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Integrated Approach to Explore Multidimensional Urban Morphology of Informal Settlements: The Case Studies of Lahore, Pakistan

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Abstract: The understanding of urban morphology as a means of exploring the materiality of urban areas has been an emerging practice amongst academics, but the reach of the methods in urban-design research has been limited. This research presents the integration of GIS application and field-work analysis as the main methods to support the interpretation of urban morphology as methodical, exploratory, and multidimensional. The Kolmogorov–Smirnov test, commonly known as the KS test, is also conducted to illustrate a contrast among the settlements. The study focuses on various dimensions of informal settlements by drawing on three case studies of informal settlements in Lahore, Pakistan. The results show heterogeneity in the urban form in terms of land-use diversity, building density, connectivity, open-space ratio, and infrastructural quality within the case-study areas. The analysis displays the context sensitivity and diversity within these settlements that provide a better understanding of how informal settlement works in relation to urban morphology. This research has the characteristics to contribute to other urban-form studies through the coherent application of the procedures to various sites. The output of mixed-use techniques exercised in this study lends itself to integration with other systematic processes related to urban areas' design, research, and planning.

Keywords: spatial structure; built form; informal urbanism; mapping; urban morphology; upgrading; urbanity; GIS

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1. Introduction

The vast development of informal settlements has become a critical geographical concern and a prime feature that defines the urban economy, particularly in the Global South [1]. These settlements result from the rapidly growing urbanization that has given rise to immense social, economic, and physical inequalities [2]. In 2015, approximately 24% of the world's population was estimated to be living in slums, equating to around one billion slum dwellers [3]. The share of these one billion dwellers is predominantly in the developing countries where informal dwellers have remained at 881 million compared to 689 and 791 million residents in 1990 and 2000, respectively [4]. It is essential to mention that about 50% of the world's slum population still resides in the Asia-Pacific region [5,6]. According to UN-Habitat, if this escalation of informal settlements remains incessant, it is probable that the global increase of these settlements may reach 3 billion by 2050 [7].

The development of informal settlements is often seen as a shelter crisis intrinsic to the Global South cities [8]. This is further attributed to a contradiction between growing property values and shelter needs for low-income populations, which are attributed to the "global city" [9]. Among many reasons, the following are the two most significant notably for developing countries. First is the rapid evolution of cities' demand for low-cost labor, which has resulted in accelerated rural–urban migration [10]. Second is the proliferation of business investments within cities, which has led to rising land prices. Consequently, the low-wage population increasingly seeks unauthorized residences near employment [11]. Governments have responded to urban informality that either results in exclusion from any upgrading plan [12] or calls for their complete demolition and displacement [13]. However, considering worldwide public policies, governments are now bound to acknowledge the existence and importance of these settlements [14]. Their distinct characteristics propound their recognition as a separate entity of urban growth. Apart from the exceptions in hazard-prone areas, most existing informal settlements can be upgraded [15]. Their improvement, however, relies on a critical yet in-depth understanding of the current urban form, morphologies, and associated qualities [16–18]. Hence, a holistic understanding of urban morphology in the context of these settlements is crucial for sustainable design interventions.

It is pivotal to look into the morphologies of these settlements that are there to stay and find ways for their improvement. Rather than evaluating specific upgrading projects or solutions, this paper aims to explore urban forms of informal settlements and discuss possible drivers for spatial variations in Lahore, Pakistan. Given that, the study explores the urban morphology of three informal settlements based on multidimensional indicators and reveals the similarities and differences using comparative analysis. In this article, the presentation of our research is structured as follows: Section 2 discusses the definitions and distinctions of the informal settlement in the local context, after which Section 3 primarily engages with the literature review on the morphologies of informal settlements. Section 4 explains the case study description, followed by Section 5 on the methodology adopted for this research. Section 6 includes the results achieved from qualitative and quantitative analysis conducted to examine the urban morphology of informal settlements. Section 7 presents the discussion based on the results, followed by conclusions and recommendations in Section 8. Finally, Section 9 highlights the limitations and prospects of this research.

2. Informal Settlements

Informal settlements are not a new phenomenon and occur in many different forms. These settlements are characterized by wide-ranging terms in literature, which define them as squatter settlements [19], shanty towns [20], popular settlements [21], and self-help settlements [22]. Moreover, they are also bear indigenous names in different countries all across the world; in Latin America, these settlements are called barrios pirates; ranchos in Venezuela; villas miseries in Argentina; favelas in Brazil, while in Asia they are attributed as bustees or jhuggis in India; kampung in Indonesia; slums or katchi abadi in Pakistan [23]. Most commonly, informal settlements in the urban context refer to the outburst of any activity that operates without formal control of the state. Such settlements lack basic facilities, services, and city infrastructure. Housing in these areas also does not comply with formal planning and building regulation. They are also often located within hazard-prone or highly vulnerable geographical regions [24]. Hence, the informal settlement is defined as an underdeveloped area formed due to illegal land occupation by low-income people who settle without attaining permission from the central and institutional authorities or their rightful owners [25]. On the other hand, the term "slum" is defined by Cities Alliance [26] as those parts of the cities neglected with appallingly poor housing and living conditions. They fall within the umbrella of informal settlements but with few different characteristics. At a household level, the UN-Habitat [27] describes slums as a group of dwellers who live under one roof with lacking infrastructure and one or more of the following conditions: drinking-water inaccessibility, poor sanitation, insecure tenure, dilapidated housing, and insufficient living area. In contrast, squatter settlements are characterized by the illegal occupation of a residential land area and a building bearing uncertain tenure and deprivation of primary infrastructure [28].

Informal settlements, slums, and squatter settlements were often used interchangeably in the past [29,30]; however, in current research, a clear distinction lies between them [31,32]. Informal settlements also differ based on the types of land acquisition that occur due to employment opportunity, invasion, or occupation of land without following up on the legal procedure and documentation [33]. Gelder [34] defines the variations within housing informality across areas, countries, and regions. Terminologies such as informal settlements, slums, and squatter settlements/katchi abadis are recognized distinctively in the context of Pakistan. This distinction also affiliates with Dovey and King's [35] way of defining these settlements. They describe them as squatters, lacking land tenure; slums, lacking space durability, water, and sanitation; and informal, implying a lack of formal control over planning, design, and construction. Likewise, slums in Pakistan are considered an inappropriate living settlement due to unsteady buildings, high density, low-quality buildings and infrastructure, poor facilities, and a shortage of amenities [36]. Tenure security is a rule here, but there is no program for improving its conditions except through political patronage [37]. On the other hand, squatter settlements are commonly called Katchi Abadi in Pakistan. These settlements are formed either through squatting or public/private land subdivision. They are attributed to a lack of tenure safety and access to the fundamental urban infrastructure [38,39]. In the literature or by-laws of Pakistan, no clear definition for informal settlements exists. However, it is generally perceived and considered for this research as a more extensive umbrella encompassing both slums and squatter. The lands are legally or illegally occupied here, and building permits are only partially granted. The main characteristics include a lack of access to the basic urban infrastructure, inappropriate housing conditions, jeopardizing the buildings' safety and the inhabitants' health [40].

3. Literature Review

Over the years, different scholars have developed ideas and theories for exploring various dimensions of the urban morphology of settlements globally. Urban morphological studies explore the materiality of an area or a neighborhood through a combination of physical analysis, urban mapping, and micro- and macroscale descriptions. A limited understanding of morphological dimensions of an area can lead to poor design interventions [41], making it an important aspect of exploration in different studies. Hillier et al. [42] examined the spatial configuration and location of the informal settlements in Santiago de Chile as essential variables in their consolidation. They developed space syntax models to quantify the spatial differences and consolidation indices at macro- and microscales. They found that edge-oriented commercial activity results from spatial integration with the surrounding urban fabric using these models. Elfouly [43] postulates a detailed analysis of street patterns with drawings illustrating the heterogeneity within the street pattern of a neighborhood on agricultural lands of Giza, Egypt. She identifies the complexity of the urban morphologies by finding the low connectivity values that characterize irregularity and inconsistency in the main features of the street pattern. Taubenböck and Kraff [44] study the multifaceted urban pattern of a small neighborhood using high-resolution optical satellite data. They identify building density, building area, and building heights as significant variables to differentiate between formal and informal settlements. These physical components are analyzed to determine structural homogeneity and heterogeneities within and across numerous settlements in Mumbai, India. Kamalipour [45] provides a detailed analysis of the fluidity of open space within the informal settlement in Pune, India, including microscale illustrations and studies of informal morphologies. He finds out that the main laneways are often shaped depending on existing pathways trajectories in the settlement. Dovey and King [35] discussed the typological perspective to understand, predict, and shape urban change in the informal settlements of Nairobi, Manila, Bangkok, Surabaya, and Bombay. They highlight that while on the one hand, morphological studies concentrate on describing urban forms, typological studies provide an understanding of classifications by types, processes, and distinct forms of urban informality.

In addition to the aforementioned diverse techniques, a set of additional dimensions of urban morphology may also be employed to explain the urban form of informal settlements. The concept of diversity is often advocated as a tool for understanding the distribution of different land uses within a city or a settlement [46]. In most cases, informal settlements lack fundamental planning for mixed land uses [47]. This indicator of land-use diversity is significant and often used in studies pertinent to active transportation, such as walking, cycling, and public transport [48,49]. The underlying principle is that a higher mix of land uses produces heterogeneity, resulting in greater accessibility in the area [50]. However, informal dwellers' households tend to prioritize living over public space. This limits the space for shared purposes, such as recreational facilities, schools, workplaces, clinics, squares, and circulation [51]. Informal settlement issues and spatial detail planning using building density are closely interrelated [52]. In recent studies [53,54], building density is considered significant evidence in urban-form studies that eventually leads to urban prosperity. However, its impacts are complex, as it can be a positive outcome in one domain and negative in others. A usual drawback of many informal settlement-upgrading programs is the focus only on providing basic services but without assessing the internal layout of the built structure. The basic idea is that the physical dimension of urban fabric (volume of useable space and activity within a geographical area) has a decisive impact on its social, environmental, and economic performance [55,56]. The dynamics of urban morphologies in informal settlements can also be explored by analyzing their street connectivity [57]. Kamalipour [58] examines street connectivity as a critical urban factor in transforming informal settlements from physical segregation to integration into the overall city system. A Composite Street Connectivity Index (CSCI), a spatial toolkit, has been developed by UN-Habitat [59] to measure street connectivity in informal settlements. This toolkit suggests that the greater the street connectivity, the more habitable, productive, and integrated the informal settlements will be. Hernández-García [60] discusses that open spaces, as with housing structures, are mainly produced by self-help and self-managed processes in informal settlements. However, a limited understanding of their morphology exists, mostly because they are often seen as spare spaces carrying negligible value to the people. Open spaces in informal settlements are public regarding ownership and accessibility but are communal in terms of use and attachment [61]. Hosni et al. [62] argue that the deficiency of open spaces in informal settlements has various negative impacts, such as degradation of environmental quality (e.g., increased urban temperature), health issues, lack of social interaction, and missing spaces for economic and livelihood opportunities. Besides these spatial indicators, infrastructure quality within informal settlements is incredibly stressed in various studies [63–65]. The six subthemes of UN-Habitat [4] identify urban housing and basic infrastructural facilities as the significant areas of concern for informal settlements. According to Hasan [66], infrastructure includes roads, water supply systems, solid waste systems, electricity, and sewerage systems. Hegazy [67] accentuates that upgrading an informal settlement requires providing basic infrastructure and services to improve informal dwellers' quality of life. An interplay between tenure and infrastructure is suggested by Kyessi [68] when it comes to upgrading informal settlements. This interaction is also apparent in Durand-Lasserve's [69] study, which advocates that in upgrading such settlements, the status of legal tenure is significant for improving infrastructure.

On the one hand, informal settlements remain a point of inquisitive debate in architecture and urban planning because of their sociocultural, political, and economic vulnerability. On the other hand, their morphologies are under-studied and insufficiently researched. Only a few studies draw out this aspect within different boundaries and contexts. This research provides a mix of qualitative and quantitative approaches based on GIS analysis and field observations. The integration of both methods allows for filling the research gaps with respect to the intersection of urban morphology and informal settlements. Furthermore, this research builds upon the emerging body of work that targets the challenges of exploring morphologies of informal settlements within a global context [70,71].

4. Case Studies

The case studies selected for the research are three informal settlements in Lahore, the second-most populous city of Pakistan, with 11.13 million inhabitants [72]. The selection of the case studies was a difficult task in this research as there were no previous records of any urban or upgrading projects conducted in Lahore informal settlements. Moreover, there was very little information about such settlements in the literature. Raw data were collected from the Lahore Development Authority (LDA), one of the implementing agencies for the formal and informal growth of Lahore. In this setting, the data were analyzed, and the research was established based on the rationale developed by Kamalipour and Dovey [73] and more recently by Jones [74]. The information on informal settlements was grouped into four criteria: typology, morphology, tenure, and connection with the urban fabric. Although typology analysis is often defined within the broader field of urban morphology [75], it is considered in terms of the development form and building material used for the case study selection. In contrast, morphology is explained in terms of the existing access network in informal settlements. Security of tenure is often used in studies [76,77] as a vital component to distinguishing urban forms of settlements as it is decisive for triggering household improvements to dwellings. Kamalipour [47] connects informal settlements with the surrounding urban fabric to show a mixture of formal and informal built-up in districts and urban infrastructures that expand along highways and railways. Hence, the case studies in this section are explained based on these criteria. Moreover, they are located within the urban boundary of Lahore, as shown in Figure 1.

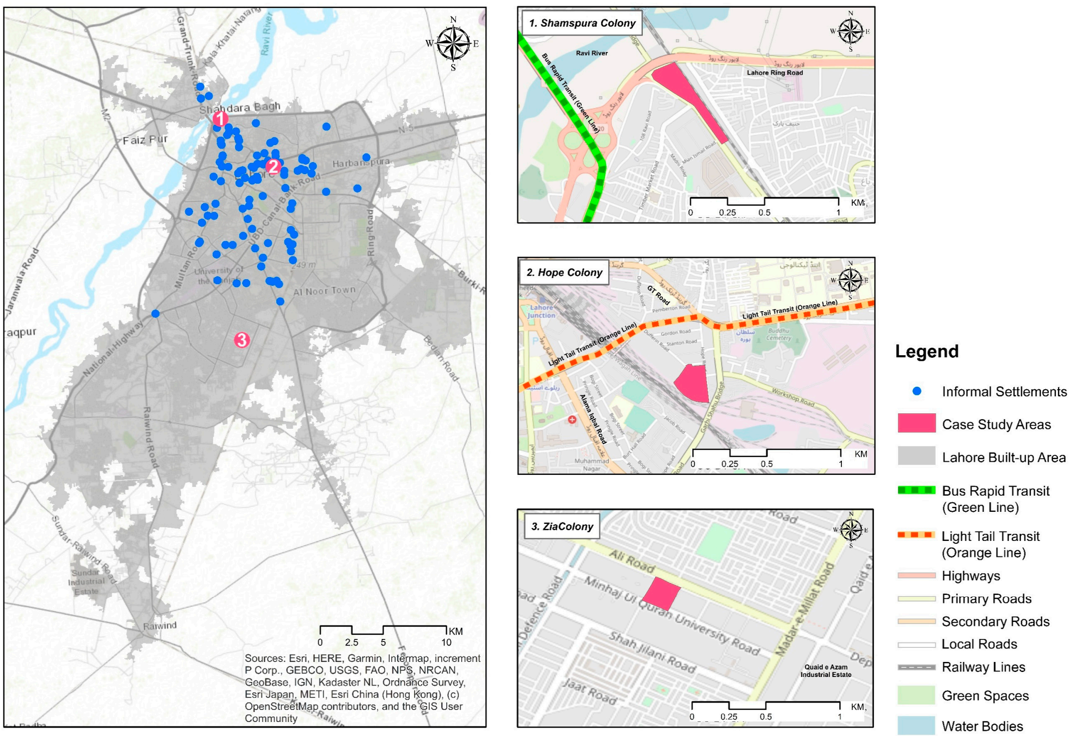

Figure 1. Spatial positioning of selected case-study areas. (Adapted with permission from ref. [78]. Copyright 2022 OpenStreetMap Foundation (OSMF). illustration by the first author). OpenStreetMap. Available online: https://www.openstreetmap.org/ (accessed on 15 June 2022).

Hope Colony (HC) is located on the northeast side of Lahore and under the Ghari Shahu Bridge. It is also adjacent to the central railway station of Lahore, giving it a prime location (see Figure 1). The settlement is spread around 0.035 km^2, and its surroundings serve as a critical nodal point for many businesses and industrial activities. The settlement shares its location within a heterogenic urban fabric comprised of formal and informal neighborhoods. Many small-scale industries and academic institutes, e.g., the University of Engineering and Technology (UET), are close to this settlement. Recently, the construction of light rail transit (LRT), an intracity train service, has also reinforced the connectivity and accessibility of this settlement to the other parts of the city. There is also a green park in the vicinity of Hope Colony; however, the use of this is only limited to the people belonging to the approved neighborhoods adjoining the other sides of this park. The built-up structure in Hope Colony comprises mid-rise building stock, which is of both katcha and pacca nature. Partial tenure is found within the settlement as those with improved structures were able to secure this while others did not improve to attain approval. A significant improvement was seen in terms of addition to floors. The building materials used in katcha structures mainly constitute galvanized sheet and mud roofs and are up to one-two stories. In contrast, pacca structures use reinforced concrete and brick as construction materials and can go up to three stories in height (see Figure 2). The case study is also a combination of organic growth and cul-de-sacs in terms of its access network. The streets are seen encroached upon by the built-up structures. This is more dominant on the upper floor, which thus makes the streets appear gloomy and dark. Electric wires and utility pipelines are also found open and intertwined within several houses, creating a severe threat to life. Moreover, these streets become mud corridors during rain, making them inconvenient and hazardous for the walkers, cyclists, and neighboring dwellers.

Figure 2. Pacca houses with brick-made structure (**left**); Katcha structure using galvanized sheets (**right**) representing buildings' typology in Hope Colony. (Source: Photos taken by the first author).

Shamspura Colony (SC) is located north of Lahore and has a total area of 0.033 km^2. It is about 1.2 km to the riverside, i.e., River Ravi, about 2 km from the bus rapid transit (BRT) line, adjacent to railway lines on the east side. It is accessible through the city's major primary roads and highways (see Figure 1). The Lahore Ring Road is one major expressway that connects this settlement to other parts of Lahore. Moreover, Lari Ada, one of the busiest public-transportation bus stops for inter- and intracity travel, is also located in the vicinity of this settlement. Shamspura Colony was included in the list of large settlements that evolved during the late 1980 s. Moreover, the Lahore ring-road project's inception in 1992 around this settlement accelerated the settlement's densification process [79]. The building structure in Shamspura Colony is comprised chiefly of multi-story development. This is mainly due to the tenure granted to the area, which triggered unplanned vertical growth. The built-up structures primarily include reinforced concrete and infill red-brick construction material. The dense building stock increases densification and causes serious overcrowding issues within the settlement. As a consequence of high density, open spaces and access are minimal. This case study is built on an irregular street network. Public spaces are limited to streets that are also encroached upon by everyday household activities such as drying or washing clothes, cooking, and drying fruits. This makes the area impenetrable due to the accumulation of such appropriations. Railway lines also temporarily served as a specific type of public space, and this space's functionality depends upon the trains' frequency (see Figure 3).

Figure 3. Railway lines providing dangerous yet temporary public space (**left**); congested street due to encroachments of buildings (**right**) in Shamaspura Colony; (Source: Photos taken by the first author).

Zia Colony is located south of Lahore and is 0.5 km away from the water body (nullah), 2.2 km from Quaid-e-Azam Industrial Estate, and 2 km from the central primary road (see Figure 1). This case study area is positioned within the civic center of the Township neighborhood, which was initially designated as a commercial hub in the integrated master plan of Lahore 2001 [80]. The settlement is built on a precious land parcel, as immense commercial areas and governmental departments surround it. The presence of industrial estate in the vicinity is also considered an essential factor in the emergence of this settlement, as the informal dwellers provide a workforce to the industry at cheap rates. No tenure is granted to the area, and it is known that the dwellers squatted the land in the year 2000. The overall condition of the area is deplorable and dilapidated. The built-up structure in Zia Colony has a high internal density with a low-rise building stock. The walls of the houses in this settlement are mostly made of unplastered bricks, sand limestone, corrugated tin, or asbestos. Many are found broken, while some dwelling units have no boundary wall. However, very few dwellings have been upgraded on a self-help basis depending on the availability of finances. In 2007, an abrupt spatial change took place within the settlement. Due to the political gains, the governmental authorities decided to bring improvement in the settlement by systematically modifying the layout of the streets. As a result, this is the only informal settlement in Lahore that has been redesigned on a grid-based street network, thus making it distinct from other case-study areas. The access network is limited to 1.5–2.0 m in this settlement which is comparatively wider than in other case studies. The street network is relatively well-connected and highly permeable due to its improved layout. Besides this, the housing condition in the Zia Colony is attributed to inadequate ventilation, cramped room spaces, shared bath and washing, insufficient cooking space, and minimal privacy for the households (see Figure 4).

Figure 4. The poor condition of housing with broken boundary walls (**left**); upgraded street conditions (**right**) in the Zia Colony (Source: Photos taken by the first author).

The selection of case-study areas was based on the secondary data acquisition from the Lahore Development Authority (LDA). The surveys for the chosen settlements were conducted over different periods: Zia Colony (February 2021), Hope Colony (March 2021), and Shamspura Colony (April 2021). However, ensuring accuracy within these settlements remains challenging because of inadequate data availability and changing micro-level practices of encroachments and transformations.

5. Materials and Methods

The study follows a comprehensive literature review focusing on understanding the morphologies of informal settlements globally. Subsequently, the methodology for this research is devised based on three components: indicator identification, data-collection and sampling methods, and data-analysis process.

5.1. Indicator Identification

As supported by the first row of Table 1, numerous studies have discussed wide-ranging indicators to determine the urban form of informal settlements. Rather than considering the informal settlement as an entire single unit, the microscaled analysis is performed at the block level to observe differences within the settlement boundaries. Instead of dividing the settlement into different grid-pattern spaces (based on 10 × 10 or any other numerical units), blocks are formulated based on the spatial features, where an organic street-layout pattern is predominant. This pragmatic approach to dividing the settlements into different parts for microscaled analysis helps keep the uniform characteristics of built space within confined limits. The five leading indicators selected for this study are diversity, building densities, connectivity, infrastructural quality, and open-spaces ratio. These indicators are chosen based on their significance, as found in literature, and relevance within the selected settlements. In the context of Lahore, these indicators play a pivotal role in building and land-use regulations [80,81], as they are the defining characteristics for understanding the morphology of informal settlements. In building by-laws and guidance on planning and infrastructure standards of Lahore [82], these five indicators hold prime importance, as they measure how well an area is developed and how it could be improved. Moreover, the choice of these indicators is also streamlined in light of the assessment criteria for defining informal settlements as stated in Lahore Development Authority (LDA) official guidelines [81,83]. According to the LDA officials, a lack or weak implementation of these indicators is prominent within the selected case studies, and advanced research in light of these indicators could be a way towards upgrading the informal settlements. These indicators are further divided into subindicators and computed in the geographical information system (GIS) except for infrastructural quality, assessed through the socioeconomic survey. The results are hence presented in the spatial form and statistical form.

Table 1. Indicators to determine multidimensional urban fabrics (illustrated by the first author).

Indicators		Literature References									
Main Indicators	**Subindicators**	**[84,85]**	**[43]**	**[86]**	**[87]**	**[88]**	**[89]**	**[40]**	**[90]**	**[91]**	**[92]**
Diversity	Land-Use Diversity (LUD)						x			x	
Building Densities	Coverage Ratio (CR)	x		x			x		x	x	x
	Floor-Area Ratio (FAR)	x							x	x	
	Surface Area-to-Volume Ratio (SAVR)	x				x					
Connectivity	Average Node Degree (AND)	x	x	x							x
	Street Density (SD)		x							x	x
Open Space Ratio	Private Space Ratio (PrSR)	x									
	Public Space Ratio (PuSR)	x								x	
Infrastructural Quality	Sanitation				x			x			
	Water Supply				x			x			
	Electricity							x			
	Waste Management				x			x			

This study attempts to develop equational models of these subindicators (see Table 1) based on their definitions, and are discussed briefly later in the discussion. Moreover, the interrelation of indicators to urban fabric is depicted in Figure 5, representing the qualitative elucidation of the numerical scale. The explanations of indicators selected for this research are explained below:

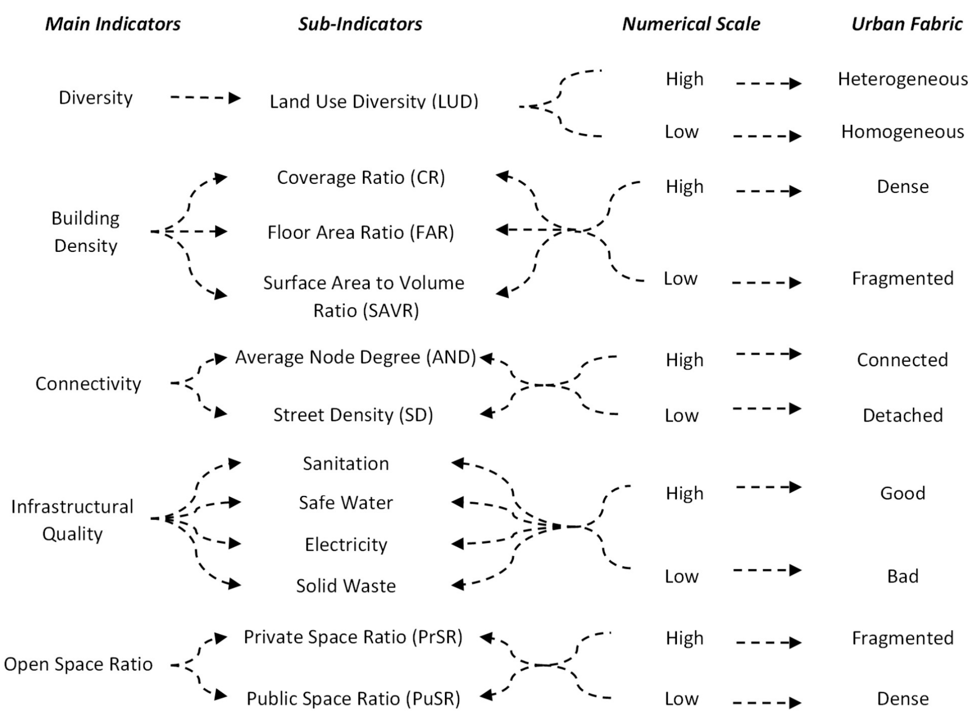

Figure 5. Relationship of selected indicators with the informal settlement's urban fabric. (Illustrated by the first author).

Diversity corresponds to the variety of land use in the settlement. The informal settlement having fewer traits of mixed-use development depicts the homogeneity of land use in the settlement. In contrast, more mixed-use development represents better accessibility to the places of interest in the community at the neighborhood level. This indicator has been measured during the fieldwork and quantified with the help of land-use overlay analysis in GIS.

Building densities quantify the urban fabric of the settlements in terms of being dense or fragmented. This indicator is categorized into coverage, floor, and surface area-to-volume ratios. The coverage ratio measures the level of occupied land in terms of building footprint at the block level, whereas the floor-area ratio measures the built-up density. The higher value of coverage ratio and floor-area ratio depicts the dense urban fabric of the settlement and vice versa. The coverage and floor-area ratios have been measured based on Equations (1) and (2), respectively. The block sizes in the below equations are calculated by GIS tools, which help calculate the numerical values of irregular and complex-shaped blocks.

$$CR_i = \frac{\sum_{j=1}^{n} BF_{ij}}{BS_i} \tag{1}$$

CR_i = coverage ratio of ith block;
BF_{ij} = building footprint of jth building within ith block;
BS_i = block size of ith block

$$FAR_i = \frac{\sum_{j=1}^{n} GFA_{ij}}{BS_i} \tag{2}$$

FAR_i= floor-area ratio of ith block;
GFA_{ij}= gross floor area of jth building within ith block;
BS_i= block size of ith block
GFA_{ij}= BF_j* S_j; where BF_j = building footprint of jth building; S_j = number of stories of jth building

Surface area-to-volume ratio (SAVR) computes building envelope fragmentation at a block level. Buildings possessing simple-shape structures, i.e., less protruding and cavities, will have a small SAVR, while complex building structures will have a greater SAVR. Smaller value to SAVR depicts a comparatively fragmented urban form, while higher value demonstrates the dense urban fabric of the settlement. The indicator of SAVR has mainly been used in studies that focus on measuring the energy efficiency of buildings [88]. SAVR is quantified with Equation (3). The height of the buildings in the equation was calculated during the fieldwork, and the database for the stories of each building was noted. For our analysis, we assumed the average story height of a building as 11 feet, which is applicable in the case of Lahore. Hence, the average height is multiplied by the number of stories to calculate the building height.

$$SAVR_i = \frac{\sum_{j=1}^{n} (BP_{ij} * BH_{ij})}{\sum_{j=1}^{n} (BF_{ij} * BH_{ij})} = \frac{Building\ Envelop}{Building\ Volume} \tag{3}$$

$SAVR_i$= surface area-to-volume ratio of ith block;
BP_{ij} = building perimeter of jth building within ith block;
BH_{ij} = building height of jth building within ith block;
BF_{ij} = building footprint of jth building within ith block.

Connectivity measures the urban fabric of a settlement in terms of connected or detached settings. The indicator is categorized into two subindicators, i.e., average node degree and street density. The average node degree is the ratio of nodes relative to street links. Blocks surrounded by more dead ends will have a lower average node degree and depicts less connectivity in the settlement, and vice versa. At the same time, street density represents the linear length of the link relative to the block size. Higher values of these subindicators illustrate increased connectivity, while lower values demonstrate a less connected urban fabric. Average node degree and street density are quantified with Equations (4) and (5), respectively.

$$AND_i = \frac{\sum_{j=1}^{n} E_{ij}}{\sum_{j=1}^{n} N_{ij}} \tag{4}$$

AND_i = average node degree of ith block;
E_i = edges on the nodes surrounded by ith block;
N_i = nodes surrounded by ith block.

$$SD_i = \frac{\sum_{j=1}^{n} RL_{ij}}{BS_i} \tag{5}$$

SD_i = street density of ith block;
RL_i = linear road length surrounded by ith block;
BS_i = block size of ith block.

The open-space ratio is an investigational indicator in this research that provides evidence of the relativeness of open space to the built-up ratio in the neighborhood. The indicator has further been subdivided into two subindicators, i.e., private-space ratio and public-space ratio. The private-space ratio indicates the extent of private space compared to the built-up density at the block level, quantified based on Equation (6). In comparison, the public-space ratio reveals the ratio of public space proportional to the built-up area of the block, which is measured with the help of Equation (7). Rudiments of these equations have been derived from the work of Pont and Haupt [93].

$$PrSR_i = \frac{BS_i - \sum_{j=1}^{n} BF_{ij}}{\sum_{j=1}^{n} GFA_{ij}} \tag{6}$$

$PrSR_i$ = private-space ratio of ith block;
BS_i= block size of ith block;
BF_{ij}= building footprint of jth building within ith block;
GFA_{ij}= gross floor area of jth building within ith block.

$$PuSR_i = \frac{AERCL_i - BS_i}{\sum_{j=1}^{n} GFA_{ij}} \tag{7}$$

$PuSR_i$ = public-space ratio of ith block;
$AERCL_i$ = area enclosed by road center line of ith block;
BS_i = block size of ith block;
GFA_{ij} = gross floor area of jth building within ith block.

Infrastructural quality is measured from the field interviews carried out alongside the physical surveys. It includes the provision and condition of utility services such as safe water to drink, sewerage and drainage, provision of electricity, and waste management that have been categorized as subindicators. The data for these subindicators were assembled through the Likert scale (explained briefly in the data-collection section), where the high value indicates good quality of utility services, corresponding to a decent urban fabric, while a low value indicates the nonexistence or atrocious quality of utility services, showing a bad urban fabric.

5.2. Data Collection and Sampling

Socioeconomic surveys were conducted in the case study areas to gather information about age, education, occupation, tenure security, and satisfaction levels for existing infrastructure in these settlements. During fieldwork, the data were collected through open- and close-ended questionnaires. Moreover, land uses of different parcels, building heights, footprints, and settlement boundaries were also explored. Observations in the form of pictorial and field notes were gathered as an additional data-collection method. Based on this spatial-data acquisition, all the former indicators were computed using the GIS except infrastructural quality, a nonspatial indicator in this research, and assessed through statistical analysis. Given this, a sample size of the case-study areas was calculated with the help of Slovin's formula, mentioned below.

$$n = \frac{N}{1 + Ne^2} \quad (8)$$

n = sample size, N = number of households, e = marginal error.

A proportionate and random sampling technique was used to conduct the household socioeconomic surveys of the case study areas. This sample size was calculated based on the number of units derived from the base maps of the selected case-study areas. The calculated sample size of all settlements is 220, divided into Hope Colony as 73, Shamspura Colony as 80, and Zia Colony as 67, with a marginal error of 10%. Data about the subindicators of infrastructural quality (water supply, sewerage, electricity, and waste management) were calculated based on a Likert scale of 1 to 3, where 1 indicates the dissatisfaction while 3 denotes the satisfaction levels of the respondents from the provision, execution, and maintenance of the provided utility services (for detailed information, see the Supplementary Information).

5.3. Data Analysis

The data were analyzed in four stages to develop a fine spatial-granularity level. The first segment entailed acquiring spatial data and satellite imageries of all the case-study settlements that had been obtained from Google Earth. In the second phase, the spatial imageries vectorized with the help of GIS and base maps of all the settlements were contrived. In the third step, errors in the spatial data were removed and rectified with fieldwork surveys. Lastly, data on building densities, land-use mix, street connectivity, and open spaces were analyzed based on field observations to validate maps developed in GIS.

Besides spatial analysis in GIS, Kolmogorov–Smirnov statistical analysis, commonly known as the KS test, was conducted to examine the possible patterns of similarities across settlements. The KS test is usually employed on a nonparametric value structure based on the null hypothesis that retrieves the similarity index across two distribution functions. In practice, this test calculates the distance across empirical distributions of different indicators under the null hypothesis. The tests suggest that if the p-value of the test is greater than 0.05 (corresponding to the confidence level of 95%) then the null hypothesis is accepted, which means the distance across the distribution is minuscule, hence validating the similarity. Conversely, if the p-value is less than 0.05, the null hypothesis is rejected, indicating a greater distance among the empirical distributions, consequently corroborating the difference.

6. Results

This section comprehensively describes the results related to urban morphology's spatial and nonspatial indicators. The first part of this section explains the outcomes of socio-economic surveys conducted. The second section presents the results achieved through the GIS spatial analysis of indicators. Based on the KS test, the last section describes the similarity and dissimilarity patterns across the three case-study areas.

To entail a relatively even distribution of gender and relative socioeconomic diversity, respondents from different age groups, educational backgrounds, and occupations were selected for the interviews, shown in Table 2. The results show that most respondents belonged to the young age group in almost all the settlements. In addition, a significant share of the respondents from these settlements are illiterate or have low education levels. Moreover, a large population performs laboring work on daily or monthly wages, whereas few people own small businesses, including corner shops, repair shops, or other services.

Table 2. Respondent's characteristics through socioeconomic surveys (first author's work).

Characteristics/Case Studies		Zia Colony		Hope Colony		Shamspura Colony	
		Freq.	**%**	**Freq.**	**%**	**Freq.**	**%**
Units		204		268		404	
Sample Size		67		73		80	
Age	<20	12	18%	10	14%	10	13%
	20–35	36	53%	25	34%	24	30%
	36–50	16	24%	32	44%	37	46%
	>50	3	5%	6	8%	9	11%
Education	Illiterate	35	52%	29	40%	26	32%
	Primary	27	40%	23	32%	27	34%
	Secondary	4	6%	13	18%	16	20%
	Graduate	1	2%	7	10%	11	14%
Occupation	Laborer	39	58%	35	48%	38	48%
	Own Business	19	28%	23	32%	32	40%
	Public Employee	4	6%	10	14%	10	12%
	Private Employee	5	8%	4	6%	3	4%
Tenure Status	Owned	44	66%	37	50%	35	44%
	Leased	9	14%	15	20%	13	16%
	Rented	7	10%	22	30%	32	40%

The outcome related to land-use diversity of selected settlements is shown in Figure 6, which reveals that the Shamspura Colony has a predominantly mixed land use in contrast to the Hope Colony and Zia Colony. This is mainly because besides residential buildings, most of the blocks in Shamspura are mixed residential/commercial. At the same time, other land uses such as clinics, primary schools, and mosques are also distributed within the settlement. However, the greater extent of blocks in the Hope Colony comprises residential land use with lesser distribution of other land uses. In the Hope Colony, a small number of commercial, residential/commercial, and public-building land uses are present. The land-use structure of the Zia Colony is distinctive from the formerly argued settlements. The existence of nonresidential land uses in the Zia Colony is accumulated on the eastern side of the settlement. Besides commercial, only the mosque as a nonresidential unit is present in the settlement. The other land uses, such as schools, primary schools, clinics, and neighborhood parks are unavailable in this settlement.

Figure 6. Land-use pattern of the case-study settlements (illustrated by the first author).

To investigate the building densities of selected settlements, coverage ratio (CR), floor-area ratio (FAR), and surface area-to-volume ratio (SAVR) indicators were examined, and their results are explained correspondingly.

Results of the coverage ratio of the settlements are illustrated in Figure 7. Coverage-ratio analysis of the settlements reveals that most of the blocks in the Shamspura Colony possess a better coverage ratio (more than 80%), corresponding to the dense urban fabric of the settlement. Compared to the Shamspura Colony, the urban fabric of the Hope Colony is less dense because only a few blocks possess more than 80%, while the others have a 70% value of coverage ratio. In contrast, only two blocks of the Zia Colony have more than an 80% coverage ratio. The rest of the blocks have a lesser value, corresponding to the least dense settlement under examination.

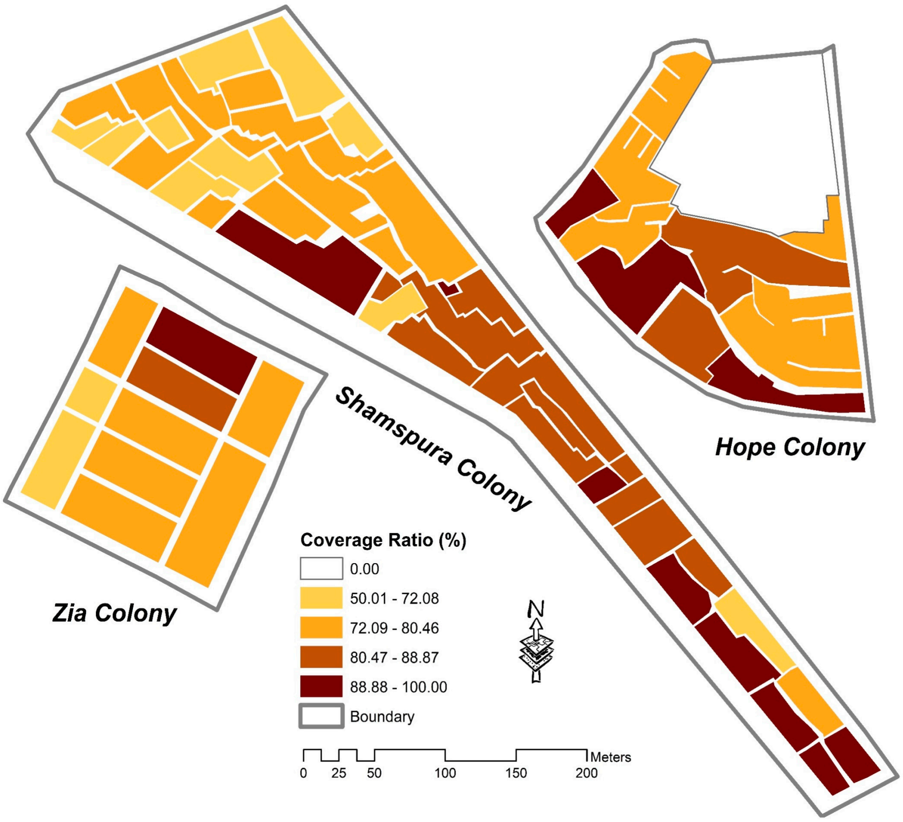

Figure 7. Coverage ratio (CR) of the settlements (illustrated by the first author).

The coverage ratio demonstrates the pattern of densities over horizontal breadth, whereas the floor-area ratio (FAR) shows both the horizontal dimension of densities and the vertical dimension. Therefore, FAR is considered an important gauge to measure the density patterns of any area. The FAR results of the case-study areas are shown in Figure 8, which indicates that FAR values vary from 0.66 to 2.90 among all the settlements. Over time, different countries and organizations have adopted distinct criteria to elucidate the FAR with density patterns. For residential land use in Vancouver, British Columbia, FAR up to 0.75 has exhibited as low density, up to 1.30 as medium density, while up to 3.0 is considered high-density areas [94]. Figure 8 shows that the FAR distribution pattern in the Shamspura Colony is distinct from the other two settlements. Most blocks in the Shamspura Colony have FAR of 1.77 to 2.90, corresponding to a compact development pattern in the settlement. In contrast, the blocks in the Hope Colony have FAR of 0.66 to 1.22, which relates to medium density, while the FAR value of less than 0.66 in the Zia Colony is associated with a less dense settlement under analysis.

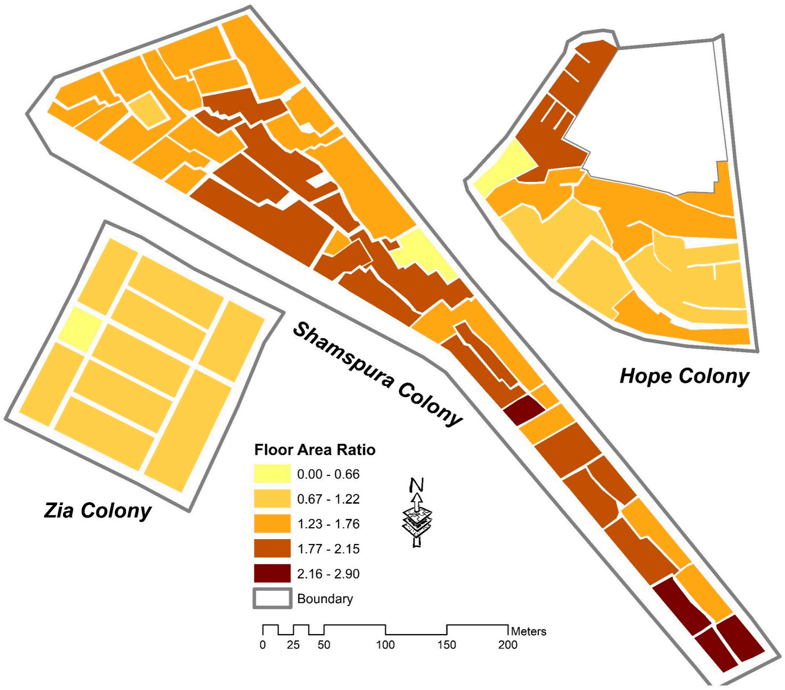

Figure 8. Floor-area ratio (FAR) of the settlements (illustrated by the first author).

Analyzed results of surface area-to-volume ratio are presented in Figure 9. This figure shows that the surface area-to-volume ratio distribution pattern suggests similarities with the FAR distribution-pattern results. Results show that the Shamspura and Hope Colony blocks possess greater SAVR values (0.52 to 0.87) than the blocks in the Zia Colony, which have a minimal value of SAVR (less than 0.16). These values correspond to the compact development structure in the Shamspura Colony and Hope Colony and the less-dense pattern in the Zia Colony. The above-discussed indicators of building densities show that the Zia Colony is relatively less dense than the Shamspura Colony and Hope Colony.

Figure 9. The surface area-to-volume ratio (SAVR) of the settlements (illustrated by the first author).

Average node degree (AND) and street density (SD) are indicators analyzed to measure informal settlements' connectivity. Average node degree is the ratio of links to nodes surrounded by the blocks and is highly dependent on the formation of road intersections (four-way, Y or T-shaped node, etc.). AND value's scale ranges from minimum 1 to maximum 4, where the maximum value indicates the greater extent of accessibility. AND indicator results are presented in Figure 10, which demonstrates that all the blocks in the Zia Colony have a greater value (3 to 3.75), which relates to the extremely high connectivity in the settlement. In contrast, the block in the Hope Colony owns the minimal values of AND (2.22 to 2.64), indicating the minimum connectivity in the settlement due to the presence of a substantial number of the cul-de-sac. In the case of the Shamspura Colony, the distribution of AND values varied broadly across the different parts of the settlement. Blocks on the southern side of the settlement possess greater AND values (approximately 3 to 3.75), whereas the blocks on the northern side have relatively lower AND values (about 2.41 to 2.85).

Street density (SD), the linear road-length ratio to the area's spatial extent, was analyzed to quantify the connectivity of the case-study areas. The results of this indicator (shown in Figure 11) show resemblance with AND indicator in the case of the Shamspura Colony and Hope Colony, whereas the values of SD vary from 0.13 to 0.26, depicting less connectivity in the settlement. In the Zia Colony's case, the SD indicator results are entirely divergent from the AND indicator. This contradiction in the results is due to the difference in the approaches of these two indicators to quantify the connectivity. The blocks of the Zia Colony possess high connectivity based on AND indicator and have a minimum level of connectivity based on the SD indicator (values less than 0.12).

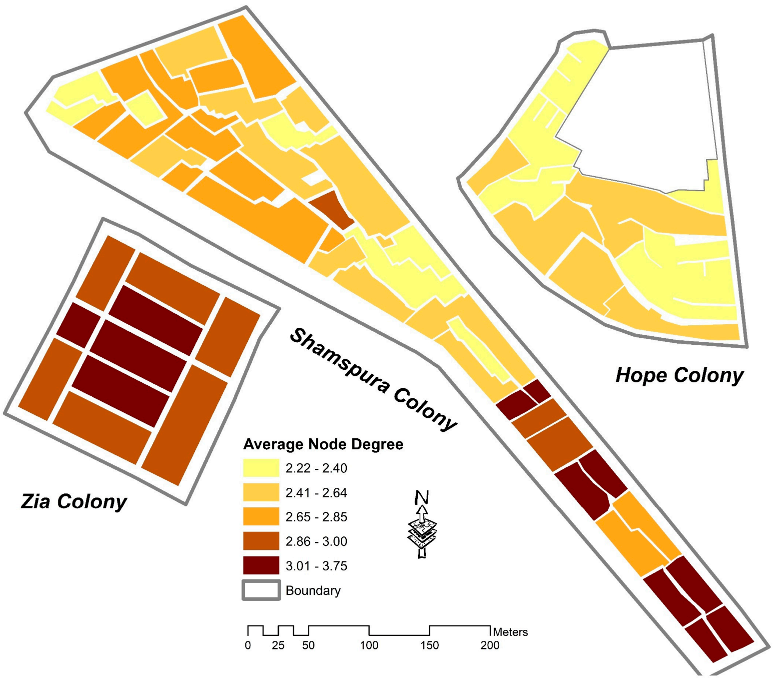

Figure 10. Average node degree (AND) of the settlements (illustrated by the first author).

Figure 11. Street density (SD) of the settlements (illustrated by the first author).

The open-space-ratio indicator investigates open spaces in the settlement with respect to the built-up magnitude of the blocks in the settlement. For detailed analysis, private-space and public-space ratio as subindicators are analyzed and described. The private-space ratio (PrSR) and public-space ratio (PuSR) are presented in Figures 12 and 13 respectively. These indicators explain the scarcity of open spaces (private or public) and the compactness of built-up structures in the Shamspura and Hope Colony. Most of the blocks in these settlements possess PrSR values less than 0.12 and PuSR values less than 0.15. In contrast, the blocks in the Zia Colony have higher PrSR and PuSR values (0.23–0.69 and 0.30–2.35, respectively), corresponding to the large open spaces and less-compact built structure.

Figure 12. Private-space ratio (PrSR) of the settlements (illustrated by the first author).

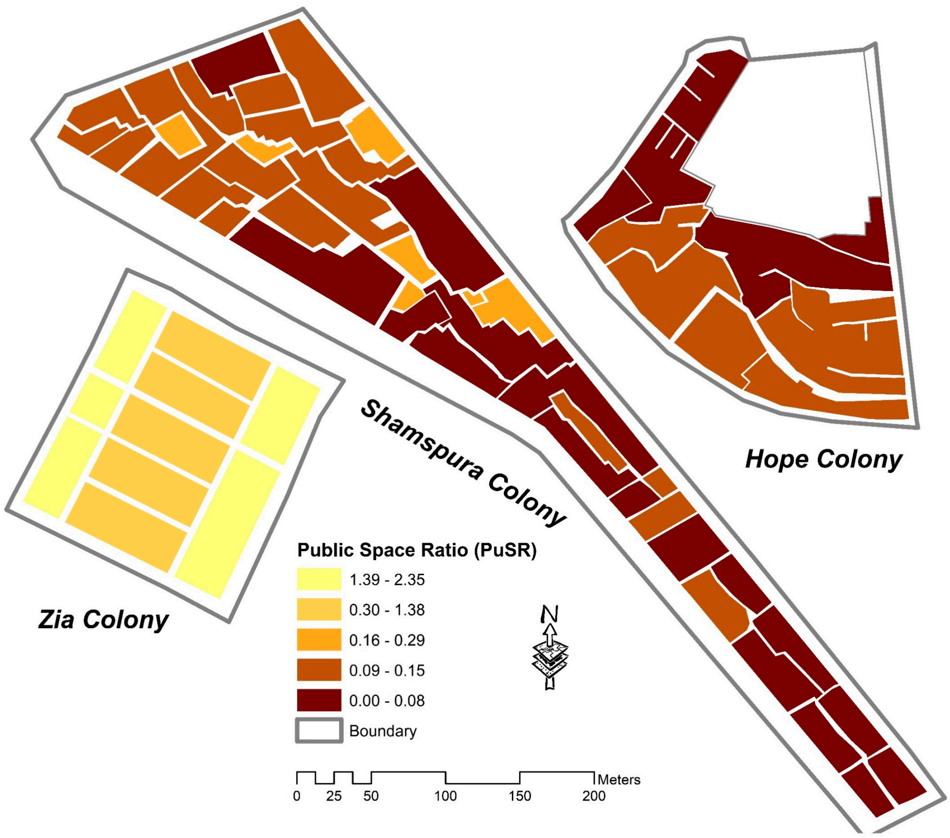

Figure 13. Public-space ratio (PuSR) of the settlements (illustrated by the first author).

Infrastructural quality, a nonspatial indicator in this research, corresponds to the quality and maintenance of utility services of the underexamined settlements. The results are developed from the socioeconomic surveys conducted in the fieldwork (Figure 14). While examining sanitation and water-supply facilities, occupants of all the settlements showed dissatisfaction levels up to 80–90 percent, depicting a highly deteriorated quality of these services. For electricity services in the settlements, 10–20 percent showed satisfaction while the rest revealed dissatisfaction. Regarding quality and maintenance of solid-waste management in the settlements, 55–70% of the population showed unhappiness.

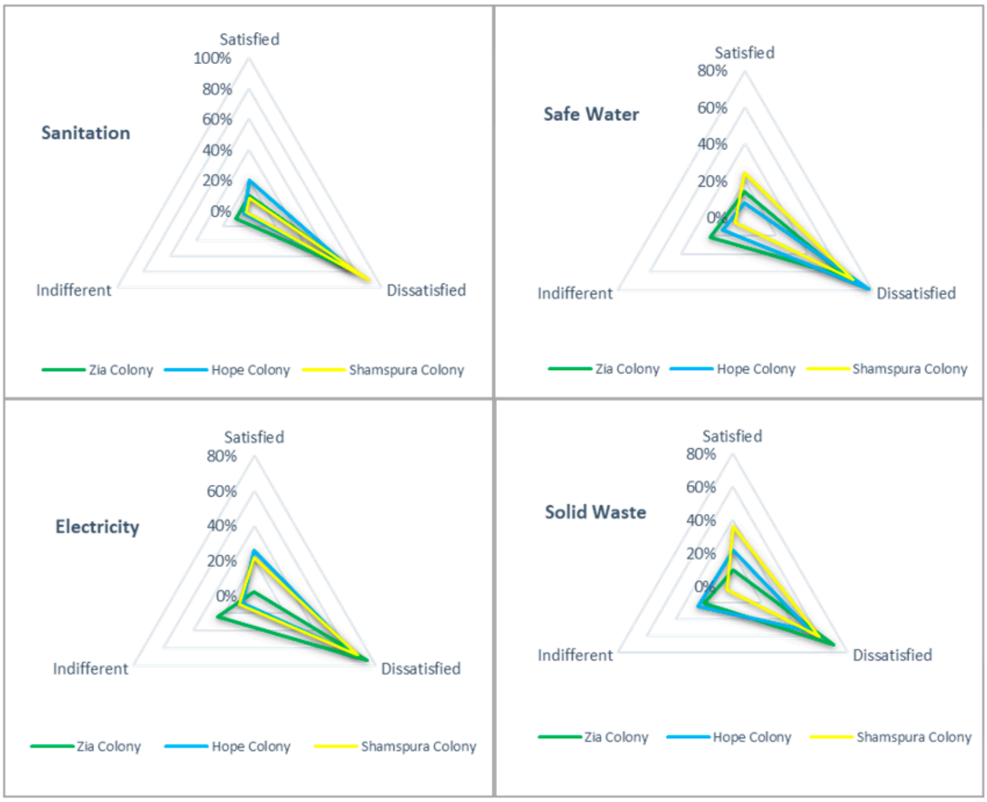

Figure 14. Respondents' satisfaction level regarding infrastructural quality within selected settlements (illustrated by the first author).

The results of the KS test are visually illustrated in Figure 15. These results demonstrate the similarities and differences across settlements. Of 27 combinations (shown in Figure 15), 52% have dissimilarity. The dominant pattern of similarity is found for street density. Infrastructural quality also shows similarity to some extent in the KS test. However, the percentage values vary in satisfaction and dissatisfaction analysis. Moreover, the KS test shows the similarity between Shamspura and Hope Colony in public-space ratio (PuSR) since their values lie in peak distribution ranges of GIS analysis.

Figure 15. KS test results performed on the distribution of indicators (illustrated by the first author).

In contrast, Zia Colony values lie in the lower distribution range. Furthermore, slight similarities are also observed between Shamspura and Hope Colony in the distribution functions of land-use diversity (LUD), coverage ratio (CR), floor-area ratio (FAR), surface area-to-volume ratio (SAVR), average node degree (AND), and private-space ratio (PrSR). However, the Zia Colony differs from these settlements in the aforementioned subindicators.

7. Discussion

The results discussed in the previous sections explain that multidimensional urban morphological indicators selected in the case studies are interrelated. They are comprehensively summarized in Table 3, where the settlement comparison is also described. The spatial and nonspatial indicators are compared with the applied standards retrieved from existing literature, national and international policies, and guidelines. Moreover, building densities, connectivity, open-space ratio, and infrastructural qualities are also scaled against different standards and guidelines used in the literature. The KS Test and GIS analysis show that the Shamspura Colony and Hope Colony have a few similar characteristics, while the Zia Colony has contrasting features. Compared to the Zia Colony, the Shamspura Colony and Hope Colony present heterogeneous land-use patterns, scarcity of open spaces, and dense structures. There could have been several reasons behind this distinction.

The differences in building densities among the selected case studies depend on their time of emergence, and hence it varies based on their growth and evolution. The values of sub-indicators like coverage ratio (CR), floor area ratio (FAR), and surface area to volume ratio (SAVR) reflect the highest building densities in the Shamspura Colony, followed by in Hope Colony, and the lowest in Zia Colony. As Shamspura Colony and Hope Colony developed several decades ago in contrast to Zia Colony, one will thus find dense, compact structures within. Over a period, as the family size increase and land availability become scarce, informal dwellers tend to adopt incremental development practices to meet their potential needs. Kamalipour [45] explained a similar incremental change in Yerawada informal settlement in India. Due to the consolidation and inadequate land in Yerawada, informal dwellers went for vertical additions by developing multiple rooms on top of their old building structures. Although this extension increased their overall living space, the settlement was gradually densified. Another reason for high densities in the Shamaspura Colony and Hope Colony is their crucial location. Shamaspura Colony is located along the main highway and major public transportation networks, making it highly accessible. Informal dwellers used this opportunity to settle in this settlement and make it denser by cultivating their livelihood by installing vegetable markets, street vending, and temporary selling stalls along the highway. Hope Colony also has a crucial location in terms of accessibility. Moreover, the prime location of the settlement along the railway station provides shelter for low-income railway employees. In contrast, the Zia Colony is closely bounded between public buildings and state-of-art commercial plazas, reducing the settlement's overall capacity to expand horizontally. The significance of location and edge-oriented commercial activity in the consolidation and densification of informal settlements is supported by Hillier et al. [42] while describing informal settlements in Santiago de Chile.

The building densities directly impact the availability of open spaces in informal settlements. The public-space ratio (PuSR) and private-space ratio (PrSR) show low values in the Shamaspura Colony and Hope Colony, which corresponds to the lack of open spaces. Due to its wide street network, these subindicator values are relatively higher in the Zia Colony. Appropriation of open spaces is the common phenomenon observed in all the selected case studies. However, sometimes these appropriations become permanent in terms of building encroachments on the streets. To increase the internal living space, informal dwellers extend the building line of their dwelling on the street. This intervention is dominant in the Shamaspura and Hope Colony, where the streets are narrow due to such alterations. In the internal streets of the Shamspura Colony, the upper story of dwelling units also encroaches to the extent of colliding, making it even hard for the sunlight to reach. Hernández-García [60] argues that the streets are the only open spaces in the informal settlements of Bogotá, and often they begin life in the context of confrontation. He explains that these spaces are invaded, privately occupied, and disappeared because informal dwellers prioritize living space over public space, resulting in a meager amount of shared-purpose land.

The morphological analysis of land-use mix shows more heterogeneity in self-organized and organically built informal settlements, i.e., Shamspura and Hope Colony, than in gridiron-pattern Zia Colony. There are predominantly residential plots in the Zia Colony with negligible other land uses. However, more land-use diversity is apparent in the other two settlements in terms of commercial, mixed residential/commercial, clinics, schools, scall-scale cottage industries, and public buildings such as mosques or municipal offices. These findings coincide with Hiller et al. [42], arguing the capacity of such a self-organized functional mix to emerge and transform over time. This transformation is due to the recurring adaptions to land use as per informal dwellers' demands and needs over time. Since the legal procedure is not followed for land-use change in such settlements, the residential building becomes converted to other uses. For instance, informal dwellers in Shamspura Colony alter their residential building use to small-scale industry and often move elsewhere to rental housing. Similarly, they usually rent their ground floor for tuck shops, car workshops, or warehouses, generating livelihood for themselves. After residential use, the commercial and residential building mix is the second dominant land use in Hope Colony and Shamspura Colony. This arrangement shows a mix of living and working, as the ground floors mainly serve commercial purposes and the upper floors have residential use. Similar patterns but different morphology of these land-use mixes are observed in the informal settlements of Istanbul [95] and Bangkok [58].

The morphological analysis in this research has studied the impact of street layout based on the connectivity index of the settlements. AND and SD indicators have produced different results based on their diverse methodological approaches. Due to the Zia Colony's grid-iron street layout pattern, the AND indicator results demonstrate a higher connectivity index of this settlement in contrast to the Shamspura Colony and Hope Colony, which have lower connectivity attributing to their organic layout pattern for the streets. This phenomenon is supported by the fact that the intersections in an organically street layout are mainly formed due to the convergence or divergence of places of interest and space utilization, resulting in the formation of Y and T-shaped junctions [43]. As Hosni et al. [62] explain, streets in informal settlements are developed without any planning and mainly on a self-help basis; these often result in cul-de-sacs reducing the overall connectivity of the settlement to the surrounding urban fabric.

A notable finding of this research reveals that all the examined settlements have poor access to sanitation, safe drinkable water, electricity, and solid-waste management. This lack of access leads to the proliferation of depreciated urban fabric prominent in all three chosen settlements, yet differences exist. The most crumbled quality of these infrastructural utilities is found in Hope Colony, as no improvement or development plans have been processed since its emergence. In this settlement, immense overcrowding and inadequacy of basic infrastructure prevail, as mentioned during fieldwork by the respondents. Moreover, due to a lack of tenure in the Zia Colony, the informal dwellers are less motivated to improve their living conditions and are deprived of governmental support. Shamspura relatively shows up as a better settlement than the previous two in terms of sewerage and electricity facilities due to having tenure and being facilitated by local governments such as Municipal Councils. Durand-Lasserve [69] emphasizes that secure tenure has a catalytic effect in bringing improvement within informal settlements. This effect manifests investment in housing, infrastructure, and overall neighborhood upgradation.

The findings of this paper are accomplished with a comprehensive methodological framework that overcomes the limitations of already used methods by combining desktop GIS analysis and fieldwork surveys. This has provided a much more diverse picture of informal settlements. The sole use of GIS analysis for these three settlements would have presented a similar urban morphological character, but integrating this with the fieldwork gave unique results on urban form and morphogenesis processes. This can be explained by the fact that satellite imageries are not explicit and have a weak resolution, especially in informal settlements of Pakistan. Street views are also not available, and the fluidity of space cannot be observed in the street network of case-study areas. Moreover, the case studies generally have a high level of coverage, often producing invisible public or private open spaces from an aerial photograph regardless of the resolution. Similarly, the built-up structure in the case studies is highly dense. It is challenging to calculate building densities even with more advanced GIS tools accurately. This needs high-resolution satellite imageries, street view, and proper reflection of shadows, which is impossible in this case. Kamalipour [45] explained in his study on informal settlements in Pune, India that in such conditions even the functional mix could be controversial, since a mix of life/work is not often recognizable without access to buildings' interiors. In the case of Pakistan, it is also hard to differentiate between informal settlements and low-income housing that has legal and formal status because of the disordered built-up nature. Moreover, there are several types within the informal settlements, e.g., slums, squatters, etc., where the range of diversity is only best-understood by fieldwork and on-site presence. Hence, microscaled analysis, particularly focused on the block level using GIS and fieldwork of the chosen settlements in this research, presented additional detail and varied outcomes.

Table 3. Summarizing the comparative analysis of the results of selected case studies (first author's work).

Indicators (Subindicators)	**Measuring Guidelines**	**Scaling the Urban Fabric**		
		Zia Colony	**Hope Colony**	**Shamspura Colony**
Diversity (LUD)	Residential to nonresidential land-use ratio should be 1 to ensure land-use heterogeneity [82]	Land-use ratio is 0.1, corresponding to the least level of land-use heterogeneity in the settlement	Land-use ratio is 0.15, depicting the unfavorable scale of land-use heterogeneity	Land-use ratio is 0.28, relatively higher than former settlements but still less than the stipulated standards
Building Density (CR, FAR, SAVR)	Higher densities lead to compact urban form [96,97]	CR, FAR, and SAVR values represent the least dense development	The subindicator values indicate medium densities	Analysis shows the highest building densities and compact development.
Connectivity (AND, SD)	Higher connectivity index leads to greater accessibility and integrated urban fabric [43,98]	The subindicators depict the highest connectivity index due to its grid iron street layout	The subindicators suggest the least connectivity index due to the presence of cul-de-sac and dead ends	AND indicator reveals a low value of connectivity index due to Y and T shape junctions except for a few blocks on the southern side.
Open-Space Ratio (PrSR, PuSR)	Built-up to open-space ratio should be three times [82]	Built-up to open-space ratio is 1.5 times, signifying the less open spaces despite wider streets.	Built-up to open-space ratio is 1.2 times, which suggests inadequate availability of open spaces	Built-up to open-space ratio is 1.1 times, which is the minimum value as compared to other case studies, depicting the utmost scarcity of open spaces
Infrastructural Quality (Sanitation, Water Supply, Electricity, Waste Management)	Higher respondent satisfaction level depicts a better quality of infrastructural services [99]	Respondent's satisfaction level for utility services was significantly lower.	Lowest level of respondent satisfaction, depicting the worst infrastructural qualities	Respondents' satisfaction levels for utility services are comparatively better than Zia and Hope Colony; however, still considered unfavorable

8. Conclusions and Recommendations

This research outlines a methodological approach where five different urban analytical indicators were assessed to understand informal urban settlements' morphology. Informal settlements vary in terms of their typologies, morphologies, and morphogenetic processes [100,101]. It is challenging to recognize such settlements' distinct and complex forms, particularly in the Global South, where a lack of data and research exists. This establishes the need to visualize and recognize different morphologies pertinent to these areas.

The results suggest that the Shamspura Colony and Hope Colony possess high building density and more compact development than the Zia Colony. As the settlement tends become older, increasing family requirements, unaffordable land prices, and relatively easy process of un-approved vertical development pressurizes the density of these settlements. Consequently, this uncontrolled growth affects infrastructure quality, leading to substandard living conditions, inadequate public spaces, and cramped circulation. The results also reveal the impact of these conditions on infrastructure, such as sanitation, insufficient access to water and electricity, and waste management. Hence, the increased densification pressure in the Shamspura and Hope Colony deteriorates the overall infrastructural conditions in the two areas. All this makes livability, functional efficiency, and long-term prosperity highly unsatisfactory. Buildings are seen as encroaching upon spaces and developing outwards. Instead, if guided vertical development is adopted for building stock, it could create spaces for various municipal investments. However, the step towards guided development demands consensus, commitment, and great compromise within different governing actors and households. Nevertheless, this pragmatic adaptation can be facilitated based on the collaboration between government and communities for redesigning, improving tenure, planning finances, and easing the regulatory framework within the settlement.

This research also reveals that land-use patterns of older and more densified settlements show a prevalent heterogeneity, as opposed to the newly developed settlements. Motivated by political gains, the governmental intervention in the Zia Colony has restructured the settlement on a gridiron layout, with commercial zones on one side of the settlement. On the other hand, the unregulated control of the local administration and organic growth of Shamspura and Hope Colony have allowed them to convert their residential building use into mixed-use by choice. The study also established that the marginalized community, i.e., the urban poor residing within these settlements, could be mapped by incorporating fieldwork and advanced analytical techniques. GIS has proven helpful in calculating the geographical extent of these settlements and aiding the overall planning process for achieving inclusive land-use planning. This study also indicates that heterogeneity in land-use mix offers shelter, opens up employment possibilities for the poor dwellers, and facilitates them to establish their relationship with various other land uses as part of future research.

Another finding of this research is attributed to street connectivity. Zia Colony possesses a gridiron layout different from Shamspura and Hope Colony, where organic layouts prevail. The AND indicator demonstrates a higher connectivity index of the Zia settlement than the Shamspura and Hope Colony. The predominant Y and T-junctions beside dead-end streets in Shamspura and Hope Colony, a feature found in organically developed settlements, reduce the accessibility to this area. When incorporated within the GIS spatial-analysis tool, this indicator contributes toward understanding informal settlements at the city level. It can further facilitate officials and stakeholders to recognize these settlements and prioritize based on multiple factors (e.g., connectivity, degree of segregation, etc.) to take up suitable interventions. Moreover, it is essential to note that connectivity is complex; addressing it through average node density (AND) and street density (SD) is insufficient. However, adapting it to reflect street typology, this indicator can be the foremost step toward understanding the urban morphologies within informal settlements.

The lack of open spaces is a common finding for all these settlements; however, the ratio of built-up to open spaces differs. The ongoing informal incremental development has eaten up all the private and public open spaces. Concerning private open spaces, open courtyards and green setbacks in built-up structures are first covered up by developing additional rooms in the built-up unit. Moreover, the extension of building lines to the streets reduces the public spaces within an overall settlement. Streets are the only "open" spaces available to their inhabitants, and they are mostly contested and subject to appropriation. Despite the morphology of the selected areas being random, unplanned, or chaotic, the presence of underlying logic to meet occupants' needs is suggested. It is held forth that informal spatiality of open spaces must be considered within the existing governmental regulations and policies, such as the Katchi Abadi Act 1992, which stresses only giving guidelines on the built-up structure of these settlements. This study is also restricted to investigating socio-cultural practices in open spaces; however, an in-depth assessment of these spaces' physical elements and features could open more channels for future research.

In the contextual study, the increasing divide between the rich and the poor has triggered the need to understand these informal settlements as an added value to the city. This study highlights that these case studies are there to stay, and rather than doing practices to evict them, the focus should lie on giving policy guidelines and resources for their upgradation. The study suggests that the role of architects and planners alongside the government is integral in investigating different settlement morphologies to devise policy interventions. This research does not suggest romanticizing these existing informal settlements. Still, there is much to learn from their self-managed practices of adapting urban morphologies as architects and urban planners. The research also advocates that the government should focus on revising the existing policies and understand that the "one size fits all" approach is not ideal for Lahore; instead, individual morphologies must be studied. Applying formal approaches based on functional, hierarchal, and deterministic planning solutions is not feasible unless they recognize different typologies of areas and then shape them accordingly.

9. Limitations and Future Research

Limitations of the study are seen as potential opportunities for further research. There were aspects and directions that this research did not touch upon because of the focus on the objectives and research questions as initially designed. These limitations also establish a new finding of this research, i.e., identifying and considering them in informal settlements' spatial analysis. Among the many factors, accessibility and accuracy of data and its refinement are crucial in exploring more about the informal morphologies of these settlements. However, they often remain undocumented and not recognized within the formal maps [102], which also remains a limitation when conducting this research. This research is limited from the perspective of both scale and scope. Spatial mapping for these settlements focuses less on the semantic and symbolic aspects than on studying their overall morphology and making them visible within the city's urban fabric. Furthermore, the analysis of chosen indicators provides limited information on the potential synergies, which is highly complex and provides an area for future research on similar case studies.

Deficiencies and missing gaps in data collection are other limitations, as the data on informality could not be found or made available in governmental and other institutional documents and archives. Direct observation is not easy in a country with extensive geography; therefore, this study could partly achieve it. The COVID-19 pandemic further added a new challenge while doing the field survey, as it was difficult to maintain social distancing with the people. In addition, given the uncertainties linked to the pandemic and its impact, the field and interview data provided point-in-time information. However, this cannot be associated with the present or future conditions. Henceforth, an extended exploration is needed with an advanced method that could establish the basis of adding new cases in the atlas of informal settlements. As part of future research, effort should be made to focus on a more in-depth measure for characterizing the urban form over different times, using various tools and methods which provide greater precision and inclusion across the globe. Currently, remote-sensing tools are rapidly being developed and can soon offer ventures to the more robust mapping of physical attributes of informality. Nevertheless, based on the findings and methodology of this research, prospective studies can also contribute to the implementation of similar research studies across the global south cities.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14137788/s1.

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