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Geospatial Assessment of Land Use and Land Cover Change and its Impact on Urban Flood Vulnerability in the Twin Cities of Pakistan

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Abstract

Worldwide land use and land cover (LULC) changes significantly disrupt the hydrological cycle, often exacerbating the risk and intensity of extreme hydrometeorological hazards such as urban flooding. Currently, urban flooding has emerged as a pressing environmental concern, posing a growing threat to environmental and urban sustainability in the rapidly urbanizing cities. In Pakistan, this phenomenon is particularly acute, where the intensity and vulnerability of urban floods have become increasingly severe due to abrupt changes in LULC and unplanned urbanization. This study investigates how land use land cover changes and haphazard urban expansion have intensified the flood vulnerability in the twin Cities of Pakistan—Islamabad and Rawalpindi from 2000 to 2023. This study employs a combination of remotely sensed satellite imagery, field data, and secondary data sources. Landsat imagery with less than 10 cloud cover were acquired form USGS official site. For flood vulnerability analysis, data were collected from primary sources through field survey. Relevant secondary data were explored from Water and Sanitation Authority, PDMA, RESCUE 1122 and Punjab Development Statistics. For classification, four land use land cover classes: built-up, vegetation, bare land, and water were analyzed using the supervised classification method. Flood vulnerability was calculated using physical, environmental, social and economic vulnerability indices. The result of LULC indicates that significant increase in built-up area and reduction in permeable surface and barren areas has been reported in both Islamabad and Rawalpindi. Comparatively, the built-up of Rawalpindi is expending rapidly. The findings reveal that both Islamabad and Rawalpindi were highly susceptible and vulnerable to urban flooding, however, the degree of vulnerability varies considerably depending on administrative governance, land use policies, and socio-economic resilience. The results indicate that the cumulative FVI of Rawalpindi (0.47) is higher than Islamabad (0.24), indicating that Rawalpindi highly susceptible and vulnerable to urban flood as compared to Islamabad. Among the subzones of Rawalpindi, the Rawalpindi Metropolitan Corporation (RMC) demonstrates the highest vulnerability, particularly in terms of social (0.67) and physical (0.56) dimensions, primarily due to dense, unplanned settlements and insufficient compliance with urban development regulations. Conversely, Chaklala Cantonment displays the lowest vulnerability score (0.36), suggesting that more structured planning can effectively reduce flood risk. The findings of this study offer a practical roadmap and valuable insights for urban planners, disaster management authorities, and policymakers to effectively address the escalating challenges of urban flooding in Rawalpindi and other similarly vulnerable urban centers in developing countries.

Keywords: Nullah Lai basin, Permeable surface, GIS, Twin Cities, Urbanization, Flood

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Introduction

Land use Land cover (LULC) change is one of the influential contributing factors in altering the local or regional environment. From the past three decades, LULC is changing rapidly and can be observed both in rural and urban areas, however, the urban land use is modifying at very alarming rate leading to severe thread environment worldwide. Urban growth is one of the indicators of LULC change, where major contributors are unplanned settlements and the haphazard expansion of cities. The unplanned expansion of built-up areas has overburdened the natural resources including water, air, green spaces, energy, etc. The unplanned and uncontrolled growth of cities is exploiting the urban agricultural land and vegetation cover, compromising on ecosystem services and deteriorating the environment (Elmqvist et al., 2013). The unplanned population concentration and urban sprawl at the cost of drainage systems, ultimately increase flood risk in cities (Congalton, 2019; Huong & Pathirana, 2013). Urbanization turns pervious surface into impervious land and triggers the runoff and risk of flood (Fernández & Lutz, 2010). In urban areas, climatic change and unplanned urbanization are major threats to flooding in cities (Miller & Hutchins, 2017). Rapid urbanization affected the extent of urban floods and caused serious urban losses (Chen et al., 2015). Rapid and unplanned urbanization, on the one hand, concentrates the population in small areas and overburdened the drainage system, on the other hand reduces permeable surface and increases flood risk. In developing countries like Pakistan, the rapid rural-to-urban migration not only accelerates environmental degradation and anthropogenic stress but also contributes to the proliferation of flood-prone informal settlements, including shanty towns and slums (Murmu et al., 2019; Patra et al., 2018). The expansion of cities in developing countries has a significant effect on climate change which eventually increased the frequency and intensity of the urban flooding. These activities are influenced by stream or river channel encroachment and abuse, increased paved surfaces and poor solid waste disposal techniques, a high level of illiteracy, a low degree of community awareness, poor environmental education, ineffective town planning laws, and poor environmental management. Additionally, climate change has exacerbated the urban flood event due to the squeezing of pervious surface (Huong & Pathirana, 2013). For example, word wide the dwellers of the slum area were found highly vulnerable and susceptible to flood hazards (Gupta, 2007; Rashid, 2000). However, this situation is very bad in Pakistan.

Pakistan is also facing the dilemma of rapid & unplanned urbanization. According to the 7th population census report of 2023, currently, 38.82 % of the population is living in urban areas (GOP, 2023), which may rise to 50% by 2025 (Malik & Wahid, 2014). Pakistan, being 5th most populous country in the world, is facing uncontrolled urbanization with increasing demand for housing and extending impervious covers in cities (GOP, 2020). The planned city of Islamabad (the capital of the country) and Rawalpindi, the 4th largest city of Pakistan are called twin cities and generally lie in the Nullah Lai basin (Kamran et al., 2023). The study aim of this study is to explore the implication of Land Use Land Cover changes on the urban flood vulnerability in the twin cities of Pakistan, i.e. Islamabad and Rawalpindi.

Expansion in a built-up area is the outcome of urbanization, reducing pervious land, increasing runoff, and ultimately emerging strong motives of the urban flood. Therefore, developing countries like Pakistan must carry out deep analysis of ever-growing urban centers through LULC studies which helpful to plan the city growth in the future (Seto, 2016).

Urbanization is a well-known issue of the 21st century, characterized by the rapid migration of populations from rural to urban areas. This migration is reshaping societies globally, presenting both merits and demerits. As cities expand, they become hubs of economic activity, innovation, and cultural exchange, offering improved access to education, healthcare, and employment. However, the rapid growth of cities, often outstrips the capacity of urban infrastructure and governance, leading to substantial social, environmental, and economic problems. In many developing countries, unplanned urban growth has led to overcrowded living conditions, increased inequality, and environmental degradation. It is estimated that by 2050, 70% of the world's population will be living in urban areas (Aziz, 2015; Malik et al., 2017). Currently, thousands of people per day are migrating from rural to urban areas, thus over-pressurizing the socio-economic resources of cities (Zhang, 2016). Associated issues of rapid and unplanned urbanization are not only improper housing, traffic congestion, lack of basic facilities, health issues, and unemployment but also pavement of land and consumption of green patches reducing pervious land (Al-Fugara et al., 2018). Urbanization and dynamically changing patterns of daily life are now becoming challenges for the carrying capacity of the environment (Cobbinah et al., 2015). Researchers have identified that in developing countries like Pakistan, lack of resources, unawareness, ignorance of laws are degrading the urban environment in terms of air quality, water resources, and urban flooding, etc.(Amir et al., 2020). South East Asia in general and developing countries like Pakistan in particular are facing the issue of rapid urbanization (Vasenev et al., 2019).

Population growth and urbanization are stressing urban centers where the built-up area is expanding and agricultural land is squeezing, ultimately reducing permeable surface which is one of the leading factors in urban flood (Zaman et al., 2020). In developing countries, to accommodate the influx of immigrants, illegal and unplanned housing projects are consuming agricultural land (Khalifa, 2015; Li et al., 2017). The driving forces like agricultural land expansion/contraction, unplanned urban growth coupled with high rate urbanization are behind land use land cover changes (Ewane, 2021). These changes are linked with human activities (Manandhar et al., 2009), which lead to changes in weather pattern by carbon emission and industrialization in urban areas. Urban sprawl has generated multiple environmental issues including disturbance of urban heat balance (Butt, 2015), and urban flooding especially during monsoon season (Akbar et al., 2022). The increasing urbanization in the study area has increased the runoff volume, which causes heavy flooding (Ahmed, 2021).

Urbanization in Pakistan is straining the urban land resources (Samie, 2017). Planned or unplanned urbanization consumes natural land resources i.e. barren land and vegetation etc. Comparatively, unplanned urbanization is more damaging to a sustainable environment than planned cities (Kuffer & Barrosb, 2011). Planned cities have designed patterns of wards/blocks and sectors etc. and their expansion pattern follows the same by-laws. Whereas, unplanned cities do not have such patterns, ignore by-laws, and expand without any futuristic approach or planning.

Land use change in terms of rapid urbanization, deforestation, etc. ultimately causes climate change like alterations in hydrological pattern, reduction in infiltration space, and increase in runoff (Loveland & Mahmood, 2014; Atif 2018, Samie, et.al., 2017; Ahmad et al., 2021). Urban growth whether planned or unplanned is a fundamental factor of land use land cover changes. LULC change is a natural and progressively time taking phenomena. Periodical detection of LULC change of a city helps not only to improve existing urban infrastructure but also, to carry out futuristic planning. In the modern era, Remote Sensing has emerged most accurate and speedy tool to monitor land use and land cover change (Abdullahi & Pradhan, 2016; Al-Sharif & Pradhan,

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2015). La Rosa & Wiesmann, 2013 have found that Remote sensing and GIS-based studies help in deciphering the spatial-temporal connotation of Urbanization (La Rosa & Wiesmann, 2013). RS & GIS techniques are gaining popularity with accurate estimation of land resources management (Hegazy & Kaloop, 2015).

Extensively LULC changes studies on Islamabad and Rawalpindi have been carried out with different perspectives. Those changes were linked to the heat island of the city (Hassan et al., 2016), or their impact on the watershed of Simply Dam, located near Islamabad (Butt, 2015). Human impacts on LULC changes in Rawalpindi along with their impact on the supply-demand of the budget of the urban ecosystem were also discussed (Khan, 2013; Bokhari et al., 2021). The perception of residents about the urban vegetation of Islamabad and Rawalpindi was also studied (Bokhari et al., 2018). However, there is a dearth of scientific studies on the impact of land use land cover transformation on urban flooding in the twin cities of Islamabad and Rawalpindi. The current study explores the nexus between LULC changes, Urbanization, and Urban flooding with reference to loss of permeable land during 2000-2023 using advance geospatial technique. Environmental problems of Islamabad, a planned city, and Rawalpindi, an unplanned city are constantly facing high population growth, high rate of urbanization and urban sprawl, and congestion (Bokhari et al., 2018).

2.0 Material and Methods

This study employs a combination of remotely sensed satellite imagery, field survey data, and secondary data sources (**Figure 01**). For the analysis of urban land use and land cover (LULC) changes, Landsat 7 (ETM+) data for the years 2000 and 2007, Landsat 8 (OLI & TIRS) for 2015, and Landsat 9 (OLI-2 & TIRS-2) for 2023 were acquired from USGS official website (https://earthexplorer.usgs.gov). Only images with less than 10% cloud cover were selected (**Table 01)**. For Flood vulnerability, risk and damages assessment, data were collected from primary sources through questionnaire survey, field observation, focus group discussion and interview while conducting an extensive field survey in the Study Area. For primary data collection multiple stage stratified sampling technique were adopted. In the first stage, sample size was determined based on 34 vulnerable areas located across 12 union councils (UCs) out of a

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total of 74 UCs in Rawalpindi District. Each of these 12 UCs was treated as a separate stratum, and a total of 386 questionnaires were surveyed from 12 union councils through random sampling method. Secondary data related flood damages were explored from Water and Sanitation Authority (WASA), PDMA, RESCUE 1122 and Punjab Development Statistics (PDS) while time series precipitation data from 1980 to 2023 were collected from Pakistan Meteorological Department (PMD) Rawalpindi.

Table I: Characteristics of Landsat

Year	Satellite	Sensor	Date	Cloud Cover by Image Scene	AOI Cloud Cover
2000	Landsat 7	Enhanced Thematic Mapper Plus (ETM+)	4/11/2000	0%	0%
2007	Landsat 7	Enhanced Thematic Mapper Plus (ETM+)	4/15/2007	0%	0%
2015	Landsat 8	Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS)	4/13/2015	0.14%	0%
2023	Landsat 9	Operational Land Imager 2 (OLI-2) and the Thermal Infrared Sensor 2 (TIRS-2)	4/11/2023	4.38%	0%

2.1 Satellite Imageries Pre-Processing & Classification

Pre-processing is essential to establish a direct link between physical aspects of land and acquired data (Butt, 2015). To remove the atmospheric effect on spectral values of imageries, atmospheric correction was carried out. The study area was extracted using Arc Map 10.7 software. In light of the objective of the study, four LULC classes, built-up (red), vegetation (green), water bodies (blue) & barren land (light brown) were used for supervised classification as shown in **Table (2)**. A sufficient number of samples of each class were collected from the study area by drawing polygons. The area enclosed by the polygon is used to represent in spectral signature of the respective class. To select each class with maximum accuracy, different band combinations were applied to enhance imageries (Gao & Liu, 2010).

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Table 2: Description of Land Use Classification

LULC Type	Description
Built-up area	The class of land includes impervious surface and anthropogenic structures like roads, buildings, concrete, and asphalt structures, etc.
Vegetation	Green belts, grasslands, forests, and cropland, etc. are part of this class of land.
Water bodies	Inundated areas, lakes, and reservoirs are counted in this class of land.
Barren land	Areas without any vegetation, built-up areas, or any type of permanent settlement are called the spatial class of Barren Land.

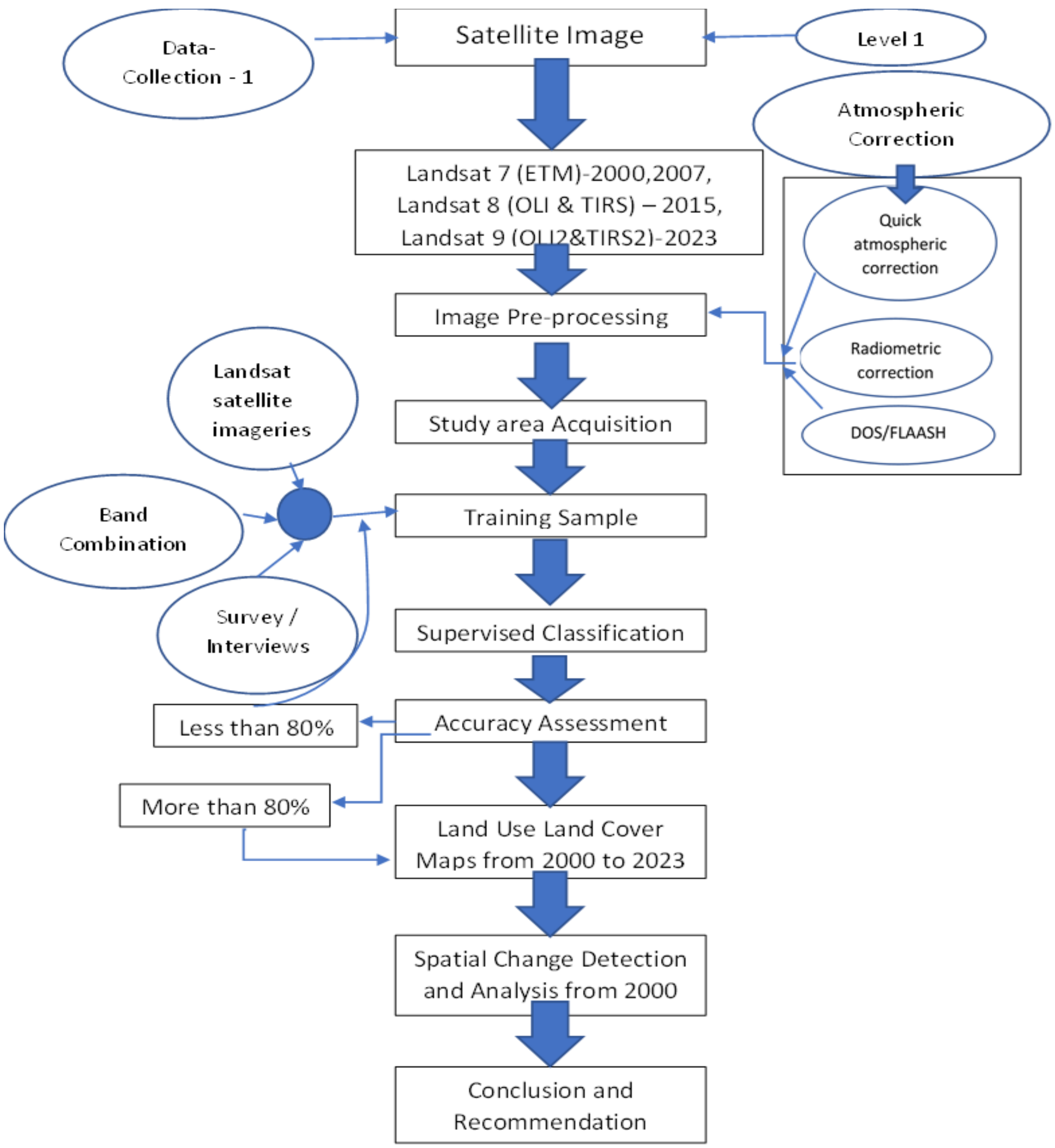

Fig 01. Research Framework

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2.2 Accuracy Assessment

To identify the level of agreement between classified images and a set of reference data, accuracy assessment was deemed essential (Congalton, 2019; Tadese et al., 2020; Aldoski et al., 2013). In LULC, accuracy assessment is a key feature and useful for validating the findings (Ahmadizadeh, 2014; Shetty, 2019; Kogo et al., 2021; Langat et al., 2021). During the post–supervised classification stage, accuracy assessment, and spatial change detection were performed. Imageries of 2000, 2007,2015, and 2023 were chosen to carry out accuracy assessment. Maps of LULC classification from 2000 to 2023 were prepared with samples of more than 80% accuracy. Change detection technique was applied to assess and quantify the LULC changes from 2000 to 2007, 2007 to 2015, and 2015 to 2023, as well as overall land use land cover change from 2000 to 2023 (**Table 03**). The result shows that overall accuracies were 94%, 84%, 84%, and 82% with Kappa coefficient values of 0.93, 0.8, 0.8, and 0.79 for the years 2000, 2007, 2015, and 2023 respectively (**Table 03**).

Table 03: Accuracy Results of LULC Classification

Year/Accuracy	**2000**	**2007**	**2015**	**2023**
Overall Accuracy (%)	94%	84%	84%	82%
Kappa Coefficient	0.93	0.8	0.8	0.79

2.3 Data Analysis

To analyze urban flood vulnerability, the collected data were analyzed using the following indices**:**

2.3.1 Flood Vulnerability Index (FVI):

To assess flood vulnerability, the flood Vulnerability Index (FVI) was calculated by analyzing its key components—social, economic, and physical-environmental factors. The FVI, a composite index scaled between 0 and 1, offers critical insights into the exposure, susceptibility, and resilience of different urban areas to flood hazards. The assessment provides a practical tool for disaster preparedness and future planning in urban flood-prone areas. Each component was quantified using the following equation (1).

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FVI=E × S/R **(Eq. 1)**

Where:

S stands for susceptibility, E for Exposure, and R for Resilience

To determine flood susceptibility, various content groups are used. Four components of multidimensional vulnerability—population, vulnerability, mortality vulnerability, agriculture, and economic vulnerability—are proposed by Huang et al. (2012). However, in the context of an urban area, the FVI system as stated by Balica et al. (2012) is more pertinent for urban areas. By classifying the components into three groups of indicators—exposure (E), susceptibility (S), and resilience (R)—a general formula for FVI is computed.

FVI=E x S/R ------ **(Eq. 2)**

With regards to urban flood indicators, the equation converts into the following.

$$FVI_{social} = \left[\frac{P_D * C_H * P_G * \%_{disables} * C_M}{P_E * \frac{A}{P} * S * W_S * E_R * E_S}\right] \text{----------------} \quad \textbf{(Eq. 3)}$$

$$FVI_{Economics} = \left[\frac{I_{ND} * C_R * U_M * U_G * H_{DI} * R_D}{F_I * Am_{inv} * D - S_C * D}\right] \text{------------} \quad \textbf{(Eq. 4)}$$

$$FVI_{sEnvironmental} = \left[\frac{U_G * R_{ainfall}}{E_V * L_U}\right] \text{-------------------} \quad \textbf{(Eq. 5)}$$

$$FVI_{Physical} = \left[\frac{C_R * T}{\frac{E_V}{R_{ainfall}} * \frac{S_C}{V_{year}} * D - L}\right] \text{-------------------} \quad \textbf{(Eq. 6)}$$

The index shows an urban area's low or high flood risk as a value between 0 and 1 **(Table 04)**. The method provides a direction to evaluate the FVI of an area for future planning and mitigation measures. In the present study, the indicators were modified to adjust them according to the socio-economic and environmental conditions of urban areas of developing countries like Pakistan.

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Table 4: Flood Vulnerability

Index value	Description
<0.01	Very small vulnerability to flood
0.01-0.25	Small vulnerability to floods
0.25-0.5	Vulnerability to floods
0.5 – 0.75	High vulnerability to flood
0.75 – 1	Very high vulnerability to flood

2.4 Profile of the Study Area

The focus of this study is Islamabad and Rawalpindi, the twin cities of Pakistan. Geographically, the study area is located in the foothills of the Margalla in the Nullah Lai basin (NLB), with elevations ranging from 500 m to 1600 m above mean sea level (**Figure 2**). Islamabad is a planned city and it was developed in 1960 (Kamran et al., 2023; Latif et al., 2017) while Rawalpindi is an old and unplanned city. The study area is highly susceptible and vulnerable to flood hazard. From 1944 to 2023, the study area witnessed 19 major flood events, but the most devastating was of 2001 flood, which took 74 lives and damaged infrastructure worth $ 0.5 Billion (JICA, 2003; JICA, 2003;WASA, 2024; Ahmed, 2021).

The annual rainfall again varies from 1223 mm in the Northern part i.e. city of Islamabad to 1240 mm in the southern part i.e. city of Rawalpindi. Maximum rainfall occurs during monsoon months of July to September.(Liu & Jiang, 2021). The climate of the area is humid sub-tropical type. The northern part of the study area consists of the well-planned capital city of Islamabad. The city is divided into 9 main zones including residential, administrative, commercial, diplomatic, industrial, and educational, etc. Being the capital of the country, it is a hub of government offices and a main attraction for people to visit. South of the I sector of Islamabad is the IJP road, further south of the road, the boundary of the historic city of Rawalpindi starts. It has industrial, residential, and extensive commercial zones thus making it 4th largest city of Pakistan. The city is flood-ridden especially during monsoon season. Local streams like Nullah Lai, poor drainage, and congested settlements make the city vulnerable to flood, especially during the monsoon season (July to September).

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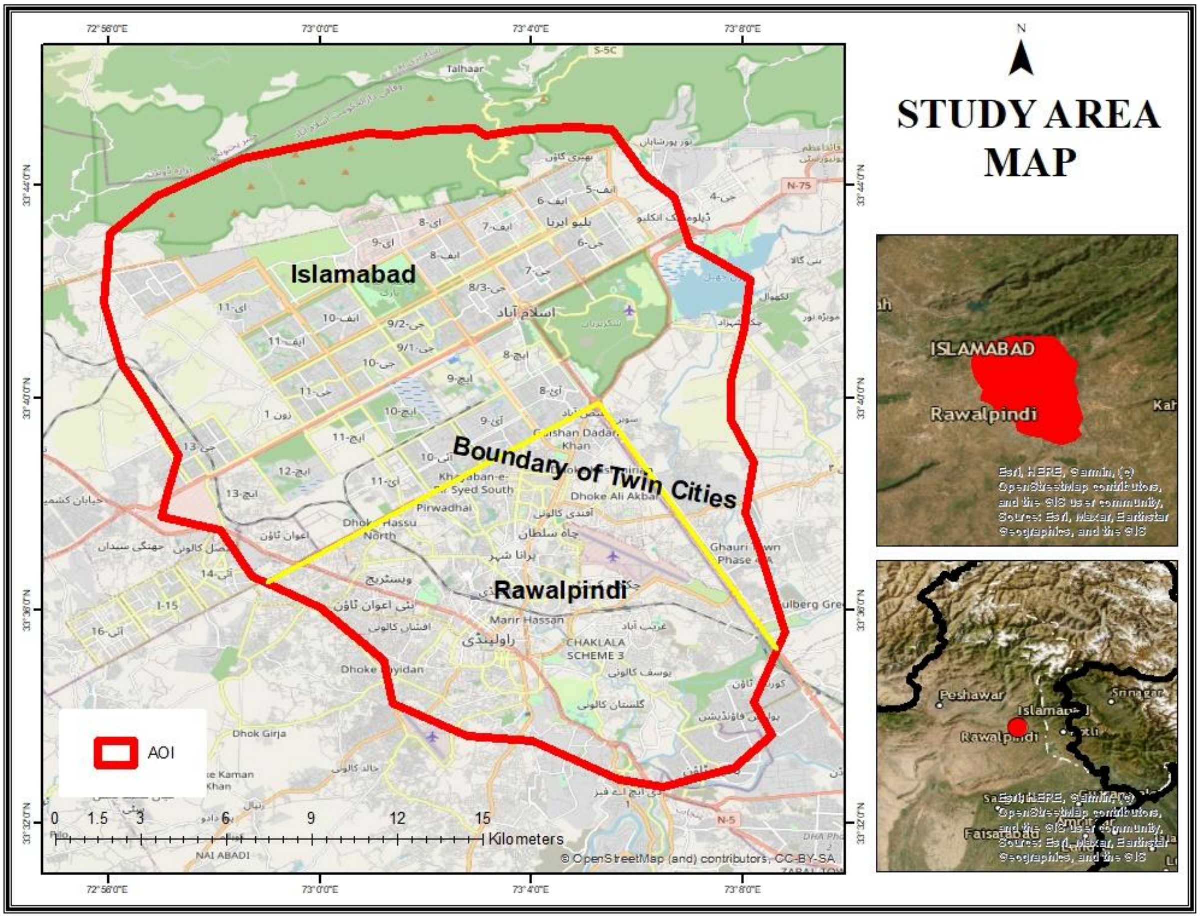

Figure 2: Map of Nullah Lai Basin - Twin cities Islamabad & Rawalpindi (Study Area)

3.0 Result

3.1. Spatio-temporal Changes in Urban Land Use and Land Cover

The analysis of land use and land cover changes reveals a dynamic transformation driven primarily by urban expansion. Overall, urbanization has led to a steady conversion of vegetation and barren land into built-up areas. However, an exception was observed during the period from 2000 to 2007, wherein vegetation cover exhibited a temporary increase. This trend reversed between 2007 and 2023, marked by significant growth in built-up areas accompanied by a noticeable decline in vegetated land. These findings indicate a continuous and accelerating pattern of land conversion, primarily characterized by the replacement of natural and undeveloped surfaces with urban infrastructure. In twin cities, in 2000, vegetative cover of 39.43% (128.35 sq.

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km) was the highest whereas, 38.72% (126.53 sq. km) of land was covered with the built-up area. Moreover, 20.74% (67.78 sq. km) land was barren followed by only 1.12% (3.65 sq. km) water. In 2007, vegetation-covered land with 59.74% (195.22 sq. km) was the highest and 30.10% (98.30 sq. km) was built-up area. Whereas, barren land reduces to 8.41% (27.48 sq. km) and water rose to 1.75% (5.73 sq. km). Barren land has been converted into built-up area and covered with vegetation. In 2015, vegetation cover and built-up areas were 49.53% (161.86 sq. km) and 33.77% (110.36 sq. km) respectively. Whereas, barren land and water bodies covered 14.27% (46.62 sq. km) and 2.44% (7.96 sq. m) respectively. In 2023 vegetation cover and built-up areas were 45.27 % (147.85 sq. km) and 41.72 % (136.25 sq. km) respectively. In 2023, barren land was reduced to 10.23% (33.4 sq. km), whereas water increased to 2.78% (9.08 sq. km) (**Table 5**). Margallah forest with extensive vegetation in the Capital City Islamabad makes the leading figure of vegetation cover. In the study area, south of the I sector, the Katarina bridge starts unplanned Rawalpindi city with extensive built-up area and scanty vegetation. In Rawalpindi, due to unplanned built-up areas, increasing impervious surface coupled with other anthropogenic factors, make the city vulnerable to urban flood. In the study area, major water bodies are Mangla Dam Lake (Islamabad territory) and Nullah Lai and its tributaries, one of the factors of the urban flood.

Table 5: Land Use Land Cover Change in Islamabad and Rawalpindi, 2000-2023

Class	**2000**		**2007**		**2015**		**2023**	
	Area		Area		Area		Area	
	Sq. km	%	Sq. km	%	Sq. km	%	Sq. km	%
Built-Up	126.53	38.72	98.38	30.10	110.36	33.77	136.25	41.72
Barren Land	67.78	20.74	27.48	8.41	46.62	14.27	33.40	10.23
Vegetation	128.85	39.43	195.22	59.74	161.86	49.53	147.85	45.27
Water	3.65	1.12	5.73	1.75	7.96	2.44	9.08	2.78
Total	326.81	100.00	326.81	100.00	326.80	100.00	326.59	100.00

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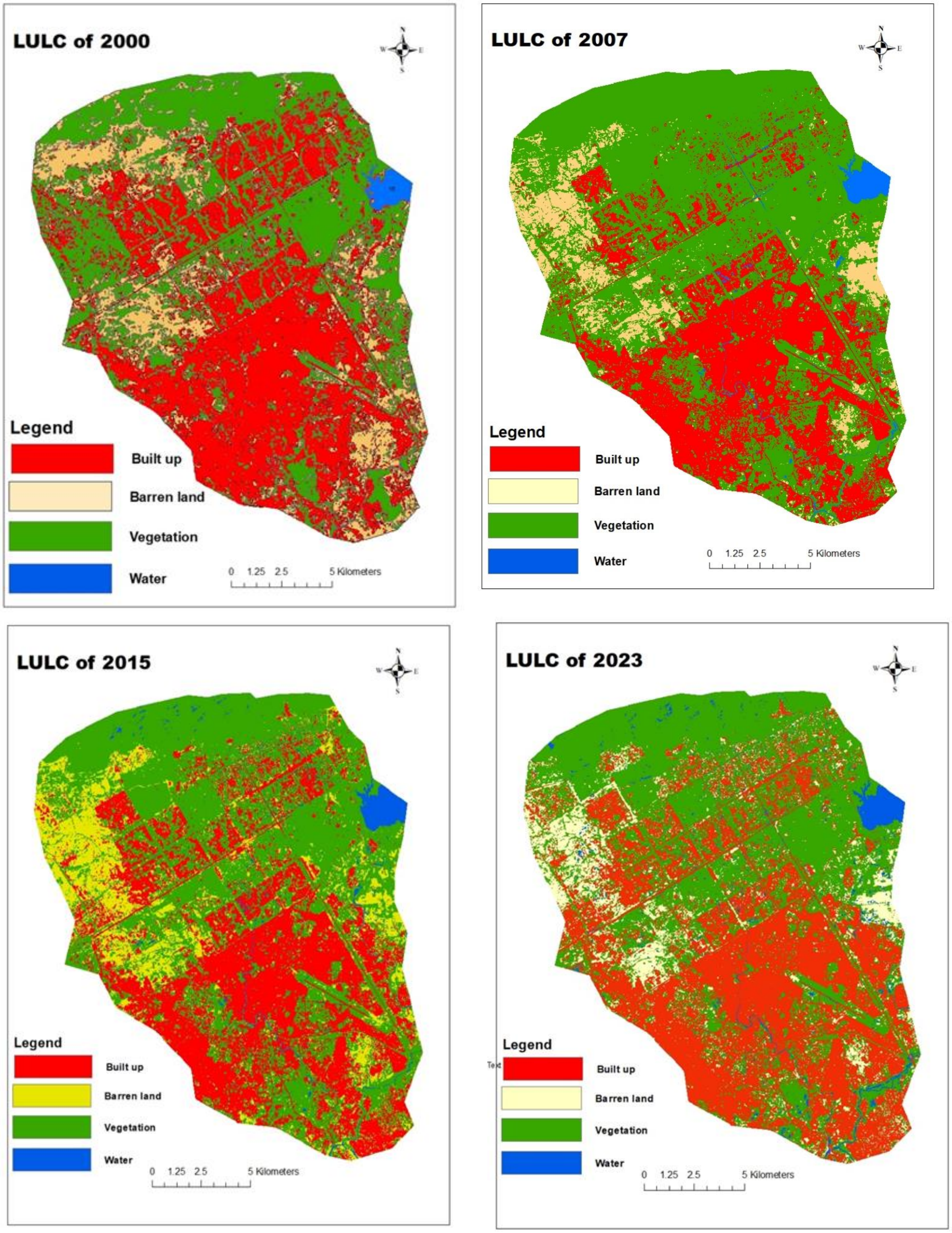

Figure 3: Land Use Land Cover Change of Map of Islamabad and Rawalpindi, 2000-2023

3.2 Change Detection

Over a period of time, one class converts into a second spatial class e.g. increasing urbanization converts vegetation and barren land into a built-up area. The study also assesses the spatial change from one class to specifically other class during particular time period. During 2000 to 2007, the bulk of barren land i.e. 44.95 sq. km (66.35%) of the land has been converted into vegetation, which is a healthy sign and outcome of extensive vegetation drive, especially in Islamabad. Where Capital Development Authority has played a leading role. Whereas, 12.91 sq. km (19 %) of barred land has also been converted into built-up areas, a sign of urbanization. As far as the built-up area is concerned, the major share of 77.43 sq. km (61.21 %) has retained its status as a built-up area. Nonetheless, 44.99 sq. km (35.57 %) of built-up area has been converted into vegetation or afforested. In case of vegetation, again bulk share i.e. 104.98 sq. km (81.5 %) has been retained by vegetation. This means very little deforestation could be seen during this period. On the other hand, 7.98 sq. km (6.20 %) and 0.77 sq. km (0.60 %) of vegetation have been converted into built-up areas and water respectively. Water class has retained its class as water i.e. 3.40 sq. km (93.18 %). The conversion of the water class, into other classes like barren land, vegetation, and the built-up area was negligible. Overall, the period from 2000 to 2007 can be considered as the best time in term of environmental sustainability. Urban co-system was maintained because of special attention by institutions in the shape of afforestation and maintaining vegetation cover of land.

Between 2007 and 2015, it is evident by the fact that only 5.45 sq. km (19.85 %) of barren land was converted into vegetation land, as compared to the previous period, when the same ratio was 44.95 sq. km (66.35 %). On the other hand, 20.89 sq. km (76.7 %) of barren land has remained as barren land. Whereas, the same ratio from 2000 to 2007 was 9.58 sq. km (14.14 %). As far as the built-up area is concerned, 88.45 sq. km (89.92 %) has maintained the status quo previously it was 61.21 %. On the other hand, only 7.09 sq. km (7.21 %) built-up area has been converted into vegetation. When we compare this change with the previous period, it reveals that the ratio of conversion of built-up area into vegetation was very high. From 2000 to 2007 44.99 sq. km (35.57 %) of built-up area has been converted into vegetation. Again, this confirmed the fact that the period from 2000 to 2007 was best in term of the preservation of urban ecology and environmental sustainability.

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Vegetation class has retained its status. Here 148.71 sq. km (76.20 %) of vegetation class has been preserved, but less than the previous period when 81.52 % of vegetation class did not change. Another alarming aspect was the increasing conversion of vegetation land into built-up land. Almost 20.14 sq. km (10.32 %) of vegetation land has been converted into built-up area. Again, the comparison indicates that from 2000 to 2007 only (6.20%) of vegetation land was converted into built-up areas i.e. urbanization. Although 4.35 sq. km (75.90 %) of water area has retained its class but far less than from 2000 to 2007, when it was 93.18 %. It means that during the years 2007 to 2015, water resources were also squeezed. Another alarming aspect is that 0.71 sq. km (12.39 %) of water area has been converted into a built-up area. Whereas from 2000 to 2007 the ratio was only 0.03 sq. km (0.85 %). Overall change assessment of the years 2007 to 2015 reflects that very little attention was paid to environmental sustainability. In the study area, the major focus was on urbanization at the cost of barren land and vegetation land.

During 2015 to 2023, 9.65 sq. km (14.26 %) and 24.35 sq. km (35.97 %) of barren land have retained their class and changed into built-up area respectively. There was a healthy sign, where 15.45 sq. km (33.18 %) of barren land has been converted into vegetation. The ratio of the same change was higher than in the previous period when it was 5.45 sq. km (19.85 %). The barren land of 1.02 sq. km (2.19 %) was converted into water indicating concern of urban ecologists. The ratio was higher than the previous period when it was only 0.07 sq. km (0.26 %). By and large, the built-up class has maintained the status quo, 101.81 sq. km (92.32 %) of land has remained as built-up area. The ratio was higher (88.92 %) during the 2007 to 2015 period. During the 2015 to 2023 period 4.54 sq. km (4.11 %) of built-up land has been converted into vegetation. It is worth mentioning here that the same ratio from 2007 to 2015 was 7.09 sq. km (7.21 %).

As far as the change assessment of vegetation land is concerned, the era was slightly better than 2007 to 2015. Here 125.69 sq. km (77.74 %) of vegetation land has retained its class. Whereas, during 2007 to 2015, the same ratio was 148.71 sq. km (76.20 %). On the other hand, 21.88 sq. km (12.53 %) of vegetation land has been converted into built-up area. During the period from 2015 to 2023, water resources were squeezed. Now 4.58 sq. km (57.65 %) of water area has retained its status. Whereas, the same ratio during 2007 to 2015 was 4.35 sq. km (75.9 %). On the other hand, during 2015 to 2023, 2.14 sq. km (26.89 %) of water land has been converted into

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vegetation. It is concluded that during the era of 2015 to 2023, authorities have been sensitized about sustainable environment. However, the efforts of forestation or expansion of water resources were compromised by rapid urbanization.

The LULC change assessment of 23 years from 2000 to 2023 indicates that overall, 32.56 sq. km (48.14 %) of barren land has been converted into vegetation land, which is a healthy sign. On the other hand, 24.35 sq. km (35.97 %) of barren land has been changed into a built-up area. As far as the built-up area is concerned, 91.39 sq. km (72.30 %) has remained as built-up area, whereas, 26.63 sq. km (21.07 %) was changed into vegetation. Although 88.46 sq. km (68.73 %) of vegetation land has retained its class as vegetation land, 20.41 sq. km (15.86 %) of vegetation land has been converted into built-up area, an outcome of urbanization. During the entire period, there was no major change in water class i.e. maintained the status quo of 3.43 sq. km (93.93 %). Mangla Dam is a major water body in the study area. Part of it i.e. 0.15 sq. km (3.97 %) has been converted into vegetation. Overall analysis of the entire period reveals that to some extent, efforts have been made for environmental sustainability through forestation and vegetation drives. In this regard, the CDA has played a leading role in the afforestation drive, whereas the Rawalpindi Development Authority has very little participation. The squeezing of permeable land has increased the danger of urban flood, which can be indicated by the number of flood events in Rawalpindi city alone. The increased trend of vegetation throughout the period is because of the Public Leading Program of Afforestation and Plantation including National Vision 2030, National Forest Policy 2010, etc. (Zaman et al., 2020). The programs were judiciously implemented by the Capital Development Authority (CDA). It is the very reason that Islamabad City is greener than Rawalpindi. During the last 20 years, CDA has planted hundreds of thousands of trees in Islamabad (Ahmed et al., 2023; Liu & Jiang, 2021). Migration from rural to urban areas is being attracted by better quality of public services, affordable housing, water supply, better infrastructure, job opportunities, etc. The provision of such facilities in rural areas will reduce rural-urban migration and unplanned urbanization. In the study area, almost 200 housing societies, the majority within the jurisdiction of the Rawalpindi Development Authority (RDA) are operating without NOC. Institutions, especially RDA and CDA should take firm measures to counter unplanned and speedy urbanization. Authorities should also promote afforestation and sustainability of natural resources/

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ecosystem of Nullah Lai basin in general and in Rawalpindi in particular. Massive campaigns for public awareness for the general public and all stakeholders should be launched to aware negative implication of built-up layer consequent ecosystem degradation. To further confirm the nexus between urbanization and urban flood, in succeeding paragraphs, a comparison of LULC of twin cities is also given.

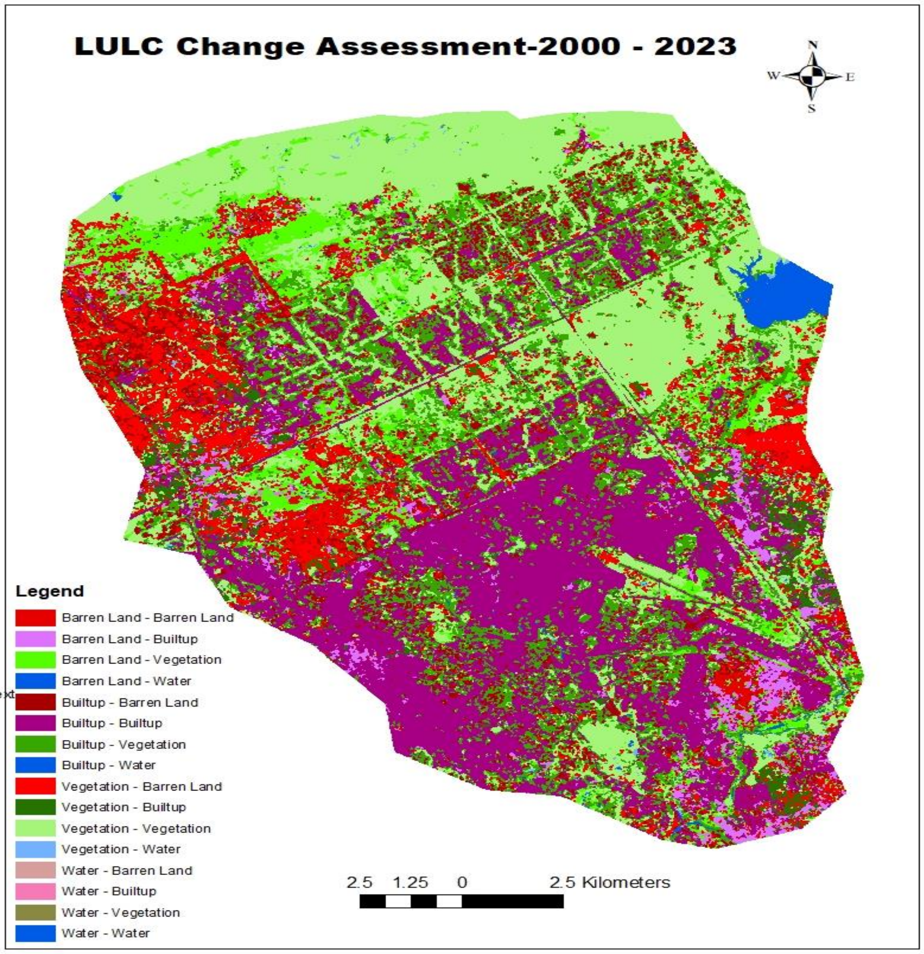

Figure 4: LULC change assessment from 2000 to 2023

During the year 2000, the percentage of built-up area in Rawalpindi was 40% higher than in Islamabad. Vegetation of the same year was 34.92% less in Rawalpindi as compared to Islamabad. In the year 2007, the same trend could be seen, when the built-up area was 49.31% more and Vegetation was 38.75% less in Rawalpindi as compared to Islamabad. In the same year barren land is 9.33% less in Rawalpindi than in Islamabad. It was because of the conversion of

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barren land into built-up areas. In the year 2015, the analysis revealed that barren land and vegetation were 10.37% and 28.10% less respectively in Rawalpindi. In 2023, the situation is further alarming, where the built-up area is 44.13% more in Rawalpindi as compared to Islamabad. In case of barren land and vegetation, the trend is reversed, where the former is 8.10% less and later is 34.45% less in Rawalpindi as compared to Islamabad. The analysis indicates that during the entire era from 2000 to 2023, there was an increasing urbanization trend in Rawalpindi. Urbanization has consumed the vegetation land and barren land, ultimately damaging the Urban ecology.

Table 6: LULC Change Detection, 2000 to 3023

Class	**2000 to 2007**		**2007 to 2015**		**2015 to 2023**		**2000 to 2023**	
	Area		Area		Area		Area	
	Sq. km	%	Sq. km	%	Sq. km	%	Sq. km	**%**
Barren Land to Barren Land	9.58	14.14	20.89	76.07	18.54	39.82	9.65	14.26
Barren Land to Built-up	12.91	19.06	1.05	3.81	11.55	24.82	24.35	35.97
Barren Land to Vegetation	44.95	66.35	5.45	19.85	15.45	33.18	32.56	48.10
Barren Land to Water	0.30	0.45	0.07	0.26	1.02	2.19	1.13	1.67
Class Total	**67.74**	**100.00**	**27.46**	**100.00**	**46.56**	**100.00**	**67.69**	**100.00**
Built up to Barren Land	2.82	2.23	2.42	2.46	3.60	3.27	6.85	5.42
Built-up to Built-up	77.43	61.21	88.45	89.92	101.81	92.32	91.39	72.30
Built-up to Vegetation	44.99	35.57	7.09	7.21	4.54	4.11	26.63	21.07
Built-up to Water	1.26	0.99	0.40	0.41	0.33	0.30	1.54	1.22
Class Total	**126.49**	**100.00**	**98.36**	**100.00**	**110.29**	**100.00**	**126.40**	**100.00**
Vegetation to Barren Land	15.05	11.69	23.18	11.88	10.98	6.79	16.86	13.10
Vegetation to Built-up	7.98	6.20	20.14	10.32	21.88	13.53	20.41	15.86
Vegetation to Vegetation	104.98	81.52	148.71	76.20	125.69	77.74	88.46	68.73
Vegetation to Water	0.77	0.60	3.13	1.60	3.14	1.94	2.98	2.32
Class Total	**128.79**	**100.00**	**195.16**	**100.00**	**161.69**	**100.00**	**128.71**	**100.00**
Water to Barren Land	0.01	0.17	0.10	1.80	0.26	3.31	0.02	0.47
Water to Built-up	0.03	0.85	0.71	12.39	0.97	12.15	0.06	1.63
Water to Vegetation	0.21	5.80	0.57	9.91	2.14	26.89	0.15	3.97
Water to Water	3.40	93.18	4.35	75.90	4.58	57.65	3.43	93.93
Class Total	**3.65**	**100.00**	**5.73**	**100.00**	**7.95**	**100.00**	**3.65**	**100.00**

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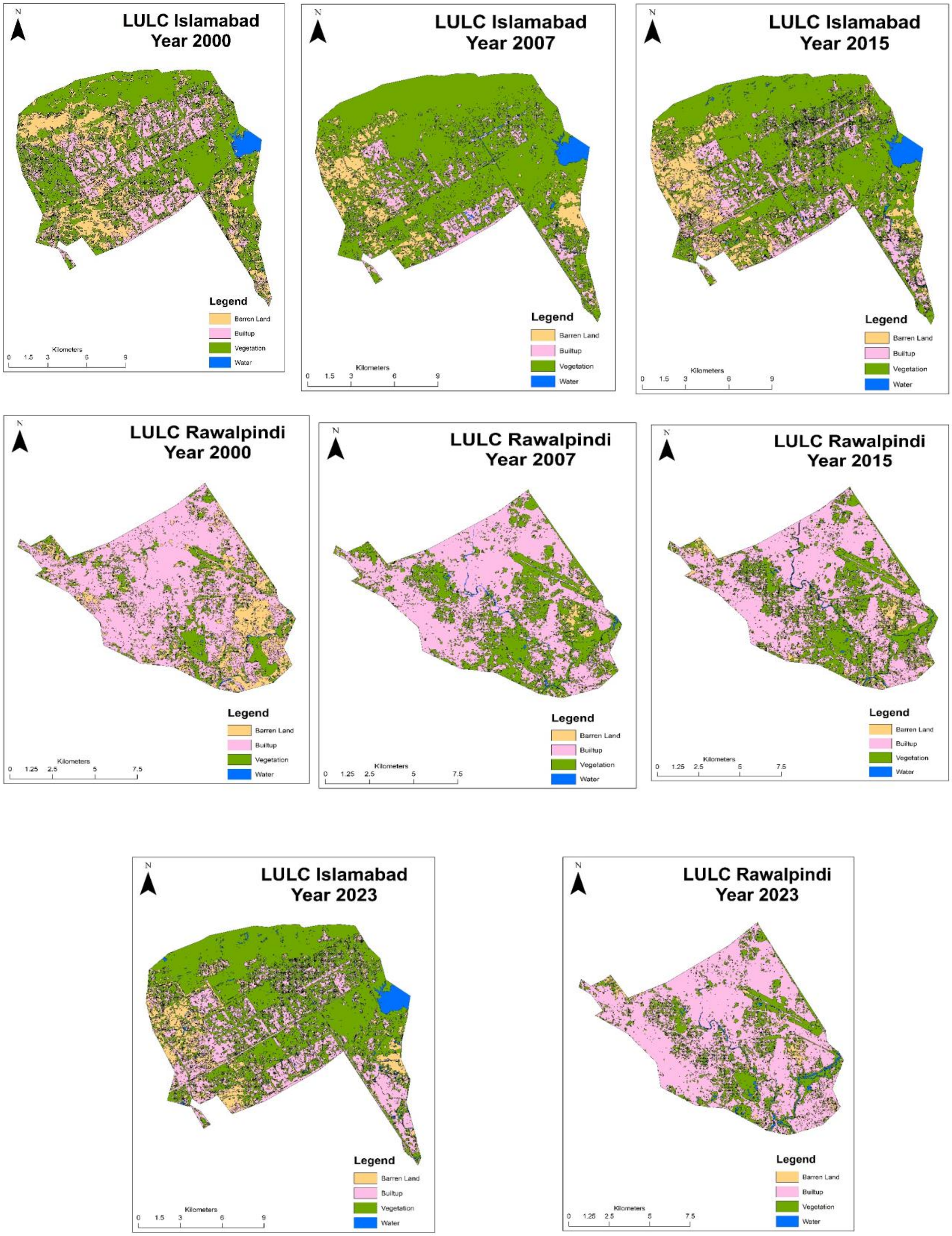

Figure 05: Comparison of Land Use & Land Cover Changes in Rawalpindi and Islamabad

Table 7: LULC Changes in Rawalpindi and Islamabad

Year	Classes	Rawalpindi		Islamabad		Gain/loss of LULC Classes
		Area sq. km	Area %	Area sq. km	Area %	Less/More in %
2000	Barren land	20.74	18.22	46.90	22.05	-3.83
	Built-up area	73.83	64.86	52.70	24.78	40.08
	Vegetation	18.97	16.67	109.72	51.59	-34.92
	Water	0.29	0.25	3.36	1.58	-1.33
	Total	**113.83**	**100.00**	**212.69**	**100.00**	**0.00**
2007	Barren land	2.66	2.34	24.82	11.67	-9.33
	Built-up area	70.86	62.25	27.52	12.94	49.31
	Vegetation	39.22	34.46	155.70	73.21	-38.75
	Water	1.08	0.95	4.65	2.18	-1.23
	Total	**113.83**	**100.00**	**212.69**	**100.00**	**0.00**
2015	Barren land	8.56	7.52	38.06	17.89	-10.37
	Built-up area	68.23	59.94	42.13	19.81	40.13
	Vegetation	35.49	31.18	126.07	59.28	-28.10
	Water	1.54	1.35	6.42	3.02	-1.66
	Total	**113.83**	**100.00**	**212.68**	**100.00**	**0.00**
2023	Barren land	5.64	4.96	27.76	13.06	-8.10
	Built-up area	80.21	70.50	56.04	26.37	44.13
	Vegetation	25.92	22.78	121.64	57.23	-34.45
	Water	2.00	1.75	7.09	3.33	-1.58
	Total	**113.77**	**100.00**	**212.53**	**100.00**	**0.00**

3.3. Impact of LULC Change and Urbanization on Urban Flood Vulnerability

Similar to other urban centers (Chang & Franczyk, 2008: Escher, 2009; Esch et al., 2009), LULC change is a major concern of urban flooding in the study area. The history of floods as indicated that Rawalpindi is highly susceptible and vulnerable to flood and remained the most flood-affected city in Pakistan. From 1944 to 2023, the study area witnessed 19 major flood events in Rawalpindi, however, one of the most devastating floods was occurred in 2001, resulting in the loss of 74 precious human lives and causing approximately US$ 0.5 million in infrastructure damage (JICA, 2003; JICA, 2003; Ahmed, 2021;WASA, 2024). Moreover, from 2007 to 2023, due to the expansion of the built-up area, and reduction of permeable land, 7 to 8 major and several

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minor flood events occurred. The analysis has confirmed that rapid urbanization especially at the cost of the urban environment, is a major factor in urban flooding in Islamabad and Rawalpindi.

The flood vulnerability of Rawalpindi and Islamabad was assessed by using the flood vulnerability index (**Equation 1-4** & **Table 8**). The flood vulnerability Index (FVI) was computed for social, economic, environmental, and physical factors for the four administrative units of Rawalpindi District. The analysis reveals considerable spatial variability in flood vulnerability and susceptibility. The overall FVI for the District Rawalpindi is 0.47 which indicates the entire Rawalpindi is highly susceptible and vulnerable to flood hazard. This is primarily attributed to abrupt change in LULC, unplanned urbanization, lack of enforcement of building bylaws, and low community awareness. From the comparative LULC analysis between Rawalpindi and Islamabad, it is inferred that a substantial increase in built-up areas in Rawalpindi, leading to reduced green space and limited water infiltration capacity (**Figure 5**). The FVI of social vulnerability is 0.62, indicating widespread exposure and susceptibility due to socio-economic constraints, such as high population density, poor housing conditions, poor drainage system and limited flood-related early warning system. According to perception of 70 % respondents, the primary trigger for flooding in Rawalpindi was identified as clogged and poorly maintained sewerage systems. The statistics of environmental vulnerability is 0.49 which is also high. The main reason of high environmental vulnerability is primarily due to the degradation of natural drainage system and the expansion of impervious surfaces. Economic and physical vulnerabilities were also significant in Rawalpindi, with FVI values of 0.375 and 0.394, respectively (**Figure 6** & **Table 8**).

The result indicates that Rawalpindi Metropolitan Corporation (RMC) recorded the highest cumulative FVI of 0.5, indicating the most flood-prone area in Islamabad and Rawalpindi cities (**Table 8**). This is primary attributed to its historic core and unplanned area, dense and unregulated settlements, inadequate drainage, poor and outdated infrastructures. The result reveals that the social FVI for RMC was highest at 0.674, indicating acute societal susceptibility. The physical FVI in RMC was 0.566, reflecting a very poor, outdated and inadequate infrastructures in Rawalpindi Metropolitan Corporation (**Table 8**). Furthermore, the spatial distribution of vulnerability indicates 33 flood-prone neighborhoods. According to field data, approximately 60%

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of the high-risk zones are located within the jurisdiction of RMC, followed by Chaklala Cantonment (22%) and Rawalpindi Cantonment (18%). The majority of households belong to low-income groups, with more than 60% residing in houses smaller than five (5) *marla*, constructed over 20 years ago (Focus group discussion & interview, 2024). The physical state of housing and proximity to Nullah Lai further exacerbate their flood risk and susceptibility. According to Manawi et al. (2020), unsustainable development, poor drainage structure, and increasing impervious surface are major contributing factors of urban flooding worldwide.

Contrary to this, Rawalpindi Cantonment (RC) recorded lower cumulative vulnerability scores of 0.4. However, RC exhibited the highest economic vulnerability (FVI= 0.6). it is attributed to unemployment, lower household incomes and limited financial capacity to implement flood mitigation measures. The result indicates that Chaklala Cantonment (CC), however, still vulnerable to urban flood hazard but has the lowest cumulative FVI at 0.36, reflecting relatively better management practices, particularly in terms of physical infrastructure and enforcement of urban planning regulations Rawalpindi city (**Figure 6; Table 8**).

Table 8. Flood Vulnerability in Rawalpindi and Islamabad

Area		FVI (Social)	FVI (Economic)	FVI (Environment)	FVI (Physical)	Cumulative FVI
Rawalpindi	Overall	0.62	0.375	0.496	0.394	0.471
	RMC	0.674	0.236	0.435	0.566	0.5
	Rawalpindi Cantt	0.674	0.326	0.333	0.196	0.4
	Chacklala Cant	0.592	0.443	0.162	0.275	0.363
Islamabad		0.36	0.17	0.14	0.12	0.24

The result in **Table (8)** shows that Islamabad also susceptible to hydrometeorological disaster including urban flooding but exhibited lowest cumulative vulnerability scores in term of social, economic and physical vulnerabilities. It is attributed to effective governance, strategic urban planning, regulated and sustainable land use practices have contributed to relatively controlled LULC changes in Islamabad (**Figure 5**). Therefore, the adverse environmental impacts have been minimized. Despite its planned urban fabric, Islamabad exhibits a very limited coping

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capacity for flood resilience, indicating that even well-designed urban environments are not entirely protected to extreme weather and hydrometeorological events.

A: Nulla Lai Flood

B: Old City of Rawalpindi after Flood

C: Murree Road Rawalpindi – Urban Flooding

D: A house of Satellite Town Rawalpindi after Flood

Figure 6: Pictures of Urban Flood in Rawalpindi

Discussion and Conclusion

The study provides a comprehensive geospatial assessment of the impact of LULC changes on urban flood vulnerability in Islamabad and Rawalpindi, the twin cities of Pakistan. From the past two decades, significant land use land cover changes have been witnessed in the study area. Between 2000 and 2023, the built-up area increased drastically with the massive decrease of

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vegetation land resulting severe environmental challenges including loss of permeable surface, increase in the frequency and intensity of urban flood, loss of biodiversity, depletion of underground water resources, etc. in the study area. The key factors of LULC changes in the study were unapproved housing societies, poor governance structure, lack of proper planning and monitoring, and the country's regional security situation. During the last decade, the Afghan war on terror (Ahmad et al. 2024) has triggered unplanned urbanization particularly in Rawalpindi. Lack of settlement plans and management practices in urban areas have resulted in unplanned built-up areas with consequent emission of CO_2 and overall environmental degradation. Apart from environmental issues and climate change, unplanned urbanization reduces pervious surface and poor drainage/sewerage system, thus leading to urban flood in Islamabad and Rawalpindi. The rapid urbanization and urban expansion have also caused numerous environmental issues including climate change, lack of basic civic amenities, and loss of permeable surfaces, contamination of ground and surface water resources, urban flooding (Shaw, 2015; Zia et al., 2022; Ahmad et al. 2020), and loss of wetlands, and biodiversity etc. (Khan, 2019; Abdul & Yu, 2020).

The findings of comparative geospatial study of Islamabad and Rawalpindi indicate that the entire study area is highly susceptible and vulnerable to urban flooding, however, the degree of vulnerability varies considerably depending on administrative governance, land use policies, and socio-economic resilience. The results indicate that the cumulative FVI of Rawalpindi is higher than Islamabad, indicating that Rawalpindi highly susceptible and vulnerable to urban flood as compared to Islamabad. Among the subdivisions of Rawalpindi, RMC is considered as the most flood-prone zone, exhibiting the highest social (0.67) and physical (0.56) vulnerability index. This elevated risk is attributed to dense, unplanned settlements, deteriorating infrastructure, and widespread non-compliance with building bylaws. In the capital city Islamabad, due to effective governance, better planning, and management, LULC changes are controlled and less harmful to the environment. Even then resilience and coping capacity of Islamabad, a very well-planned city has partial capacity, not fully protected (cf. Latif et al., 2017; Jamshed et al., 2020). Whereas, in Rawalpindi, uncontrolled and unplanned urbanization has raised numerous environmental issues including most importantly urban flood and water crises. Over the past three decades, the city has experienced unregulated and haphazard urban expansion and rapid urbanization. This uncontrolled

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growth has significantly changed the natural landscape, replacing permeable land surfaces with impervious structures i.e. built-up areas. The rapid expansion of built-up areas, coupled with poorly designed drainage and sewerage systems, has exacerbated the risk, frequency and intensity of urban flooding in the Rawalpindi. Increased impervious surface and unplanned drainage/sewerage systems have resulted in heavy floods, e.g. flood of 2001 which cost 74 lives, and infrastructure damage of $ 0.5 billion. Moreover, from 2007 to 2023, due to the expansion of the built-up area, and reduction of permeable land, eight major and several minor flood events occurred. Due to unplanned urbanization, Rawalpindi city has remained a major victim of those urban floods. The majority of these events can be directly attributed to the reduction in natural infiltration zones and the proliferation of impervious surfaces. From the findings of comparative LULC changes analysis it is confirmed urbanization and rapid urban land use land cover changes are a major factor of urban flooding in Rawalpindi city. The finding of this study further strengthened the concept that rapid and unplanned urbanization is a strong contributing factor to urban flooding (cf. Zafar & Zaidi, 2019).

From the finding of this comparative geospatial study it is inferred that unplanned urban growth is a critical driver of flood vulnerability and urban expansion significantly increases hydrological risk in urban centers. The findings of the present study establish a clear causal relationship between urbanization, the loss of permeable surfaces, and the rising incidence of urban floods particularly in Rawalpindi. The study emphasizes the urgent need for an integrated and resilient urban flood management strategy including strict land-use regulation, rehabilitation of drainage infrastructure, to mitigate future flood risks and promote sustainable urban resilience community-based risk reduction approaches, and enhancement of institutional capacities to mitigate future flood risks and promote sustainable urban resilience. Strengthening coordination among relevant departments and prioritizing resilient urban planning can significantly reduce flood vulnerability and safeguard lives and livelihoods in the twin cities.

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