance of the areas used initially for urban development and once they were used up, it invades productive agriculture areas directly.

Accuracy Assessment Results

The error matrix for classification 2025 is shown below as an example. The overall accuracy was 87.5% and the kappa statistic was 0.82. The user and producer's accuracy for built-up was 91% and 89% respectively. The producer's and user's accuracy for agriculture were 85% and 83% respectively. Thematic mapping requires the minimum recommended values of 85 percent

(Anderson et al., 1976), which are exceeded by these values. The sampling scheme was random and field GPS points were used reducing the bias.

Table 3: Confusion Matrix for 2025 Classification.

References/ classified	Built-up	Agriculture	Water	Other	Total	User's accuracies
Built up	89	6	2	3	100	89%
Agriculture	5	85	4	6	100	85%
Water	2	3	90	5	100	90%
Other	4	6	4	86	100	86%
Total	100	100	100	100	400	-------
Producer's Accuracy	89%	85%	90%	86%	-------	-------

Overall Accuracy = (89+85+90+86)/400 = 87.75%; Kappa = 0.82.

Comparison with Regional Studies

This 384% increase from the last census over 25 years is much higher than in other similar sized Pakistani cities such as Bhalwal (210%) and Chakwal (175%) during the same number of years (Qureshi and Rana, 2020). This indicates that Jauharabad-Khushab is also experiencing a special influx which may be attributed to its industrial linkage (POF) and also the highway corridor effect has a significant impact there. But similar scenarios as those observed in Indian peri-urban fringes where the rate of expansion of land values exceeds population growth (Sudhira et al., 2004).

Discussion of Reclassification Utility

The reclassification technique was successful in segregating SBD and heterogeneous landscapes. In areas with arid conditions, the main source of spectral confusion was between fallow agriculture and the barren land, which we were able to eliminate by collapsing non-urban classes. Misclassification did take place, however, when bare soil had reflectance similar to that of unsealed roads. Further investigations are required that combine data from synthetic aperture radar (SAR) to help differentiate built-up areas and dry agriculture.

Conclusion

This study has quantified urban sprawl's level in Jauharabad-Khushab Twin Cities for the first time in 26 years using satellite data which has value from 2000 to 2025. The main findings are:

1. Built-up area expanded by 384%, from 5.1 km^2 to 24.7 km^2, with two major pulses (2005–2010 and 2020–2025).
2. In the cases of decrease of agricultural and water bodies, there was a total loss of productive land and natural features, attributable to urban growth, with a loss of 56% agricultural land and 53% other land, while 275% of water bodies were lost.
3. The reclassification methodology was validated by accuracy assessment where high reliability was obtained (87.5% overall; Kappa 0.82).
4. The main reasons for rise of housing society development, expansion of commercial corridor along the Sargodha-Mianwali Road and real estate speculation.

Immediate policy measures are needed. If the twin cities do not introduce a land use zoning ordinance and agricultural protection buffer, there will be no chances to preserve the last remaining farmland in the future. The suggested measures are: A. a green belt around the urban core; B. mandatory vertical housing to curb horizontal sprawl; C. promote brownfields redevelopment; and D. periodic satellite surveillance every 2-3 years. There is a need for further research, including the socioeconomic survey, to provide insights into the source of such sprawl (speculation or demand).

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