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Influence of Morphological Characteristics on the Sustainability of Underserved Settlements: A Case Study in *Jaffna* Municipality and its Urban Fringe, Sri Lanka

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Abstract: Underserved settlements are crucial in providing housing and employment opportunities for the poor urban and their spontaneous spatial patterns pose challenges to sustainable urban development. This study examines the morphological characteristics of underserved settlements and their influence on the sustainability in the *Jaffna* Municipal area and its urban fringe in Sri Lanka. Primary data were collected through a structured questionnaire survey with 341 underserved settlements using a stratified random sampling technique. Focus group discussions and interviews were made with representatives of the community-based organizations and ground-level officers, and administrative officers of government institutions, local authorities, academics, and social activists respectively. The secondary spatial and statistical data were obtained from Google Earth and government departments. SPSS statistical software was used to analyze the data collected via a questionnaire survey using descriptive, and inferential statistics, while ArcGIS 10.4 software was used for geo- spatial analysis. Morphology results showed that underserved settlements are distributed in clusters with R values ≤ 0.16; consist a wide range of building patterns, specifically linear, triangular, rectangular, circular, regular, and irregular where the average building density is 107.48 underserved settlements/km ^{2} and average building coverage is 0.30 km ^{2}. Building coverage accounts for 99.12% of the variation in building density, whereas building area accounts for 96.74% of the variation; euclidean building distance accounts for 10.30% of the variation and road density accounts for 17.53%. Furthermore, this study found that building area, coverage, and road density have a positive relationship with building density, whereas euclidean building distance has a negative relationship. The underserved settlements' building forms do not comply with building regulations, resulting in a faulty layout and a congested built environment. The majority of settlements do not obtain permission to build their houses because they have less than six perches of land, are occupying land reservations, or lack legal land tenure. The disordered expansion of densely built-up houses, noncompliance with building regulations, poorly accessible road networks, and lack of environmental protection all have negative effects on the environment, health, sanitation, economy, and socio-cultural values of not only underserved settlements but also the entire urban environment. As a result, the structure and form of underserved settlements must be optimised to drive sustainable development.

Keywords**:** Underserved settlements, Morphological characteristics, Sustainability, Urban environment, Jaffna Municipality, Urban fringe.

Introduction

Underserved settlements (USSs) have become important in developing countries' urban housing sectors. In Sri Lanka, USSs refer to housing units that lack essential services, adequate living space, adequate structure, and tenure security (Ekanayake, 2001; Gunetilleke, Cader, & Fernando, 2004; UN-HABITAT, CEPA & Sevanatha, 2013). The spread of USSs is depending on geographical factors, rural-to-urban migration, poor urban governance, poverty, and low-income, which has positive and negative consequences (Mahabir et al. 2016; UN-HABITAT 2020; Zhang et al., 2020).

Asia has the largest share of the world's underserved population, and the region is home to around 560 million dwellers (UN DESA, 2020). In Southern Asia, the urban population is growing faster than the capacity of cities to support them, and USSs proliferate in many countries of the region. By South Asian standards, urban areas in Sri Lanka rank highly for livability, and living and housing conditions are generally better than in South Asian megacities' USSs (UN-HABITAT, 2016). However, much literature indicates that substandard living conditions in the USSs have become a pressing concern in the capital city of Colombo, Sri Lanka (Ekanayake, 2001; Gunetilleke, Cader, & Fernando, 2004; Niriella, 2012; UN-HABITAT, CEPA & Sevanatha, 2013; Kumara, 2015; Subasinghe, 2015; Lakshman, Alikhan, & Azam, 2019; Rasnayake, 2019). On the other hand, cities outside of the Western Province are not spared from the problem of the USSs.

Researchers are currently concentrating on the spatial structures of USSs as the key to comprehending this sector and developing effective management strategies. The development of remote sensing [RS] and geographic information system [GIS] technologies have assisted in this quest, and a growing number of studies are using high-resolution aerial images (Kuffer & Barrosb, 2011; Srifuengfung, 2012; Kohli et al., 2015; Kuffer, Pfeffer, & Sliuzas, 2016; Wurn et al., 2017; Veriah, 2018; Friesen et al., 2019). Researchers have adopted different methods, such as object-oriented feature extraction, space syntax, and spatial metrics, to extract and monitor spatial information for USSs and analyze their morphological characteristics (Kuffer & Barrosb, 2011; Kit, Lüdeke, & Reckien, 2012; Ahmed, Hasan, & Maniruzzaman, 2014; Gevaert et al., 2017). According to some studies, informal economic activity makes significant contributions to the spatial, social, economic, and environmental aspects of the area (Swai, 2019). However, these activities harm the built environment in residential areas due to aesthetic disorders, street trading, traffic jams, visual obstructions, indiscriminate waste disposal, and land use conversion (Farinmade, Soyinka, & Siu, 2018). USSs occur in both developed and developing cities and are associated with socio-economic, environmental, and administrative factors (Soyinka & Siu, 2018). McCartney et al. (2018) articulated the morphological structure of USSs by analyzing the impact of social, economic, and political factors; situational and site factors; building typologies, and configurations of circulation space. Some studies have investigated the typology of USSs (Ishtiyaq & Kumar, 2011; Brata et al., 2018). Arora et al. (2016) have discussed how the morphology of the dwelling unit reflects dwellers' requirements and living circumstances by adopting a grounded theory approach. Mukeku (2018) has focused on the urban morphology and socio-economic analogies in the Kibera USSs, while Kamalipour (2016) has considered the relationship between urban morphologies and street life intensity to explore the capacities of informal urbanism in Khlong Toei, and Bangkok. Most studies focused on morphological descriptions of USSs in a single city, but some studies moved beyond that and compared the spatial patterns of USSs in cities across countries (Kuffer & Barrosb, 2011; Sirueri, 2015; Kuffer, Pfeffer, & Sliuzas, 2016; Zhang et al., 2020). Sirueri (2015) has discussed assessing the morphological characteristics of USSs and comparing the spatial patterns of USSs between two cities, namely Nairobi and Dar es Salaam. Here, the dimensions of density, size, shape, and pattern have been used to assess the morphology of USSs, whereas density, connectivity, circuitry, and complexity were employed to assess the road network within the USSs. A similar type of work has been undertaken by Zhang et al. (2020) where they employed spatial, quantitative, and qualitative approaches to examine the morphological characteristics of USSs in the cities of Dar es Salaam, Mwanza, and Kigoma in Tanzania. Following that, they addressed how the morphological characteristics of USSs influence the sustainability of urban environments and how to tackle this issue. Even though many scholars focused on the morphological characteristics of USSs in various ways, most studies overlooked how USSs' morphology influences their sustainability, except for Zhang et al. (2020).

Many initiatives have been undertaken to upgrade and relocate the USSs in Sri Lanka (Jagoda, 2009; Dayaratne, 2010; Samaratunga & Hare, 2013). Despite the government's concerted efforts, the housing supply for underserved communities remains critical, and improvements in the quality and quantity of housing remain less than satisfactory (Jagoda, 2009). Residents in USSs face various issues and challenges to sustain their lives; they are viewed as barriers to urban development (Sirueri, 2015). Thus, if urban development is to be sustainable, the USSs must be transformed into sustainable ones (Chambers & Conway, 1992; Soma, Sukhwani, & Shaw, 2022). For this, it is vital to comprehend the USSs' morphological context and how it influences their sustainability.

In the context of Sri Lanka, literature on this topic of USSs' morphological characteristics has not been sufficiently developed. There are only a few studies covering the subject of morphological characteristics of settlements in Sri Lanka. Senadheera et al. (2019) conducted a qualitative study on the topic of making residential buildings sustainable through building regulations, with a focus on sustainable construction principles, sustainability measurement factors suitable for residential buildings, negative features of the plan approval process, and proposed solutions to enhance the sustainability of residential buildings. However, they have focused on the sustainability measurement factors suitable for formal residential buildings and failed to address the building practices in USSs, which have different morphological characteristics than formal residential areas as stated by Kuffer, Pfeffer & Sliuzas (2016). Thus, this study attempts to fill that knowledge gap of building morphology and the pattern of the settlement by addressing the following research questions:

(1) What are the morphological characteristics of USSs in the *Jaffna* Municipality and its urban fringe and how these characteristics influence their sustainability?

(2) Is there a relationship between USS building density and building area, building coverage, building distance (Euclidean distance), and road density?

Material and Methods

Study area

The *Jaffna Municipality* and its urban fringe in Sri Lanka were chosen as the study area. It is located in the *Jaffna* Peninsula's southern part in Sri Lanka, between 9^0 36' 30" N – 9^0 42' 90" N and 79^0 88' 10" E – 80^0 08' 20" E (Fig. 1). The extent of the area is 44.54 km^2 and is naturally bounded in the south by the *Jaffna* lagoon. It includes 68 Grama Niladhari Divisions (GND), with a total population of 121,762 (JDS, 2021). There are 22622 USSs in the *Jaffna* District, of which 13.34% are within the *Jaffna Municipality* and its urban fringe (JDS, 2021). The USSs of Jaffna city's coastal areas, from *Columbuthurai* to *Navanthurai*, indicated poor living conditions in which most basic amenities were either lacking or inadequate, resulting in the entire underserved area developing into an imminent threat to the environment, health, and sanitation of not only that area but the entire city.

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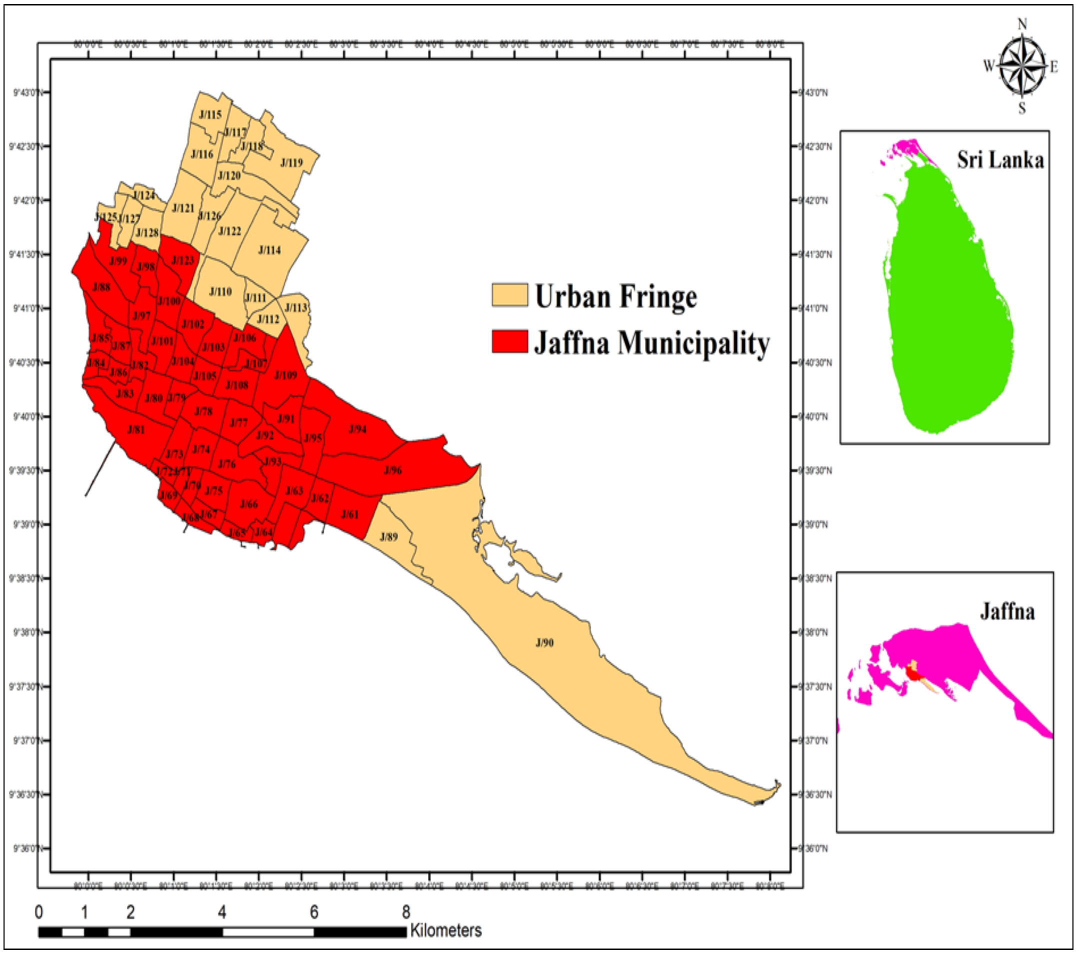

Fig. 1. Map showing the *Jaffna* municipality and its urban fringe.

Source: Prepared by the researcher based on Survey Department [SD], 2021

Conceptual framework

This conceptual framework illustrates how the morphological characteristics of USSs—such as density, housing quality, land use, accessibility, and spatial layout—shape the social, economic, environmental, and institutional dimensions of sustainability, which in turn determine the overall sustainability of USSs through balanced development, improved living conditions, and integration into urban systems.

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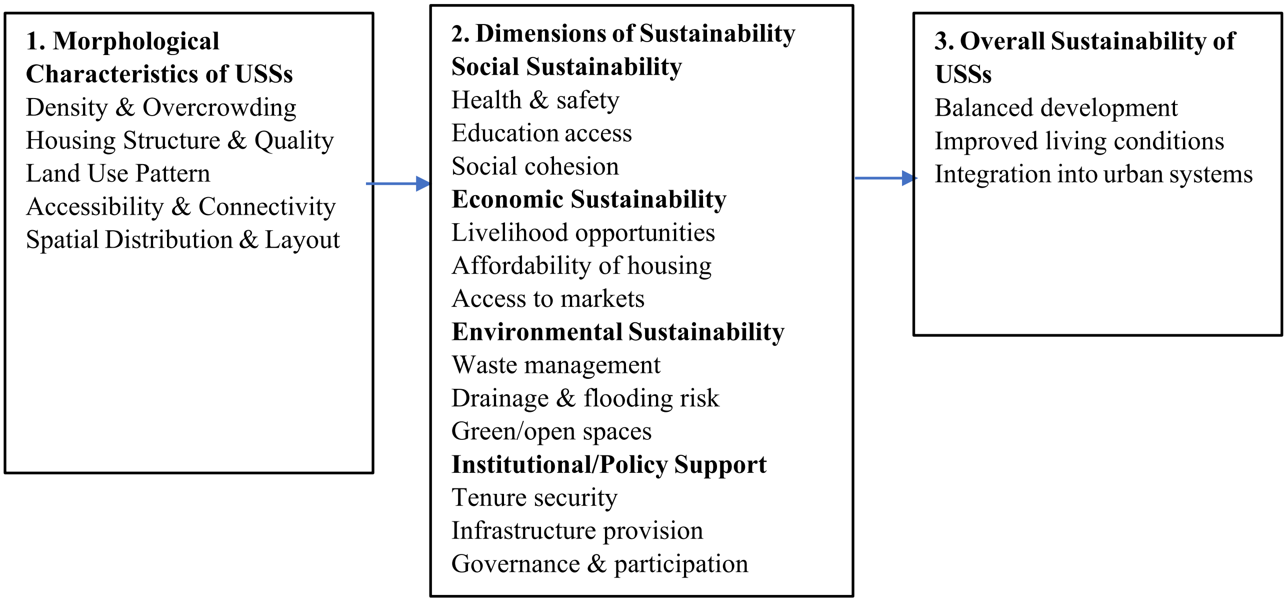

Fig. 2. Conceptual framework of the morphological characteristics of USSs and their sustainability.

Source: Developed by the researcher, 2021

Sampling

The total number of USSs in the *Jaffna Municipality* and urban fringe is 3019 (Field survey, 2020 & 2021), which is the study's total population. According to Krejcie and Morgan's (1970) findings, 341 USSs were chosen as the study's sample. As shown in Table 1, a proportionately distributed stratified random sampling technique was used to select samples from the population. The random numbers were generated using the "RANDBETWEEN" formula in MS Excel.

Table 1. Distribution of sample underserved settlements in the *Jaffna* Municipality and urban fringe.

Housing condition (Strata)	Administrative divisions (Strata)			
	Jaffna Municipality (Urban)		*Nallur* Pradeshiya Sabah (Urban fringe)	
	Population	Sample	Population	Sample
Temporary settlements	348	39	128	14
Semi-Permanent settlements	289	33	113	13
Permanent settlements	2064	233	77	9
Total	2701	305	318	36

Source: Field survey, 2020 & 2021

Methods of data collection

This study used both primary and secondary data. Table 2 summarizes secondary data obtained from various sources.

Table 2. List of secondary data used in the study.

Type of Data	Year of Acquisition	Data Format	Source
Raster			
Satellite imagery	2020	Geo Tiff	Google Earth
Vector			
GND boundary	2020	Shape file	Survey Department (SD)
Road	2020	Shape file	Urban Development Authority (UDA)
Pond	2020	Shape file	*Jaffna* Divisional Secretariat (JDS)
Statistics			
Statistical handbook	2020	Hard copy	JDS, *Nallur* Divisional Secretariat
Building regulations	2021	Hard copy	UDA

Source: Developed by the researcher, 2021

Direct field observation [DFO], transect walks, structured questionnaire surveys [SQS], key informant interviews [KIIs], and focus group discussions [FGDs] were made as primary data collection for this study. DFO was conducted from August 2020 to December 2021 to comprehend the morphology of the USSs.

An SQS was carried out with 341 USSs from August 2021 to December 2021 to assess the morphological characteristics of USSs under the criteria of the type of house; the number of floors/levels of settlement; the materials used to build the house: wall, floor and roof; the number of rooms and room types; floor area and floor area per person; minimum plot size; plot coverage; ground level plinth area; internal dimensions of rooms, toilet, and kitchen; internal heights of rooms, toilet, bathroom, and corridor; window area of rooms, toilet, and bathroom; frontage; rear space; side space; distance between latrine pit and well; and road access. FGDs were conducted with representatives of community-based organizations [CBOs] and ground-level officers, as well as KIIs with officers of government institutions, local authorities, academics, and social activists, to obtain further information about the impact of USSs' morphology on their sustainability and measures to mitigate the impacts.

Morphological analysis

The morphology of USSs was primarily examined using the GIS technique, which included variables such as building distribution, density, area, and pattern.

The building distribution

The spatial distribution of USSs within the study area was analysed using the Average Nearest Neighbour (ANN) method in the Spatial Statistics tools of Esri ArcGIS. The Nearest Neighbour Ratio (R) compares the observed mean distance between points with the expected mean distance under a random spatial distribution (Aziz et al., 2012). The equation for the R calculation is given below.

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$$R = \frac{r_{\text{obs}}}{r_{\text{exp}}} \qquad (1)$$

where r_{obs} is the observed mean nearest-neighbour distance and r_{exp} is the expected mean nearest-neighbour distance for a random pattern.
The observed mean distance is calculated as:

$$r_{\text{obs}} = \frac{1}{N}\sum_{i=1}^{N} d_i$$

where d_i is the distance from point i to its nearest neighbouring point, and N is the total number of points.
The expected mean distance for a random spatial distribution is given by:

$$r_{\text{exp}} = \frac{1}{2}\sqrt{\frac{A}{N}}$$

where A represents the total area of the study region and N is the number of points.

If $R = 1$, the spatial pattern is random.
If $R < 1$, the pattern indicates clustering.
If $R > 1$, the pattern indicates dispersion

The building density

The density of USSs was calculated in two ways. Firstly, kernel density, an ArcGIS Spatial Analyst Tool, was used to calculate the density of USSs, where density is calculated as a magnitude per unit area from point features using the kernel function to fit a smoothly tapered surface to each point. The surface value is greatest at the point's location and decreases as one move away from the point, reaching zero at the search radius distance from the point (Kalinic & Krisp, 2018). The output cell size and search radius (bandwidth) for the type of kernel used in single kernel interpolation were set to default values. The single kernels were visualized by scaling density values in a choropleth map so that higher densities are shown in darker tones and lower densities are shown in lighter tones (Leitner, Arden & Heukelbach, 2009). Subsequently, density was calculated based on GNDs. The number of settlements per unit area is generally referred to as the settlement density, and the formula for calculating the USS density is provided below (Zhang et al., 2020).

$$\text{USS density} = \frac{\text{Number of USSs}}{\text{Land area}} \qquad (2)$$

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The building area and coverage

To find out and calculate the size and coverage of the USSs, buildings were digitized from Google Earth satellite images in the geometry type of polygon. Thereafter, by using the calculate geometry function of ArcGIS, the area of buildings was calculated. Building coverage is defined as the ratio of the total area of buildings to the entire area of the corresponding administrative region. The building coverage ratio of USSs is calculated based on the below-mentioned formula (Zhang et al., 2020).

$$\text{Building coverage ratio} = \frac{\text{Building area} \times 100}{\text{Site area}} \quad (3)$$

The building pattern

The following steps were followed to determine the building pattern of USSs. A digitized USS shape file in the geometry type of polygon was added to ArcGIS. The coastline, road, railway, and pond were chosen as determining features for the pattern of USSs based on the literature and study area context, and the above- mentioned shape files were added to ArcGIS and the pattern of USSs was found.

Road connectivity

To analyze the road connectivity, the number of edges, nodes, and total road lengths were used. First, the network data set was built from the street feature class in a geodatabase (gdb), and the road's nodes and edges were derived. Following that, various indices based on these variables were developed to characterize all aspects of the road network's connectivity. The following formulas were used to calculate circuitry (α), complexity (β), and connectivity (γ).

α = ((L-V) +1)/ (2V-5)

β = L/V

γ =L/ (3*(V-2))

Where L is the number of links and V is the number of nodes.

The alpha (α) index measures the circuitry of a road network; that is the number of complete cycles in a network (Sirueri, 2015; Zhang et al., 2020). The index ranges from 0 (0%) to 1 (100%). The beta (β) index reflects both the complexity and completeness of a road network (Sirueri, 2015; Zhang et al., 2020). This is done by expressing the ratio of links to nodes. When β<1 is present, it indicates that the network is disconnected; β=1 indicates a single circuit; β>1 indicates that the road network connectivity in an area is greater. The gamma (γ) index measures the extent to which the nodes are connected. It is also a ratio of links and nodes, and its value ranges from 0 -1 (Sirueri, 2015; Zhang et al., 2020). Gamma is independent of the number of nodes within the road network. The value of 1 denotes a completely connected road network, whilst 0 indicates a lack of connectivity. All of these indices are crucial for understanding road connectivity (Sirueri, 2015; Zhang et al., 2020).

The road density

The morphology of roads was assessed in terms of road density. The density of roads was calculated in two ways. Firstly, linear density, an ArcGIS Spatial Analyst Tool, was used to calculate the density of roads, where density is calculated for magnitude per unit area from polyline features that fall within a radius around each cell. Following that, density was calculated based on GNDs. The formula used to calculate the road density is given below.

$$\text{Road density} = \frac{\text{Length of road}}{\text{Land area}} \quad (4)$$

The relationship between morphological features of the underserved settlements

The correlation function of Microsoft Excel's "Analysis Toolpak" was used to examine the relationship between the independent variables of building area, building coverage, building distances, and road density and the dependent variable of building density. The correlation coefficient ranges from -1 to +1. The relationship between the variables becomes weaker as the correlation value approaches zero, and vice versa as it approaches one, indicating a stronger relationship (Kapoor & Kapoor, 2016; Kafle, 2019). Following that, using regression analysis in MS Excel, the impact of building area, building coverage, building distances, and road density on building density was investigated. Regression analysis estimates the relationship between the dependent and independent variables, as well as the magnitude of change in the dependent variable when the independent variable varies (Kapoor & Kapoor, 2016). Eventually, the outcomes of the analysis were represented in the form of tables and scatter diagrams.

The housing standard

The housing standard of USSs was assessed using descriptive statistics based on data collected from the SQS in terms of the criteria mentioned in the data collection section of 3.4. The extent to which the settlements comply with building regulations was examined using the UDA building regulations. Data on the influencing factors for the design of houses in contravention of building codes and regulations in the study area was gathered through KIIs and qualitatively analyzed. Furthermore, by combining all the data collected in the field, it was qualitatively analyzed how the morphological characteristics of USSs influence their sustainability (Fig. 3).

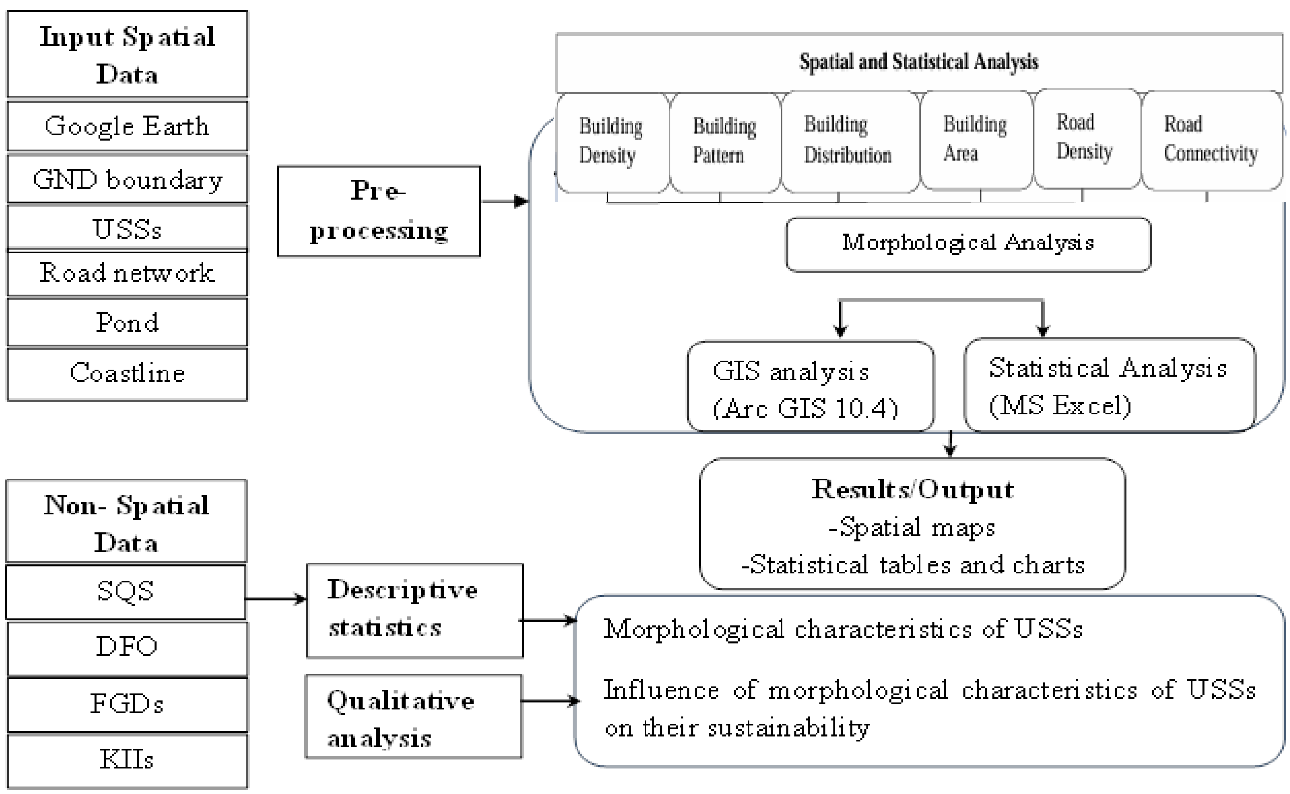

Fig. 3. -Flow chart of the study's methodological framework.

Source: Developed by the researcher, 2021

Results

The morphology of USSs was first analyzed using the GIS technique, with variables specifically building distribution, density, area, and pattern, and the results are summarized below.

The building distribution of USSs

The distribution of USSs in *Jaffna* Municipality and its urban fringe is spatially clustered with an R-value of 0.16 (z-score = -88.104938; p-value < 0.001). The null hypothesis in this study is that there is no spatial pattern among the USSs within the study area. With small z-scores, there is a small probability, which is less than 1% likelihood, that this clustered pattern could be a result of random chance, so the null hypothesis is rejected. The distribution of USSs was further analyzed according to the GNDs. The ANN values are calculated and tabulated in Table 3. USSs are clustered in 56% of GNDs, particularly in *Nedunkulam, Columbuthurai East, Passaiyoor West, Thirunagar, Reclamation East* and *West, Small Bazar, Jaffna Town East*, *Athiyady, Fort, Koddady, Navanthurai South* and *North, New Moor Street, Ariyalai East* and *South East, Vannarpannai North West, Sangiliyan Thoppu,* and *Thirunelvely Centre North*. The USSs' pattern is dispersed in 15% of GNDs, including *Jaffna Town West, Sirampiady, Ariyalai Center North, Ariyalai Center South,* and *Vannarpannai North,* where the R-value is greater than 1. Furthermore, USSs are found in the remaining GNDs in a random or nearly random pattern (R=1).

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Table 3. ANN statistics and distributional pattern of underserved settlements.

GND	OMD (m)	EMD (m)	NNR	z-score	p-value	Pattern
Overall	13.1167	80.30	0.1633	-88.10	0	Clustered
61	31.10	77.48	0.4013	-9.51	0	Clustered
62	19.01	33.76	0.5630	-5.79	0	Clustered
64	22.03	24.51	0.8990	-0.64	0.5217	Random
65	11.04	21.98	0.5024	-6.60	0	Clustered
67	10.89	20.64	0.5274	-8.43	0	Clustered
68	7.02	7.99	0.8790	-7.06	0	Clustered
69	6.58	7.67	0.8572	-7.14	0	Clustered
70	35.04	31.93	1.0976	0.81	0.4157	Random
71	11.10	10.43	1.0640	0.71	0.4752	Random
72	12.27	23.65	0.5187	-4.60	0.0000	Clustered
73	3.52	3.05	1.1554	1.86	0.0633	Dispersed
74	18.99	27.80	0.6833	-4.06	0.0000	Clustered
75	65.70	65.10	1.0093	0.07	0.9416	Random
77	59.62	45.98	1.2967	1.61	0.1084	Random
78	15.38	32.95	0.4667	-3.06	0.0022	Clustered
79	25.03	8.73	2.8655	7.14	0	Dispersed
80	12.02	14.13	0.8504	-1.49	0.1370	Random
81	21.11	34.92	0.6044	-6.33	0	Clustered
83	24.53	45.28	0.5417	-3.61	0.0003	Clustered
84	16.90	24.08	0.7019	-3.82	0.0001	Clustered
85	13.01	20.65	0.6302	-9.57	0	Clustered
86	11.41	12.54	0.9096	-1.55	0.1219	Random
87	13.74	13.25	1.0372	0.53	0.5981	Random
88	23.48	36.22	0.6483	-5.26	0	Clustered

89	30.42	46.79	0.6502	-7.02	0	Clustered
90	62.45	167.17	0.3736	-8.64	0	Clustered
94	73.10	39.40	1.8552	4.33	0	Dispersed
96	41.78	32.26	1.2951	2.04	0.0418	Dispersed
98	43.24	31.38	1.3781	2.29	0.0222	Dispersed
99	26.38	45.84	0.5756	-3.98	0.0001	Clustered
109	20.26	39.37	0.5145	-6.16	0	Clustered
110	32.31	27.97	1.1553	1.22	0.2207	Random
114	16.20	39.78	0.4072	-11.05	0	Clustered
122	13.95	12.70	1.0984	1.25	0.2119	Random

Source: Calculated by the researcher, 2021

The building density of underserved settlements

The kernel density estimation results are shown in Fig. 4. According to that, the minimum density is 0, the maximum density is 6791, the mean density is 73, and the standard deviation is 41. The geographical distribution of USSs is most prevalent in the city's coastal belt when compared to inland areas. As shown in Fig. 4a, they are particularly congested as clusters along the western and south-west coasts. Their spatial distribution, on the other hand, is constrained by their proximity to the coast. Subsequently, the USS density was calculated based on GND, and the equation used to calculate the USS density is mentioned in section 3.5. Fig. 4b shows the density of USSs based on GND.

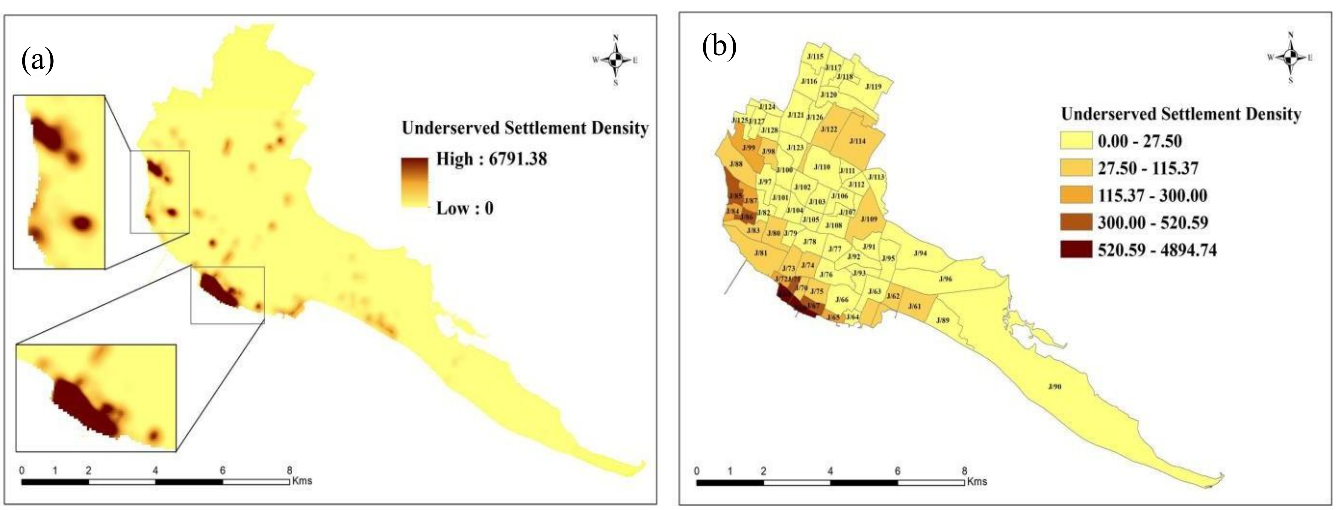

Fig. 4. Density of underserved settlements in the study area: (a) kernel density, (b) the density of USSs based on GND.

Source: Prepared by the researcher based on Jaffna District Secretariat, 2021

The average density of USSs is 107 USS/km^2. Of the GNDs, *Passaiyoor West, Thirunagar, Reclamation East* and *West, Gurunagar West, Small Bazar, Jaffna Town East, Navanthurai South* and *North, Moor Street South* and *North,* and *Vannarpannai North West* have a USS density higher than average. The highest USS densities are found in *Reclamation East* and *West,* which have densities of 4895 and 4269 USS/km^2, respectively. Simultaneously, the lowest USS density is found in *Ariyalai East,* which has a density of 1 USS/km^2.

The building area and coverage of underserved settlements

The underserved building area consists of 0.30 km^2. According to Table 5, the largest underserved building area is in *Reclamation East,* followed by Reclamation West and Navanthurai North. The average building coverage ratio of USSs in the study area is 1.06%. The *Reclamation East* and *West* divisions have the highest underserved building coverage, with USSs covering 66.8% and 51.21% of the area, respectively. The *Ariyalai Center North* and *South* have the lowest underserved building coverage, with 0.02%. The building coverage of USSs in the study area is shown in Table 4.

Table 4. Building coverage ratio of underserved settlements.

GND	Building area (km^2)	Site area (km^2)	Building coverage ratio	GND	Building area (km^2)	Site area (km^2)	Building coverage ratio
61	0.00537	0.69	0.78	81	0.00421	1.1	0.38
62	0.00321	0.46	0.70	83	0.00153	0.4	0.38
64	0.00116	0.4	0.29	84	0.00345	0.18	1.92
65	0.00418	0.16	2.62	85	0.01037	0.34	3.05
67	0.00666	0.2	3.33	86	0.00486	0.19	2.56
68	0.12692	0.19	66.80	87	0.00218	0.32	0.68
69	0.08193	0.16	51.21	88	0.00341	0.78	0.44
70	0.00097	0.2	0.48	89	0.00487	0.51	0.95
71	0.00338	0.07	4.82	90	0.00261	9.9	0.03
72	0.00283	0.14	2.02	94	0.00028	1.46	0.02
73	0.00122	0.38	0.32	96	0.00044	2.12	0.02
74	0.00297	0.39	0.76	98	0.00064	0.66	0.10
75	0.00129	0.37	0.35	99	0.00170	0.41	0.41
77	0.00059	0.44	0.13	109	0.00359	0.98	0.37
78	0.00070	0.5	0.14	110	0.00080	0.96	0.08
79	0.00028	0.27	0.11	114	0.00524	1.17	0.45
80	0.00169	0.5	0.34	122	0.00273	1.09	0.25

Source: Developed by the researcher, 2021

The building pattern of underserved settlements

The USSs in the study area have a range of building patterns, namely linear, triangular, rectangular, circular, regular, and irregular. The linear pattern is represented by USSs along roads, railway lines, canals, and coastlines. USSs are found in a linear pattern along the coast from *Nedunkulam* to *Navanthurai North*, on railway lines from *Rasavinthoddam* to *Alupanthy port*, and in front of the University of *Jaffna's* new girls' hostel. Furthermore, linear patterns of USSs can be found along some pathways, such as *Rajasingham Road, Beach Road, Convent Road, Esplanade Road*, and *Cross Roads*. The linear pattern is represented by 2938 USSs, 1005 of which are based on the coastline, 142 on railway lines, and the remainder on roadways. USSs with a triangular pattern have formed in *Navanthurai North*, between the *Navanthurai-Oddumadam Road* and *Jaffna Ponnalai Point Pedro Road*. The pattern is composed of approximately 101 USSs. The semi-circular building pattern is represented by about 23 USSs. These USSs can be found near *Kannathiddy, Thevarir, and Cheddiyarthoddam ponds*. Furthermore, USSs in *Reclamation East* have encroached on the prawn cultivation site and built around a portion of the lagoon site. Rectangular patterns are found where roads intersect perpendicularly. The rectangular layout is represented by nearly 164 USSs. Shapeless buildings are constructed for human comfort without any planning, resulting in an irregular pattern in the study area. In this pattern, roads grow out of the gabs of structures, while buildings grow out of the gabs of space. These types of USSs are found all around the study area. Concurrently, USSs with regular patterns were established at *Vasanthapuram* of *Nedunkulam* and *Navanthurai North, Tharakulam* and *Gurunagar's Flats sites*, and the *Ponnamapalam sites* of *Passaiyoor East.* Fig. 5 depicts linear (a), semi-circular (b), triangular (c), rectangular (d), shapeless (e) and regular (f) building patterns of USSs in the study area.

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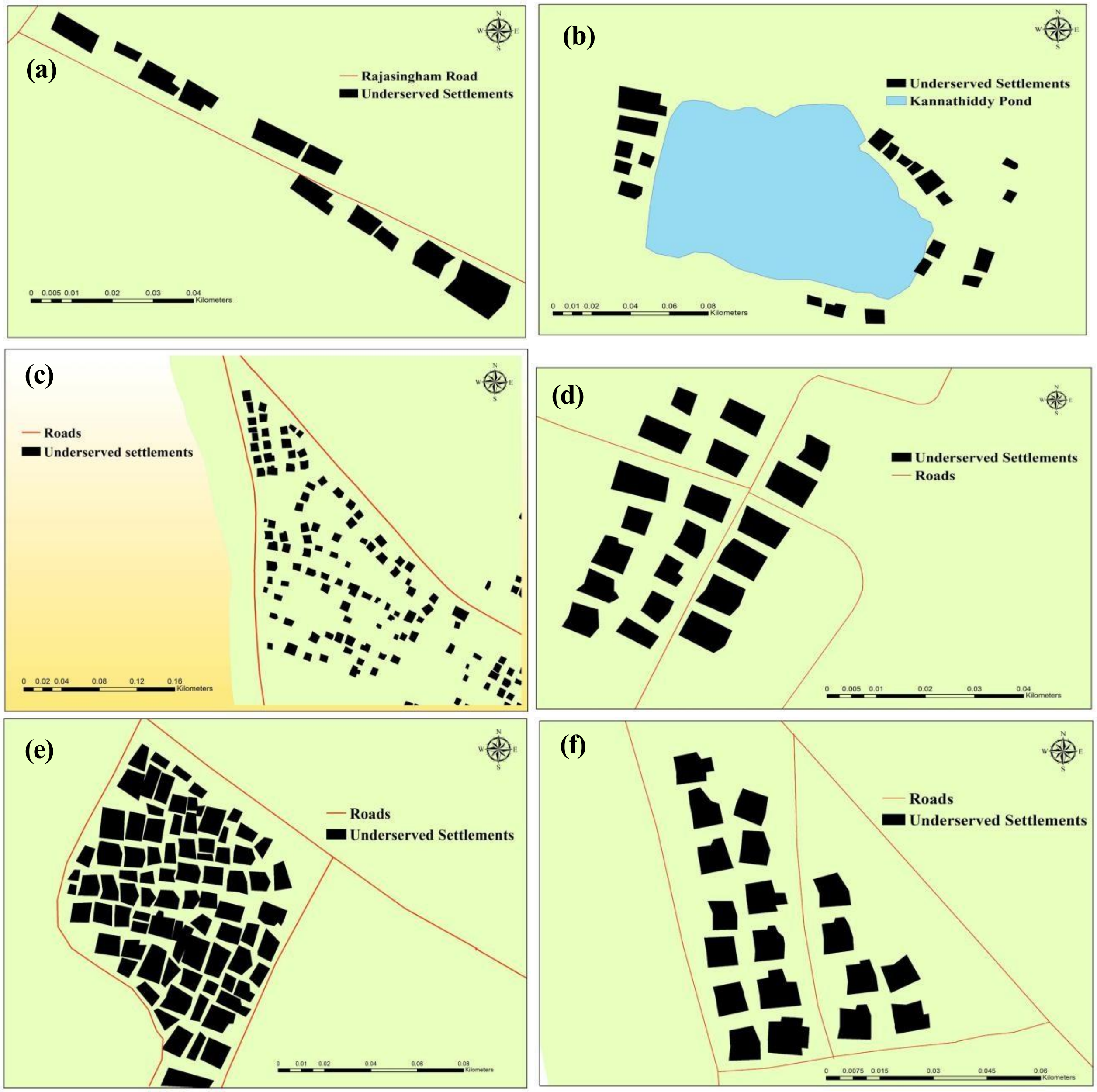

Fig. 5. Building pattern of underserved settlements in the study area: linear (a), semi-circular (b), triangular (c), rectangular (d), shapeless (e) and regular (f).

Source: Prepared by the researcher based on Google Earth, 2021

According to UDA administrative officers, settlements in *Reclamation East* and *West* followed a regular pattern when they were established. However, due to the concentration of the population in a limited space, settlements became congested, resulting in an irregular building pattern. In contrast, *Vasanthapuram* settlements had irregular building patterns until 2020, but now the land has been regularized and the settlements have been built in a regular pattern. Fig. 6 depicts the transformation of the *Vasanthapuram* settlement's building pattern in 2002, 2015, and 2021, respectively.

Fig. 6. Transformation of building pattern of the Vasanthapuram settlement.

Source: Google Earth, 2002-2021

Road connectivity and density

A well-developed transportation network is crucial for the settlement area's social and economic development because it connects places and people. The road network of the selected divisions consists of 3161 nodes (V), 4748 links (L), and a total length of 305.35 km. The road connectivity indices were computed and tabulated, as shown in Table 5. The average alpha index is 0.31, which equals 31%. The highest alpha value is assigned to the *Passaiyoor West,* indicating that the division has a very high degree of circuitry or that a more significant number of nodes are well connected. *Ariyalai East,* and *Thirunelvely Centre North,* have very low levels and poorly connected nodes. On average, the beta index is 1.58. All the selected divisions have a value greater than one, indicating that the area's road network connection is better. *Passaiyoor West* has the highest beta value, while *Thirunelvely Centre North* has the lowest. The average gamma is 0.54. *Passaiyoor West* has the highest gamma value, while *Thirunelvely Centre North* has the lowest.

Table 5. Alpha, Beta, and Gamma road connectivity indices.

GND	L	V	A	β	γ	GND	L	V	α	β	γ
61	167	127	0.16	1.31	0.45	81	229	160	0.22	1.43	0.48
62	235	108	0.61	2.18	0.74	83	133	86	0.29	1.55	0.53
64	73	39	0.48	1.87	0.66	84	58	36	0.34	1.61	0.57
65	73	33	0.67	2.21	0.78	85	180	129	0.21	1.4	0.47
67	41	29	0.25	1.41	0.51	86	88	44	0.54	2	0.7
68	147	82	0.42	1.79	0.61	87	150	100	0.26	1.5	0.51
69	121	60	0.54	2.02	0.7	88	124	92	0.18	1.35	0.46
70	71	41	0.4	1.73	0.61	89	147	91	0.32	1.62	0.55
71	87	50	0.4	1.74	0.6	90	118	99	0.1	1.19	0.41
72	54	26	0.62	2.08	0.75	94	119	90	0.17	1.32	0.45

73	120	83	0.24	1.45	0.49	96	153	119	0.15	1.29	0.44
74	109	81	0.18	1.35	0.46	98	105	65	0.33	1.62	0.56
75	99	57	0.39	1.74	0.6	99	185	126	0.24	1.47	0.5
77	209	137	0.27	1.53	0.52	109	313	231	0.18	1.35	0.46
78	215	151	0.22	1.42	0.48	110	212	159	0.17	1.33	0.45
79	107	63	0.37	1.7	0.58	114	135	114	0.1	1.18	0.4
80	151	91	0.34	1.66	0.57	122	220	162	0.18	1.36	0.46

Source: Developed by the researcher, 2022

According to the study area's road density analysis based on the line density, the minimum density is 0, the maximum density is 27.98, and the mean density is 12.71± 7.68. Subsequently, as indicated in section 3.5, the road density was calculated based on GND. According to that, *Gurunagar West* has the highest road density of 54 km of road /km^2, while *Ariyalai East* has the lowest density of 2 km of road/km$^{2.}$

Relationship between morphological characteristics of underserved settlements

The relationship between the independent variables of building area, building coverage, building distance (Euclidean distance), road density and the dependent variable of building density is shown in Fig. 7.

a) b)

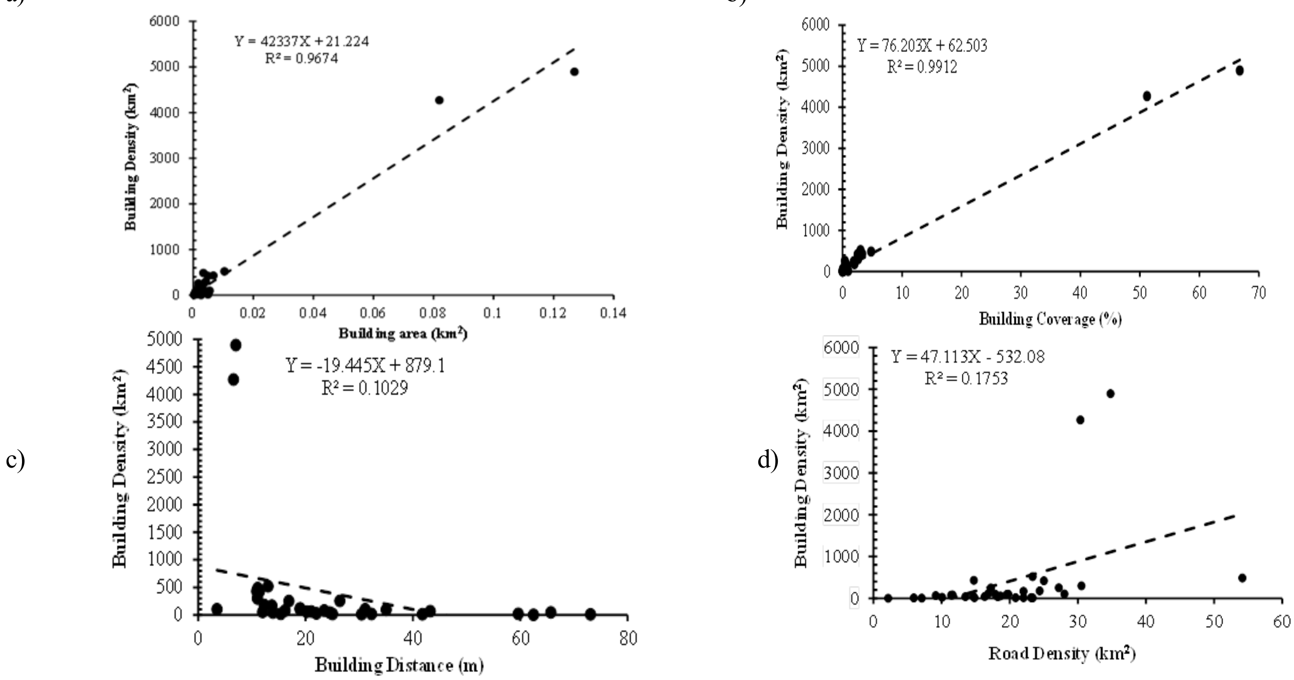

Fig. 7. Relationship between morphological characteristics of underserved settlements.

Source: Created by the researcher, 2021

As seen in Fig. 7, the building area and coverage have a strong positive correlation with building density. Building density increases along with building area and coverage. *Reclamation East* and *West* divisions have the largest building areas and coverage. Simultaneously, building density is also the highest in the divisions. Building distance has a weak negative relationship with building density. Building density tends to decrease with the increase in building distance. The study found that the average building distance between buildings is 13 m. The Reclamation East and West account for 7 m, for the lowest building distance. Many buildings are very close together in this area and have a disordered orientation, and the typical distance between buildings in these divisions gradually shrinks over time. Road density has a moderate positive correlation with building density. Building density tends to increase with the increase in road network density. Convenient transportation can promote economic development within settlements. In the study area, economic activity is concentrated along the main roadways, and the underserved buildings are also concentrated along these roadways. In many circumstances, buildings are typically built in the USSs first, and then roads are built around them. Building coverage accounts for 99% of the variation in building density, whereas building area accounts for 97% of the variation; building distance accounts for 10% of the variation, and road density accounts for 18%.

Housing quality and standards

Data collected via a SQS related to the morphological characteristics of USSs were analyzed, and the results are summarized under the following subtitles.

Housing structure and setbacks of the settlement

In the study area, 16% of USSs are temporary, 13% are semi-permanent, and 71% are permanent. 94% of permanent USSs are single level, with the remainder having one or more floors. In the study area, 4% of USSs have no rooms or partitioned space, 37% have a single room, 39% have two rooms, and the remaining USSs have more than two rooms. Bedrooms are available in 96% of the USSs. Furthermore, 37% have an inside kitchen, 24% have an outside kitchen, and 39% do not have a separate kitchen and have designated a portion of their living room for cooking needs. Furthermore, 76% of USSs have either inside or outside toilet facilities, while the remaining USSs share toilets with their neighbours or use common toilets due to the lack of individual toilets. Fig. 8 depicts the housing structures and room layout of the USSs in the study area.

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Fig. 8. Housing structures of underserved settlements (a,b,c), and room structure of underserved settlements (d, e) and front, side, and rear spaces (f,g,h).

Source: Field Survey, 2020 & 2021

Building height is the distance between the access road level and the roof level. All USSs in the study area are low-rise buildings, with 96% being less than 7 m in height. According to the UDA's building regulations, the following setbacks must be maintained in a settlement based on its height, as shown in Table 6.

Table 6. Setbacks of the underserved settlement.

Building category	Building height (m)	Minimum site frontage (m)	Rear Space (m)		Side Space (m)	
			When no NLV is taking this end	When NLV is taking this end	When n o NLV is taking this end	When NLV is taking this end
Low rise	<7	6	2.3	2.3	1	2.3
	7 to < 15	6	3.0	3.0	1	3.0
Intermediate rise	15 to < 30	12	4.0	4.0	1.0 & 3.0	4.0
Medium rise	30 to < 50	20	4.0	5.0	3.0	5.0
High rise	50 to < 75	30	5.0	6.0	4.0	6.0
	≥75	> 40	5.0	6.0	5.0	6.0

*NLV: Natural Light & Ventilation

Source: UDA, 2022

According to the survey, 71% of USSs do not have the required frontage. The area further away from any street is referred to as “rear space.” If there are multiple entrances, the back space should be the one that is farthest away from the widest street. 94% of USSs in the study area do not maintain rear space in accordance with standards. Furthermore, 56% of USSs lack side space on both sides; 33% have side space on at least one window side despite failing to meet regulations; and the remaining have side space on both sides. USSs in *Passaiyoor East* and *West, Reclamation East* and *West, Gurunagar East* and *West, Small Bazaar,* and *Navanthurai South* have insufficient frontage, rear space, and side space.

Material used to construct the settlement

Based on the materials used to construct the settlement walls, 7% are made of mud/cadjan, 22% are made of pressed soil blocks/metal sheet/planks, 13% are made of unplastered bricks/cement blocks, and the rest are plastered walls. According to the floor materials, bare soil is used in 1% of the USSs, mud is used in 2%, rough concrete/cement is used in 87%, and tiled floors are used in the remaining USSs. According to the materials used to build the settlements' roofs, 1% have cadjan roofs, 28% have metal sheet/vinyl sheet roofs, 61% have asbestos, and the rest have brick tile/concrete roofs. Fig. 9 depicts the materials used to construct the USSs’ wall, floor and roof respectively.

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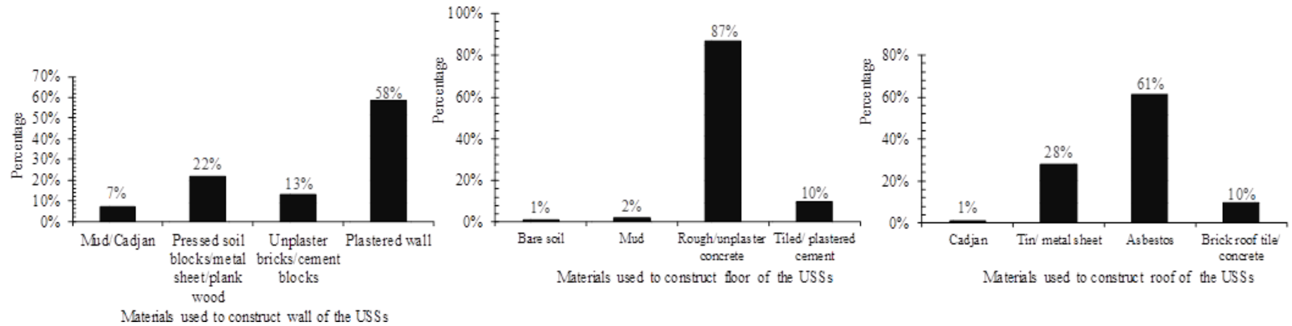

Fig. 9. Material used to construct the underserved settlements.

Source: Questionnaire survey, 2021

Minimum plot size, ground-level plinth area, plot coverage and floor area

According to UDA building standards, the minimum plot size for residential areas is 6 perches/150 square meters (m^2). Despite the fact that 71% of USSs do not meet the minimum plot size standard. 52% of USSs in *Passaiyoor East* and *West, Reclamation East* and *West, Gurunagar East* and *West, Small Bazaar,* and *Navanthurai South* have a perch of 2.5 or less. According to NHDA building requirements, the ground level plinth area of the settlements should not be less than 550 ft^2 and should include the bedroom, room, kitchen, living room, and toilet. However, the minimum plinth area is less than the standard in 85% of USSs.

The maximum plot coverage allowed by the UDA for a dwelling unit is 65%. Despite this, 71% of the USSs' plinth area covers more than 65% of the land area. In particular, 52% of the USSs have plot coverage that exceeds 80%.33% of the USSs in the study area have less than 250 ft^2 of floor area, 52% have 250-550 ft^2, and the remaining USSs have more than 550 ft^2. In 81% of USSs, floor space per person is less than 85ft^2, 85-160 ft^2 in 15%, and more than 160 ft^2 in the remaining USSs.

Internal dimensions (width and area) and internal heights

According to UDA building regulations, the internal average heights of the living room, bedroom, and kitchen should not be less than 2.8 m on average, with a minimum of 2.4 m at the lowest point. Furthermore, the toilet, bathroom, and corridor should all have interior heights of at least 2.2 m. Figure 10a shows the standard internal heights of rooms. Based on UDA building regulations, if a housing unit has only one room, the minimum width of the room should be 3.0 m and the minimum area should be 11 m^2. If a housing unit has more than one room, the first room should have a minimum width of 2.5 m and a minimum area of 9.5 m^2, while the additional rooms should have a minimum width of 2.5 m and an area of 8.5 m^2. The kitchen should have a minimum width of 1.8 m and a minimum area of 5.5 m^2. Furthermore, the minimum width of the bathroom or toilet should be 1 m, and the minimum area should be 1.7 m^2. If both the toilet and the bathroom are annexed, the minimum width should be 1.5 m and the minimum area should be 2 m^2. Figure 10b depicts the standard internal dimensions of rooms.

However, 82% of single-room USSs do not maintain the internal dimensions of the habitable room. The first room's building standards are not met in 85% of multi-room USSs, while the second room's building standards are not met in 94% of USSs. The internal dimensions of the kitchen are not maintained in 86% of USSs. Furthermore, 77% of USSs with toilet facilities overlook the toilet's internal dimensions, while 60% of USSs overlook the bathroom's internal dimensions. 74% of USSs with attached bathrooms and toilets do not take internal dimensions into account. Internal living room heights are not maintained in 29% of USSs in the study area, internal bedroom heights are not maintained in 25% of USSs, and internal kitchen heights are not maintained in 27% of USSs. Furthermore, 29% of USSs fail to maintain corridor height, 20% fail to maintain bathroom height, and 21% fail to maintain toilet height. Internal heights are frequently overlooked in the temporary and semi-permanent USSs in the study area.

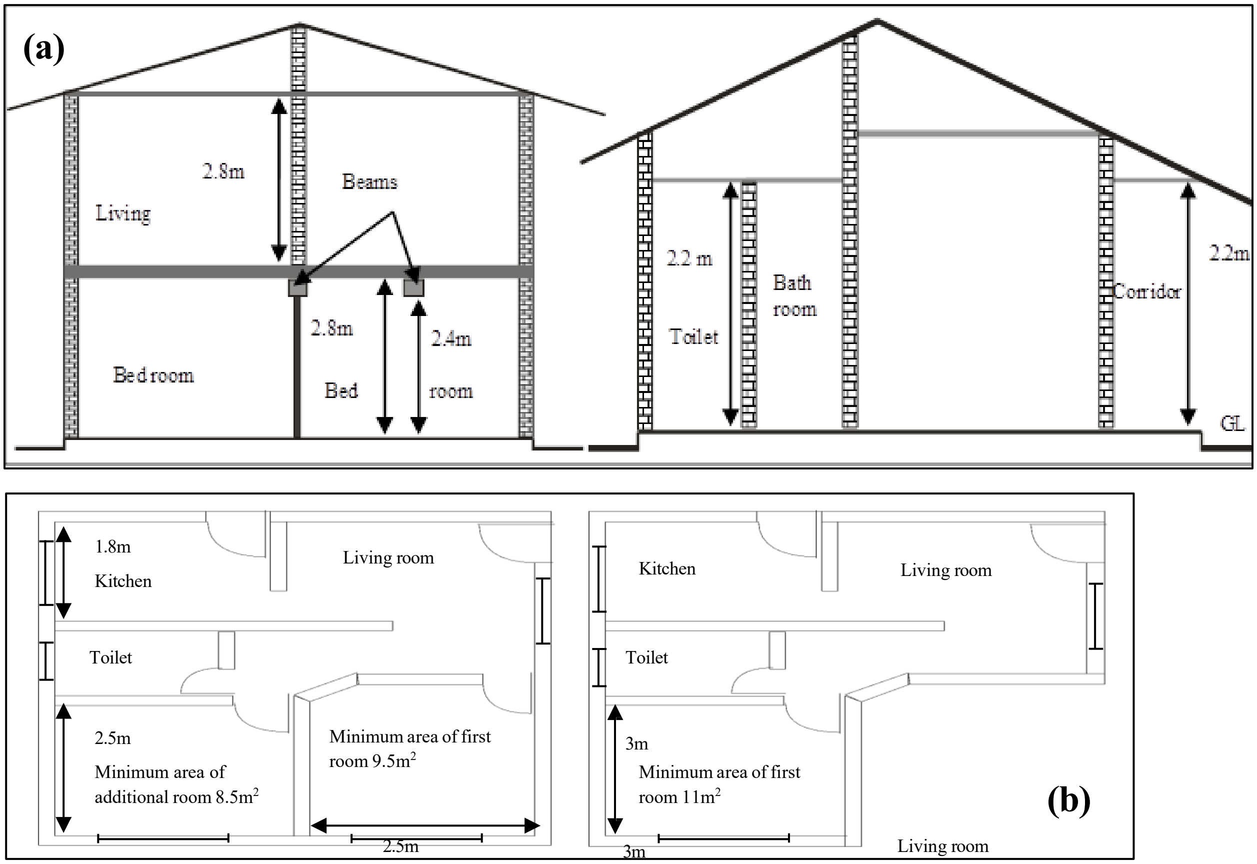

Fig. 10. The standard internal heights of house (a) and dimension of rooms (b).

Source: Created by the researcher based on UDA, 2022

Window area of rooms, toilet, and bathroom

According to the UDA's building regulations, the space for natural ventilation and light in the bathroom and toilet is calculated using the following formula. Simultaneously, UDA insisted that 100% of the openings in the bathroom and toilet be openable. The window area in all other rooms is calculated as follows: Windows and openings shall not be less than one-fifth of the floor area of such a room or space, and at least 50% of such openings or windows shall be openable. The standard window area of rooms, toilets, and bathrooms are depicted in Fig. 11.

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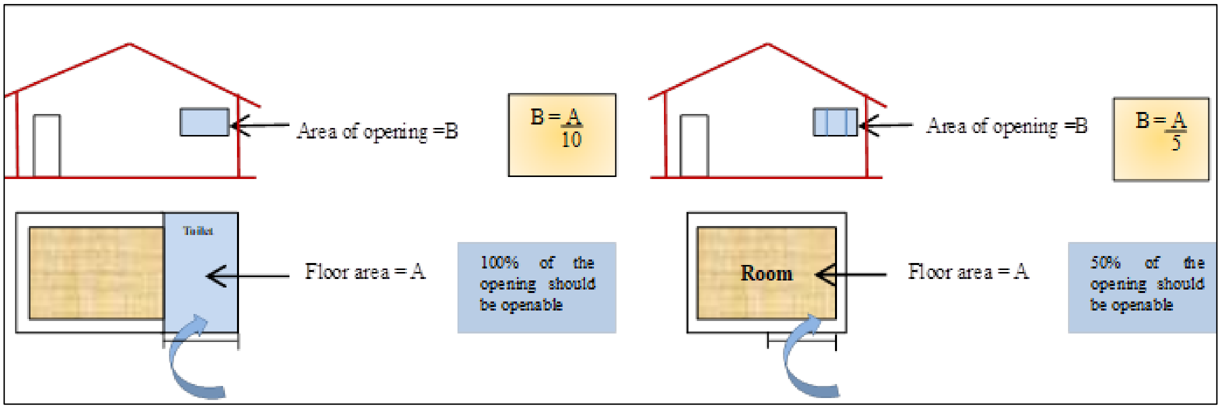


Fig. 11.- The standard window area of rooms, toilet, and bathroom.

Source: Created by the researcher based on UDA, 2022

9% of the USSs in the study area lack windows. 53% of USSs do not maintain the window area of their rooms, and 64% do not maintain the window area of their bathrooms and toilets. A lack of adequate ventilation and lighting was reported by 84% of respondents. Because of their highly congested layout and faculty arrangements, 66% of the USSs do not receive enough natural ventilation and light, particularly in *Passaiyoor East* and *West, Reclamation East* and *West, Gurunagar East* and *West, Small Bazaar,* and *Navanthurai South.*

Distance between toilet pit and well

Sealed pits were found in 83% of the USSs in the study area, while non-sealed pits were found in the remaining USSs. According to JMC requirements, if the toilet has a sealed pit, there must be at least 25 feet [ft] between the toilet pit and the well; if the toilet has a septic tank and soakage pit, there must be at least 50 ft between the toilet pit and the well. Conversely, the UDA insisted on a 60 ft distance between the toilet pit and the well if the toilet has a septic tank and soakage pit. Fig. 12 depicts the standard distance between the toilet pit and the well.

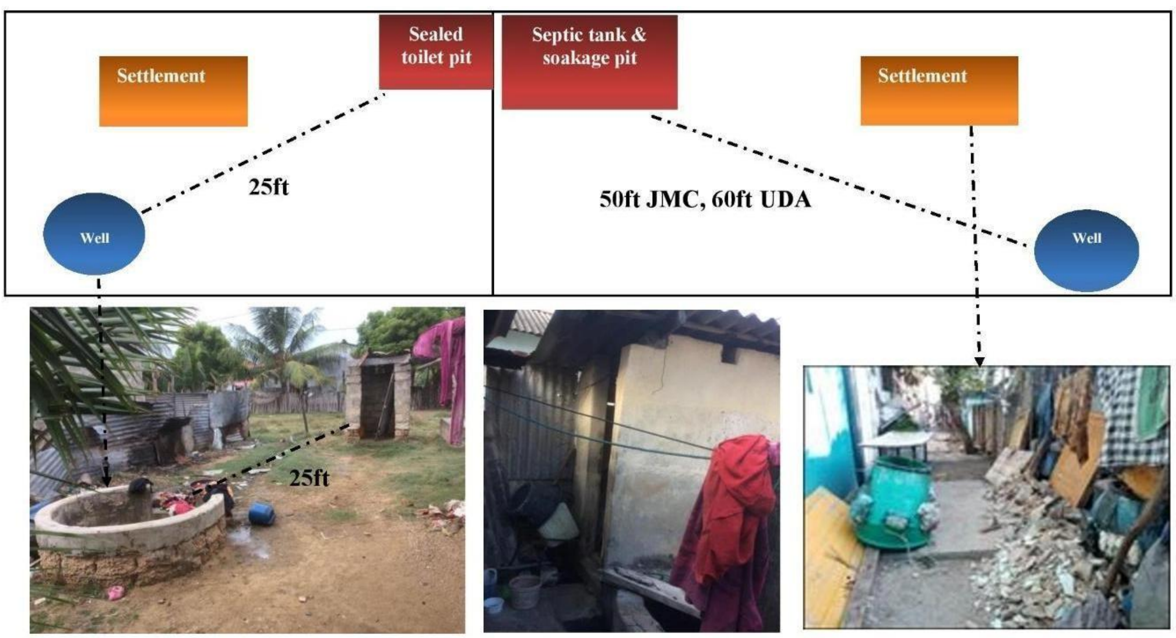


Fig. 12. The Standard Distance between toilet pit and well.

Source: Field Survey, 2020 & 2021

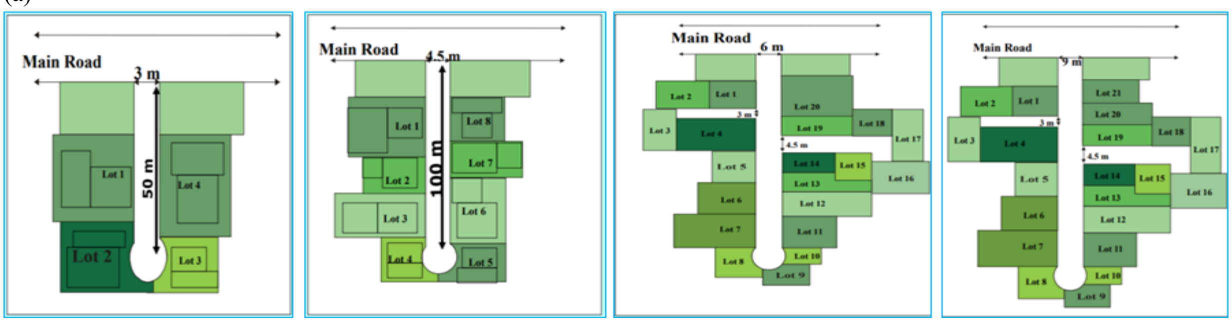
However, in the research area, 83% of USSs with sealed toilet pits and 3% of settlements with non-sealed toilet pits do not maintain the distance between the latrine pit and the well. Especially, USSs in *Passaiyoor East* and *West, Reclamation East* and *West, Gurunagar East* and *West, Small Bazaar*, and *Navanthurai South* do not meet the aforementioned standards, with less than 7.62 m between the sealed toilet pit and the well. During the DFO, the toilet pits of the USSs in the aforementioned divisions were found on the road, inside the house, and in the sea.

Accessibility

Maintaining access to residential units is an important component. According to UDA building regulations, 3 m wide and 50 m or less in length road serves maximum of 4 lots (maximum dwelling units per lot is two);

4.5 m wide and 100 m or less in length road serves maximum of 8 lots; 6 m wide road serves maximum of 20 lots; and 9 m or more wide road serves more than 20 lots. Even though accessibility is lacking in 52% of USSs, it is especially lacking in *Passaiyoor East* and *West, Reclamation East* and *West, Gurunagar East* and *West, Small Bazaar*, and *Navanthurai South.* During the DFO, it was observed that the USSs had encroached on the roads, narrowing them and making the areas inaccessible. Figure 13a depicts standard settlement accessibility, while Figure 13b depicts underserved area accessibility.

(a)



(b)

Fig. 13. Standard settlement accessibility & accessibility in underserved areas.

Source: Field Survey, 2020 & 2021

According to the survey, 64% of USSs did not receive approval for settlement construction, while 36% received approval for settlement construction but did not receive consent for house expansion. Simultaneously, 27% of respondents have a very poor understanding of the approval procedure, 37% have a poor understanding, and the remainder have a fair understanding. The majority of USSs in *Passaiyoor East* and *West, Reclamation East* and *West, Gurunagar East* and *West, Small Bazaar,* and *Navanthurai North* and *South* were found to violate building regulations, resulting in a faulty layout and a congested environment. *The Assistant directors and town planners of UDA asserted that,* "The majority of residents in USSs did not obtain permission from authorized organizations for construction and expansion because they lacked legal documentation for the property and the plot size was less than 6 perch. Within their authorized boundaries, UDA emphasizes the importance of strictly adhering to building codes. However, they are unable to maintain plot coverage; internal dimensions and heights of rooms, kitchen, and toilet; lighting; ventilation; front, back, and side space facilities; distance between toilet pit and well; and access roadways due to insufficient plot size. Simultaneously, due to a lack of space inside their homes, house expansions and encroachments on reservations occurred over time, and the entire area became an imminent threat to health and sanitation. The UDA encountered limitations in controlling unauthorized settlements as a result of the decentralization of powers to local authorities."

Administrative officers of JMC stated that, "They are unable to take action against settlements that violate building codes due to the influence of political power." *Academics and social activists asserted that*, "One of the primary reasons for the growth of spontaneous USSs is the lack of a mechanism to regulate development activities, as well as the dysfunction of institutional activities caused by political unrest.

How do the morphological characteristics of USSs influence their sustainability?

The sustainability of underserved settlements is profoundly shaped by their morphological characteristics, each of which introduces distinct but interrelated challenges. High building density, a common feature of these settlements, produces overcrowded conditions, restricts ventilation and natural light, and creates unhealthy living environments. It simultaneously imposes severe strain on already fragile infrastructure networks— particularly water, sanitation, and roads—while also undermining environmental resilience by increasing impervious surfaces and exacerbating drainage and flood risks. Similarly, the prevalence of excessive building coverage combined with undersized internal areas reflects highly inefficient land use. These conditions leave little or no space for open and green areas, limit household adaptability for future expansion, and contribute to social and health difficulties, such as poor indoor air quality, that erode social sustainability. The predominance of irregular, organic, and haphazard building patterns further compounds these vulnerabilities. Such disordered spatial arrangements generate inefficient road networks, restrict accessibility, and constrain the provision of services and emergency responses, while also curtailing economic mobility and residents' ability to access markets and employment. Compounding this is the problem of inadequate road density and weak connectivity, where narrow, irregular, and encroached roadways reduce access to essential services, hinder transportation, and intensify exposure to hazards, particularly by obstructing emergency relief operations during crises. Finally, widespread non-compliance with formal housing standards—including regulations on plot size, floor area, setbacks, and ventilation—produces overcrowded and unsafe living environments. These conditions not only undermine social and environmental sustainability but also magnify health risks and diminish d9

isaster resilience, leaving communities highly vulnerable to external shocks. Collectively, these morphological deficits establish a structural pattern that entrenches poverty, weakens resilience, and renders underserved settlements fundamentally incompatible with the principles of sustainable urban development.

Discussion

The influence of underserved settlements' morphological characteristics on their sustainability

Building characteristics of underserved settlements

Many spatial variables are important in understanding the morphology of USSs. Based on previous research, this study used spatial variables of building distribution, density, area, and pattern to perform morphological analysis first. The distribution pattern of USSs in the study area was examined using ANN analysis. The findings revealed that settlements are generally distributed in clusters with R values less than one. The R value in this case is 0.16. Furthermore, the spatial distribution of USSs differs across divisions. USSs are clustered in 20 divisions and distributed at random or in a dispersed manner in the remaining divisions. According to Sirueri (2015), underserved communities tend to congregate in divisions where there are available vacant lands, informal employment opportunities, and easy access to products and services. Overcrowding is a major issue in the aforementioned divisions because of the highest settlement density. The study found that the USSs in the study area have a range of building patterns, specifically linear, triangular, rectangular, circular, regular, and irregular. According to road density analysis, the average road density is 10.87 km of road/km^2. *Gurunagar West* has the highest road density of 54 km of road /km^2, while *Ariyalai East* has the lowest density of 2 km of road /km$^{2.}$

Relationship between building characteristics of underserved settlements

Subsequently, the relationship between building density and the other aforementioned morphological characteristics was revealed. Building area and coverage have a strong positive correlation with building density, indicating that building density increases with building area and coverage. The *Reclamation East* and *West* divisions have the largest building areas and coverage. Simultaneously, building density is also the highest in the divisions. The Euclidean building distance has a weak negative relationship with building density. Building density decreases as the Euclidean building distance increases. According to the study, the OMD between buildings is 13.12 m. The lowest OMD is 7.02 m and 6.58 m, respectively, for the *Reclamation East* and *West.* In this area, many buildings are very close together and have a haphazard orientation. During the FGDs, community leaders stated that the typical distance between buildings in these divisions has gradually shrunk over time. Road density has a moderate positive correlation with building density. Building density tends to increase in tandem with road network density. Convenient transportation can promote economic development within settlements (Zhang et al., 2020). Economic activity in the study area is concentrated along the main roadways, and underserved buildings are also concentrated along these roadways. In many circumstances, buildings are typically constructed in underserved areas first, and then roads are built around them. In a nutshell, the study found that building area, coverage, and road density have a positive relationship with building density, whereas Euclidean building distance has a negative relationship. These findings are supported by the previous studies. According to Zhang et al. (2020), there is a positive relationship between building area and building density, as well as between road density and building density. However, they did claim that there is a weak negative relationship between Euclidean nearest neighbour distance and building density.

Housing standards of USSs

Subsequently, the adaptability of housing standards in USSs was assessed using the UDA building regulations. The study's findings revealed that USSs disregard UDA building standards in terms of minimum plot size; plot coverage; internal dimensions of area, width, and height; window area of rooms, toilets, and bathrooms; settlement setbacks; and distance between toilet pit and well. 70.96% of USSs do not meet the minimum plot size standard of 6 perch, and the plinth area of settlements covers more than 65% of the land area. The WHO insisted on a minimum of 85 ft^2 of floor space per person. However, 81.23% of USSs have less than the standard. As a result, overcrowding is a major concern in underserved areas. The majority of USSs, particularly in *Passaiyoor East* and *West, Reclamation East* and *West, Gurunagar East* and *West, Small Bazaar, Navanthurai North* and *Navanthurai South,* failed to meet building standards. Residents of the USS were denied permission to build houses for a variety of reasons, including constructing settlements in undesirable geographical areas, constructing settlements on less than 6 perches of land, and lacking legal land tenure. The vast majority of the USSs in the reclamation area were built before 1986. As the number of families increased, they fragmented their settlements and expanded them by encroaching on roads, drains, and coastal areas. As a result of their inability to follow building regulations, they became a congested setup. All USSs are connected by roads in the study area with a minimum γ value of 0.4. However, accessibility is lacking in 52% of the USSs. The USSs in *Gurunagar East* and *West, Reclamation East* and *West, Small Bazzer, and Navanthurai South* are lacking in accessibility. The USSs have encroached on the roads in this area, narrowing them and rendering the areas inaccessible.The study's findings are supported by a previous study conducted in the study area by UNDP et al. (2006). They claimed that the area has grown to pose an immediate threat to the health and sanitization of not only that area but also the entire city due to disregard for building regulations, which led to a faulty layout and a congested environment. Zhang et al. (2020) emphasized that the spatial forms of USSs in Tanzania did not adhere to the principles of sustainable development in terms of economic, societal, and environmental protection. Therefore, the morphological characteristics of USSs have an impact on both their sustainability and the urban environment in which they live. However, Zhang et al. (2020) stress that USSs can be better aligned with the sustainable development goals by optimizing the structure and form of their elements.

Morphology of USSs and served settlements

The results showed that USSs and served settlements have different characteristics in terms of size, density, pattern, and site characteristics. In comparison to served settlements, which typically have larger building areas, the majority of USSs in the study area have small, substandard building sizes. Settlement densities are high in USSs while they are low to moderate in served settlements. USSs either lack or have abandoned public spaces, whereas served settlements have functioning public green spaces within or near their areas. In terms of patterns, USSs do not follow the setback standards and have an organic layout structure with disorganized settlements and road layouts. Served settlements, in contrast, have planned regular roads, regular layouts and are completely compliant with building regulations. USSs are formed in hazardous areas that are also close to vital infrastructure and sources of income. But formal areas are developed on plots of land that are suitable for residential areas and have the necessary infrastructure in place. The study by Kuffer, Pfeffer, & Sliuzas (2016) also confirmed that the size, density, pattern, and site characteristics differed between underserved and formal built-up areas by examining the physical characteristics of USSs and served settlements in Asia, South America, and Sub-Saharan Africa. Accordingly, the study addressed the research questions of what the morphological characteristics of USSs are and how these characteristics influence their sustainability.

Conclusions

The study's findings provided two possible contributions. First, the morphological characteristics of USSs were examined, and the results indicated that action should be taken promptly to prevent the formation and expansion of USSs. The study focused on the potential link between the morphological characteristics of USSs and their sustainability. According to the study, the morphological characteristics of USSs, specifically overcrowding and disregarding the building standards, lead to a faulty layout and congested environment and have a negative impact on the sustainability of USSs as well as the urban environment. Furthermore, to reduce problems with USSs and establish cities without USSs, the development of USSs must be aligned with spatial and sustainable development. Controlling building density to improve living conditions and land use efficiency; choosing land for construction to avoid areas with high environmental risks; protecting ecological spaces; maximizing land space through the development of two or multi-story buildings; regulating and controlling settlement layout; providing awareness; developing coordination among multiple stakeholders; increasing the physical, human, economic, and social capital of USSs, and strengthening existing laws and regulations are some of the strategies that can be used to promote sustainable development of USSs and the urban environment. Urban sustainable development emphasizes people-orientation and capacity-building as a three-dimensional coordinated development of society, economy and ecology. The city's spatial organization at different scales can influence all three dimensions. A hot topic in urban sustainable development research is determining how to guide a city to form a reasonable spatial form while promoting sustainability (Zhang et al., 2020). More comprehensive research is needed at this time to investigate the mechanisms underlying the relationship between the morphological elements of USSs and their functional development to make more innovative recommendations to promote USSs' sustainable development.

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