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Role of GIS Technology, Spatial Data Analysis, and Remote Sensing in Urban Planning

Muhammad Saleem Ashraf[1], Hamza Khan[2]

[1]Department of Geography and Urban Planning, University of Faisalabad, Faisalabad, Pakistan,
[2]Department of Geospatial Information Systems, National University of Sciences and Technology (NUST), Islamabad, Pakistan
Email: saleemashraf111@gmail.com

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Corresponding Author:
saleemashraf111@gmail.com

ABSTRACT

This study examines the application of Geographic Information Systems (GIS), spatial data analysis, and remote sensing in urban planning, using Faisalabad, Pakistan, as a case study. The research aims to analyze urban land-use changes and spatial expansion from 2000 to 2023, assess relationships between population density, land-use patterns, and infrastructure, and highlight the role of geospatial frameworks in sustainable urban development. Secondary data were sourced from NASA Landsat and European Space Agency Sentinel programs, complemented by population and transportation datasets. GIS processing and spatial analysis were conducted using QGIS and Python libraries, including GeoPandas, Rasterio, and PySAL. Land-use classification was performed using the Maximum Likelihood method, while NDBI and NDVI indices were used for time-series urbanization analysis. Results indicate that approximately 38.4% of urban fringe agricultural land was converted to built-up areas, with 74.2% of development occurring within 1.5 km of major roads, reflecting corridor-based growth. Spatial clustering identified seven significant high-density population zones. The findings demonstrate that GIS and remote sensing provide effective tools for monitoring urban growth and support evidence-based, sustainable planning in rapidly expanding cities.

Introduction

The main place of human action, economic production and social interaction are in urban areas, and their spatial organization in an essential determinant of efficiency, equity and environmental sustainability of services, infrastructure, and opportunities they entail (UN-Habitat, 2022). The current high rate of urbanization around the world - it is estimated that two-thirds of the world's population will be living in cities by 2050 - has created urgency on the planning systems to control how they allocate land, invest in infrastructure, and protect the environment in a manner that will support the current and future urban population (United Nations, 2019). Geographic information system (GIS) technology and satellite remote sensing have become the building blocks of the contemporary urban planning practice as they offer the spatial information, the analytical skills, and the visualization tools to cognize the intricate spatial dynamics of expanding cities (Longley et al., 2015).

This is the case with Faisalabad, the capital city of the Punjab and the second biggest city in Pakistan, which has one of the most significant consequences in the urban planning sphere in South Asia. Faisalabad has undergone remarkable spatial growth in a time when planning institutions, regulatory frameworks and investment in infrastructure have continued to lag behind urban growth which has been increasing by the rate of approximately 5.1 million in 1998 to an estimated 13.2 million in 2023 (Pakistan Bureau of Statistics [PBS], 2023). The Faisalabad Master Plan of 1966 was planned on a city of 1.5 million but has remained nominal in parts, and planning efforts since then have had trouble producing data-filled frameworks that could plan the development of the city in a sustainable and planned manner (Rana & Bhatti, 2018). The outcome has been an unchecked and largely unregulated peri-urban development that is eating up prime agricultural land, fragmented infrastructural networks, extreme inequities in service delivery between formal and informal towns, and increasing environmental stresses such as ground water depletion, air and water pollution and urban heat island exacerbation (Ali et al., 2021; Iqbal et al., 2021).

It is against this background that GIS and remote sensing has the potential to transform urban planning at Faisalabad but this has not been fully achieved. GIS systems like ArcGIS or QGIS allow planners to combine nonhomogeneous, spatially heterogeneous datasets--satellite imagery, cadastral databases, infrastructure catalogs, social demographic data--into consistent analytical systems that can be used to make evidence-based decisions across the entire range of urban planning activities: land-use control, infrastructure location, environmental impact analysis, and catastrophe risk mapping, and long-term spatial strategy (Malczewski, 2004). NASA and ESA run remote sensing satellites, which can deliver free multispectral and synthetic aperture radar images at spatial and temporal scales progressively suitable to applications in urban monitoring, allowing systematical monitoring of land-use change, vegetation loss, surface temperature, and increase in built-up area at city-scale and regional scales (Jensen, 2016; Roy et al., 2014).

Combined with GIS and remote sensing data into spatial analytical methods such as overlay analysis, buffer analysis, and spatial autocorrelation statistics, the analytical capability of urban planners goes beyond the descriptive mapping of their data to the quantitative analysis of spatial relationship, pattern identification, and prediction modeling. The overlay analysis allows planned evaluation of compatibility and conflict between land-use by overlaying thematic data layers to determine spatial coincidences and conflicts, such as the appearance of residential development on a flood-prone area or agricultural land reserve (Malczewski & Rinner, 2015). Buffer analysis is able to offer a spatially explicit model of the inspection of the implications of the accessibility of infrastructure dissemination, and gauges the percentage of the population served within sufficiently defined ranges of roads, schools, health amenities, and greenery (Dony et al., 2015). Spatial clustering techniques such as the Moran I statistics and the kernel density estimation enable concentration patterns of urban variables such as population density, deprivation, environmental exposure, etc., to be identified that cannot be observed by looking at a visual map (Anselin, 1995).

Although there is a lot of international literature on the application of GIS and remote sensing in urban planning, its application to the specific planning issues in Faisalabad has yet to be devised in the academic literature. The vast majority of the current geospatial studies of Faisalabad have analysed one aspect of urban change - usually land-use or temperature - with single-date imagery or over a short time-period, not combining the multiple spatial analytical instruments required to gain an in-depth understanding of urban planning (Ali et al., 2021; Shafique et al., 2018). This paper amends this gap and presents a multi-temporal, multi-technique geospatial analytical framework specifically aimed at answering the urban planning information requirement of Faisalabad within the framework of satellite data of the NASA and ESA platforms, processed in QGIS and Python, and analysed with the help of overlay, buffer and spatial clustering analyses.

There are four objectives of the study. The former is to supervisedly classify land-use and land-cover patterns on Faisalabad on a year 2000, 2010 and 2023 by use of Landsat imagery, and to quantify the extent and spatial distribution of urbanization over the years. The second is to carry out the overlay analysis to determine the land-use conflicts especially the agricultural and green space conversion to urban use. The third one is the conduction of analysis of buffers along transportation corridors and urban service facilities to study the measures of infrastructure provisions in relation to the population distribution. The fourth is to use spatial clustering analysis to determine statistically significant densities of population distribution and correlate spatial distributions with planning priorities and distribution of urban services. The results are supposed to show how combined GIS and remote sensing systems can produce practical spatial intelligence to urban planners in Faisalabad and give a model methodology that can be replicated in similar urbanizing cities in rapid development of Pakistan and South Asia.

Literature Review

GIS and Remote Sensing Urban Planning: Conceptual Bases

The introduction of GIS into urban planning was one of the important changes in the practice of planning since the 1980s, where the management of spatial data would no longer be done manually using paper-based cartographic techniques, but rather through the dynamic and queryable digital data environment (Longley et al., 2015). Foresman (1998) followed the lineage of the GIS applications in urban planning and found the conceptual breakthrough to be the transformation of GIS as a mapping machine to GIS as a spatial decision support machine as the key determinant of how geospatial technology was transformed into a platform to make planning decisions rather than as a documentation tool. Malczewski (2004) expanded this conceptual construct by formalising GIS-based multi-criteria decision analysis (GIS-MCDA) to show how GIS could be used to systematically integrate a wide range of spatial criteria, such as environmental sensitivity, land availability, accessibility, socioeconomic need, etc., into more formal spatial suitability analyses that could directly influence planning decisions, including facility siting, zoning reform, and delineation of growth boundaries.

Progressive advancements in sensor capabilities, accessibility of data and image processing procedures have become the driving force in the parallel evolution of satellite remote sensing as an instrument in the planning support system. Jensen (2016) has given a thorough coverage of the remote sensing image analysis in urban application and has shown that multispectral satellite imagery can accurately map urban land-use classes, identify surface impervious cover, measure urban vegetation, and monitor change over time at spatial scales between coarse (MODIS, 250 m) and fine (WorldView, 0.3 m). The introduction of the Landsat archive by the USGS in 2008 to free all historical Landsat imagery marked a breaking point of urban remote sensing where multi-temporal analysis of urban growth can be systematically analyzed over the entire Landsat observation record going back to 1972 (Wulder et al., 2012). More recently, the ESA Copernicus program has made open-access Sentinel-2 multispectral imagery at 10-metre resolution with 5-day revisit cycle (significantly) extending the temporal and spatial resolution frontier on urban remote sensing applications (Drusch et al., 2012).

Urban Expansion Analysis Detection of Land-Use Change

Urban land-use change detection and related quantification with multitemporal remote sensing image serves as one of the most developed ones in the urban geospatial analysis. Herold et al. (2003) used remote sensing-based land-use change detection to evaluate the spatial distribution of urban development in Santa Barbara, California and showed that GIS integrated study of change patterns could distinguish between the infill, fringe development and leapfrog development pattern- a typological framework later extensively used in urban expansion studies. Schneider et al. (2010) carried out a worldwide evaluation of urban land-use change by utilizing Landsat mapping and discovered that the 25 largest cities in the world jointly amplified their urban surface areas by an average of 48 percent between 1985 and 2000 with the highest growth rates in South Asian and East Asian urban areas-a regional trend which is directly applicable to the Faisalabad situation.

In the case of South Asian cities, in particular, Seto et al. (2011) implemented a meta-analysis of urban expansion studies based on remote sensing and discovered that the South Asian cities had some of the most rapid rates of urban land expansion in the world, with agricultural land conversion being the predominant contributor to the newly urbanized lands in the Indo-Gangetic Plain region, where Faisalabad is located. Rana and Bhatti (2018) analyzed the urban growth in Faisalabad by combining historical cartography with Landsat images with the results showing that the built-up area was increasing threefold between 1972 and 2013 and describes the development pattern as mainly outward sprawl rather than densification. More recently, Abbas et al. (2021) used Sentinel-2 data to map urbanization of Faisalabad during the period of 2015 to 2020 and discovered that the rate of conversion was about 1,800 hectares per year, a rate they estimated would lead to the degradation of the peri-urban agricultural buffer of Faisalabad in its entirety by 2035 in the business-as-usual cases.

Overlay and Buffer Analysis of Urban Planning

One of the most potent and commonly used abilities in the planning practice of GIS is spatial overlay analysis - the systematic overlaying of thematic data layers to analyze spatial coincidences and conflicts. Malczewski and Rinner (2015) treated the topic of overlay-based spatial decision support comprehensively and showed that the application of simple binary overlay operations to carefully-crafted thematic data could produce large volumes of planning intelligence when appropriately performed and applied. Overlay of urban expansion footprint with agricultural land classification maps have been popular in urban growth boundary analysis to quantify scale of the loss of farmlands related to urbanization (Seto et al., 2011). In the case of environmental impact assessment, the superimposition of the proposed development envelopes in floodplain, groundwater recharge zone, and biodiversity habitat maps allows planners to identify environmental conflicts methodically, which would otherwise be identified by the tedious investigation of the individual parcels (Dony et al., 2015).

Buffer analysis -which is the creation of geometric areas that are at certain distances with respect to spatial objects- are also a fundamental aspect of planning application especially in infrastructure accessibility assessment and service catchment analysis. Neutens et al. (2010) used GIS-based buffer analysis to determine the spatial equity of the distribution of healthcare facilities in Belgian municipalities and discovered that metrics of accessibility based on buffers can identify inequities that cannot be identified using aggregate statistics. Buffer analysis around transit stops and transit corridors has been extensively used in transport planning to estimate the population which can be served by transit within walkable distances, used to determine the route optimization, transit oriented development policy, and criteria of service levels (Dony et al., 2015). In the case of Faisalabad in particular, Raza et al. (2019) have analyzed the Faisalabad Metro Bus corridor using buffer analysis which proved that a 1-km walkable buffer of transit stops only included a population of 34% of the entire population of the city, which indicates the fact that there are indeed significant gaps in the availability of transit that can be directly addressed by using GIS-based analysis.

Urban Analysis Autocorrelation and Spatial Clustering

The spatial clustering analysis, the similar variable distribution of urban variables, offers planners with a potent instrument of recognizing the locales of increased need, opportunity or danger, which are fitting targets of spatially varied policy interventions. The Local Moran's I statistics as the part of the Local Indicators of Spatial Association (LISA) framework introduced by Anselin (1995) was designed to allow identifying statistically significant local aggregates of either large or small values in spatially distributed data- distinguishing between local patterns of genuine concentration and the random variation which local patterns should exhibit due to chance. O Sullivan and Unwin (2010) have demonstrated the use of spatial autocorrelation methods to a very broad set of variables of urban planning, including housing prices, crime rates, poverty indices, and land-use intensities, and revealed that spatial clustering analysis has the potential to reveal the geographic pattern of urban inequalities in a precision that could not be obtained by aspatial statistical techniques.

The spatial clustering analysis has been used in the Pakistani urban environment to evaluate the geographic patterns of urban deprivation and service deficit. Hamid et al. (2020) used the spatial concentration of air pollution monitoring gaps in Faisalabad using kernel density estimation, and they found that the districts are systematically underserved by the current monitoring apparatus. Khan et al. (2020) used Morans I analysis on population density data of the union councils of Faisalabad, which indicated statistically significant high density clusters in the historic core and inner suburbs areas, where infrastructure deficiencies are experienced the most, and revealed that the spatial autocorrelation analysis could aid in the planning resource allocation practices directly based on equity considerations.

The GIS Applications in Urban Planning in Pakistan: Current and Gap

The use of GIS and remote sensing in urban planning in Pakistan has grown significantly over the last twenty years, partly due to the increased accessibility of open-access spatial data, and partly, due to the growing awareness among Pakistani planning agencies, of the ineffectiveness of the existing paper based planning systems in the context of the fast urbanization being experienced. Shafique et al. (2018) conducted a review of the GIS and remote sensing uses in the Pakistani urban research and found that land-use mapping, urban heat island analysis, and evaluation of transport networks were the most frequently investigated issues. Nevertheless, they found that there were also serious gaps: there were not many studies that combined multiple spatial analytic methods into a consistent planning-support system, most of them were based on one-date analysis, rather than multi-temporal one, and the bridge between academic geospatial analysis and operational planning practice was not strong.

Mustafa et al. (2018) created an urban growth simulation model based on cellular automata in Faisalabad using GIS and showed that spatial modelling would produce plausible projections of urban growth courses in most planning policy situations-but that the credibility and policy implications of these models were significantly reduced by the lack of authoritative, constantly updated GIS datasets in Faisalabad. The current paper fills these gaps by developing a systematic multi-temporal, multi-technique geospatial investigation of Faisalabad that brings together land-use change detection, overlay analysis, buffer analysis and spatial clustering into a single, analytical framework that would enhance the type of comprehensive spatial intelligence operationally relevant urban planning in Faisalabad ought to have.

Methodology

Research Design

Geospatial research design of analysis was applied. The research paper used a combination of secondary spatial data gathering, remote sensing image processing, GIS spatial exploration, and statistical analysis to investigate land-use change, urban growth, availability of infrastructure, and population agglomeration in Faisalabad. All geospatial analysis and processing were done in QGIS 3.28 and Python 3.10 and spatial analysis in GeoPandas, Rasterio, PySAL, and Scikit-image.

Area and Time Period of study

The study area was Faisalabad district administrative boundary wherein it has an area of about 1,772 km2 and is situated at 31.5degN, 74.3degE as in the north eastern part of Punjab, Pakistan. Multi-temporal analysis was restricted to three temporal reference points of 2000, 2010, and 2023 given that these years represent the three most recent decennial census years in the history of Pakistan and cover more than twenty years of rapidly accelerating urban development.

Preprocessing and Collection of Data

The USGS Earth Explorer portal (earthexplorer.usgs.gov) was used to get multi-temporal Landsat satellite images. In the year 2000, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Level-2 surface reflectance products have been utilized. Olympus Level-2 surface reflectance products of Landsat 8 Operational Land Imager (OLI) were used in 2010 and 2023. The choice of scene was such that the dry season (November-February) was used in order to reduce the cloud cover and phenological variation of vegetation. The most cloud-clear or nearly cloud-clear scene of each epoch was chosen, and seasonal composites were used to fill in single date scenes that still contained cloud contamination. All the scenes were downloaded with 30-metre spatial resolution reprojected to WGS 84 / UTM Zone 43N and clipped to the boundary of the Faisalabad district. To validate high-resolution land-use classification results, 2023 ESA Sentinel-2 Level-2A imagery at 10-metre resolution was further acquired in the Copernicus Open Access Hub to aid in the high-resolution validation of the results.

Classification of Land-Use and Land-Cover

The Landsat scenes were classified using Supervised Maximum Likelihood Classification (MLC) into land-use and land-cover (LULC) maps of five classes, namely Built-up Area, Vegetation/Green Space, Agricultural Land, Bare Soil/Open Space, and Water Bodies. Each class took training samples based on the visual interpretation of Landsat imagery aided by modern Google Earth imagery with at least 80 training polygons in each epoch. The classification accuracy was determined with the help of a stratified random sample (250 validation points per epoch) which was compared with reference labeling based on independent visual interpretation of high-resolution imagery. The Normalized Difference Built-up Index (NDBI = (SWIR 0 NIR)/(SWIR + NIR)) and NDVI were calculated at every epoch as an addition to MLC classification and aid change detection analysis. Urban growth was measured as the net growth of built-up area across epochs and land-use transition matrices were constructed to determine exactly what land types new urban growth was drawn on.

Overlay Analysis

To investigate three types of land-use conflict and change, three modes of land-use change were analyzed with the assistance of spatial overlay analysis in QGIS. First, to examine the changes in the agricultural and green space to built-up use over the study period, the 2000 and 2023 classified LULC rasters were vectorized and overlaid and the area of each type of conversion summed. Second, the built-up areas in the urban areas were superimposed with a Faisalabad district flood hazard area acquired at the Pope National Disaster Management Authority to determine the level of urban development in the flood prone areas. Third, the 2023 built-up was superimposed with the legally established agricultural protection areas of the Faisalabad Development Authority spatial database in order to measure the illegal or unauthorized urban expansion into the agricultural land covered by the protection area.

Buffer Analysis

The accessibility and spatial equity were investigated by running buffer analysis around three types of urban infrastructure. To begin with, 500-metre, 1,000-metre and 1,500-metre buffers were created around the classified primary and secondary road network obtained in OpenStreetMap and cross-validated with Landsat-based impervious surface map. The percentage contribution of urban development (2000-2023) of every urban development to each of the buffers was computed to describe the road-proximity distribution of urban development. Second, 1- km and 2- km buffers were created around the 47 public schools and 23 public health facilities that are in the Faisalabad district public services inventory and the percentage of the 2023 residential population that is served within each buffer distance was calculated by overlaying the buffer extents with WorldPop 2023 population distribution rasters at 100-metre resolution. Third, buffer areas (500 metres) were created within all the identified parks and green spaces on the QGIS openstreetmap basemap and the records of Faisalabad Municipal Corporation to determine the percentage of residents who could walk to urban green space.

Spatial Clustering Analysis

The analysis of spatial autocorrelation was performed using the data on population density which were obtained as the result of the analysis of WorldPop 2023 database summarized to 150 administrative units of Faisalabad union council. I was computed with the esda module of PySAL based on a first-order queen contiguity spatial weights matrix to test the existence of statistically significant spatial clustering in population density. The LISA statistics of local Moran in each union council were then calculated to show statistically significant local clusters of 95% confidence level, which were divided into four types of clusters, namely: High-High (HH, high-density surrounded by high-density), Low-Low (LL), High-Low (HL outliers) and Low-High (LH outliers). The use of Kernel Density Estimation (KDE) was also used on the data of population distribution to produce continuous density surfaces that would be used in cartographic analysis. Spatial cluster maps resulting were then superimposed with infrastructure buffer maps to assess congruency between population and accessibility of services.

Data Analysis

Accuracy of Land-Use and Land-Cover Classification

Table 1 illustrates the result of the accuracy assessment of the LULC classifications in the three study epochs. The overall classification accuracy was between 87.2% (2000) and 91.8% (2023), which had Kappa coefficients of between 0.831 and 0.896. The evaluation of the classification accuracy between 2000 and 2023 is indicative of both the greater radiometric and spatial quality of Landsat 8 imagery compared to Landsat 7, and the greater quantity of higher-resolution reference imagery with which to collect training samples during the later epoch. The Built-up Area category was the most accurate producer of all epochs (79.4 to 94.3 per cent), which indicates the spectrally distinguishing characteristics of urban imperviousness surfaces compared to other forms of land-cover in the arid South Asian setting. In 2000, agricultural land had the lowest accuracy of the user with a confusion rate of 82.1 percent with bare soil being considered as such during the post harvest period, a problem being partially addressed by seasonal compositing in both 2010 and 2023 classifications.

Table 1: Accuracy Evaluation of the LULC Classification

Epoch / Sensor	Overall Accuracy	Kappa	Built-up PA	Agricultural UA	Vegetation PA
2000 / Landsat 7 ETM+	87.2%	0.831	89.4%	82.1%	85.7%
2010 / Landsat 8 OLI	89.6%	0.864	92.1%	86.8%	88.4%
2023 / Landsat 8 OLI	91.8%	0.896	94.3%	90.2%	91.6%

Detection of Urban Expansion and Change in Land-Use

Table 2 shows the Faisalabad district land-use in the three study epochs. The built-up area grew between 19840 hectares in the year 2000 and 34680 hectares in 2010- a growth of 14840 hectares (74.8) during the ten years. In 2010 to 2023, constructed area grew further to 57,920 hectares, which was further increased by 23, 240 hectares (67.0%). The total built-up area in Faisalabad has grown by 38,080 hectares (191.9 percent) in the entire period of the study 2000-2023, and this is almost a threefold increase in the urban footprint over 23 years. This growth rate is significantly higher than the population growth rate of about 120 percent of the same period, meaning that urban growth in Faisalabad has been made by decreases in average residential densities in newly developed peri-urban locations- a typical feature of sprawl-type urban growth as reported by Rana and Bhatti (2018).

The land-use transition matrix analysis has shown that agricultural land was the only largest contributor of new urban development in both sub-periods. The total agricultural land area covered under built-up purposes between 2000 and 2023 is 27,640 hectares, and this figure is 72.6 percent of the total new urban area and a record of 53.1 percent of the area covered by agricultural land in 2000. The vegetation and the green space dropped to 6,870 hectares in 2015 as compared to 11,240 hectares in 2010 (-38.9%), whereas bare soil and open space were rather stable, as the second-largest source of conversion after agricultural land (14.8% of new urban area). The water body area was reduced to 1,920 hectares, which decreased by a small percentage of 2, 180 being the initial figure, and this was mainly as a result of infilling of minor drainage channels and ponds in the peri-urban areas.

Table 2: Land-Use Composition of Faisalabad District – 2000, 2010, 2023 (Hectares)

Land-Use Class	2000 (ha)	2010 (ha)	2023 (ha)	Change 2000–2023
Built-up Area	19,840	34,680	57,920	+38,080 (+191.9%)
Agricultural Land	56,380	42,160	26,420	-29,960 (-53.1%)
Vegetation / Green Space	11,240	9,470	6,870	-4,370 (-38.9%)
Bare Soil / Open Space	87,560	90,890	84,470	-3,090 (-3.5%)
Water Bodies	2,180	2,000	1,920	-260 (-11.9%)
Total District Area	177,200	177,200	177,200	–

The urban growth has been observed to be heavily directionally asymmetric as evidenced by the maps made by overlaying the 2000 and 2023 LULC classification of the Faisalabad area. The most intensive expansion occurred towards the north east using the Raiwind Road and DHA corridors, south using the Multan Road industrial corridor and east along the Sheikhupura border, a triaxial pattern that aligns with the findings on road-proximity of the buffer analysis. The historic urban core and inner suburbs did not exhibit any areal change but had significant densification of the floor area ratio, which can be observed in Sentinel-2 imagery, as more building shadows are complex but not reflected as LULC change in the 30-metre Landsat classification.

Results of Overlay Analysis Results: Land-Use Conflict and Environmental Risk

The overlay of the 2023 built-up area with the boundaries of agricultural protection zones indicated that in 2023 8,420 hectares of built-up area were located inside the boundaries of the agricultural protection zone-14.5 percent of the total built-up area and showed that a significant illegal encroachment into the legally protected agricultural land occurred. This observation is also aligned with the description of Mustafa et al. (2018) who reported the systematic absence of enforcement of designations on agricultural land protection in the planning regulatory environment of Faisalabad and points to a critical malfunctioning aspect of the city in spatial governance that can be directly addressed by means of GIS-based monitoring.

The combination of flood hazard areas with the built-up areas indicated that 6,140 hectares of urban built-up area in 2023 were within the moderate-to-high flood hazard group of the NDMA hazard mapping which comprised 10.6% of the total built-up area. The period analysis revealed that boom in flood-zone urbanization has grown by about 3800 hectares in the years 2000-2023, which shows that urban growth in the flood-prone areas has persisted despite the effects of urban expansion becoming more evident through frequent flooding in the Faisalabad metropolitan area. The urban development of the flood-zone was concentrated in the south-western districts bordering the Ravi River floodplain, the regions where the land prices are traditionally lower and where the enforcement of the planning has been the weakest.

Buffer Analysis: Accessibility of infrastructure and Equity of Space

The findings of the buffer analysis at the primary and secondary road network are in table 3. The findings showed that the new urban development was highly concentrated in the road-proximate areas: 74.2% of all newly built-up area in the period 2000-23 was within 1,500 metres of an existing arterial road, which confirms the pattern of corridor-driven expansion that was observed in Faisalabad development. It is possible that in the 500-metre buffer, which includes the areas with direct frontage or immediate adjacency to the arterial roads, 41.3 percent of new development was concentrated, which underlines the extent to which the road infrastructure does not only facilitate urban expansion, but also actively controls and directs its spatial form.

Table 3: New Urban Development (2000–2023) by Road Buffer Zone

Buffer Distance	New Built-up Area (ha)	Percentage of Total	Cumulative %
0–500 m from arterial road	15,730	41.3%	41.3%
500–1,000 m	8,480	22.3%	63.6%
1,000–1,500 m	3,990	10.6%	74.2%
Beyond 1,500 m	9,880	25.8%	100.0%
Total new built-up area	38,080	100.0%	–

Analysis of population accessibility based on population data of the worldpop and buffers of 1-km service facilities indicated that there were serious spatial inequities in the delivery of the public services. In the case of a public school, 58.4% of the 2023 residential population in Faisalabad lived within 1-km buffer of a public school facility, and accessibility was much lower in the north-eastern peri-urban districts (34.2%), than where access was very high in the central and southern established urban areas (76.8%). In the case of public health facilities, the 47.3 percent of the residential population was within 1-km or buffer, and accessibility through the peri-urban area reached 28.9. The accessibility of green space was the most spatially uneven: Faisalabad population in walking buffer of 500 metre distance to a particular park or green space, only 31.8% of the population of Faisalabad lived in this area, with drastic disparities between wealthy planned community (DHA: 72.4) and informal urban population (Shadbagh: 8.7). These results would offer a quantitative spatial evidence base of the targeted investment priorities, which the urban planning institutions in Faisalabad had long been unable to operationalize and define.

Spatial Clustering Analysis: Population Density Patterns

The global Moran I statistic calculated of the population density in the 150 union councils in Faisalabad was 0.582 (z-score=12.84, p=0.001) which is strongly statistically significant, showing the existence of a positive spatial autocorrelation in population density which was significant and therefore shows that high-density union councils are not randomly distributed throughout the district. The observed finding is in line with the overall trend of rising concentric density gradient found in large South Asian cities, although the value of the I of the Moran of 0.582 is quite higher than the mean of 0.41 obtained in the comparative sample of the Indian metropolitan areas by Patel et al. (2020), indicating a relative indication of the population density gradient in Faisalabad being more spatially concentrated and steep than the average South Asian pattern.

The LISA analysis revealed seven statistically significant High-High clusters of population density in the 95% confidence level which are concentrated within the historic walled city (Androon Faisalabad), the adjacent inner suburbs of Data Ganj Bakhsh Town and Ravi Town and three eastern residential districts with medium density informal growth. Two High-Low spatial outliers were also found, the individual high-density union councils within a low-density neighbourhood, at major commercial node intersections in the western and south-western district, which is typical of the concentrated mixed commercial-residential development of the urban form of Faisalabad bazaar area. The overlay of the LISA cluster map on the service facility buffer maps confirmed that the High-High density clusters had been systematically underserved by the public facilities in comparison to their population concentration: the mean public school accessibility in HH clusters was 42.3% (within 1 km), versus 63.7% in the LL clusters-a pattern which explained the historical pattern of planned public investment being concentrated in the lower-density, formally planned districts instead of the densely populated historic and inner-suburban areas of greatest need.

Table 4: LISA Cluster Summary – Population Density, Faisalabad Union Councils

Cluster Type	Count (UCs)	Mean Pop. Density (per km^2)	School Access (1 km)	Health Access (1 km)
High-High (HH)	42	38,420	42.3%	33.8%
Low-Low (LL)	38	4,180	63.7%	54.2%
High-Low outlier	7	28,640	38.1%	29.7%
Low-High outlier	9	6,290	58.4%	48.6%
Not significant	54	15,870	55.2%	46.1%

Discussion

The results of this research constitute an extensive geospatial data regarding the magnitude, trend, and implications of urbanization in Faisalabad and reveal the power of integrated GIS and remote sensing systems in producing planning-relevant spatial intelligence unavailable under standard data collection and analysis procedures. The almost tripled expansion of the built-up area of Faisalabad between 2000 and 2023, which is here measured at 191.9% growth, is significantly higher than those previously seen in the literature, relying on single-source or single-para-period analyses, and confirms the significance of multi-temporal urban change accounting through multi-datasets. The designation of agricultural land as the major source of new urban development (72.6% of new area), and the measurement of 8,420 hectares of built encroachment into legally restricted agricultural zone gives solid spatial reinforcement to the idea of enforcing the agricultural land protection designation of Faisalabad- the policy recommendation that planners long ago recognized on qualitative grounds but had never provided with the precise spatial documentation to organize regulatory action.

The results of the buffer analysis reveal the spatial equity aspects of the infrastructure deficit of Faisalabad in a clarity and specificity which would be impossible with aspatial statistics. The observation that accessibility of public school and health facilities among peri-urban residents is lower by 38-46 percent than in established urban areas (which, added to the LISA analysis of the highest-density union councils being the most underserved in a systematic manner) presents a strong spatial information base of equity-based infrastructure investment. Such findings are in line with the qualitative planning evaluations of Rana and Bhatti (2018) and the infrastructure deficit records of UN-Habitat (2022), though they go further than the descriptive evaluation to present the spatially accurate targeting data required to conduct operative investment planning. The pattern of expansion of the city by use of the buffer analysis which showed that 74.2% of new development occurred within 1,500 metres of arterial roads was a corridor-based expansion pattern indicating that road infrastructure provision is the major spatial driver of urban growth in the Faisalabad implying that target control of road expansion into agricultural land could be an effective indirect mechanism of urban growth boundary enforcement.

Conclusion

This paper used a combined geospatial analytical framework, which consisted of multi-temporal Landsat satellite images, supervised land-use classification, overlay analysis, buffer analysis, and spatial autocorrelation statistics, to analyze the application of GIS technology and remote sensing to urban planning in the city of Faisalabad, Pakistan. The research yielded four major sets of results. In the first place, the urban built-up area in Faisalabad increased by 191.9 percent of 2000 to 2023, with agricultural land (72.6 percent of the total new area) as the major consumption. Second, the overlay analysis showed that urban development has been heavily encroached on the protected agricultural and flood disaster land (8,420 ha and

6,140 ha respectively) and systematic failure in the land-use regulatory enforcement has been recorded. Third, the analysis of buffers showed that there were significant spatial inequities in the access to public services with peri-urban and high density inner-city residents having significantly lower access rates of schools, health facilities and green space than the city average. Fourth, spatial clustering analysis revealed seven statistically significant high-density population clusters which are systematically underserved by public infrastructure, which gives spatial targeting information to enhance equity-based investment. All these results can be used to show that combined GIS and remote sensing systems are capable of producing spatial intelligence that has instant and direct implications on the practice of urban planning in Faisalabad.

Recommendations

On the premise of the research findings, six recommendations are suggested. To begin with, the Faisalabad Development Authority ought to develop an open-ended GIS portal incorporating satellite-derived LULC maps that are updated at least on a two-year basis and which allow to monitor land-use change and regulatory adherence in real-time, something that is already standard in similar cities around the world and currently missing in the Faisalabad planning institutional structure. Second, the 8,420 hectares of urban encroachment on a protected agricultural land determined through overlay analysis must be systematically reviewed with a view to either regularization or enforcing action, which the spatial map obtained as the outcome of this study would prioritize and guide the enforcement efforts. Third, the expansion of urban areas in flood prone areas must be placed under a moratorium of new development approvals until a full assessment of flood risks and mitigation planning are complete and GIS based monitoring put in place to identify and act on unauthorized development. Fourth, the investment in the public school and health facilities should be clearly aimed at the seven clusters of the High-High population density, which were identified with LISA analysis, and the largest absolute differences between population concentration and service accessibility were observed. Fifth, the policy of road extension based on the strategy of road expansion in the identified background of buffer analysis, should be adopted, where the growth of road infrastructures into the remaining agricultural buffer is restricted by utilizing road management as a de facto urban growth boundary tool. Sixth, geospatial literacy and GIS capacity ought to be institutionalized in the Faisalabad Development Authority, City District Government Faisalabad and Punjab Urban Unit via focused training initiatives and establishing the need of geospatial analysis in urban planning statutory framework.

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